ACTIVITIES WITH CENTRAL AND EASTERN EUROPE

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INTRODUCTION

During the 1980s, the U.S. began to come to terms with the environmental legacy and by-products resulting from the Cold War and the associated arms race. Among the many dangers posed by past practices were widespread contamination of ground and groundwater, leaking or deteriorating containment vessels that were allowing the seepage of radioactive and/or chemical wastes into the ground and water, as well as the escape and transport of airborne contaminants. These and related issues demanded attention and illustrated the need to redirect resources from weapons production to environmental restoration and waste management.

Office of Environmental Management

In 1989, the U.S. Department of Energy (DOE) responded to these concerns by establishing the Office of Environmental Management (EM) and delegated to this office the responsibility of cleaning up the U.S. nuclear weapons complex. Now in its tenth year, EM’s mission has three primary objectives: 1) to assess, remediate, and monitor contaminated sites and facilities; 2) to store, treat, and dispose of waste from past and current operations; and 3) to develop and implement innovative technologies for environmental cleanup.

EM faces a challenging job. A 1997 DOE report entitled Linking Legacies, stated that DOE manages 36 million cubic meters of waste comprised of seven fundamental waste categories: high-level, low-level, transuranic, and mixed low-level radioactive waste as well as, hazardous, by-product material, and “other” waste. In addition, EM has oversight of more than 5,100 contaminated buildings and facilities awaiting decontamination, decommissioning, and dismantling. This challenge requires the identification of technologies and scientific expertise from a variety of sources including industry, academia, national laboratories, and the international community.
EM Office of Science and Technology

The Office of Science and Technology (OST) conducts an aggressive program for the deployment of innovative solutions to address DOE’s environmental remediation needs. OST investments provide the scientific foundation for new approaches and technologies that bring about significant reductions in risk, cost, and schedule for EM mission completion.

The mission of OST is to provide the full range of science and technology resources needed to deliver and support fully developed, deployable technological solutions to the environmental remediation problems faced by EM. These resources include providing basic and applied research, technology demonstrations, and technical assistance for deploying technologies.

The OST International Program Office (IP) is responsible for the identification, evaluation, acquisition, and demonstration of international technologies that can accelerate DOE cleanup operations. The goal of IP is to pursue collaborations among government organizations, educational institutions, and private industry to identify technologies that can address the environmental remediation needs of DOE. Through international agreements, OST engages in the cooperative exchange of information, technology, data on technology development and demonstrations, as well as involvement with scientific exchanges.

The EM IP seeks out and leverages foreign technology, data and resources in keeping with EM’s mandate to protect public health and the environment through the safe and cost effective remediation of the DOE’s nuclear weapons sites. IP works closely with foreign governments, industry and universities to acquire innovative environmental technologies, scientific and engineering expertise, and operations experience that will support EM’s objectives. These international resources are used to manage the more urgent risks at DOE sites, secure a safe workplace, help build consensus on critical issues, and strengthen DOE’s science and technology program.
Cooperative programs with the international scientific community meet DOE domestic cleanup objectives by:

- identifying, evaluating, acquiring and demonstrating EM-related technologies, thereby leveraging investments and providing cost-savings;
- improving access to international technical information, scientific expertise, and technologies applicable to domestic needs; and
- fostering the development of innovative environmental technologies by increasing U.S. private sector opportunities in EM-related areas.
ENVIRONMENTAL MANAGEMENT ACTIVITIES IN CENTRAL AND EASTERN EUROPE

EM is collaborating on environmental remediation issues with countries in Central and Eastern Europe including: Poland, Hungary, and the Czech Republic.

Central and Eastern Europe: An Environmental Perspective

During 40 years of central planning, the focus in Central and Eastern Europe (CEE) was on fulfilling industrial production goals with little regard for the natural environment. The emphasis was on rapid industrialization, with an emphasis on heavy industries and mining, which resulted in detrimental effects to the environment. Industrial practices, dating back hundreds of years also contribute to the serious and extensive degradation of the environment in CEE. The reliance on coal as an energy source, combined with low energy prices, provided few incentives to find alternate, less polluting, methods of generating energy. Additionally, the “closed society” produced limited public information on the state of the natural environment and allowed little public input. Today, the region is struggling to cope with the severe ecological damage that resulted from these policies.

The four major sources of pollution in the region are: industry, mining and energy production; waste generated by the former Soviet military; municipal waste; and agricultural production. Industry accounts for much of the air pollution, solid waste, and water
pollution. Coal combustion is used to meet the majority of the region’s electric and heat energy needs. Brown coal, which is less efficient and produces more detrimental environmental impacts than hard coal, has been used traditionally. Industrial and municipal waste disposal and wastewater treatment facilities are severely underdeveloped. Agriculture contributes significantly to water pollution as “non-point sources” of pesticide, fertilizer and animal waste runoff.

Revitalization of contaminated soil and landscape is a priority, especially in heavily industrialized areas. The disposal of hazardous waste is one of the more pressing problems. Significant amounts of hazardous waste are stored on-site at the source in so-called temporary storage facilities. There are few modern facilities for the disposal of hazardous waste.

The Russian Federation Military, which occupied 59 sites in Poland from 1945 to September 1993, caused significant ecological damage in that country. These former military sites were located primarily in the western and northwestern parts of Poland and were previously occupied by German troops during World War II. Between 1990 and 1993, the Polish State Environmental Inspectorate inspected 21 bases suspected of being the most polluted. They discovered severe environmental damage and estimated the cost of all reclamation work at over $US 100 million. A common finding was evidence of petroleum derivatives in the ground and waste dumps. The report indicated that no evidence of radioactive substances or poisonous warfare agents was discovered.

As the countries of Central and Eastern Europe continue their transition to a market economy and prepare for European Union accession, the markets for environmental technologies and services will grow in these countries. It is estimated that environmental investments totaling $US 100 billion to $US 150 billion will be needed in the ten accession countries over the coming years in order to comply with EU environmental requirements. Cost-effective technologies and strong environmental management skills will be needed in this enormous undertaking.
Administrative Framework for Cooperation

In 1995, the “Agreement for Technical Exchange and Cooperation between the Department of Energy of the United States of America and the Institute for Ecology of Industrial Areas of the Republic of Poland in the Area of Environmental Restoration and Hazardous Waste Management” was signed to promote international scientific collaboration.

The overall objective of this international partnership is to assist DOE in meeting its domestic environmental restoration and waste management goals. This is met by identifying, evaluating, acquiring and demonstrating technologies that are safer, more efficient, and less expensive than many of those currently in use; by encouraging the introduction and use of environmental technologies and services developed outside the U.S.; and by bringing leading scientists together from the countries in the region to develop innovative solutions to environmental problems. This working partnership results in cost-effective, innovative technology demonstration projects that are applicable to environmental contamination in Poland, at DOE facilities, and at other sites worldwide.

The IETU’s historical experience with environmental problems has led to the development of a well equipped, experienced and knowledgable organization. The IETU has developed expertise in numerous areas of environmental science. In addition, the extensive environmental contamination problems in Poland provide an excellent large scale test bed for the testing of U.S. developed technologies designed to address hazardous contamination. These demonstrations allow the rapid collection of cost and performance data that can be applied to sites found throughout the DOE complex. With these data, successful technologies can be utilized at DOE sites, thus accelerating the deployment process.
Joint Coordinating Committee for Environmental Systems

The Joint Coordinating Committee for Environmental Systems (JCCES) was established to manage the activities conducted under the auspices of the DOE/IETU agreement. The JCCES meets annually to review and approve proposals, assess program progress, and evaluate potential future activities. The JCCES is currently co-chaired by Dr. Ewa Marchwinska, Institute for Ecology of Industrial Areas (IETU-Polish acronym), Director of International Cooperation, and Mr. Gerald Boyd, DOE Acting Deputy Assistant Secretary for Science and Technology, Office of Environmental Management. JCCES membership consists of specialists from both countries who represent each technical area of cooperation.

OST participation in the JCCES ensures that the areas of technical cooperation address the most critical needs of the EM Focus Areas. JCCES projects are reviewed and evaluated by focus area technical staff for scientific merit, applicability to key DOE site needs, and relevance to DOE users.

Program Implementation Team

In collaboration with OST, the following organizations are contributing to the management and implementation of activities under the auspices of the JCCES.

Institute for Ecology and Industrial Areas

In 1992, following the decision by the Polish Minister of Environmental Protection, the IETU, a former branch of the Institute of Environmental Protection, established itself as a separate, independent organization. The ratio of scientific staff to administration staff was greatly increased, departments were reorganized, and overall financing was restructured.
Located in Katowice, in central southern Poland, IETU conducts scientific research that provides the basis for the formation of Poland’s national environmental policies and regulations. Working closely with government agencies, universities, and the private sector, IETU conducts environmental research projects for local and national policy makers. In addition, IETU conducts domestic and international environmental education activities through the dissemination of publications and the hosting of workshops. Through international agreements, IETU collaborates with the global environmental community, leveraging foreign technology, data, and technical expertise.

The IETU has a staff of 130 and focuses primarily on the following environmental issues:

- Air, water and soil pollution
- Waste management
- Contaminant migration and transformation
- Assessment of human health risk due to environmental exposure
- Development of pollution prevention technologies
- Development of environmental quality management methods

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Risk Abatement Center for Central and Eastern Europe

In response to the critical need for comprehensive, cost effective, environmental risk assessment and reduction strategies in the region, IETU, established the Risk Abatement Center for Central and Eastern Europe (RACE) in 1996. RACE serves as a regional center that provides a forum for implementing significant policy changes, transferring technology, increasing public awareness and coordinating activities aimed at solving environmental and natural resources problems in CEE. As a non-governmental, international, cooperative research and education center, RACE utilizes risk based tools for prioritizing problems and managing the environment with regard to social, legal, economic, and political considerations.

A goal of RACE is to create local, regional, and international support for the utilization of environmental policy tools. Through local and regional networks, RACE promotes the advantages of applying innovative risk assessment strategies in place of current regional practices. RACE offers decision-makers opportunities to learn the benefits of applying risk management through the use of case studies, pilot projects, demonstrations, and workshops. RACE also conducts public awareness campaigns and works with governmental organizations to promote the acceptance and implementation of these innovative strategies.

Additionally, through the establishment of international agreements, RACE serves as a global forum for the exchange of information and experiences regarding the development of risk-based environmental strategies.

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Florida State University
Institute for International Cooperative Environmental Research (IICER)

Florida State University (FSU), through the Institute for International Cooperative Environmental Research (IICER), conducts international environmental research which is used by federal agencies as well as by the private sector. The goal of these research activities is to facilitate collaboration with environmental scientists in Russia, Hungary, the Czech Republic, Poland, and other Central and Eastern European countries. Under its cooperative agreement with OST, the IICER oversees numerous tasks that contribute to the success of OST’s International Programs.

Based at FSU, IICER serves as a conduit through which the United States can benefit from the expertise and experience Central and Eastern European scientists have gained from years of addressing environmental contamination problems under extreme and difficult conditions. The IICER assists DOE by identifying technical experts and technologies in CEE that have potential application to environmental remediation needs within the DOE complex. Promising technologies are evaluated in situ as a rapid and cost effective method of providing OST with necessary cost and performance data.

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Characterization Technology Opportunities in Poland: A Market Assessment

The U.S. Government has recognized the market opportunity in Poland, both in overall exports and in environmental products. The U.S. Department of Commerce declared Poland as one of the top ten “Big Emerging Markets” for U.S. exports in the next decade, specifically mentioning Poland’s growing environmental services sector.

Under the auspices of the JCCES, the University of Tennessee conducted a study of EM developed characterization technologies that may be applicable to the environmental needs of Poland. The purpose of this study was to describe existing technologies currently being used in the region and to provide information for U.S. technology providers on Poland’s environmental market. As Poland has experienced many of the same environmental challenges as the U.S., it is not surprising that many U.S. developed technologies have significant relevance and applicability to Poland’s growing environmental market.

The study consisted of compiling information on environmental waste sites in Poland for which U.S. characterization technologies could be applied. An overview of the geographic, demographic, and political climate in Poland is provided as it relates to the environmental conditions and technology market in this country. The report documents the state of Poland’s current environmental situation, including specific industrial and defense locations. Detailed information on the most severely contaminated sites is provided, including types of contaminants, sources of the contamination, and the environmental risks associated with these sites. The environmental market in Poland is presented by geographic region, industry, and environmental medium (air, water, soil, solid waste). Regulations and other drivers influencing remediation activities are detailed, as are potential sources of funding to assist in the clean up effort.
Factors influencing Poland’s environmental market:

An excerpt from “Characterization Technology Opportunities in Poland: A Market Assessment”

Poland’s environmental products and services market is growing due to several factors:

- The economy is stabilizing, environmental needs now take a higher priority on the political agenda.
- Internal awareness of environmental degradation and its consequences has grown over the last several years, resulting in growing public awareness and involvement.
- Environmental legislation has been enacted and is being enforced.
- International and domestic financing is increasingly available to support environmental efforts.
- Privatization of state enterprises requires an environmental assessment of the type and quantity of waste at each location.
- Poland’s desire to join the EU mandates that it comply with the environmental standards of the EU.

A significant portion of this document is dedicated to the presentation of characterization technologies developed to assist in the remediation of DOE sites. The technologies reviewed are available from industry, or are currently being developed by EM. Over 250 characterization technologies are presented in this report. A description of each technology is provided, including the type of contaminants the technology characterizes and company contact information.

To obtain a copy of this study, contact:

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**Bioremediation of Petroleum Contaminated Soil: The Czechowice Oil Refinery Technology Demonstration Project**

*Background*

DOE landfills are estimated to contain over 3 million cubic meters of buried waste. This waste exists in a variety of forms, including petroleum hydrocarbons, and has the potential for contaminating the environment. DOE sites include over 5,700 individual plumes contaminating over 600 billion gallons of water and 200 million cubic meters of soil. Given that currently available clean-up technologies are inadequate or unacceptable due to excessive costs, increased risks, long schedules or the production of secondary waste streams, the mission to identify and evaluate innovative remediation technologies is critical.

Petroleum contamination of soils represents a widespread problem in the DOE complex, at other governmental sites and throughout the public sector. For more than 100 years the Czechowice Oil Refinery in Poland, formerly the Vacuum Oil Company, has been producing petroleum products for industrial and commercial applications. During the early 1930s, the addition of several new product lines and processes transformed the refinery into the largest petroleum processing facility in Poland.

Today, with a production exceeding millions of tons per year, the refinery faces many new challenges. Years of production-oriented philosophy have created environmental conditions that now present risks to human health and the environment. The disposal practices for process wastes generated by crude oil refinement have created conditions that are unacceptable under current environmental standards in Poland. The use of unlined lagoons for process waste disposal was the industry norm for many years, not only in Poland but also in the United States. As late as the 1980s the U.S. was using unlined process waste lagoons, while in Poland the practice is still used. The existence of the problems at the Czechowice facility site offers opportunities for DOE to rapidly demonstrate and refine technologies used to degrade low pH, aged, hydrocarbon-contaminated soils.
Project Description

The Bioremediation of Hydrocarbon-Contaminated Soils Project is being managed and implemented under the auspices of the JCCES. The project, which started in 1996, utilizes the broad technical expertise of the IETU, Westinghouse Savannah River Company (WSRC), Ames Laboratory and the IICER at Florida State University. The overall objective of the project is to identify and develop promising advances in the area of bioremediation of hydrocarbon-contaminated soils. The goal is to return these technologies to the U.S. for application within the DOE complex. For this project, the approach has been to conduct a full-scale remediation demonstration targeting petroleum contaminated soil at the Czechowice Oil Refinery using innovative bioremediation technologies. Additional objectives include training of IETU personnel, and transferring bioremediation technology to IETU, and other CEE organizations. This collaboration provides the basis for international technology transfer of new and innovative remediation technologies that can be applied at sites throughout Poland, CEE, and the DOE complex. The partnership not only includes the use of a Polish refinery as the demonstration site and in-kind support from the refinery, but also shared Polish/U.S. responsibilities in fiscal, construction and engineering management of the project.
The Czechowice Oil Refinery project demonstrates not only specific characterization and remediation technologies, but also the U.S. decision-making process that is used to determine how to implement remedial technology. A risk-based decision making approach was completed to guide the final technology selection and remedial design. This approach provided a plan that takes into account the intended future use of the site as a “green zone” between the refinery and the local population.

The Czechowice Oil Refinery project makes innovative use of proven techniques and remediation tools that are used to remove and/or destroy contaminants via biostimulation of indigenous microbes. The basic concepts of this technology are applicable to sites in the DOE complex having similar problems, especially those with low pH, hydrocarbon-contaminated soils. These sites include Oak Ridge, Hanford, Savannah River, Idaho, and Brookhaven.

Project Participants

**U.S. Department of Energy:** EM is sponsoring this project to identify and develop environmental restoration/waste management technologies that may be applicable for the clean up of DOE sites in the U.S., and to promote the use of U.S. environmental technologies abroad.

**Institute for the Ecology of Industrial Areas:** IETU provides local management and technical experts who work with their U.S. counterparts in the design and implementation of this project.

**Czechowice Oil Refinery:** The refinery is the site of the demonstration activities. The refinery supplies the logistical support and staff necessary to set-up and implement the field phases of the project.

**Florida State University:** FSU provides overall project management as well as technical support in the areas of toxicology, risk assessment, and hazardous waste management.

**Ames Laboratory:** Ames assisted in the planning, implementation, and evaluation of the site characterization phase of the project.

**Westinghouse Savannah River Company:** WSRC assists in the planning, implementation, and evaluation of the remediation portion of this project.
Project Design

The waste stream from the refinery process (a thick, viscous semi-liquid) historically was discharged to a series of lagoons, which now contain several million gallons of this heterogeneous and previously uncharacterized waste material. It was expected that subsurface soil might be heavily contaminated with hydrocarbons.

Bioremediation is generally attempted by employing biostimulation, a process in which the conditions for microbial growth are optimized by supplying adequate amounts of electron acceptor(s), water and nutrients (e.g., nitrogen, phosphorus and trace elements), to the contaminated material. Because biodegradation rates for petroleum hydrocarbons are fastest under aerobic conditions, maintaining adequate oxygen levels and moisture control were two of the key scientific considerations associated with this project.

This bioremediation demonstration project focuses mainly on the clean-up technique known as “biopiling”. The biopile process is very similar to active bioventing, where air, as an oxygen source, and other amendments are forced through the vadose zone sediments either by vacuum extraction or by injection to stimulate the microbial oxidation of the hydrocarbons. As the name implies, biopiling is an ex situ process. The contaminated material is excavated and recombined or amended with other materials before being placed in an engineered structure to support and stimulate the biological reactions necessary to oxidize the hydrocarbons.

A treatability study of the material to be remediated was completed by the IETU/WSRC team. This study documented the physical and chemical parameters necessary to maintain a high rate of microbial biodegradation of the contaminants. The study indicated that the material selected for the technology demonstration contained petroleum sludge, soils contaminated with crude and processed oil, other petroleum by-products as well as process waste from the refining of crude oil. The predominant contaminants of concern were polycyclic aromatic hydrocarbons (PAHs) including benzopyrene, a known carcinogen. Also
found were benzene, toluene, ethyl benzene and xylene (known collectively as BTEX) and very recalcitrant high molecular weight compounds, the remnants and residue from decades of the acid refining process.

The treatability study, along with the completed characterization study, provided information necessary to design and deploy the remediation system. From these studies, it was determined that bioremediation, specifically a biopile system, was the most appropriate method of remediation for this site. This system is capable of providing the conditions necessary to maintain the biological activity needed to degrade the contaminants.

A biopile system was constructed utilizing contaminated soil amended with wood chip waste (to reduce bulk density). This biopile was constructed in the existing excavated lagoon. The lagoon bottom was sloped toward a sump that was connected to a leachate collection system. The leachate collection system, consisting of perforated piping, was placed on top of a dolomite base. A cell divider (constructed of clay) separated active and passive sections of the biopile. (Active implies forced introduction of air, steam, and other amendments via pumps or fans, while passive uses a DOE-developed technology know as Baroballs that make use of fluctuations in atmospheric pressure to “pump” air through the biopile.) This two-part system was requested by the refinery to provide a direct comparison of an active and passive system. The sump and its associated pump recirculates any collected leachate to the top of the biopile.

To ensure that an adequate supply of moisture was available, water from the existing waste water treatment facility at the refinery is applied to the biopile. The high concentration of bacteria in the wastewater also serves as a source

The transformation of the waste lagoons: from contaminated sludge to green-space.
of inoculum. One year of biopile operation resulted in a plateau of contaminant breakdown. This indicated that the lower molecular weight compounds that are most easily degraded have been consumed. As a result, surfactants are being applied to the biopile to improve the bioavailability of the remaining contaminants.

**Project Accomplishments**

During the operation of the biopile, unique indigenous microbes have been discovered. Due to the long operating history of the refinery and the use of an acid cracking process to refine the crude oil, indigenous microbial communities have adapted to the low pH environment and low temperature climate. These conditions are of interest to DOE, since many of DOE’s sites have acidic wastes and are located in colder climates.

The project has currently identified 36 microbial isolates, which may exhibit properties and capabilities currently unreported in the scientific literature. Microbial analysis and isolation will provide the opportunity to determine if any of these microorganisms are unique and, thus, patentable for use at contaminated DOE sites with conditions similar to those found in Poland. By identifying and patenting unique microorganisms/bioprocesses, DOE would be ensuring that these organisms are available for use throughout the DOE complex and the world.

**Fiscal Year 1999 Activities**

The Fiscal Year 1999 project collaborations between DOE and IETU include: Effectiveness of Surfactants, Microbial Patentability Study, and the Completion of a Comprehensive Report on the Bioremediation Project.

*Effectiveness of Surfactants*

Various surfactants are being evaluated during Fiscal Year 1999 for application to the biopile. Candidate surfactants that exhibit a high probability for success will be chosen for use in the biopile, and their effectiveness at increasing the bioavailability of the remaining high molecular weight compounds will be determined.

In conjunction with the continued operation of the biopile, *in situ* long-term monitoring devices are being considered for deployment in the biopile to determine their effectiveness.
in providing long-term automated data collection. Installation of these devices in the biopile will generate field data, which upon evaluation could support immediate deployment of these devices at DOE sites.

**Microbial Patentability Study**
Microbiological laboratory techniques are being used to isolate and culture pure strains of each identified microorganism. Once isolated, the unique properties (biochemical, physiological, and molecular) of each strain are identified and a literature/patent search will be conducted to determine if the organism (and/or a bioprocess based on the organism) has been isolated or registered previously. The patent process will continue into Fiscal Year 2000 for those organisms (and/or bioprocesses) that show scientific promise and that have not yet been patented.

**Completion of a Report on Bioremediation**
A detailed and comprehensive report on the bioremediation project will be completed and published. This report will assist the DOE in identifying new areas of research through which the specific techniques learned during this study can be applied to the environmental remediation needs of the DOE complex.

**Proposed Fiscal Year 2000 Activities**

**Molecular characterization of acidophilic microbes**
As described above, detailed characterization of promising microbes will be continued in Fiscal Year 2000. The various responsibilities for the characterization activities will be divided between the IETU and WSRC, with the final products being patent applications.

**Bioremediation of Nitroaromatic Compounds**
Nitroaromatic compounds are common and widespread contaminants at industrial and military sites worldwide, and within the DOE complex. As a result of years of previous research and the on-going activities at the Czechowice Oil Refinery biopile project, IETU and DOE have well-developed and integrated microbiological capabilities at their disposal. The application of bioremediation to nitroaromatic compounds will be examined and studied for potential future use at DOE sites.
Phytoremediation Project: An Integrated Approach to the Remediation of Heavy Metal Contaminated Land

Background

The DOE complex faces a wide variety of environmental contamination problems, including heavy metal contamination of soil. DOE sites at Oak Ridge, Hanford, Argonne, Savannah River, Idaho, and Brookhaven all have extensive heavy metal contamination in soils. Currently, very few of technologies exist for the remediation of heavy metal contaminated soils. Existing technologies are best applied to small areas with high levels of contamination, and are quite expensive. There is, however, a need within the DOE complex for technologies that address low to moderate levels of soil contamination over relatively large areas.

Decades of mining and non-ferrous metals smelting within the Upper Silesia region of Poland have resulted in extensive heavy metal contamination, similar to those found at sites within the DOE complex. Additionally, soil conditions in many of the prime agricultural areas of Poland do not meet national standards for contaminant concentrations, and are thus placed under restrictions. Persistent pollutants, most notably heavy metals, are the major reason for these restrictions. Remediation of these lands continues to be a major objective for the Polish government and developing technologies for remediating large, heavy-metal contaminated areas also is an objective for DOE.

Phytoremediation, defined as the extraction of pollutants by plants, is a technology which has shown promise in removing heavy metals from soil. In the case of heavy metals, phytoremediation uses selected plants species to take up soil metals into the plant matter which is then harvested and disposed of appropriately. The Upper Silesia region of Poland offers an opportunity to rapidly conduct environmental research and to refine phytoremediation technologies that result in mutual benefits to the U.S. and Poland.
Project Description

Under the auspices of the JCCES, a phytoremediation project was initiated to demonstrate and refine this technology for removing heavy metals from soil. This project combines the DOE need for an effective and efficient technology to remediate moderate levels of heavy metal contamination over relatively large areas with the IETU’s experience and qualifications in this area. The goal of this project is to evaluate and refine phytoremediation as a method to remediate heavy metal contaminated soil in a cost-effective manner for application at DOE sites.

This area of research has lead to an interest in the commercialization of this technology for environmental remediation. Considerable research has been reported on the laboratory-scale application of phytoremediation; however, little information is available concerning the cost, performance, and advantages of full-scale application. An objective of this project is to optimize full-scale application of phytoremediation and to develop and document the results. Different species of plants, which have the ability to take up and sequester moderate to high levels of heavy metals are being evaluated. In addition, the effects of ethylenediaminetetraacetic acid (EDTA) to increase the availability of these metals to the plants and the use of a field-portable chlorophyll fluorometer (see page 28 for technical description) to optimize the phytoremediation process also were investigated. The target metals for this project are lead and cadmium.

Project Accomplishments

Site Identification and Treatability Study

Using an IETU database on soil contamination in the Katowice province, FSU and IETU evaluated four potential sites for this project. Candidate sites were initially identified based on existing vegetation (indicating potential for plant growth); minimal relief; proximity
to water and electric supplies; road access; Pb (Lead) concentrations between 500 and 5000 ppm; and contamination limited to approximately the top 30 cm of soil. IETU collected soil samples from each of the candidate sites for analyses. Based on the results, and in consultation with FSU and Phytotech, two candidate sites were selected for more extensive characterization and evaluation using treatability studies.

Treatability studies were conducted using technical guidance provided by Phytotech and soil samples collected from the two candidate sites. These studies determined the potential applicability of phytoremediation by providing further characterization of the soil samples, determining if the sites would support the growth of metal-accumulating plants, and analyzing the need for soil amendments to optimize the phytoremediation process. The treatability studies consisted of two experimental activities: soil sampling and analysis and growth chamber experiments which included soil amendments application. The purpose of the growth chamber studies was to evaluate the growth potential of selected plant species and to determine the soil amendment protocol necessary to optimize plant growth and heavy metal uptake. The tests indicated that: (a) both of the selected sites were able to support growth of all plant species tested; (b) that the most efficient amendment was a combination of dilute solutions of organic and inorganic acids; (c) that independent of the amendment selected, spinach accumulated the highest concentrations of Pb and Cd in its shoots; and (d) that corn, spinach, and a cross of cabbage x rape showed promise for use in field-scale experiments of phytoremediation.

Project Participants

- **DOE EM** is sponsoring this project to identify and develop environmental remediation technologies that will be of use in the clean up of DOE sites in the U.S.

- **IETU** provides local management and technical experts who work in collaboration with their U.S. counterparts in the design and implementation of this project.

- **FSU** provides overall project management as well as technical support in areas of toxicology, risk assessment, and hazardous waste management.

- **Phytotech** is a leading U.S. firm that specializes in commercializing the application of phytoremediation. Phytotech has considerable experience with this technology and provides valuable technical assistance.

- **Special Technologies Laboratory** evaluated and compared laser fluorescence in an effort to establish signature anomalies for plants affected by heavy metals.

- **Central European Advanced Technologies** developed and field validated a portable chlorophyll fluorometer for evaluating heavy metal content as measured by plant stress.
Upon selection of the final site, additional field tests were performed. Three plant species and three soil treatment strategies were tested in 3m x 3m field plots. Based on the results of these experiments, two plant species/treatment combinations were selected for full-scale evaluation.

Field-Scale Demonstration
At the completion of site and species/treatment selection, a field-scale demonstration was conducted to identify and quantify the relative costs and performance of phytoremediation. The field-demonstration plot consisted of a one-hectare area with lead concentrations ranging from 200-500 mg/kg. Costs associated with the effort were recorded in generic units (e.g., man-hours, tractor-hours, volume of amendment applied, etc). Initial analysis of these results shows that the procurement and application of soil amendments represents the greatest portion of the costs associated with phytoremediation.

Metal Accumulating Species Screening
In conjunction with the field demonstration, additional investigations of potential heavy metal accumulating plant species native to Poland were conducted. The goal of these studies was to identify plant species that maximize the overall removal of metal from soil. These investigations were based on the assumption that plants growing in contaminated areas (such as the mine tailings piles and soils adjacent to smelting operations found in the Silesian region of Poland) may have adapted to high metals concentrations by absorbing those metals. Based on decisions made cooperatively between FSU, IETU, Phytotech and the Polish Institute for Plant Growth, 26 plant species were chosen for investigation. Among these species, a cultivar of Polish sunflower performed extremely well, taking up concentrations of lead that compare with the best known metal accumulating plant species while producing large quantities of biomass.

Evaluation of the Soil Amendment: EDTA
Phytoremediation often relies heavily on soil amendments/chelating agents to mobilize otherwise unavailable metals from soil. A commonly used amendment is EDTA. Prior to this project, concern had been raised over the potential effects of repeated application of EDTA on the environment. The project team, in cooperation with the University of Silesia, evaluated those effects by determining the toxicity of soil amendments to soil microbiota. These studies, the first of their kind, showed that no adverse effects of EDTA were observed on soil microbiota. It was shown that, in specific situations, there was enhanced microbial
activity following amendment application, possibly as a result of increased availability of essential nutrients. These results are promising and address concerns raised by U.S. regulators on the effects of EDTA on the soil community.

**Optimization of Phytoremediation with Chlorophyll Fluorometry**
An ongoing aspect of the phytoremediation project has been the integration of *in situ* monitoring instrumentation with the field activities. An innovative field-portable chlorophyll fluorometer has been developed by the Technical University of Budapest and is being commercialized by Central European Advanced Technologies. This instrument has been deployed in conjunction with the phytoremediation experiments. Activities focused on optimizing the timing and magnitude of amendment application by monitoring plant stress. The important contributions of the chlorophyll fluorometer instrument and associated software relates to the timing of amendment application. The amendment process results in death (maximum plant stress) to the plant while it is removing metals in its maximum range of uptake. This instrument indicates the period of maximum plant uptake and, therefore, when the terminal amendment should be applied. Other significant findings were that crops seem to be more sensitive to irrigation than was previously presumed and that a longer delay between amendment application and harvesting may enhance overall metal removal.

**Plant Species/Soil Amendment Investigations**
Based on the prior results of field and plant screening activities, the project team continued investigations at both laboratory and field scale to optimize plant species and amendment protocol combinations. A promising result of this research concerns the utilization of compounds that enhance plant metabolism and increase respiration. These compounds appear to enhance the uptake of metals when used in combination with other amendments.

**Fiscal Year 1999 Activities**
The Fiscal Year 1999 project collaborations between DOE and IETU include: Continuation of Evaluation of the Soil Amendment: EDTA, Management of Contaminated Crops, Amendment Application Technology, Streamlined Site Characterization and Treatability Studies, Soil and Plant Amendment Studies, and U.S. Field Deployment of Phytoremediation.
Continuation of Evaluation of Soil Amendment: EDTA

The current process for heavy metal phytoextraction involves the application of chelating agents and acids to soils in order to enhance the uptake of heavy metals by the plants. The need for multiple crops of these phytoremediating plants over numerous growing seasons presents the possibility of adverse ecological impacts from the effects of repetitive amendment applications.

Soil microbial toxicity tests are being conducted using current phytoextraction soil amendments. Further investigations on soil biology are being performed with respect to the identification of EDTA levels that are toxic to soil microbes. During the course of laboratory experiments, it is planned to determine the EDTA dose which results in a breakdown of soil biological activity. The results of these studies will be integrated into an ecological risk assessment for this technology.

Management of Contaminated Crops

After harvesting, phytoremediation plant material contains high concentrations of metals and may need to be treated as a hazardous material with the appropriate handling considerations. Various methods for harvesting and disposing of the contaminated plants are being investigated. Harvesting considerations include timing the harvest to minimize material loss through plant tissue aging and decomposition, managing the physical harvesting to maximize the recovery of contaminated material while using standard agricultural methods and handling the harvested materials to minimize loss and adverse impacts to human and non-human receptors.

Amendment Application Technology

As previously reported, the application of amendments associated with phytoremediation contributes significantly to the costs of applying phytoextraction technologies. Those costs are a function of the cost of the materials as well as the labor-intensive methods currently used in the application process. The project team is developing a mechanized approach to amendment application that utilizes modified agricultural equipment and should result in a faster, more uniform and accurate application of amendments to target soils. A design protocol is being developed that will be tested under full field conditions during the FY99 growing season.
*Streamlined Site Characterization and Treatability Studies*

Site characterization activities and treatability studies currently are conducted sequentially prior to the initiation of phytoextraction. The purpose of these activities is to describe the nature and extent of contamination at the target site and to determine under what conditions the proposed plant species will extract the target contaminants. This process is time-consuming and expensive. An approach is being developed that integrates these two steps into a single effort leading to rapid decisions concerning the feasibility of phyto-extraction for a given site, while reducing both effort and cost.

*Soil and Plant Amendment Studies*

During this project, new specialized plants species and soil amendments were identified that show promise for phytoextraction. These plants and amendments are being applied in a field scale demonstration to evaluate their effectiveness and costs. The results will be compared to the previous demonstrations, ensuring the promotion of the most efficient and cost-effective practices. In addition, the information acquired by the streamlined site characterization and treatability studies is being used to support the deployment of these plant species and amendments.

In conjunction with these studies, the project is continuing to screen native plant species with promising metal accumulating capabilities. This involves propagating native species at laboratory and/or experimental plot scales. Target species are being raised in heavy metal-contaminated soils and will then be harvested and analyzed for metal concentrations. The applicability of planting winter crops is also being investigated for the potential to produce an additional harvest each year.

*U.S. Field Deployment of Phytoremediation*

A goal of this task is to identify and evaluate DOE sites for deployment of this technology. Phytoextraction is ready for field application at DOE sites, and a site identification process is being conducted. This includes identifying an appropriate DOE site based on the applicability of phytoextraction, developing working relationships with technical and support contacts, and initiating the necessary DOE permitting processes. After the site is identified and the site characterization process is completed, a test plan and treatability study will be conducted. It is anticipated that field-demonstration studies will be implemented in the U.S. during Fiscal Year 2000.
Proposed Fiscal Year 2000 Activities

Computerized Application of Soil Amendments (Phytoremediation)

Results from the phytoremediation field studies indicate that approximately 70% of the cost of phytoremediation is associated with the purchase and application of soil amendments. Since the need for amendments is a function of soil metal concentration and speciation, it would be possible to minimize the use of amendments if information concerning the nature and spatial distribution of soil metals is used to control the application of amendments. The automated amendment application technology that has been developed by the IETU will be modified to accept computerized input to control application rates. It is estimated that amendment application rates could be reduced by as much as 50%, yielding an overall reduction of up to 30% of the cost of phytoremediation.

Evaluation of Novel Mercury Remediation Technology

Mercury contamination is widespread throughout the DOE complex, at many other federal facilities and at industrial facilities throughout the world. A firm in Poland has developed a technology for reducing the bioavailability of ionic forms of mercury in groundwater (and, possibly, soil). This technology shows promise for reducing the risks posed by certain forms of mercury contamination and is ready for field-testing. Preliminary discussions with the developers indicate that an industrial site in Southern Poland may be suitable for field testing this technology. Appropriate site characterization studies will be conducted to determine whether or not this site would be appropriate for field testing of this technology. If the results of this evaluation are positive, initial set-up and testing will be conducted in anticipation of full field testing in Fiscal Year 2001.

Expedited Site Characterization: Visitor’s Day

On May 27-28, 1996, the JCCES sponsored a “Visitors’ Days” at the IETU and Czechowice Oil Refinery to highlight cooperative activities and to demonstrate, for the first time in Europe, the DOE Expedited Site Characterization (ESC) methodology for streamlining the characterization of contaminated sites. The Visitors’ Day demonstration drew approximately 300 visitors including members of the U.S. Department of Defense (U.S. Air Force),
and a number of DOE contractors. Also in attendance were representatives from: U.S. Foreign Commercial Service, the Polish Consul of Bratislava, U.S. Embassy in Poland, Poland National Fund of Environmental Protection and Water Management, Polish Academy of Sciences, Polish State Scientific Committee for Scientific Research, Polish Ministry of Environmental Protection, Polish Natural Resources and Forestry, Polish Ministry of Defense, Environmental Protection Bank, and Polish Ministry of Trade and Industry.

This demonstration allowed specialists to participate in the evaluation of ESC, an integral part of the Czechowice Oil Refinery Project. The demonstration provided numerous benefits to both regulators and others including: a tour of the field site, a hands-on demonstration of advanced characterization technologies by end-users and providers, an examination of existing market potential, networking with environmental providers, access to ESC methodology, and interaction with environmental professionals. Visitors’ Day also included an open session that provided the attendees with a project overview and explanation of the joint international projects between the DOE and Poland.

**International Environmental Information Exchange: Conference Sponsorship**

The International Symposia and Exhibitions on Environmental Contamination in Central and Eastern Europe is an on-going series which focuses on the environmental problems and solutions of Central and Eastern Europe and the issues relating to the environmental security of the region. Using a global perspective, experts discuss and demonstrate equipment, innovative technologies and management methods that can be used to address environmental problems within the DOE complex and worldwide.

*John Lehr, Associate Deputy Assistant Secretary, DOE/EM/OST provides remarks regarding the importance of international cooperation during the Warsaw ‘98 event.*
The First International Symposium and Exhibition on Environmental Contamination in Central and Eastern Europe was held in Budapest in 1992. The symposium drew more than 400 experts from 40 nations and resulted in a 1,000 page proceedings, detailing research findings on topics ranging from coal tar cleanup to uranium-laced well-water. The meeting was attended by several European heads of state, representatives from numerous U.S. Federal Agencies, including the DOE, and dozens of Western environmental technology firms.

DOE recognized the value of this conference as an international platform for sharing information and identifying environmental technologies that could assist in meeting their environmental restoration and waste management goals. At the second symposium held in 1994, DOE shared billing as a major sponsor with the Hungarian Ministry for Environmental and Regional Policy, Sandia National Laboratories, and the U.S. Environmental Protection Agency, among others. The symposium has continued to expand to include formal partnerships with universities in Poland, Hungary the Czech Republic, and Russia.

Based on the conference’s success, DOE continued its sponsorship of the Third (Warsaw ‘96) and Fourth (Warsaw ‘98) International Symposium and Exhibition. The Fifth International Symposium and Exhibition, which DOE also will support, will be held September 12-14, 2000 in Prague, Czech Republic.

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The Development and Field-Testing of a Chlorophyll Fluorometer for Evaluating Soil Contamination through Plant Stress

The project is being conducted by Central European Advanced Technologies and the Department of Atomic Physics of the Technical University of Budapest.

Chlorophyll fluorescence can be used to measure plant stress and provide real-time data collection concerning the effects of the phytoremediation process on the plants. By optimizing the phytoremediation process, a more efficient, cost-effective system can be developed. In June 1997, a progress report was submitted entitled, “Development of Field Measurement Program, IETU Training and Evaluation of Field Performance of Prototype Instrument,” which included information about placing the system into operation, finalizing the measurement program, training of an IETU technician, and performance of the instrument in the field. This report assisted the IETU/DOE team in the application of a chlorophyll fluorometer to its phytoremediation project.

This instrument and related software measures the plant’s ability to initiate photosynthesis. This response is an accepted measure of plant “stress” and has been shown to be an indicator of heavy metal uptake. The portability and real-time data delivery of this instrument make it a cost-effective for evaluating the status of plants in contaminated environments. The sophisticated simplicity of the instrument makes it powerful and easy to use.
EM is continuing a project with the Czech Technical University in Prague to evaluate the performance and radiation/chemical stability of Polyacrylonitrile (PAN) as a binder for inorganic ion exchange materials such as Ammonium Molybdophosphate (AMP). This material has been tested for removal of cesium from acid wastes at Idaho National Energy and Engineering Laboratory (INEEL) and showed exceptional removal efficiencies and capabilities for cesium. Studies of the compatibility of PAN with alkaline solutions indicated that the presence of high nitrate concentrations causes some changes in the material; PAN appears to be more stable in acid solutions like those found at DOE sites. The early development and testing of PAN was supported by the Efficient Separation and Processing Crosscutting Program (ESP) and subsequent testing was continued by the Waste Management Program at INEEL. Annual progress reports were issued during the ESP work, and several papers were presented at technical meetings. The results are summarized in a paper entitled “Applications of New Inorganic-Organic Composite Absorbers with Polyacrylonitrile Binding Matrix for Separation of Radionuclides from Liquid Radioactive Wastes” which
was presented at a NATO Advanced Research Workshop held in Dubna, Russia in 1998. This project is being continued through FY 2000, with continuous testing to determine the optimization for the degradation process.

**Review of Advanced Separations Technologies in the Czech Republic**

Under a contract with EM, the Czech Nuclear Research Institute conducted a project entitled, “Review of Advanced Separations Technologies in the Czech Republic”. The review covers technologies in use or under development that deal with solvent extraction, ion exchange, and adsorption.

*For additional information regarding these activities and/or for a copy of the aforementioned report, contact:*

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