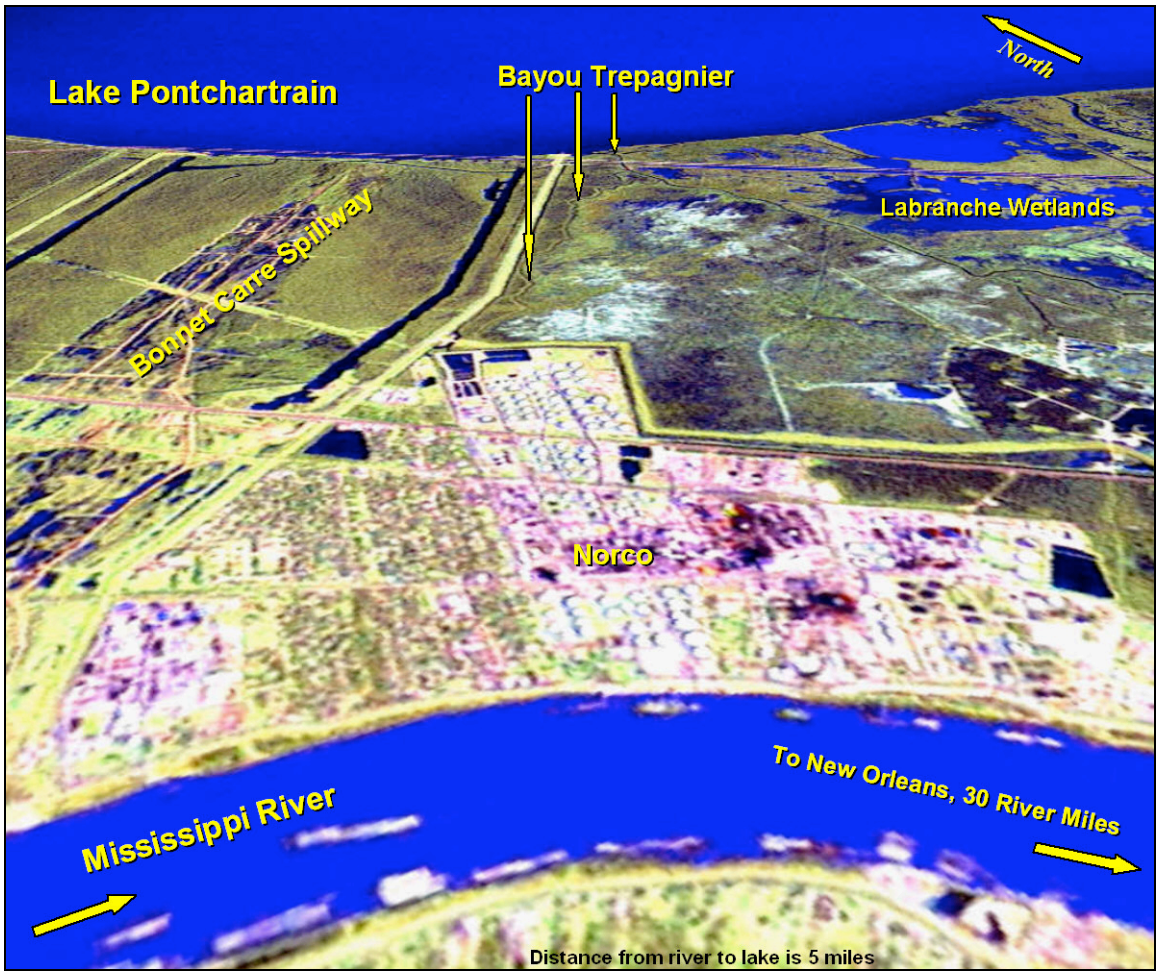
Hazardous Materials in Aquatic Environments of the Mississippi River Basin



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Final Technical Report
(January 1, 1993 – September 1, 1999)
Issued: December 2003
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DOE Award #DE-FG21-93EW-53023

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Abstract

In December 1992, the CBR was awarded a five-year grant of $25M from the US Department of Energy Office of Environmental Management (DOE-EM) to study pollution in the Mississippi River system. The ***Hazardous Materials in Aquatic Environments of the Mississippi River Basin*** project was an interdisciplinary, collaborative research and education project aimed at elucidating the nature and magnitude of toxic materials that contaminate aquatic environments.

This project funded 15 collaborative cluster multi-year projects and 41 one-year initiation projects out of 165 submitted research proposals. This project was carried out by 134 research and technical support faculty from Xavier University (School of Arts and Sciences, and College of Pharmacy) and Tulane University (Schools of Liberal Arts and Sciences, Engineering, Medicine, and Public Health and Tropical Medicine), and 173 publications and 140 presentations were produced. More than 100 graduate and undergraduate students were trained through these collaborative cluster and initiation research projects. Nineteen Tulane graduate students received partial funding to conduct their own competitively-chosen research projects, and 28 Xavier undergraduate LIFE Scholars and 30 LIFE Interns were supported with DOE funding to conduct their mentored research projects.

Studies in this project have defined: 1) the complex interactions that occur during the transport of contaminants, 2) the actual and potential impact on ecological systems and health, and 3) the mechanisms through which these impacts might be remediated. The bayou and spoil banks of Bayou Trepagnier were mapped and analyzed in terms of risks associated with the levels of hydrocarbons and metals at specific sample sites. Data from contaminated sample sites have been incorporated into a large database and used in GIS analyses to track the fate and transport of heavy metals from spoil banks into the surrounding marsh. These data are crucial to understanding how heavy metals move through wetlands environments. These data, coupled with plume characterization data, indicate that Bayou Trepagnier is a model system for understanding how wetlands populations of fish, amphibians, and plants respond to long-term hydrocarbon and metals contamination.

The CBR has fifteen years of experience in developing model aquatic ecosystems for evaluating environmental problems relevant to DOE cleanup activities. Using biotechnology screens and biomarkers of exposure, this project supports other CBR research demonstrating that chemicals in the environment can signal/alter the development of species in aquatic ecosystems, and show detrimental impacts on community, population, and the ecosystem, including human health. CBR studies funded through this grant have resulted in private sector investments, international collaborations, development of new technologies, and substantial new knowledge concerning the effects of hazardous materials on human and ecosystem health. Through the CBR, Tulane and Xavier Universities partnered with DOE-EM to lay groundwork for an effective research agenda that has become part of the DOE long term stewardship science and technology program and institutional management of the DOE complex.

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Executive Summary

Since 1989, Tulane and Xavier Universities in partnership as the Center for Bioenvironmental Research (CBR) have focused on the environment as a major strategic focus for research, education, and communication. The Tulane/Xavier partnership is a complementary relationship, with the Xavier focus on education and graduate work, and the Tulane emphasis and experience in education, research, and technology development and transfer. In December 1992, the CBR was awarded a five-year grant of $25M from the US Department of Energy Office of Environmental Management (DOE-EM) to study pollution in the Mississippi River system. The ***Hazardous Materials in Aquatic Environments of the Mississippi River Basin*** project was an interdisciplinary, collaborative research and education project aimed at elucidating the nature and magnitude of toxic materials that contaminate aquatic environments. The Mississippi River Basin represents a model system for analyzing and solving contamination problems that are found in aquatic systems worldwide. In the past 15 years, the CBR has assisted DOE in the development of a knowledge base and systematic strategies for determining the public health and ecological effects of waste and the level of work needed to protect the environment and public health. Risk assessment management strategies developed through this CBR project have given guidance in determining scientific bases for cleanup activities, the evaluation of potential health and ecological effects, and selection and implementation of remedial alternatives.

This project funded 15 collaborative cluster multi-year projects and 41 one-year initiation projects out of 165 submitted research proposals. This project was carried out by 134 research and technical support faculty from Xavier University (School of Arts and Sciences, and College of Pharmacy) and Tulane University (Schools of Liberal Arts and Sciences, Engineering, Medicine, and Public Health and Tropical Medicine), and 173 publications and 140 presentations were produced. More than 100 graduate and undergraduate students were trained through these collaborative cluster and initiation research projects. Nineteen Tulane graduate students received partial funding to conduct their own competitively-chosen research projects, and 28 Xavier undergraduate LIFE Scholars and 30 LIFE Interns were supported with DOE funding to conduct their mentored research projects.

This project was divided into three components: collaborative cluster and initiation research projects, technical support cores, and education/research training activities. CBR established a comprehensive, annual external review and selection process for funding awards to investigators for collaborative cluster and initiation research projects. The major accomplishment of the Field Work and Chemical Analysis Cores was that standardized analytical and sampling protocols were developed for inorganic and organic compounds in water/soil/biotic samples and field collection/delivery. The Data Management Core designed, created, and implemented an efficient database with full functionality and flexibility. This data management system links sample tracking and test results with data (field, personnel, spatial, analytical procedure, QA/QC) from Tulane and Xavier researchers working in Bayou Trepagnier. The overall goal of the Education/Research Training component was to develop a comprehensive environmental education program to produce Tulane and Xavier graduates who are competent to carry out the DOE-EM mission. The project developed a master plan and an infrastructure to facilitate the coordination of programs, build upon existing strengths and resources, and promote the maximal utilization and efficiency of resources between the two universities.

Studies in this project have defined: 1) the complex interactions that occur during the transport of contaminants, 2) the actual and potential impact on ecological systems and health, and 3) the mechanisms through which these impacts might be remediated. The bayou and spoil banks of Bayou Trepagnier were mapped and analyzed in terms of risks associated with the levels of hydrocarbons and metals at specific sample sites. Data from contaminated sample sites have been incorporated into a large database and used in GIS analyses to track the fate and transport of heavy metals from spoil banks into the surrounding marsh. These data are crucial to understanding how heavy metals move through wetlands environments. These data, coupled with plume characterization data, indicate that Bayou Trepagnier is a model system for understanding how wetlands populations of fish, amphibians, and plants respond to long-term hydrocarbon and metals contamination. The hydrocarbon plume, characterized in Bayou Trepagnier through fate and transport studies, is composed of a variety of polyaromatic hydrocarbons (PAHs) that are not only toxicologically hazardous, but also bind receptors related to endocrine functions. Such binding can cause disruptions of endocrine functions in fish and amphibians, resulting in adverse effects on development and reproduction. Studies concerning how these PAHs bind specific target receptors not only provide information about previously undefined ecotoxic effects, but also serve as the basis for new technologies for hazard monitoring and remediation.

The CBR has fifteen years of experience in developing model aquatic ecosystems for evaluating environmental problems relevant to DOE cleanup activities. Using biotechnology screens and biomarkers of exposure, this project supports other CBR research demonstrating that chemicals in the environment can signal/alter the development of species in aquatic ecosystems, and show detrimental impacts on community, population, and the ecosystem, including human health. CBR studies funded through this grant have resulted in private sector investments, international collaborations, development of new technologies, and substantial new knowledge concerning the effects of hazardous materials on human and ecosystem health. Through the CBR, Tulane and Xavier Universities partnered with DOE-EM to lay groundwork for an effective research agenda that has become part of the DOE long term stewardship science and technology program and institutional management of the DOE complex.

I. Introduction

Since 1989, Tulane and Xavier Universities in partnership as the Center for Bioenvironmental Research (CBR) have focused on the environment as a major strategic focus for research, education, and communication. In December 1992, the CBR was awarded a five-year grant of $25M to study pollution in the Mississippi River system. The US Department of Energy Office of Environmental Management (DOE-EM) made funding. The Hazardous Materials in Aquatic Environments of the Mississippi River Basin project was an interdisciplinary, collaborative research and education project aimed at elucidating the nature and magnitude of toxic materials that contaminate aquatic environments of the Mississippi River Basin. The project was intended to be aquatically oriented, have relevance to DOE, but at the same time be specific to the aquatic environment in Louisiana, and focus on the fate of contaminants in the ecosystem in terms of natural degradation. The Mississippi River Basin represents a model system for analyzing and solving contamination problems that are found in aquatic systems worldwide. These research and education projects are particularly relevant to the US Department of Energy's programs aimed at addressing aquatic pollution problems associated with DOE National Laboratories.

A. Priorities of the Department of Energy (DOE)

The DOE environmental restoration and waste management (EM) mandate is driven by complex State and Federal regulations that have grown since the 1980's to address a variety of environmental problems. The current system may be producing cleanup outcomes that are not necessarily in the best public interest in terms of protecting health and the environment or in addressing issues of costs. DOE has established a system for setting priorities for cleanup projects with decisions based on:

- Potential risks both to individuals and the environment;
- Costs of the various cleanup alternatives; and
- Social and economic concerns of the affected communities.

The DOE risk-based approach to establishing priorities consists of two essential phases: risk assessment, which provides the scientific basis for characterizing the potential risks from exposure; and risk management, which integrates risk and nonrisk factors in the development of remedial options and for decision-making and priority setting. To meet the growing interest in risk-based EM approaches, DOE will benefit from an increase in the knowledge pertaining to risk assessment and risk management.

Achieving a risk-based approach to EM must include a coherent strategy for evaluating potential off-site human and ecological exposure to wastes and the potential risk associated with these exposures. During the past 15 years, the CBR has assisted DOE in the development of a knowledge base and systematic strategies for determining the public health and ecological effects of waste and the level of work needed to protect the environment and public health. Risk assessment and management strategies developed through this CBR project have provided guidance in determining scientific bases for guiding cleanup activities, the evaluation of potential health and ecological effects, and the selection and implementation of remedial alternatives.

B. Project Description

Through this DOE-EM grant, the CBR, or Recipient, has developed and implemented activities designed to enhance DOE's fulfillment of its goals in support of its EM mission. The Recipient's project description included eight tasks.

TASKS TO BE PERFORMED

Task 1: Survey of National and International Information – Under the terms of this grant, the Recipient reviewed existing literature and database systems, and contacted national and international experts, in order to expand the existing knowledge base, and to verify and assess the current status of information on EM problems associated with major aquatic systems. This survey focused on the Mississippi and Gulf of Mexico systems and other aquatic systems affected by large industrial complexes.

Task 2: Systems Analysis of Environmental Exposure and Monitoring – A systems study of the critical environmental pathways which result in human and ecological exposure to contaminants was undertaken including targeted efforts in hazard identification, fate and transport of contaminants in aquatic systems, ecological effects, routes of human exposure, and exposure-response relationships.

Task 3: Technology Development for Protection of Aquatic Systems and Human Health – Tulane and Xavier researchers focused their efforts on the development, testing, and application of technologies to address problems identified as serious risks to human health or to the ecology of the aquatic environments and/or industry-intensive sites located near major water systems.

Task 4: Environmental Assessment Workshops and International Activities – The grantee conducted workshops and conferences to assess adequacy and acceptability of existing databases, technologies, equipment, and models. The purpose was to go beyond the classical models of environmental impacts of contamination in order to move the state of the art forward to develop approaches to land use planning based on sound scientific analysis of causes, routes, mechanisms, and effects of contaminants ultimately released to the aquatic environment.

Task 5: Education, Training, and Outreach – The grantee has developed a model pipeline curriculum that addresses all phases of the education spectrum. This integrated education and training program addressed important environmental aspects of energy production and use. Courses and curricula as developed reflect Tulane and Xavier's commitment to an integrated approach to EM problems.

Task 6: National Challenge Activities – The results of research in Task 2 were used to identify national and international challenge activities that required crosscutting research, particularly with states of the former Soviet Union.

Task 7: Technology Transfer – During the project period, the Tulane/Xavier team created an environment in which faculty involved in fundamental research were continually informed on the

ongoing, practical problems faced by EM site managers. In turn, EM personnel were exposed to emerging technologies and fundamental discoveries that could affect their daily problems.

Task 8: Program Management – The grantee carried out management functions necessary to administer the grant and to assure effective information transfer among program participants.

II. Results and Discussion

The project completed five years of funding beginning in December 1992 through December 1997 with a no-funds extension in August 1998 extending the period of performance to September 1, 1999. During this time period, this project funded 15 collaborative cluster multi-year projects and 41 one-year initiation projects out of 165 submitted research proposals. This project was carried out by 134 research and technical support faculty from Xavier University (School of Arts and Sciences, and College of Pharmacy) and Tulane University (Schools of Liberal Arts and Sciences, Engineering, Medicine, and Public Health and Tropical Medicine) who participated in this project. More than 100 graduate and undergraduate students were trained through these collaborative cluster and initiation research projects. Nineteen Tulane graduate students received partial funding to conduct their own competitively-chosen research projects, and 28 Xavier undergraduate LIFE Scholars and 30 LIFE Interns were supported with DOE funding to conduct their mentored research projects. During the project period, 173 publications and 140 presentations were produced.

The Mississippi River basin was selected for studying the entry of industrial contaminants into aquatic ecosystems, the movement of these compounds through environmental phases, and their influence on various species. The following areas were chosen as major sampling sites:

- **Bayou Trepagnier** – a typical fresh to brackish water ecosystem that receives large volumes of mixed petroleum wastewater. Designated a "natural and scenic stream" in the Natural and Scenic River Act of 1970, this 3_ mile bayou flows in a northeasterly direction through a cypress-tupelo swamp. This bayou was selected for study based upon its known contamination by metals, chemicals, oil, and grease.
- **Bayou Traverse** – an unpolluted marsh ecologically and hydrologically similar to Bayou Trepagnier. This site was used as the control site to Bayou Trepagnier.
- **Devil's Swamp** – a typical freshwater ecosystem adjacent to the Mississippi River with mixed pollution from discharges from industrial activities and leachate from hazardous waste sites. Including a man-made lake, this swamp is polluted by a variety of nearby industrial complexes, including an abandoned hazardous waste disposal facility.
- **Tunica Swamp** – a relatively pristine body of water located 20 miles up river from Devil's Swamp. Ecologically and hydrologically similar to Devil's Swamp, but not polluted, this site was used as the control site to that swamp.

The DOE site of Oak Ridge was chosen as a comparative reference site to Bayou Trepagnier due to its similar characteristics and contaminants. Oak Ridge has mostly flowing surface water and a "pseudo tidal" effect from water flowing into fluctuating reservoirs. Contaminants at Oak Ridge include chlorinated solvents, PCBs, heavy metals, and radionuclides. The site contains a variety of hydrocarbon and heavy metal contaminants that are also found in the water and sediments of Bayou Trepagnier. Interactions included visits to Oak Ridge by Tulane/Xavier researchers,

administrators and student trainees and interns. Oak Ridge National Laboratory (ORNL) worked closely with project investigators to provide research support and expertise in a variety of areas, including the design of Quality Assurance/Quality Control (QA/QC) protocols for sampling and analytical components of the project.

A. CBR Capacity

The mission of the Center for Bioenvironmental Research (CBR) is to conduct and coordinate research and teaching to enhance global understanding of environmental issues and provide solutions through innovative communication and technology. Founded in 1989, the CBR is an innovative partnership between a Historically Black College or University (HBCU) and a major research university that encourages scientists from multiple disciplines to work together to investigate and resolve environmental problems. Under the leadership of Dr. John McLachlan, Weatherhead Distinguished Professor in Environmental Studies at Tulane University and an internationally recognized environmental scientist and administrator, the CBR has earned a reputation for its scientific research into the environmental problems of Louisiana. In extending its spheres of influence to national and global problems of the environment, the CBR has brought unique focus that reflects a community-based perspective in conjunction with scientific rigor.

Tulane and Xavier Universities have developed a close working relationship in the past 15 years, aided by a common vision of academic excellence and the development of high quality educational opportunities for minorities and women. The Tulane/Xavier partnership is an effective joint venture between majority and minority universities. It is an extremely complementary relationship with respect to environmental restoration and waste management, with the Xavier University focus on education and graduate work, and the Tulane University emphasis and experience in education, research, and technology development and transfer. Optimizing research capabilities of Tulane and educational resources at Xavier, the reputation of both institutions enhances the ability of the CBR to solicit resources, recruit staff and faculty, sponsor conferences, and execute successful marketing of its education and research programs.

The relationship between Tulane and Xavier Universities is the foundation of the CBR and serves as a working model for all its collaborations. Since the CBR integrates academic structures, it has the freedom to advance teaching and research by creating flexible working groups to address specific needs and problems. Administrators and researchers team up with government, private, academic, and community partners to make use of the best intellectual and technological resources. The partnerships catalyzed by the CBR exist at local, regional, and international levels resulting in community-based solutions to environmental health problems.

1. Tulane Capabilities

Since its inception Tulane University has grown into one of the nation's premier institutions of higher learning known widely for both its undergraduate teaching and cutting-edge research. Tulane University ranks among the top 10 private universities in technology transfer and among the top 25 in the amount of federal research funding. The University enrolls a diverse student body of 12,000 students from all 50 states and nearly 100 foreign countries in its undergraduate, graduate and professional schools. The University ranks in the top 10 in Environmental Law Studies, the top 15 in Public Health and International Law, and the top 25 in Biomedical Engineering. Tulane is recognized as both a member of the Association of American Universities

and a Carnegie-1 research university, one of the few in the South. Tulane University has established itself as a powerful engine of economic development for New Orleans and Louisiana. Tulane is the largest private employer in Orleans Parish and ranks 12th in the State of Louisiana.

2. Xavier Capabilities

Xavier University of Louisiana is the nation's only institution of higher education that is historically African American and Catholic. Xavier prepares its students to assume roles of leadership and service in society. This preparation takes place in a pluralistic teaching and learning environment that incorporates all relevant educational means, including research and community service. Xavier University has grown in enrollment in the past 10 years with a current enrollment of nearly 4,000 students. Nearly half of the Xavier students are from Louisiana, while the rest come from 39 other states, the District of Columbia, the Virgin Islands, and 27 countries. The student body is predominantly African American (nearly 90%), but the university is open to all. More than half of its students major in the natural or health sciences. The preeminence of Xavier in training undergraduates in science is reflected in its first-place ranking in the placement of African-American graduates in medical schools for the past 10 years. In addition, Xavier is first nationally in the number of African American students earning undergraduate degrees in both the life sciences and the physical sciences. Over 40% of all recent graduates enroll in professional and graduate schools. The National Science Foundation has designated Xavier University as a "Model Institution for Excellence". The Southern Association of Colleges and Schools accredit Xavier University.

B. Overview of Research

This project was divided into three components: collaborative cluster and initiation research projects, technical support cores, and education/research training activities. For purposes of this grant, a cluster project was defined as one or more closely related collaborative, multidisciplinary research projects in which a group of investigators employs a synergistic approach to the solution of problems in the same general area of research. An initiation project typically involved a single investigator. The purpose of the initiation project was to undertake pilot work, usually lasting no more than one year, which would lead to the successful submission of an externally funded proposal or the development of a collaborative cluster project.

Following a recommendation by the December 1995 external review panel, CBR set up technical cores, in addition to research support, to work with the competitively selected cluster and initiation projects funded yearly under the grant. These technical cores were fieldwork, chemical analysis, data management, and education. Technical support cores conducted activities essential to support research projects as well as the overall grant objective of assisting in the characterization of selected field sites. The education/research training core was designed to create and coordinate curricula and related educational activities at both Tulane and Xavier Universities with emphasis on fostering environmental studies programs in addition to training students in areas of environmental research. Participants in core groups performed work as targeted by the external review panel and produced interdisciplinary publications related to the project. The core approach established flexible teams of researchers who not only provided project support, but also helped develop the infrastructure utilized to support CBR's expanding environmental research efforts.

1. Technical Cores

a. Research Support

The research support team provided the necessary administrative support to assure that the scientific and educational goals of the project were obtained and that all DOE reporting requirements were fulfilled. This team provided administrative oversight to the annual external review and selection process for funding research projects, communication and outreach with DOE and related federal/state agencies on research results, and coordination and development of new research projects and partnerships related to this project.

CBR established a comprehensive, annual external review and selection process for funding awards to investigators for collaborative cluster and initiation research projects. A request for proposals was issued each fall (September) for the funding period February 1 to January 31 of the following year. Each interested principal investigator submitted a pre-proposal letter of intent. These letters would be categorized by content in one of the following major areas: 1) Biological Sciences, 2) Engineering, 3) Health Effects, and 4) Physical Sciences. External review panelists, including DOE personnel, academics, and other consultants, were selected each year based on their expertise in these four areas and on DOE staff recommendations. Primary and secondary readers were assigned for each proposal. The panel convened in the first week of December to attend a project poster session with all project participants, to discuss the merits of the submitted proposals, and to make recommendations for funding status.

Since this project involved numerous investigators at two institutions, it was imperative to have well-organized modes of communication among researchers and project administrators. This was facilitated through meetings that rotated among the 3 participating campuses (Xavier University, Tulane uptown and downtown campuses). All investigators were encouraged to attend. At each meeting, investigators from one or two selected projects presented their current research findings. These presentations fostered interactions among participants across projects and resulted in the development of new, interdisciplinary research teams. At poster sessions, investigators presented their research and answered questions from reviewers, DOE administrators, faculty, students and representatives from state and federal regulatory agencies. This venue provided investigators with important feedback related to their work.

In July 1997, this project sponsored a summary conference, *Bayou Trepagnier: Characterization, Fate & Transport, Ecological Effects and Risk Analysis*, in New Orleans. The meeting provided a forum for scientists studying the Bayou Trepagnier site to share their research data and discuss future work in the EM area. The meeting was attended by 123 people. Those attending included representatives from the Louisiana's Department of Environmental Quality, the petrochemical industry, regional environmental groups, the New Orleans Mayor's Environmental Office, as well as numerous investigators and students from Tulane, Xavier and other area universities. CBR and project research investigators formed new research collaborative partnerships.

b. Field Work and Chemical Analysis Cores

Field Work and Chemical Analysis Cores of research faculty were identified to provide chemical analysis and field work infrastructures to support CBR environmental research efforts with the following goals: assure standardized analytical procedures and collection protocols were utilized for chemical analysis of field samples; provide and maintain written analytical and collection protocols for the project; conduct sample preparation and chemical analysis for samples collected; assure that all proper permits were obtained prior to field sampling; ensure that proper laboratory health and safety precautions were taken; conduct appropriate QA/QC exercises to demonstrate data accuracy; coordinate with other technical cores to ensure standardization of data sampling, analysis, and entry into data management system.

Through the efforts of these two cores as well as the data management group, ecological, histopathological and analytical data have been compiled into a single database for use in modeling uptake of contaminants and possible ecological consequences of contaminant exposure in the system. Over the project period, for example, more than 6,000 fish were archived in the Tulane University Museum of Natural History through efforts of the Field Work Core.

During the project period, the Coordinated Instrumentation Facility (CIF) provided technical support in the following areas: 1) high quality analytical services, including trace metals, and volatile and semi-volatile organic analyses, to project research faculty; 2) cost-effective maintenance of equipment used in research at Tulane and Xavier facilities; 3) application support to researchers for analytical projects; and 4) interface with the other technical support cores. The Inorganic Analysis laboratory was used for determination of heavy metals and other inorganic pollutants in water, soil and tissue. In particular, the CIF successfully completed a performance evaluation for the analysis of arsenic, cadmium, chromium, cobalt, copper, lead, nickel, and zinc. The Organic Analysis laboratory was used to establish environmental capabilities. In particular, methods were developed for the sample preparation of soil and water samples and for the analysis of two common pollutants, hexacholorobutadiene and hexachlorobenzene. In October 1997, the organics lab successfully completed a performance evaluation for the analysis of polyaromatic hydrocarbons (PAHs).

The major accomplishment of these two cores was that standardized analytical and sampling protocols were developed for the analysis of inorganic and organic compounds in water/soil/biotic samples and field collection/delivery. The protocols were designed to be flexible enough that the individual analytical requirements could be met, while still guaranteeing that the data could be reported and evaluated in a consistent matter. Proposed protocols were reviewed by core faculty and by Oak Ridge National Laboratory, and then distributed to all members of the cores.

Research conclusions of the Chemical Analysis Core include:

- Using the ASE extraction method, the CIF found evidence for concentrations of 4-_-nonylphenol in the ppm range in sediments from Bayou Trepagnier. Since 4-nonylphenol is an established xenoestrogen, this finding indicates that manifestations of endocrine disruption observed in fish and other organisms collected from Bayou Trepagnier may be caused by the presence of this known industrial contaminant.
- Using the ASE extraction method, the CIF also found evidence for elemental sulfur in sediments from Bayou Trepagnier. Since the movement of heavy metals such as lead through

aquatic systems is strongly influenced by the levels of sulfide ion available, the presence of elemental sulfur may be important in determining the rate of lead movement down the Bayou.

- Upon comparison studies of specific metals (lead, zinc, cadmium, manganese, copper, chromium, vanadium, and arsenic) at the two field sites, it was determined that Bayou Trepagnier samples had higher metal content than those from Bayou Traverse.

Major research conclusions of the Field Work Core include:

- Whole fish data (taxonomy, number, length, weight) plus analytical results of all gathered data were added to the existing database, summarized and published. Main findings include that fish in Devil's Swamp are concentrating contaminants at higher than environmental levels; many species of fish from Devil's Swamp are in worse physical condition than fish from the reference site; seasonal shifts to benthic feeding presumably related to food availability predispose some species to higher contamination risk than at other times; and the pattern of tissue contamination in the system is not consistent with the hypothesis that transmission is primarily through the food chain.
- Review of fish catch data revealed that Bayou Trepagnier supports a greater variety of fish than either Bayou Traverse or Bayou LaBranche due to habitat differences between the sites. Bayous Traverse and LaBranche are more open, marsh-bordered bayous, whereas much of Bayou Trepagnier is forested. Trees lining the shore of the bayou provide shade and habitat for fishes.
- It was determined that fish diversity in Bayou Trepagnier was similar to that in reference bayous (Traverse and LaBranche), but effort-adjusted fish catch and species richness was significantly lower in the most contaminated portions of Bayou Trepagnier than elsewhere in the bayou.
- It was determined that there was a significant decline in the benthic community along a contamination gradient, including a significant decrease in diversity of the meiofaunal community.
- For the forest floor flora, including seedlings of woody species as well as herbaceous species, stem density appears depressed at the contaminated site. As for biomass data, large variation among plots, especially at the contaminated site, precludes assertion of a significant difference. In contrast, forest floor species richness and diversity are greater at the contaminated than at the reference site, and relative density patterns of common species are very different among sites.
- The combination of low-density yet diverse forest floor vegetation in the contaminated site may be an indication that adverse soil quality has affected competitive interactions. Alternatively, the sites may have different seed banks or seed input sources.

c. Data Management

The Data Management Core (DMC) was established to modernize and facilitate efficient communication, sample tracking, QA/QC, and dissemination of data collected under the DOE-EM grant. Research data included inorganic and organic analytical results from various labs, location values and biological samples. The data were collected, reviewed, and stored in a central electronic repository (database) accessible to all investigators. The database was interfaced to

the Geographic Information System (GIS) and tightly linked to its spatial capabilities. The DMC developed tools for electronic access to the database, digitized geographic features in the bayou using the Global Positioning System (GPS), analyzed data and generated maps using GIS.

Upon conclusion of this project, the data management infrastructure frame consisted of:

- a populated centralized database;
- automated data entry points that capture critical information from field core and sample preparation areas;
- a Relational Laboratory Information Management System that merges analytical instrumentation to the central database;
- the configuration and establishment of a CBR GIS laboratory; and
- a database design that accurately relates to and reflects the existing data flow.

Project achievements by this core included:

- standard forms and file formats for direct input of analytical results from laboratories;
- video and environmental atlas server configuration; and
- interfaced video multimedia to web and environmental atlas.

This core designed, created, and implemented an efficient database with full functionality and flexibility. This data management system links sample tracking, test results, field data, personnel data, spatial data, analytical procedure data, and QA/QC data from both Tulane and Xavier Universities researchers working in Bayou Trepagnier.

A modeling research group within DMC analyzed data from the database to develop models to predict ecological risk and biological uptake in the Bayou Trepagnier watershed. The faculty team developed a bioaccumulation model of the spotted gar food-web based on the work of Gobas (1993) using site-specific data collected by CBR investigators. It is applicable for investigating the bioaccumulation of hydrophobic organic chemicals in fish. Preliminary results modeling tert-octyl phenol indicated the need for measurements of organism lipid fractions, densities of lipids, organic carbon in sediment and organic matter in water. In addition, model validation will be strengthened with additional chemical analyses of organisms at different trophic levels and analyses of whole body concentrations in fish. This type of modeling has the potential to be a useful tool in assessing the responses to hypothetical changes within the ecosystem. The model framework was presented at the Ecological Summit ’96 in Copenhagen.

2. Education/Research Training

The overall goal of the Education/Research Training component of this project was to develop a comprehensive environmental education program to produce graduates from Tulane and Xavier Universities who are competent to carry out DOE's mission of environmental restoration and waste management. A major objective was to attract minority students into environmental careers. Educational strategies were identified to foster a professional workforce of scientists, engineers and technologists necessary to carry out the DOE mission. The DOE-EM project developed a master plan and an infrastructure to facilitate the coordination of programs, build upon existing strengths and resources, and promote the maximal utilization and efficiency of resources between the two universities. Activities included inviting guests and coordinating field trips with a variety of collaborative partners to share information on environmental education

programs; conducting, attending, and presenting at meetings, workshops, and conferences to enhance communication between Xavier and Tulane faculty about DOE-sponsored programs; initiating communication strategies to stimulate student interest in environmental studies; and developing curricula, seminars, and scholarships/ internships that form the foundation of training for students undertaking scientific careers.

The implementation of coordinated curricula, in particular, enabled Tulane and Xavier to combine their strengths in a synergistic manner and to utilize common resources and faculty. During the project period, Xavier University approved an Environmental Studies minor for science majors and an Environmental Science track for non-science majors (2 separate programs of study). In 1995, an Environmental Chemistry major in the Chemistry Department was approved by the Xavier University Academic Council. At Tulane University the environmental curriculum was reviewed and a revised set of requirements for the coordinate major in environmental studies was developed. A BS degree in Environmental Engineering was implemented at Tulane in 1993, and the program was made available to Xavier students who followed the 3+2 track to obtain a BS degree in physics from Xavier and a BS in Environmental Engineering from Tulane. A BS/MSPH combined degree program was also developed for Xavier undergraduates interested in public health degrees from Tulane. Between 1995 and 1998, the number of Environmental Studies majors at Tulane grew from 20 to 51.

During 1994 and 1995 Xavier University instituted 4 new courses with an environmental emphasis: *Seminar in Environmental Communications*, *Survey of Environmental Chemistry*, *Ecosystem Biology*, and *Chemical Toxicology*. During the same period, Tulane instituted a basic introductory course, *Introduction to Environmental Studies*, open to all Tulane and Xavier students. Tulane introduced *Environmental Chemistry* the same year. During the 1996/7 academic years, Tulane introduced an advanced course *Writing in Environmental Biology* with a companion course in the spring entitled *Exploring Environmental Issues*. Both universities were successful at efforts to infuse environmental topics into the overall curriculum to promote environmental literacy in all academic fields. Environmental Faculty Enrichment Seminars were held in May 1996 and 1997 including field trips to environmentally stressed rural and urban sites. The second year was devoted to the planning of the Mississippi River Basin Colloquium course. The Tulane interdisciplinary *Mississippi River Colloquium* was introduced in fall 1997 to 25 students; *Conservation Biology* was also developed and taught that fall. *Ecological Design* and *Environmental Mediation* were introduced in spring 1999. Xavier Environmental Forum Newsletters and the Tulane Enviro-Counterculture Catalogs were produced by and for students during this period.

Early in the project, a DOE-sponsored scholarship program was instituted at Xavier in which undergraduates were encouraged to apply for LIFE (Living Intelligently to Foster Earthcare) scholarships covering a research project during the academic year and/or summer internships. The scholars and interns were assigned faculty mentors to supervise them in research projects conducted during the academic year and summer internships. Monthly mentoring meetings with LIFE Scholars were held to obtain regular updates on their research projects. Poster presentation sessions were held each fall. Often the students spent the summer in government laboratories, particularly affiliated with DOE, to further enhance their education. During this project period, there were 28 LIFE Scholars and 30 LIFE Interns with 11 different majors and 29 faculty

mentors. Between 1996 and 1998, some Tulane doctoral students received partial funding from DOE for CBR Scholarships; 19 graduate students representing 10 departments with 13 different faculty advisors were funded to conduct research on environmental issues. For a complete listing, see Appendix B. In addition, more than 100 undergraduate and graduate students received support for training as part of the research team of investigators funded for this project.

C. Accomplishments of Collaborative Clusters

Studies in this project have defined: 1) the complex interactions that occur during the transport of contaminants, 2) the actual and potential impact on ecological systems and health, and 3) the mechanisms through which these impacts might be remediated. This project has been particularly relevant to the US DOE Environmental Restoration and Waste Management programs aimed at solving aquatic pollution problems in the DOE complex.

1. Biological Fate, Transport & Ecotoxicity of Toxic & Hazardous Waste in Mississippi River Basin (1993-1996): This project assessed the levels of xenobiotics in Devil's Swamp and studied their biological fate, transport, and exotoxicity and ultimately their potential toxicity to humans. The project developed a pharmacokinetics model for xenobiotic absorption and storage, distribution, and excretion by fish and crayfish. Studies to evaluate the physiological and biochemical effects of cadmium in the red swamp crayfish provided the first evidence in a crustacean that cadmium exposure results in hyperglycemia. Analysis of cypress cores from Bayou Trepagnier for heavy metals suggests cypress is a good indicator of long-term contamination patterns.

2. Assessment of Mechanisms of Metal-Induced Reproductive Toxicity (1993-1996): This cluster focused on field studies of the La Branche wetlands including Bayou Trepagnier. The group found that sediments contained high amounts of iron and aluminum at all sites and found significant amounts of lead, chromium, manganese and zinc. Additionally, all sites revealed the presence of saturated and unsaturated hydrocarbons over the 4 to 20-carbon chain length. Parameters monitored were sediment metal concentrations, nutrients, (phosphates, nitrates, nitrites, ammonia), water parameters (pH, alkalinity, temperature) and chlorophyll a concentrations. Many environmental parameters differed for Bayou Trepagnier when compared to those of neighboring bayous. Laboratory exposure studies of crayfish to metals revealed a time dependant accumulation of lead in all tissues studied except the ovaries. Chromium exposure studies demonstrated bioaccumulation in the heptatopancreas and muscle but not in other tissues. Biomarker studies for heavy metal toxicity include: 1) metallothionein induction in catfish hepatocytes; and 2) male reproductive markers (ploidy, superoxide dismutase, nitric oxide synthase and reactive oxygen species). Polarographic studies have revealed the bioaccumulation of lead and chromium in tissues of bullfrogs from Devil's Swamp and of lead in tadpoles exposed in the laboratory. Lab studies in crayfish indicate that metal treatments at the studied concentrations and lengths of exposure do not appear to interfere with oocyte maturation. This implies that this species may reproduce in metal contaminated environments and perpetuate the movement of metal in the food chain.

3. Bioremediation of Selected Contaminants in Aquatic Environments (1993-1996): The primary goal of this collaborative cluster was to determine the extent of

natural biodegradation of hazardous organics and biosorption of hazardous organics and heavy metals by the consortia of bacteria (aerobic, anaerobic, sulfate reducing, methanotrophic), fungi (mycorrhizal, white rot), and plants. This group performed anaerobic serum bottle studies to determine the toxicity of carbon tetrachloride in samples taken from Devil's Swamp, Bayou St. John, and Lake Pontchartrain. One focus was filamentous fungi, which have a greatly underutilized potential for bioremediation especially in terrestrial habitats. As a result of research during this period, it was determined that *Marasmiellus troyanus*, a litter rot species, is a potential effective method for bioremediation. Work was completed on the development of a method of encapsulating fungi in alginate for delivery to field studies for bioremediation. Another research study concluded that both sulfate reducing bacteria and methanogens are effective in the removal of chlorophenols. Studies on HCBD showed that anaerobic degradation of these low-soluble compounds is possible.

4. Pore-Level Flow of Microorganisms (1993-1998): Understanding the detailed pore-level behavior of microorganisms through porous media is essential for the development of effective *in situ* bioremediation strategies. This group developed integrated experimental and computational models of the pore-level behavior of microorganisms. The models included the detailed analysis of convection and diffusion of contaminant and microorganisms within micropores. During the project period, collaborations were initiated with the Center for Biofilm Engineering, an NSF-supported National Engineering Research Center, at Montana State University. In addition, these studies included chemotactic responses of swimming microorganisms to local concentration gradients. Microorganisms modify the pore structure due to adhesion to each other and the surrounding pore. These models incorporate reaction kinetics of these organisms to the toxic contaminant, and should predict patterns of bacterial transport related to *in situ* remediation. A fluid-dynamical model of porous media is under development. This model uses the immersed boundary method with randomly placed point forces used to approximate obstacles in the flow. This new method is computationally inexpensive, and may allow the simulation of flow through complex three-dimensional porous media.

5. Natural and Active Chemical Remediation of Toxic Metals, Organics and Radionuclides (1993-1996): The underlying theme of the research is that chemical remediation does occur naturally, and an understanding of such processes will help both in determining the fate of contaminants and in developing novel remediation strategies. Accordingly, the research cluster faculty chose to divide into two sub cluster sections, one, which studies natural, and the other active remediation. Among topics studied in natural remediation were the fate of heavy metal and organic contaminants discharged into aquatic environments, and the development of new technology to accurately assay metal contaminants partitioned into soils, water, and tissue. Among study topics in active remediation were the development of novel polymeric membranes and microporous solids for the entrapment of heavy metals, and the development of hybrid chemo-enzymatic oxidative schemes for aromatics decontamination. This group successfully synthesized a new polymer material designed to remove heavy metal ions from wastewater. Researchers also investigated the role of sediment acid volatile sulfides (AVS) in limiting the concentration of heavy metals in the water column. Data suggest that the Barataria estuary, in contrast to Bayou Trepagnier, has a limited capacity to absorb heavy metals via exchange reactions with sediment AVS. Earlier research has indicated that bayou bottom sediments are contaminated with lead, zinc, and chromium, but this project

has shown that spoil banks are the major source of contaminated water and sediment in the Bayou Trepagnier ecosystem.

6. Expert Geographical Information System (1993-1996): This cluster designed a GIS application to evaluate key indices of heavy metals bioaccumulation and histopathological effects on selected fish species in the Devil's Swamp and Bayou Trepagnier ecosystems. A 3-dimensional view of Devil's Swamp was created using the USGS elevation data combined with soil permeabilities. One group included enhancement of the design of the conceptual databases necessary to model various thematic data describing geographical, topographical, and environmental features of Bayou Trepagnier. A high quality human-computer intelligent interface was designed to support and facilitate the decision process for environmental impact assessment. Remediation Technologies Selection Program software was developed to evaluate and recommend a remediation technique for a given contaminated site, specifically in aquatic environments.

7. Fate & Transport of Radionuclides in Belarus Following Chernobyl Catastrophe (1993 Initiation Project-1996): This project studied the transport and fate of radionuclides in the Iput River basin including modeling the movement of contaminants. A non-linear curve-fitting scheme that can automatically interpolate and produce a mapping of the distribution of contaminants was developed. In addition to utilization of traditional methods that use systems of differential equations, the project developed the technique of neural networks as a way of mechanistically looking at the problem of radionuclide distribution.

8. Hazardous Wastes in Aquatic Environments (1994-1996): This cluster studied the uptake, accumulation, metabolism, toxicity and physiological effects of various environmentally important contaminants, inorganic and organic, in several wetland species that are interrelated through food webs. Researchers investigated the potential for developing and linking chemical and biological methods of remediation so as to encapsulate bioaccumulated ions in stable waste forms such as ceramics and/or zeolites. During the project period, ion-exchange materials were developed that are excellent for removal of either actinides or heavy metals from solution. These materials have high selectivity for the toxic ions and are therefore ideal for use in integrated chemical/biological remediation processes, which use duckweed (*Lemna gibba*) as the primary harvester of the pollutant metal ions.

9. Ecological Sentinels of Aquatic Contamination (1994-1996): The cluster examined the effects of contamination at population and community levels of aquatic ecosystems by integrating data from biomarker studies into models. The purpose of the study was to determine the fate of environmental contaminants in fish from a lateral floodplain swamp in the lower Mississippi River system, and assess the ecological risks contaminants pose for fish and other aquatic organisms in the system. The study concluded that although environmental levels were low, fish bioaccumulated contaminants, exhibiting higher concentrations at larger sizes and weights. The low environmental levels of contamination coupled with the lack of obvious community-level effects suggest that the effects of contamination in this system are mainly chronic (sublethal) and manifested mainly at the population and suborganismal level. In studying the cores of bald cypress trees located 2000 feet from Bayou Trepagnier, considerable amounts

of lead and zinc were discovered. This large amount of heavy metals located in rings corresponds temporally to the establishment of refineries in the adjacent area.

10. Biomarkers of Exposure and Ecotoxicity (1994-1998): The cluster identified and published biomarkers of exposure and ecotoxicity in wild fish and frogs exposed to multiple pollutants. Quantifiable histopathological biomarkers in the liver of spotted gar fish from Devil's Swamp have been developed from studies at Bayou Trepagnier. The Cytokine IL-1_, for example, was shown through these studies to be a reliable biomarker of exposure in ranid frogs exposed to Bayou Trepagnier sediments. The black bullhead catfish has been identified as a sentinel species for evaluation of the impact of contaminated sediments. Histopathological biomarkers in the gills of smallmouth and largemouth buffalo fish were identified as indicators of general fish health in contaminated ecosystems. Biomarkers of neuro-, immuno-, and developmental toxicity were identified in frogs exposed to contaminants from Devil's Swamp and Bayou Trepagnier. Field and laboratory studies indicate that frogs are excellent sentinel organisms for immune suppression. The information generated by this biomarkers research cluster resulted in an integrated multivariate model of biomarker responses in wild fish from contaminated ecosystems typical of the Mississippi River Basin.

11. Sensitive Rapid On-Site Immunoassay for Heavy Metals (1995-1999): Monoclonal antibodies to specific metal-chelate complexes were developed for quick, cost-effective assessments of metal contamination at field sites. The assay used an antigen inhibition format to measure the soluble metal ions. The sensitivity of the metal ion immunoassay can be modulated by changing the structure of the inhibiting antigen. Methods were developed to enable the extraction of heavy metals from soil and sediment samples in the field without recourse to strong acids, high temperatures, or cumbersome equipment. Additional funds were leveraged from the DOE Natural and Accelerated Bioremediation Research Program (NABIR) for a three-year project to conduct research and development activities to construct and test a hand-held, battery-operated instrument to conduct environmental immunoassays in the field. This new project complements the biological reagent development and characterization activities funded by the DOE-EM grant.

12. Flocculation Studies in Environmental Processes (1995 Initiation-1998): This cluster studied flocculation phenomena in suspensions and emulsions resulting from the process of aggregation of suspended particles. Flocculation is not only a determining factor in natural environmental processes, but also constitutes a tool for the cleaning of hazardous waste waters which contain suspended solid and emulsified oils. The research included study of some interfacial phenomena, which affect natural environmental processes, as well as separation processes used for volume reduction of two-phase wastes. In particular, the project was a collaborative effort at both experimental and theoretical levels to better understand flocculation kinetics in model hazardous suspensions. The goal of this project was to better understand the fundamental mechanisms that are the basis of flocculation processes, and to specifically produce remediation as well as modeling and predictive tools. These can be used for practical applications of environmental engineering to Bayou Trepagnier and relevant DOE sites.

13. Fate and Transport Modeling in Louisiana & Belarus (1996 Initiation Prj-1998): This cluster formulated the problem of aquatic transport in the Iput River of Belarus and applied that knowledge to the transport of sediment and pollutants in the aquatic environments of Louisiana. A hydrodynamic model (DYNHYD5) was developed. The computed velocities, depths, and segment geometry from DYNHYD5 was used as input to the water quality model (WASP5) to predict heavy metal and PAH fate and transport in the Bayou. Output from these models provided the means of quantifying the affect of water depth, flow rates, tidal surges, and water chemistry on lead concentrations and the sediments of the bayou. It was found that the tidal action of the bayou is effective in dispersing the water column lead in both the upstream and downstream directions. Cohesive and non-cohesive sediment transport under conditions of tidal flow was successfully simulated. Results indicated that during high tide fine silts and clays entering the Bayou will distribute throughout the bayou, but sands will sediment within the first 200 meters. Under high flows from the tributaries into the bayou, penetration of the silts and clays is reduced due to the backwater effects produced by the tributary flow.

14. Process Dynamics of Lead Transport (1997-1998): These studies were conducted to determine the quantity and rate of accumulation of heavy metals, especially lead, in the growth rings of bald cypress trees growing in the area beyond the spoil bank to determine the mobility of contaminant in a contaminated wetlands system. Findings indicated that lead contamination is lower in trees along the spoil bank where soil is more heavily contaminated with lead than in the area further inland where the soil is less contaminated. Why bald cypress trees located in less contaminated soil are more heavily contaminated with lead than the bald cypress trees located in the adjacent soils which have significantly higher lead contamination is not known. One variable that may have an influence on these phenomena is the unique growth pattern of cypress in dry versus wet environments. In wet environments the roots system is more robust and may therefore have greater exposure. In the cypress-tupelo community abutting Bayou Trepagnier, rates of lead uptake differ in bald cypress trees depending upon the community and microhabitat; lead may also be much more mobile in this community in comparison to other forested ecosystems.

15. Hydrophilic Polymeric Membranes (1997-1998): The goals of this research project were to fabricate and characterize polyphosphazene-based hydrophilic membranes and test the membranes for the separation of radionuclides cesium and strontium. Membranes were fabricated with charged or highly polar side chain groups, which impart anti-fouling characteristics on the membranes and make them suitable for separation applications involving mixed wastes. The choice of incorporating these functional groups into a polyphosphazene backbone was based on the known stability of phosphazene polymers to thermal, chemical, and radiolytic attack and the relative ease of functionalizing polydichlorophosphazene base-polymer.

III. Conclusion

This grant, awarded to the CBR in 1992, represents an integrated, synergistic minority/majority partnership between Tulane University and Xavier University that creates joint basic research and public outreach opportunities supportive of DOE's environmental restoration mission. The objectives of the grant were to provide a vertically integrated program of basic and applied

research, technology development, technology transfer, and education in support of DOE-EM programs relating to environmental restoration and waste management in aquatic systems.

During the project period, the bayou and spoil banks of Bayou Trepagnier were mapped and analyzed in terms of risks associated with the levels of hydrocarbons and metals at specific sample sites. Data from contaminated sample sites have been incorporated into a large database and used in GIS analyses to track the fate and transport of heavy metals from spoil banks into the surrounding marsh. These data are crucial to understanding how heavy metals move through wetlands environments. These data, coupled with plume characterization data, indicate that Bayou Trepagnier is a model system for understanding how wetlands populations of fish, amphibians, and plants respond to long-term hydrocarbon and metals contamination. The hydrocarbon plume, characterized in Bayou Trepagnier through fate and transport studies, is composed of a variety of polyaromatic hydrocarbons (PAHs) that are not only toxicologically hazardous, but also bind receptors related to endocrine functions. Such binding can cause disruptions of endocrine functions in fish and amphibians, resulting in adverse effects on development and reproduction. Studies concerning how these PAHs bind specific target receptors not only provide information about previously undefined ecotoxic effects, but also serve as the basis for new technologies for hazard monitoring and remediation.

Initial characterization of fish populations from Bayou Trepagnier indicated that the species diversity is low. Some field validations of biomarkers of mixed chemical exposure in spotted gar developed in Devil's Swamp were verified in Bayou Trepagnier gars. A multivarite model for assessing ecotoxicity in fish and frogs was developed. Variables included in the model were: pathology biomarkers, taxonomy, trophic structure, health/disease, molecular biomarkers, and population dynamics. Specific biomarkers of exposure in fish were described and published. These biomarkers include ectopic gonads in the Japanese medaka fish (*Oryzias latipes*), developmental heart defects in medaka, liver lesions (melanomacrophage centers) in the spotted gar, gill lesions in two species of buffalo fish, esterase depression in the liver and brain of spotted gar and other species. The cytokine interleukin 1 (IL-1ß) was shown to be an evolutionarily conserved biomarker of exposure to heavy metals (mercury) and organics such as hexachlorobenzene. Initial biomarkers results indicated that Bayou Trepagnier is an ideal site for studying endocrine disruption and reproductive/developmental impacts of mixed chemical pollution typical of DOE sites.

The CBR studies funded through this grant have resulted in US private sector investments, international collaborations, development of new technologies, and substantial new knowledge concerning the effects of hazardous materials on human and ecosystem health. Some of the accomplishments resulting from this DOE-sponsored collaboration are summarized below.

New Knowledge from Basic Research (Project Tasks 1-3 & 6): DOE-EM research at CBR resulted in 56 studies and 173 publications with support for more than 300 faculty and students at Tulane and Xavier Universities. While the focus of these studies is the Mississippi River Basin as related to DOE cleanup operations, their ultimate applications clearly go beyond state and institutional boundaries with technological applications to public and private interests throughout the world. Reflecting this applicability, the project:

- Provided a more complete understanding of problems of contaminated aquatic systems;

- Undertook a research program for the development of new technologies related to hazard monitoring; and
- Produced models to exemplify how the cleanup technology development process can be guided through ecological and risk analyses;

Ecosystem Characterization (Project Tasks 2, 3 & 7): This project conducted studies of identification, characterization, and monitoring of contaminants in Bayou Trepagnier as well as the characterization of histopathological, physiological, and molecular biomarkers of exposure in support of the DOE-EM mission. By characterizing the magnitude and ecotoxicity of contaminants in aquatic environments of the Mississippi River Delta Basin, this research has resulted in an integrated ecosystem database of pollutants including heavy metals, hydrocarbons, and other organic compounds. These data have been used for other DOE-EM studies that have developed biomarkers of ecotoxicity in contaminated wetland environments. These data have also been used to assess actual and potential impacts of these contaminants on ecological systems and health as well as the mechanisms leading to remediation method selection.

Technology Development (Project Tasks 2 & 3): Innovative environmental technologies resulting from this project support the DOE-EM mission in two areas, namely hazard monitoring and risk assessment with appropriate remediation based on that assessment. These results advance the current state of knowledge in remediation technologies and can result in substantial cost savings for DOE and other public and private entities in future remediation efforts. Some of these technologies include:

- ***"Molecular Machines" for Hazard Monitoring and Risk Assessment:*** Through artificial cell engineering, the goal was to utilize biological receptor response for assessments of bioavailability and risk for contaminants in the environment. These "molecular machines" would replace both the contaminant measurement phase of risk assessment, and the biomarker validation phase which in current work is carried out by exposing animals to field sediments in a lab. Application of these new technologies potentially represents considerable savings for DOE in hazard assessment work related to risk-based prioritization of sites to clean up. Development of these technologies will produce a new generation of simple devices that can detect exposure and also be calibrated to predict risk and associated cleanup levels. These constructs may also be adapted for use in binding contaminants to accomplish cleanup.

- ***Endocrine Disruptor Research for Environmental Hazard Monitoring:*** As with the "molecular machines," this study utilizes the novel concept of biological receptors as an indicator of contamination. This study differs in its use of *in vitro* and *in vivo* assays to determine hormonal activity of various chemicals at concentrations measured in the environment. The global impacts of environmental estrogens and other endocrine-disrupting chemicals have become a major international concern due to potential long-term impacts on human health and entire ecosystems. Results from these studies could ultimately be utilized to assess the type of risk in various ecosystems.

- ***Sensitive Rapid On-Site Immunoassay for Heavy Metals:*** Further research on the immunoassay will contribute to developments in the metals and radionuclide remediation

product line of the DOE-EM subsurface contaminant focus area as well as its characterization, monitoring and sensor technology-crosscutting program.

- ***Polymeric Membranes for Separations of Contaminants from Water:*** Development of this technology could contribute to advances in the short-lived radionuclide product line in DOE-EM efficient separations and processes crosscutting program. The Hanford Site's Tri-Party Agreement requires that tritiated water be treated or removed.

- ***Pore-level Microorganism Behavior Modeling for Optimizing Bioremediation:*** New developments in modeling have been achieved that track the movement of microorganisms through various environmental media. The models assess responses of swimming microorganisms to local contaminant concentration gradients and account for microbial adhesion to each other and to surrounding pore structures. This modeling advance will aid significantly with *in situ* remediation efforts. These studies relate to the development of technologies for the DOE subsurface contaminant focus area.

- ***Bioremediation Techniques Utilizing Fungi and Bacteria:*** A patent application for encapsulating fungal strains that degrade hydrocarbons has been submitted. This research contributes to remediation processes in the organics and the DNAPL product lines in the DOE-EM subsurface contaminant focus area.

Preliminary work has been initiated to explore the design of molecular machines that will incorporate the use of functional bio-molecules, usually receptor molecules, coupled to a biosensor to detect hazardous chemical: receptor interaction. The activated biosensor responds by giving off or absorbing photons of light. These biologically engineered constructs are fixed to support systems which may be solid or flexible but can be placed in the field and monitored by light storage devices or connected to electronic monitoring systems. Tulane and Xavier Universities have the capacity to handle all stages, including formulation of the devices. The Tulane Department of Biomedical Engineering, for example, has a laboratory for artificial cell engineering which will is instituting cutting edge technologies for the combination of biological systems with artificial materials.

International Collaboration (Project Tasks 4 & 6): CBR, in collaboration with two institutes in the Republic of Belarus, namely the Institute of Radioecological Problems (IREP) and the Committee on Radiation and Environmental Monitoring (CREM), studied transport and fate of radionuclides in the Iput River Basin. The result is a modeling system that can automatically interpolate and produce a mapping of the contaminants' distribution. This research on "real world" catastrophic radionuclide contamination from Chernobyl has direct applications and benefits to DOE sites where predictive modeling of aqueous phase fate and transport of pollutants is essential.

Education and Public Outreach (Project Task 5): DOE-EM funding has enabled the CBR to deliver on its commitment to educate and inform the public on human and ecosystem health at local, regional, national, and international levels. A comprehensive education program aimed at producing graduates who can successfully carry out the DOE mission of environmental restoration and waste management was developed. In addition to the "greening" of existing

courses, Environmental Studies programs and new environment-related courses were added to the curricula at both universities. Through outreach efforts and educational resources of both universities, DOE-EM funding has made environmental issues accessible at a local level. Xavier University, in particular, has increased awareness of environmental risks and related health factors among minority communities that are traditionally underserved in these areas.

Through the rapid advances in information technology, the CBR has utilized the international outreach and educational capabilities of the Internet. Through its home web site (www.cbr.tulane.edu) and its latest research site (http://e.hormone.tulane.edu), the CBR is providing an educational service and interactive forum where the general public, students, educators, journalists, policy makers, and scientists can obtain accurate, timely information on environmental issues. It has become a "virtual" classroom for many high schools and colleges throughout the nation. The CBR sites are continually changing with the needs of its users.

Public and Corporate Involvement (Project Task 7): The project has yielded significant advances in public outreach and communication of these environmental risks. Some work was conducted in cooperation with Shell Oil Company, which had produced a remediation plan for Bayou Trepagnier. Information gathered by Shell and by the DOE-funded CBR researchers was shared freely, and the CBR was asked to advise Shell concerning the suitability of proposed remedial actions. Corporate interest in this DOE-EM research resulted in more than $2M of related investments from Shell Oil, TRW, Freeport McMoRan, and Uniroyal during the project period.

Related Research Important to DOE (Project Task 8): The research conducted through DOE-EM support has resulted in significant enhancement in fundamental knowledge specifically targeted to environmental issues of concern to DOE. One leveraged source of additional funding was a four-year CBR project (September 1996 to 2000) as a part of the DOE Environmental Management Science Program to conduct an interdisciplinary ***Environmental Analysis of Endocrine Disrupting Effects from Hydrocarbon Contaminants in the Ecosystem.*** The objective of this project was to determine how environmental contaminants, namely hydrocarbons, act as hormones or anti-hormones in different species present in aquatic ecosystems. Major components of the research included:

- a biotechnology based screening system to identify potential hormone mimics and antagonists;
- an animal screening system to identify biomarkers of endocrine effects; and
- a literature review to identify compounds at DOE sites that are potential endocrine disruptors.

Species of particular interest in this study were those that can serve as sentinel species (e.g., amphibians) and thus provide early warning signals for more widespread impacts on an ecosystem and its wildlife and human inhabitants. The activities employed by this project to determine these impacts included development of biotechnology screens (*in vitro*), animal screens (*in vivo*), other analyses of aquatic ecosystem biomarkers of exposure, and real-time data collection and dissemination through innovative environmental informatics.

This project elucidated how chemicals in the environment, including those from DOE activities, can signal (and alter) the development of a number of species in aquatic ecosystems. These

signals can have detrimental impacts not only on an organismal level, but also on community, population, and entire ecosystem levels, including humans. Results from this research project provided information on endocrine disrupting contaminants for consideration in DOE risk analyses for determining cleanup levels and priorities at contaminated DOE sites.

The CBR has fifteen years of experience in developing model aquatic ecosystems for evaluating environmental problems relevant to DOE cleanup activities. Using biotechnology screens and biomarkers of exposure, CBR research has demonstrated that chemicals in the environment can signal the development of species in aquatic ecosystems, as well as show detrimental impacts on community, population, and the ecosystem, including human health.

With a three-year $2.5M cooperative agreement beginning in 2001 with the DOE National Energy Technology Laboratory (NETL) Industry and University Program, the CBR has focused on the critical long-term stewardship needs associated with the nation's nuclear waste legacy. This program has assisted the DOE in defining, creating, and implementing a research agenda that is cost-effective, credible, and scientifically sound to ensure protection of human health and the environment for future generations. The CBR project uses the best available expertise within the two universities as well as partnerships with other academic, public, and commercial entities. Through the CBR, Tulane and Xavier Universities have partnered with the Office of Environmental Management to lay the groundwork for an effective research agenda that has become part of the DOE long term stewardship science and technology program and institutional management of the DOE complex.

List of Acronyms & Abbreviations

AA	Atomic Absorption (Spectrometer)
ACS	American Chemical Society
ASE	accelerated solvent extraction
ASMS	American Society of Mass Spectrometry
ATA	anaerobic toxicity assay
ATR	attenuated total reflectance
AVS	acid volatile sulfides
CBR	Center for Bioenvironmental Research
CF	chloroform
CHNOS	Carbon, Hydrogen, Nitrogen, Oxygen and Sulfur Analyzer
CHO	chinese hamster ovary
CIF	Coordinated Instrumentation Facility
COC	colloidal organic carbon
COD	chemical oxygen demand
CT	carbon tetrachloride
DMC	Data Management Core
DOC	dissolved organic carbon
DOE	US Department of Energy
DOE-EM	US Department of Energy Office of Environmental Management
DSC	differential scanning calorimetry
DYNHYD5	hydrodynamic model
EcR/RXR	ecdysone receptor
ECD	electron-capture detector
ED-XRF	Energy Dispersive X-ray Fluorescence (Spectrometer)
EEOB	Ecology, Evolution & Organismal Biology (EEOB)
EFES	Environmental Faculty Enrichment Seminar
EM	environmental restoration and waste management (Department of Energy)
ENST	Environmental Studies (Tulane University)
ERE	ecdysone response element
ESIT	Environmental Studies Instructional Technology (Tulane University)
FETC	Federal Energy Technology Center
FID	fire-ionization detector
FTIR-ATR	Fourier transform infrared-attenuated total reflectance
GC	gas chromatography
GC/MS	Gas Chromatograph/Mass Spectrometer
GCRL	Gulf Coast Research Laboratory
GFAAS	Graphite Furnace Atomic Absorption Spectrometer
GIS	Geographical Information System
HCB	hexachlorobenzene
HCBD	hexachloro-1,3-butadiene
HBCU/MI	Historically Black Colleges and Universities and Minority Institutions
HCBZ	hexachlorobenzene
HMW DOC	high-molecular weight dissolved organic carbon

ICP	inductively-coupled plasma
ICP-AES	Inductively Coupled Plasma - Atomic Emission Spectrometer
IEC	ion-exchange capacity
IEF	isoelectric focusing
IL	interleukin
IREP	Institute of Radioecological Problems (Minsk, Russia)
LAS	Liberal Arts & Sciences
LIFE	Living Intelligently to Foster Earth Care (Xavier University)
LUMCON	Louisiana University Marine Consortium
MC	methylene chloride
MCB	Molecular and Cellular Biology (Tulane University)
MPB	methane-producing bacteria
NMR	Nuclear Magnetic Resonance (Spectrometer)
ORNL	Oak Ridge National Laboratory
PAH	polyaromatic hydrocarbons
PCB	polychlorinated biphenyls
PCR	polymerase chain reaction
POC	particulate organic carbon
POP	sulfonated poly[bis(3-methyphenoxy)phosphazene]
PTFE	polytetrafluoroethylene
PPB	parts-per-billion
PPM	parts-per-million
QA	quality assurance
QC	quality control
RFP	request for proposal
RIOMAR	river-dominated ocean margins
RLIMS	Relational Laboratory Information Management System
SAXS	small-angle X-ray scattering
SEM	scanning electron microscope
SPHTM	School of Public Health & Tropical Medicine (Tulane University)
SRB	sulfate-reducing bacteria
SRT	solids retention time
TCE	trichloroethylene
TDC	Technology Development Core
TEM	transmission electron microscope
TGA-MS-IR	Thermal Gravimetric Analyzer- Mass Spectrometer-InfraRed (Spectrometer)
TMA	thermal mechanical analyzer
TRI	Toxic Release Inventory
TU	Tulane University
USGS	US Geological Survey
UTM	Universal Transverse Mercator
WASP5	water quality model
WAXD-SAXS	wide & small-angle X-ray diffraction
WIC	water-in-CO2
XRD	X-ray diffractometer
XRF	X-ray Fluorescence (Spectrometer)

XU	Xavier University
XUSEC	Xavier University Student Environmental Club

Appendix A

List of Publications & Presentations

Hazardous Materials in Aquatic Environments of the Mississippi River Basin

List of Publications in Peer Reviewed Journals

Abdelghani, A.A., Pramar, Y.V., Mandal, T.K., Tchounwou, P.B., and Heyer, L. Levels and Toxicities of Selected Inorganic and Organic Contaminants in a Swamp Environment. Journal of Environmental Science and Health. 1995, B30(5): 717-731.

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Anderson, M.B., Preslan, J.E., Jolibois, L.S., Bollinger, J.E. and George, W.J. Bioaccumulation of Lead in Red Swamp Crayfish (Procambarus clarkii) Journal of Hazardous Materials. 1997, 54: 15.

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Pintauro, P.N. "Polyphosphazene-Based Membranes for SPE Fuel Cells," DARPA Direct Methanol Fuel Cell Program review meeting, November 6-7, 1997. Sante Fe, New Mexico.

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Pintauro, P.N., Guo, Q., Tang, H., and O'Connor, S. "Polyphosphazene-Based Membranes for PEM Fuel Cells," Spring National Meeting of the Electrochemical Society, May 3-8, 1998. San Diego, California.

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Ramamurthy, V. "Molecular Dynamics of Chemical Reactions within Zeolites," NSF Workshop on Photoresponsive Materials, November 4-8, 1996. Catalina Island, CA.

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Thiyagarajah, A., and Hartley, W.R. "Hyaline Droplet Nephropathy and Other Renal Lesions in Selected Fish Species from a Contaminated Swamp in the Mississippi River Basin," 16th International Symposium of the Society of Toxicologic Pathologists, June 22-26, 1997. Beaver Creek, Colorado.

Thiyagarajah, A., and Hartley, W.R. "Pathology of Sailfin Mollies (*Poecilia latipinna*) and Sheepshead Minnows (*Cyprinodon variegatus*) from a Petrochemical Contaminated Bayou," Ninth International Symposium on Pollutant Responses in Marine Organisms (PRIMO 9), April 27-30, 1997. Bergen, Norway.

Thiyagarajah, A., and Hartley, W.R. "Prevalence of Gill Protozoans in Fish from Selected Swamps in Louisiana," Symposium on Pathogens and Diseases of Fish in Aquatic Ecosystems: Implications in Fisheries Management, June 3-4, 1997. Portland, Oregon.

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Thiyagarajah, A., Hartley, W.R., and Anderson, M.B. "Histopathology of a Lung Cyst in a Spotted Gar (*Lepisosteus oculatus*) from a Contaminated Bayou in Louisiana," 15th International Symposium of the Socirety of Toxicologic Pathologists, June 9-13, 1996. St. Louis, Missouri.

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Thiyagarajah, A., Hartley, W.R., Broxson, M., and Major, S. "Pigments and Other Lesions in the Liver of Two Species of Buffalo Fish from the Mississippi River Basin," Joint Meeting of the American Fisheries Society Fish Health Section and Eastern Fish Disease Workshop, July 19-22, 1995. Syracuse, New York.

Thiyargarajah, A., Hartley, W.R., Mizell, M., and Nelson, C. "Yellow Bullhead Fish (*Ictalurus natalis*) as Sentinels of Aquatic Ecosystem Health," International Symposium

on Ecosystem Health and Medicine: Integrating Science, Policy, and Management, June 19-23,1994. Ottawa, Ontario, Canada.

Tsega, Y. Eschenazi, E., and Michaelides, E.E. "Dynamics of Particle Dispersion in Double Frequency Driven Fluid Flows," 49th Annual Meeting of the APS Division of Fluid Dynamics, November 24-26, 1996. Syracuse, New York

Wang, W., and O'Connor, S.E. "Synthesis and Characterization of Polyallylphosphazenes," Southeast/Southwest Regional American Chemical Society Meeting, Decembewr 1995. Memphis, Tennessee.

Watanabe, K.H., Regens, J.L, Hodges, D.G., Johnson, K., and Swalm, C.M. "Evaluating the Bioaccumulation of Heavy Metals and Organics in an Aquatic Environment," HSRC/WERC Joint Conference on the Environment, May 21-23, 1996. Albuquerque, New Mexico.

Watanabe, K.H., Regens, J.L, Hodges, D.G., Johnson, K., and Swalm, C.M. "The Application of Ecological Modeling to Assess the Bioaccumulation of Contaminants in an Aquatic Ecosystem," Ecological Summit 96, August 19-23 1996. Copenhagen, Denmark.

Watanabe, K., Bart, H., Hartley, W. and Martinat, P. "Mathematical Modeling of Bioaccumulation and Population Dynamics in Bayou Trepagnier," conference on Bayou Trepagnier: Characterization, Fate & Transport, Ecological Effects and Risk Analysis, July 14, 1997. New Orleans, Louisiana.

Watanabe, K.H., Martinat, P., and Bart, H.L., Jr. "Bioaccumulation of Hydrophobic Organic Chemicals in the Spotted Gar (L. *oculatus*)," International Society for Ecological Modeling , August 2-6, 1998.

Whitbeck, J.L. "Bayou Trepagnier: Can We Detect Impacts on the Terrestrial Ecosystem?" University of New Orleans conference Clean Enough? A Conference on Mississippi River Quality, September 1997. New Orleans, Louisiana.

Whitbeck, J.L. "Effects of Long-Term Heavy Metal Pollution on Mycorrhiza Establishment and the Mycorrhizal Fungal Community in a Bottomland Hardwood Forest," Soil Ecology Society Meeting, May, 1997. Manhattan, Kansas.

Whitbeck, J.L., Barmore, J., Carroll, J., Florian, E. and Stevens, B. "Impact of Long-Term Heavy Metal Pollution on Hardwood Bottomland Forest Productivity, Plant Community Structure and Plant Metal Accumulation," University of New Orleans' conference Clean Enough? A Conference on Mississippi River Quality, September 1997. New Orleans, Louisiana.

Whitbeck, J.L., Carroll, J. and Stevens, B. "Impact of Long-Term Heavy Metal Pollution on Hardwood Bottomland Forest Plant Community Structure and Productivity," 1997 meeting of the Ecological Society of America. New Orleans, Louisiana.

Williams, K., and Zhang, J.H. "Infrared Spectroscopic Study on Some Cobalt(II) Phosphate Solids," 3rd Annual HBCU/Private Sector Energy Research and Development Technology Transfer Symposium, April 1995. Atlanta, Georgia.

Wycisk, R., Pintauro, P.N., Wang, W., and O'Connor, S.E. "Polyphosphazene Ion-Exchange Membranes," 7th Annual Meeting of North American Membrane Society, May 1995. Portland, Oregon.

Wycisk, R., and Pintauro, P.N. "Fabrication and Characterization of Polyphosphazene Cation Exchange Membranes,: North American Membrane Society Annual Meeting, May 1996. Ottawa, Canada.

Wycisk, R., Graves, R., and Pintauro, P.N. "Sulfonated Polyphosphazenes: a New Class of Separator Materials for PEM Fuel Cells," Electrochemical Society Fall Meeting, October 1996. San Antonio, Texas.

Xu, S, John, V., McPherson, G., Grimm, D., Akkara, J., and Kaplan, D. "The Removal of Aromatics from Aqueous Streams through Enzymatic Polymerization," 16th International Symposium on Biotechnology for Fuels and Chemicals, May 1994. Gatlinburg, Tennessee.

Xu, S, John, V., McPherson, G., Akkara, J., and Kaplan, D. "On Coupling Chemical and Enzymatic Oxidations to Remove Armoatics," ACS Conference on Emerging Technologies in Hazardous Waste Management VI, September 1994. Atlanta, Georgia.

Xu, S, John, V., McPherson, G., Grimm, D., Akkara, J., and Kaplan, D. "A Chemical-Enzymatic Methoid to Remove Aromatics from Aqueous Streams, August 1994. Washington, DC.

Zhang, J.J., O'Connor, S.E., Tao, C., and O'Connor, C.J. "Hydrothermal Synthesis and Magnetic Study of Cobalt (II) Phosphate Complexes," 209th ACS National Meeting, April 1995. Anaheim, California.

Appendix B

Intellectual Development
Scholars & Interns

Hazardous Materials in Aquatic Environments of the Mississippi River Basin

Xavier University LIFE (Undergraduate) Scholars & Interns, 1992/3 - 1997/8

Student Name	Program	Major	Mentor
Lawrence Carter III	1992/3 Scholar	Chemistry	Jian Zhang, PhD
Camille Fouche	1992/3 Scholar		
Temperance Smiley	1992/3 Scholar	Biology	Peter Martinat, PhD
Tamara Mosby	1992/3 Scholar	Philosophy	Beverly Wright, PhD
Randy Dorsey	93/4 Scholar/Intern	Pharmacy	Richard Ochillo, PhD
Tamara Mosby	93/4 Scholar/Intern	Philosophy	Beverly Wright, PhD
Temperance Smiley	93/4 Scholar/Intern	Biology	Peter Martinat, PhD
LaMoyne Williams	93/4 Scholar/Intern	Biology	Howard Mielke, PhD
Lauren Nicholas	93/4 Scholar/Intern	Communications	Stephen DuPlantier, PhD
Randy Dorsey	94/5 Scholar/Intern	Pharmacy	Richard Ochillo, PhD
Tamara Mosby	94/5 Scholar/Intern	Philosophy	Beverly Wright, PhD
Temperance Smiley	94/5 Scholar/Intern	Biology	Peter Martinat, PhD
LaMoyne Williams	94/5 Scholar/Intern	Biology	Howard Mielke, PhD
Lauren Nicholas	94/5 Scholar/Intern	Communications	Stephen DuPlantier, PhD
Tiffany Zeno	94/5 Scholar/Intern	Communications	Stephen DuPlantier, PhD
Shea Conway	94/5 Scholar/Intern	Political Science	Stephen Peychaud, PhD
Sherrika Daniel	95/6 Scholar	Chemistry	Shubha Kale Ireland, PhD
Kefla George	95/6 Scholar	Biology	Shubha Kale Ireland, PhD
Clanford Johnson	95/6 Scholar	Chemistry	Guangdi Wang, PhD
LaMoyne Williams	95/6 Scholar	Biology	Howard Mielke, PhD
Tiffany Zeno	95/6 Scholar	Communications	Stephen DuPlantier, PhD
Jameel Ugdah	95/6 Scholar	Engineering	Biman Das, PhD
Monique Davis	95/6 Intern	Pharmacy	Tien Huang, PhD
Deshawn Fontenot	95/6 Intern	Pharmacy	Patience Obih, PhD
James Harry	95/6 Intern	Pharmacy	Patience Obih, PhD
Kimberly Houston	95/6 Intern	Pharmacy	Patience Obih, PhD
Patricia Kimani	95/6 Intern	Chemistry	Robert Blake, PhD
Chad Broussard	96/7 Scholar	Communications	Stephen DuPlantier, PhD
Jeandele Frank	96/7 Scholar	Biochemistry	Tuajuanda Jordan-Starck, PhD
Clanford Johnson	96/7 Scholar	Chemistry	Guandgi Wang, PhD
Kefla George	96/7 Scholar	Biology	Shubha Kale Ireland, PhD
Dorothy Lewis	96/7 Scholar	Chemistry	Rosemary Effiong, PhD
Rena Price	96/7 Scholar	Chemistry	Guangdi Wang, PhD
Adonis Taylor	96/7 Scholar	Biology	Shubha Kale Ireland, PhD
Jameel Ugdah	96/7 Scholar	Physics	Biman Das, PhD
Julian White	96/7 Scholar	Biochemistry	Patience Obih, PhD
Breshana Johnson	96/7 Intern	Chemistry	Jian Zhang, PhD
Jarrett Cain	96/7 Intern	Chemistry	Jian Zhang, PhD
Lawrence Chatmon	96/7 Intern	Biology	Etim Eduok, PhD
Kora Cooper	96/7 Intern	Biology	Marc Welt, PhD
Jamila Davison	96/7 Intern	Biology	Shubha Kale Ireland, PhD

Xavier University LIFE (Undergraduate) Scholars & Interns, 1992/3 - 1997/8

Student Name	Program	Major	Mentor
Joseph Grier	96/7 Intern	Physics/Engineering	Biman Das, PhD
Shandra Mobley	96/7 Intern	Psychology	Reginald Gougis, PhD
LaDonna Nettles	96/7 Intern	Computer Science	Theresa Beaubouef, PhD
Loan Nyguyen	96/7 Intern	Pharmacy	Patience Obih, PhD
Mamie Thomas	96/7 Intern	Biochemistry	Robert Blake,PhD
Terry Wand	96/7 Intern	Biology	Shubha Kale Ireland, PhD
Christopher Watts	96/7 Intern	Chemistry	Rosemary Effiong, PhD
Kamisha Dantzler	97/8 Scholar	Biology	David Buckalew, PhD
Christina Davis	97/8 Scholar	Physics	Elia Eschenazi, PhD
Tiffany Pennick	97/8 Scholar	Biology	David Buckalew, PhD
Derrick Robinson	97/8 Scholar	Biology	Michelle Bell, PhD
Julian White	97/8 Scholar	Biochemistry	Patience Obih, PhD
Christina Bolden	97/8 Scholar	Chemistry	Guangdi Wang, PhD
Nafessa Hunt	97/8 Scholar	Biology	Stephen Glaseen, PhD
Dorothy Lewis	97/8 Scholar	Chemistry	Guangdi Wang, PhD
Karmon Mitchell	97/8 Scholar	Biology	Shubha Kale Ireland, PhD
Allen Parker	97/8 Scholar	Biology	Michelle Bell, PhD
Terry Wand	97/8 Scholar	Biology	Shubha Kale Ireland, PhD
Rhonda Alexander	97/8 Intern	Biology	David Buckalew, PhD
Reginald Berry	97/8 Intern	Pharmacy	Tien Wang, PhD
Kora Copper	97/8 Intern	Biology	Marc Welt, PhD
Jamila Davison	97/8 Intern	Biology	Shubha Kale Ireland, PhD
Jeandele Frank	97/8 Intern	Biochemistry	Tuajuanda Jordan-Starck, PhD
Dallis Green	97/8 Intern	Biology	Etim Eduok, PhD
Nicholas Jones	97/8 Intern	Chemistry	Etim Eduok, PhD
Monique Lewis	97/8 Intern	Chemistry	Guangdi Wang, PhD
Trimiko Melancon	97/8 Intern	English	Michelle Levy, PhD
Shanda Mobley	97/8 Intern	Psychology	Reginald Cougis, PhD
LaDonna Nettles	97/8 Intern	Computer Science	Alex Coles, PhD
Loan Nguyen	97/8 Intern	Pharmacy	Patience Obih, PhD
Christian Onuh	97/8 Intern	Pharmacy	Patience Obih, PhD
Kevin Simmons	97/8 Intern	Biology	LeMoyne Williams
Christopher Sparrow	97/8 Intern	Chemistry	Etim Eduok, PhD
Courtland Stimely	97/8 Intern	Computer Science	Alex Coles, PhD
Diane Sweezer	97/8 Intern	Political Science	Sally O'Connor, PhD
Erica Taylor	97/8 Intern	Biology	David Buckalew, PhD
Latoya Woods	97/8 Intern	Biology	David Buckalew, PhD

CBR (Graduate) Scholars, 1996/7 - 1998/9

Student Name	Program	Department	Mentor
Regina Graham	1996/7 Scholar	MCB*	Gary Hoyle, PhD
Lloyd Jolibois	1996/7 Scholar	Anatomy	Mary Lou Anderson, PhD
Kevin Lorick	1996/7 Scholar	MCB*	William Toscano, PhD
Paul Taverna	1996/7 Scholar	Biomed Engeering	Kirk Bundy. PhD
Bridgette Collins	1996/7 Scholar	MCB*	John McLachlan, PhD
Ramzi Kafoury	1997/8 Scholar	Pulmonary Disease	Mitchell Friedman, MD
Gerald Goldstein	1997/8 Scholar	Env Health Sciences	William Hartley, DSc
Regina Graham	1997/8 Scholar	MCB*	Gary Hoyle, PhD
Glen Irvin	1997/8 Scholar	Chemical Engeering	Vijay John, PhD
Gerhard Piringer	1997/8 Scholar	Civil & Env Engeering	Sanjoy Bhattacharya, PhD
Stacey Ricci	1997/8 Scholar		
Mingyi Wen	1997/8 Scholar	Env Health Sciences	William Hartley, DSc
Brian Vuillemenot	1997/8 Scholar	MCB*	Gary Hoyle, PhD
Richard Madura	1997/8 Scholar	Civil & Env Engeering	Sanjoy Bhattacharya, PhD
Jin Xu	1997/8 Scholar	Pathology	Gil Morris, PhD
Gerald Goldstein	1998/9 Scholar	Env Health Sciences	William Hartley, DSc
Regina Graham	1998/9 Scholar	MCB*	Gary Hoyle, PhD
Brian Vuillemenot	1998/9 Scholar	MCB*	Gary Hoyle, PhD
James Delahanty	1998/9 Scholar	MCB*	Diane Blake, PhD
Mingyi Wen	1998/9 Scholar	Env Health Sciences	William Hartley, DSc
Corey Lambert	1998/9 Scholar	EEOB**	Tom Bianchi, PhD
Melissa Shettlemore	1998/9 Scholar	Biomed Engeering	Kirk Bundy, PhD
Gerhard Piringer	1998/9 Scholar	Civil & Env Engeering	Sanjoy Bhattacharya, PhD
Holly Wyatt	1998/9 Scholar	Env Health Sciences	William Toscano, PhD
Virginia Lyle Jennings	1998/9 Scholar	Philosophy	Michael Zimmerman, PhD

MCB* = Molecular & Cellular Biology

EEOB** = Ecology, Evolution & Organismal Biology