Decontamination Systems and Information Research Program

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Abstract

During the five plus years this Cooperative Agreement existed, more than 45 different projects were funded. Most projects were funded for a one year period but there were some, deemed of such quality and importance, funded for multiple years.

Approximately 22 external agencies, businesses, and other entities have cooperated with or been funded through the WVU Cooperative Agreement over the five plus years. These external entities received 33% of the funding by this Agreement.

The scope of this Agreement encompassed all forms of hazardous waste remediation including radioactive, organic, and inorganic contaminants. All matrices were of interest; generally soil, water, and contaminated structures. Economic, health, and regulatory aspects of technologies were also within the scope of the agreement.

The highest priority was given to small businesses funded by the Federal Energy Technology Center (FETC) and Department of Energy (DOE) involved in research and development of innovative remediation processes. These projects were to assist in the removal of barriers to development and commercialization of these new technologies. Studies of existing, underdeveloped technologies, were preferred to fundamental research into remediation technologies. Sound development of completely new technologies was preferred to minor improvements in existing methods. Solid technological improvements in existing technologies or significant cost reduction through innovative redesign were the preferred projects. Development, evaluation, and bench scale testing projects were preferred for the WVU research component.

In the effort to fill gaps in current remediation technologies, the worth of the WVU Cooperative Agreement was proven. Two great technologies came out of the program. The Prefabricated Vertical Drain Technology for enhancing soil flushing was developed over the 6-year period and is presently being demonstrated on a 0.10 acre Trichloroethylene contaminated site in Ohio. The SpinTek Centrifugal Membrane System was a unique separation process introduced through the Agreement that is now being used at the Los Alamos National Laboratory.

Based on the cost to the USDOE for both technologies and considering their usefulness in cleaning up contaminated sites, no other technologies developed through USDOE provide or have the propensity to provide as great a return on investment and impact on environmental remediation. These technologies alone make the \$10.3 million USDOE investment in the WVU Cooperative Agreement a tremendous investment.

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Executive Summary

The West Virginia University (WVU) Cooperative Agreement was initiated in late 1992 and terminated August 1998. Its purpose was to help small businesses funded by the United States Department of Energy (USDOE) solve problems and remove barriers to the commercialization of their remediation processes. Additionally, WVU Researchers were to develop workable systems that would eliminate lapses in the current technologies, bringing research to the Gate 5 Demonstration Level.

Studies of existing, underdeveloped technologies, were preferential to fundamental research into remediation technologies. Sound developments of new technologies were chosen instead of minor improvements to existing methods. Solid technological improvements in existing technologies and significant cost reduction through innovative redesign were also coveted projects. Development, evaluation, and bench scale testing projects were the desired research component of WVU investigators.

During the five plus years this WVU Cooperative Agreement existed, more than 45 different projects were funded. Most projects were funded for a single year. However, some projects, deemed of such quality and importance, were funded multiple years. Fourteen projects were funded over a two-year period, seven over a three-year period, one over a four-year period, and one over a five-year period.

Cooperation occurred with many entities while accomplishing the research. At least four small businesses developing remediation technologies for the USDOE, Vortec, Inc., SpinTek, Inc., ThermoChem, and GeneSyst, were aided by the WVU researchers.

Other outside entities were also funded through the WVU Cooperative Agreement to cooperate in various projects being conducted by the WVU researchers. They were the Institute of Gas Technology, Nilex Corporation, RMI Environmental Services, and the Waste Policy Institute. Others participated by donating materials, time, sites etc. Those were Ashland Petroleum, Applied Sciences and Swanson Plating. Many government agencies participated with the WVU researchers including the Corps of Engineers, USEPA at Cincinnati, Ohio, Oak Ridge National Laboratory, and the Pacific Northwest National Laboratory.

The value of the WVU Cooperative Agreement was proven during the efforts to fill lapses in current remediation technologies. The Prefabricated Vertical Drain enhanced soil flushing is a very low cost alternative to conventional *pump and treat*. It is able to reduce soil clean up times to a three to five-year period rather than the typical 20 years using the pump and treat system. It also has the ability to clean fine grain *in-situ* contaminated soils, such as clays, having low permeabilities on the order of 1×10^{-6} or 1×10^{-7} . Pump and treat systems are not applicable in soils that have these low permeabilities. The total cost for five (5) years of research and development, plus two (2) pilot plant studies, was approximately \$1.25 million. Articles featuring the Prefabricated Vertical Drain Technology have been published in *Initiatives* and as a *FETC Success Story* on the FETC web site. This technology is presently being demonstrated on a larger scale at the former NRC site in Ashtabula, Ohio.

Another impressive technology developed and applied through the WVU Cooperative Agreement is the SpinTek Centrifugal Membrane System. Four projects were funded at WVU on this technology at a cost of

\$500 thousand. Many articles throughout the USDOE have been written featuring this novel separation process technology. The technology has also been shown at the former NRC site in Ashtabula, Ohio for removing micelle surfactant and monomer surfactants from the TCE contaminant laden groundwater extracted from *in-situ* soil flushing operations through prefabricated vertical drains. This surfactant recovery and recycle results in a significant reduction in surfactant costs as well as greatly reducing costs to biodegrade the residual surfactant prior to the release of water to the environment. This technology has been adopted for use at the Los Alamos National Lab. Additionally, an aluminum industry company adopted the technology to remove the oil from oily waste waters generated in the pressing and extruding of billet aluminum.

Based on the cost to the USDOE for these technologies and considering their usefulness in the clean up effort, there are no other technologies developed through the USDOE that have provided or have the propensity to provide as great a yield. The technologies alone, based upon the research completed at West Virginia University, make the \$10.3 million USDOE contribution in the WVU Cooperative Agreement a excellent investment.

Introduction

In 1992, the Director of the Department Of Energy, Morgantown Federal Energy Technology Center (FETC) approached West Virginia University (WVU) and proposed a *Cooperative Agreement* between DOE/FETC and WVU. It's goal would be for WVU faculty and other resources to serve as the research arm for DOE/FETC in the area of hazardous waste site remediation. This would involve undertaking problems which were or may be barriers to proving a technology which would allow commercialization of the process.

Recognizing that the bulk of new jobs created are created by small businesses, the Federal government has mandated contracting goals in all sectors of government having contract responsibilities and capabilities. FETC's management recognized that small businesses are creative thinkers, technically competent beyond their resource base. The lack of adequate resources, i.e. manpower, money, equipment and computer modeling skills, often created an unsurpassable barrier for small businesses to get their ideas and inventions to the marketplace.

To assist the small businesses and provide resources and expertise in hazardous waste site remediation, FETC entered into the Cooperative Agreement with West Virginia University.

The funding for the first two years of the Cooperative Agreement was spread throughout the University in small grants (\$50-75k) from an internal proposal solicitation listing DOE/FETC's needs. Those researchers rising to the occasion resulted in there being readily identified a few core areas of competency. They were: confinement or barrier technology; fluid flow through porous media; and *in-situ* remediation techniques consisting of both chemical and biological processes. The investigators were encouraged to be continually talking and interacting with the small businesses to know their problems and needs for assistance. These became articulated as FETC's needs and provided new directions for research by the faculty. The third year of the Cooperative Agreement was sharply focused where successful investigators were closely tied to an explicit remediation technology and the small businesses involved in that particular technology. Once a problem or need was articulated and defined, FETC provided funds through the Cooperative Agreement Director to bring expertise from one of a number of resources (WVU, Marshall University, University of North Dakota Energy and Environmental Center, Institute of Gas Technology, et al) to address that need.

As the program matured the Cooperative Agreement focused on research and development associated with hazardous waste remediation problems existing at Department of Energy, Corps of Engineers, and private sector sites. The Agreement was built on a unique combination of resources coupling university researchers with DOE sponsored small businesses, leading towards field testing and large scale demonstrations of environmental technologies. Most of the Agreement's projects were categorized in the technology maturity Levels under Gate 3, Advanced Development, Gate 4, Engineering Development, or Gate 5, Demonstration.

The Cooperative Agreement supported efforts of both West Virginia University and outside entities through vigorous subcontracting efforts. Outside entities included private industries and other colleges and universities.

Over time, the objectives of the Cooperative Agreement evolved to:

- Couple WVU researchers with DOE funded small businesses to solve problems and remove barriers to commercialization of remediation processes.
- Identify and initiate development and demonstration of workable systems to fill gaps in current technologies bringing research to the Gate 5 Demonstration level.
- Train and prepare students to enter into industrial and agency positions in the waste and site remediation professions.

The scope of the Agreement encompassed all forms of hazardous waste remediation including radioactive, organic, and inorganic contaminants. All matrices were of interest; generally soil, water, and contaminated structures. Economic, health, and regulatory aspects of technologies were also within the scope of the agreement.

The highest priority was given to projects or interactions with the small businesses funded by FETC and DOE doing research and development on innovative remediation processes. These projects were to assist in the removal of barriers to development and commercialization of these technologies. Studies of existing, underdeveloped technologies were preferred over fundamental research into remediation technologies. Sound development of completely new technologies was preferred over minor improvements in existing methods. Solid technological improvements in existing technologies or significant cost reduction through innovative redesign were preferred projects. Development, evaluation and bench scale testing projects were preferred for the WVU research component.

During the five plus years the WVU Cooperative Agreement existed some 45 different projects were funded. Most of the projects were funded for only a one year period but there were some that were deemed of such quality and importance that they were funded for multiple years. The Agreement funded fourteen over a two-year period, seven over a three-year period, one over a four-year period, and one over a five-year period. Over 22 external agencies, businesses, and entities have cooperated with or been funded through the WVU Cooperative Agreement. Approximately 33% of the funding received by the Agreement was allocated to these external entities.

Systematic Assessment of the State of Hazardous Waste Clean-up Technologies

Year/Task Number: 1993/MC-1
1994/MC-1

PI: Mitchell T. Berg
Industrial Engineering Department
West Virginia University
Morgantown, WV 26506

Technical Summary

The purpose of this effort was to provide DOE with a database tool containing information on pertinent environmental remediation technologies to aid in technology transfer to their sites. The research was initiated to first develop a database of currently available and emerging remediation technologies, followed by the compilation of a list (in database form) of existing and currently available databases.

The methodology began with screening DOE hazardous waste sites; then a conceptual model to classify DOE hazardous waste problems was developed. The deliverables were beta-versions of databases entitled Environmental Remediation and Restoration Database (ERRD), and Database of Environmental Information Sources (DEIS). The databases were encoded in FOXPRO 2.5 for Windows.

The project concept appeared to be feasible and useful, however it became apparent by the third quarter of 1992 that the project course needed to be altered. Initially the main focus for evaluation of the data concentrated on encoding records on 79 technologies. When the project was terminated only 43 of the technology records could be considered complete and the other 36 had very little information at all. Practically, the project did not produce a completely useable product for the DOE.

This task was the first project that was initiated through the WVU Cooperative Agreement under the direction of the National Research Center for Coal and Energy (NRCCE) in October 1992. The work was discontinued when the CEE department began managing the Cooperative Agreement.

Use of Prefabricated Vertical Drain Enhanced Soil Flushing for *in-situ* Soil Remediation

Year/Task Number: 1993/MC-2A
1994/MC-2A
1995/1.1
1996/1.2
1997/1.5

PI: Mohammed Gabr
Department of Civil Engineering
North Carolina State University
Raleigh, NC 27695-7908

This research was supported over a five year period beginning with laboratory bench scale studies and culminating in a field application at an abandoned Ashland Oil and Refining site in Weston, WV.

Technical Summary

In general, the effectiveness of the soil flushing process is limited by the extent with which the contaminant is extracted from the soil and solubilized in the flushing solution, and the ease with which the flushing solution moves through the contaminated soil. Generally, for fine grained soils, both the extraction of the contaminant from the soil and movement of flushing solution are less than that observed for large grained soils (i.e., sands). Thus, soil flushing is not always effective for remediating contaminated aquifers and the use of “pump and treat systems” on an extremely long term basis is often required.

Prefabricated Vertical Drains (PVD's) can be used to shorten the drainage path of the flow and therefore expedite the soil flushing process. Because the installation process is relatively simple and inexpensive, fluid extraction using this process can prove to be practical and cost-effective. Compared to conventional well fields and drains, the use of PV drains would expedite the contaminant recovery and reduce both labor and material costs.

The PVDs can be economically placed. The installation of a 0.10 acre site with PVDs on a 3-foot spacing is estimated to take 3 days or less. Fluids can be vacuum extracted or injected through the PVD's. With this close spacing, the resulting short flow path (1.5 feet) for travel of the contaminant, very low permeability soils (like clays with $k=10^{-6}$, 10^{-7} cm/sec) can be remediated as well as the higher permeability granular soils. By extracting fluids from the PVDs, the location of the contaminant can be determined and one can then work with only those PVDs located in the exact contaminant area. This greatly reduces the volume of injected and extracted liquids generated and allows complete control of the mobilized contaminants.

Work conducted on the project included laboratory tests, pilot scale testing and analytical model development. Laboratory tests included flexible wall permeability tests on soil specimens with and without a PVD installed. Bench-scale tests using large scale reactors, referred to as Smear Cells, were conducted to evaluate the equivalent diameter, long term performance, and zone of influence of the PVDs. In addition, several pilot scale Contaminant Recovery Cells (CRCs) were used to evaluate the flow characteristics of the soil samples and the concept of soil flushing using the PV drains in various installation arrangements. Sodium chloride (NaCl) tracer (100 and 1,000 mg/l) was used for discerning the concept of contaminant recovery using the PVDs system. Soil samples were prepared from sand and clay by preparing a mixture of 80% Ottawa sand and 20% kaolinite. An analytical model for the design of PVD systems for soil remediation was also developed. The field site selection and investigation was done following procurement of a site in Weston, WV. This site was owned by Ashland Petroleum Co. and had LNAPL and DNAPL contamination present in the groundwater. A pilot scale field experiment was performed to find air and fluid flowrates per PVD. Also, several grab samples were acquired during testing and tested for BTEX concentrations.

The project was successful as fluids were able to be extracted and injected through the PVD's. The follow on pilot demonstration of this technology was conducted at the RMI Ashtabula site during the spring and summer of 1998. (See 1997 Task 1.5 "Pilot Scale Demonstration of TCE Flushing Through Prefabricated Vertical Drains at the RMI Extrusion Plant in Ashtabula, Ohio.) A larger demonstration project is planned for late 1998.

In-situ Bioremediation of Chlorinated Organic Solvents

Year/Task Number: 1993/MC-2B
1994/MC-2B
1995/1.2

PI: William A. Sack
Department of Civil & Environmental Engineering
West Virginia University

Technical Summary

The purpose of this research was to evaluate and optimize the ability of methanogenic, methanotrophic and other bacteria for cost-effective biotransformation of chlorinated aliphatic compounds (CAH) such as TCE found at DOE sites. The research plan involved the systematic manipulation of environmental conditions in the subsurface for the purpose of enhancing the rate and extent of biodegradation of candidate CAH compounds. Also, the use of prefabricated vertical drains (PVD) for addition of amendments was evaluated.

Batch and column studies were performed. Three different column arrangements were investigated: 1) separate anaerobic and aerobic columns, 2) sequential anaerobic/aerobic columns, 3) simultaneous anaerobic/aerobic columns.

The project was successful as it discovered that the simultaneous column configuration more effectively optimized the symbiotic relationship between methanogens and methanotrophs and promoted more complete destruction of the CAH compounds. The results also showed that column configurations can handle TCE shock load as TCE removal rates increase with increasing concentrations of TCE in the influent. It was also found that peroxide is a better oxygen source than gaseous oxygen due to the infinite solubility of peroxide in water. Furthermore, it was also discovered that although the PVD's were successful in adding organic amendments to the system, clogging was a problem and was responsible for most of the system headloss (96.8%) and could use further investigation.

Dust Control Methods for In-situ Nuclear and Hazardous Waste Handling

Year/Task Number: 1993/MC-4
1994/MC-4

PI: Felicia Peng
Department of Mining Engineering
West Virginia University

Technical Summary:

The overall objective of this program was to study the *in-situ* particulate matter and volatile organic compound (PM/VOC) control technologies for excavation of hazardous and nuclear waste sites. A hazardous waste excavation information system (HWEIS) was developed for searching and selecting PM/VOC control technologies for the said application.

The project goals were successfully met. The deliverable was the HWEIS database computer package. It has a user-friendly interface and on-line assistance to store all the information associated with the control of *in-situ* PM/VOCs. It will be useful for information updating and searching as well as decision-making for hazardous waste excavation.

Chemical Destruction of Chlorinated Organic Compounds

Year/Task Number: 1993/MC-6
1994/MC-6
1995/2.1

PI: Kung Wang
Department of Chemistry
West Virginia University

Technical Summary

The purpose of this research project was to first evaluate the existing technologies for the destruction of PCBs by chemical methods. The focus was mainly on the current commercial processes as well as procedures recently published in the literature, including dechlorination of PCBs by sodium and other alkali metals, by the use of a strong base, by catalytic dechlorination, and by photochemical degradation. Development of a new chemical treatment procedure for dechlorination of PCBs was also a major goal.

A literature review produced excellent review articles for the dechlorination of PCBs by the following chemical methods: 1) dechlorination of PCBs by sodium and other alkali metals, 2) destruction of PCBs by the use of a strong base, 3) catalytic dechlorination of PCBs, and 4) photochemical dechlorination of PCBs. The first method, dechlorination of PCBs by sodium, was repeated in the laboratory using sodium naphthalene (NaNAPH) as an electron carrier for PCB destruction. It was found that the reaction was essentially complete within a few minutes with reduction of chlorobenzene concentration from 595 ppm by weight to less than 1 ppm. With the establishment of the NaNAPH as a baseline for comparison, an alternative electron carrier was sought. The literature indicated that 1-dimethylaminonaphthalene (NaDMAN) could be used instead of NaNAPH; in the literature however, it had been applied to aliphatic chlorides and not to aromatic chlorides. This research effort extended the use of NaDMAN to aromatic chlorides such as chlorobenzene. The efficiency of dechlorination was similar to that of the NaNAPH.

This research project was successful at meeting its objectives and it delivered an extremely valuable dechlorination process by improving an existing one. First, it thoroughly evaluated the literature on the available dechlorination processes. In addition, it improved one of the processes by replacing the NaNAPH with NaDMAN. The NaDMAN is a more attractive reagent than NaNAPH because NaNAPH is classified as a priority pollutant by EPA and its use is restricted. It is also difficult to separate NAPH from other organic products after the dechlorination process is complete. Contrarily, the NaDMAN can be regenerated by neutralizing the aqueous solution for easy recovery and reuse, minimizing pollution to the environment and reducing the cost of the dechlorination process.

Development of Organic Sensors: Monolayer and Multilayer Self-Assembled Polyion Films for Gas-Phase Chemical Sensors

Year/Task Number: 1993/MC-7
1994/MC-7

PI: Harry Finklea
Department of Chemistry
West Virginia University

Technical Summary

The goal of this project was to design a chemical sensor based on a surface acoustic wave device. It was expected that development of a small gas-phase sensor would be useful for detecting and quantifying select organic vapors in unsaturated soil.

Over the two years this project ran, no useable results were obtained.

Winfield Lock and Dam Assistance Program

Year/Task Number: 1993/MC-9
1994/MC-9
1995/3.1

PI: Raymond J. Lovett
National Research Center for Coal & Energy
West Virginia University
Morgantown, WV 26506

Technical Summary

The site of the former ACF Industries, Inc. railroad tank car maintenance shop was contaminated by various organic and inorganic chemicals. The company abandoned the site in March 1986 and the U.S. Army Corps of Engineers (ACE) acquired the site, which was needed for the approach to expansion of the Winfield Locks and Dam. The extent of contamination, and most explicitly, the presence of dioxin at the site, had been inadequately documented before the ACE took possession of the land. The ACE, when it became aware of the extent of contamination, undertook a study which culminated in the publication of an Engineering Evaluation and Cost Analysis (EE/CA) in May 1992. The EE/CA was made public with a 30 day response period. The net conclusion of the EE/CA was that the ACE would incinerate the contaminated soil. The combination of citizen perception that they had not been appropriately informed of the problem and the proposal to incinerate the soil led to a concerted effort by the citizens to have the EE/CA reconsidered. The concerted effort, which included the involvement of the WV Congressional delegation, successfully led to reconsideration of the issue by the Army.

The subsequent reevaluation by the Army took nearly 7 months; the results, an Action Memorandum for the site, was released in December 1992. The Action Memorandum proposed that the soil be excavated, stored in temporary buildings, then remediated after further study.

As a result of the public involvement in the lock issue, Senator Robert C. Byrd of West Virginia and the Senate appropriations committee published some language which involved the Department of Energy and West Virginia University (WVU) in the problem. The role of the DOE was to assist WVU financially in their efforts to safeguard the health and safety of the citizens and investigate the application of DOE technology in remediation of the site. The DOE-WVU effort was funded through the WVU Cooperative Agreement and consisted of direct assistance to the area around the site as well as certain technological investigations directed towards the choice of the eventual remediation technology (or technologies).

West Virginia University became involved in the project in August of 1992. Shortly after that time, a formal program to involve WVU in the solution to the remediation problem began. The WVU involvement was two-pronged. WVU interacted extensively with the citizens of Eleanor (and Putnam County) providing

technical, logistical and financial assistance in their efforts to understand and evaluate the ACE plans for remediation. A primary objective for WVU was to inform the citizens of possible health and safety problems with proposed operations. Additionally, WVU interacted with the U.S. Army Corps of Engineers to implement appropriate technology at the site.

Through the WVU Cooperative Agreement numerous projects were funded at WVU during the years 1993 and 1994 including MC-1, MC-2A, MC-2B, MC-4, MC-6 and MC-7 to support the cleanup effort.

During late 1995 the US Corps of Engineers made the decision to excavate the contaminated material from the Winfield Lock and Dam site, place it in containers and ship it to Utah for disposal. This was accomplished over the next 18 month period.

Assessments of Technologies for Hazardous Waste Site Remediation: Non-Treatment Technologies and Pilot Scale Test Facility Implementation

Year/Task Number: 1994/MC-10

PI: Dave Locke
BDM Federal Inc.
1199 Van Voorhis Road
Morgantown, WV 26505

Technical Summary

The purpose of this evaluation was to review the different barrier systems that have been identified or proposed by DOE contractors as methods of preventing the further contamination of soils and groundwater resources at the various DOE former weapons manufacturing sites. A systems engineering approach was followed in evaluating the potential barrier systems. A review of literature discussing *in-situ* barrier materials for barrier systems was conducted to identify the various technologies available to support *in-situ* barrier deployment for the Hanford DOE site as well as for other sites.

In the conclusion of the MC-10 project, it was recommended that the remediation technology selected for DOE sites should be “as non-intrusive as possible and should not foreclose on future potential remediation activities that might be desired or required at [DOE] sites. The circulating air barriers and the freeze barrier fits this description.” Since technology selection is a crucial part of the remediation process, this report was successful at delivering meaningful results.

Another recommendation that was proposed was that additional research be conducted in support of the Circulating Air Barrier and the Permeation (Cone Grout) Chemical Grout Barrier. This proposal led the project into two subsequent areas of research which were initiated in 1995 under Task MC-26 “Development of Standard Test Protocols and Design Models for *in-situ* Formed Barriers”.

Remediation of Hazardous Sites with Stream Reforming: I Study of Feasibility and Development of Instrumentation, II Pressurized Pulsed Combustor Fluidized Bed Studies (MTCI)

Year/Task Number: 1994/MC-11
1995/2.4

PI: Victor Mansour
Manufacturing & Technology Conversion International Inc.
6001 Chemical Road
Baltimore, MD 212216

Technical Summary:

The objective of the Phase I effort was to establish the design basis for a pressurized indirectly heated reactor based upon the MTCI steam-reformer technology that was being operated at atmospheric pressure and at an industrial process scale (1-5 tons/hour). The effect of pressure enhancement of the technology would be to increase the capacity of the system substantially.

A preliminary test plan matrix was prepared for experiments to be conducted in the pressurized, indirectly-heated steam reformer using a quantity of solid or liquid feedstock waste. This unit, after being pressure tested, was determined to be unsuitable for the pressurized operations. With concurrence from the DOE and the University, some additional funding was made available to build a pressurized unit to code. The unit was designed, built, and leak checked. However, there were insufficient funds to complete the Phase I test program. The unit was shipped to the Baltimore facility where it will eventually be reassembled and tested and the results reported to DOE and the University.

The goal of the project was not achieved due to a series of assumptions made by MTCI with respect to the utilization of the original two-tube characterization unit.

Design of an Improved Model for VOC Recovery Predictions

Year/Task Number: 1994/MC-14

PI: K. Aminian & S. Ameri
Petroleum & Natural Gas Engineering Dept.
West Virginia University
Morgantown, WV 26506

Technical Summary

One of the major environmental problems is soil and groundwater contamination with volatile organic compounds (VOCs). Many potential groundwater contaminants are introduced at or near the surface due to chemical spills, leakage from underground tanks, subsurface waste disposal, etc. The movement of fluids in the so-called vadose or unsaturated zone between the atmosphere and groundwater (saturated zone) has received an increased interest in the recent years due to the environmental concerns. Soluble components may migrate in the aqueous phase through the vadose zone to groundwater. Volatile components may move by mass flow and diffusion in vapor (gas) phase. Furthermore, a wide class of environmental contaminants consisting of organic compounds of low water solubility including many industrial solvents and automobile and jet fuels can occur as separate liquid phase in the soil. Contamination of aquifers generally occurs by infiltration of liquid substances through the unsaturated zone of the aquifer system.

Numerous processes have been designed to volatilize and extracted volatile organic compounds from contaminated soils. Though VOC remediation technology is being actively deployed, significant aspects of the technology are not well understood. The accurate prediction of contaminant distribution and movement in the unsaturated zone can significantly enhance the technical and economical success of contaminant removal process. As a result, the unsaturated zone studies have shifted toward contaminant migration. Research in unsaturated soils has mainly been involved with the development of procedures and numerical models to quantify unsaturated water flow and contaminant transport. Most field studies have come from government, private industries, and other agencies interested in disposing of waste while minimizing groundwater pollution. Field-scale validations are expensive and have been implemented only in few cases. Laboratory models have served as an alternative solution to reduce the magnitude and cost of field-scale studies. However, there is a lack of multi phase experimental studies that include all phenomena associated with the vadose zone.

Existing numerical procedures assist in quantifying some processes occurring in the unsaturated flow and solute transport phenomena. However, their application has not been widely implemented and their use is still limited. The complexity and dynamic interaction of the unsaturated processes has posed a challenge to current research. Although extensive research has been conducted to quantify and qualify processes such as multi phase flow transport, diffusion, dispersion, sorption, chemical transformation, chemical equilibrium,

and volatilization, no numerical model has been developed to effectively quantify the interaction of all unsaturated processes in heterogeneous porous media. The ability of an integrated physical model to evaluate and monitor all processes occurring in the unsaturated soil media would greatly aid existing numerical models in evaluating field-scale unsaturated problems. The main objective of this research study was to design a three dimensional physical model capable of monitoring VOC transport in both the saturated and unsaturated porous media.

The design of the physical model was performed in conjunction with Department of Civil and Environmental Engineering at Rutgers University. The design process was performed in three phases:

1. Conceptual design in which functional representation of the model was developed.
2. Dimensioning of the model in which a computer model was selected to optimize the dimension and location of monitoring devices for different sources and soil conditions.
3. Final design in which all features of the model and monitoring devices were dimensioned and specified for construction.

Conceptual Design

A preliminary conceptual design was prepared in cooperation with Mr. N.S. Soler and Dr. M. H. Maher at the Environmental Engineering Department at Rutgers University. Specifically, the quantification of the dynamic, temporal, and spatial interaction of processes such as advection, diffusion, sorption, degradation/biotransformation, and volatilization was identified as the main conceptual component of the design process. Source, soil media and monitoring devices were defined as the primary physical elements of the model.

Dimension of the Model

The dimensioning of the model was conducted by selecting and implementing a computer model capable of simulating advective flow in the unsaturated soil media. The selected model was the Princeton Model by Michael Celia which was run to simulate unsaturated flow under different soil conditions, and the dimensions of the model were identified. The simulation runs were conducted by Mr. Soler of Rutgers University. Three types of soils including the Troup Loamy Sand, Norfolk Sand, and Bethany Loam of varying hydraulic properties, were selected to determine the range of plume dimensions with time. It was determined that plume monitoring within a period of 24 hours was appropriate. After considerations of monitoring time, soil types, and costs, a squared model box of 75 centimeters was determined to be suitable for monitoring unsaturated processes of soils presenting higher permeabilities than those of the Norfolk Sand soil.

Final Design

The conceptual design presented the basis for the final design. A major component of the final design was the selection of the monitoring devices. Of all moisture content and pressure monitoring devices, the less

intrusive devices are the Bouyoucos gypsum blocks and the pressure transducers by Omega. The gypsum blocks with approximate dimensions of 15 x 30 x 40 millimeters present some intrusive properties that would interfere with the unsaturated flow if located within the soil media. Consequently, it was decided to accommodate the gypsum blocks at the boundaries.

Twenty five (25) lateral and forty five (45) bottom cells enclosing the model box will be installed to quantify air/vapor pressure and liquid flow. Of the 45 bottom cells, twenty five (25) cells will measure vertical flow and gas pressure. The remaining twenty (20) bottom cells located at the perimeter of the cell arrangement will measure the lateral flow reaching the lateral cells. The perimeter bottom cells will be tied to the 25 lateral cells. The bottom and lateral cells will be assembled by an exterior metal frame.

Inside the cell structure, a framed box will contain the soil and support the gypsum blocks at the boundary. The framed box walls will be of sieve material of appropriate dimensions to contain the soil while allowing lateral and vertical fluid flow. If it is determined that the sieve allows particle filtration to the boundary cells, a geogrid will be placed inside the framed box. Each lateral cell will have two gypsum blocks, pressure monitoring devices which allow for air/vapor release and flow monitoring, liquid flow monitoring devices which allow for liquid release, and sampling ports. Similarly, each bottom cell will have one gypsum block that will be supported by the framed box, and devices for gas and liquid measurements. With these monitoring devices, gas flow, moisture content, and fluid flow will be measured with time and space.

Environmental Pollution Control Devices Based on Novel Forms of Carbon

Year/Task Number 1994/MC-17
 1995/2.5
 1996/2.4
 1997/4.2

PI: 1994-1997
 John W. Zondlo
 Alfred H. Stiller
 Albert Brennstainer
 Department of Chemical Engineering
 West Virginia University

 1994-1995
 R. Terry K. Baker
 Nelly M. Rodriguez
 Materials Research Dept.
 Penn State University
 University Park, PA

Technical Summary:

The purpose of this research was to assess the feasibility of using novel electrochemical carbonaceous devices to remove radionuclides and heavy metal contaminants from aqueous streams. Initially the project was to be a joint effort between Penn State University (PSU) researchers and West Virginia University (WVU) researchers. The PSU researchers were to develop and characterize the novel carbon forms and WVU researchers were to address the fabrication, behavior and analytical utility of these novel carbonaceous materials. Reviewing the work after the first two years it was determined that the novel carbon forms being produced by the PSU researchers were already available on the open market in very similar or identical forms at a much lower cost. Funding for the PSU researchers was curtailed and testing was concentrated on the commercially available carbon forms.

The types of carbon material were tested for their ability to remove radionuclides and heavy metal ions from aqueous samples via electroplating and electrosorption. Removal efficiencies above 90% were obtained for the reductive removal of cadmium, lead and copper. Long-term removal of lead over using electroplating on carbon nanofibers, vapor grown carbon fibers and carbon foam decreased the concentration of a 100 ppm lead feed to less than 10 ppm. Even after 72 hours, the carbon nanofibers showed no sign of saturation. For the 72 hour period, a capacity of $1.025 \text{ g}_{\text{Pb}}/\text{g}_{\text{carbon fibers}}$ was realized. An even greater capacity is expected at saturation.

Removal via electrosorption using carbon nanofibers produced similar results, but with an early drop-off of efficiency and a much smaller capacity ($7.1 \times 10^{-4} \text{ g}_{\text{Pb}}/\text{g}_{\text{carbon fiber}}$ for a 57 hour period). This was due to the neutralization of the charge on the carbon surface caused by the electrosorption of the positively charged metal ions. It was envisioned that for aqueous streams, electrosorption would be applied to remove

radionuclides and other metal ions that had reduction potentials more negative than that of water.

The recovery of metals was demonstrated using lead ions. The recovered effluent resulted in a 7-fold concentration of lead after reversal of the potential applied to the carbon material. This resulted in a decrease in the volume of lead waste by one-seventh.

The removal of nickel ions from solution directly onto the bare carbon materials was inefficient. By plating a small amount of copper onto the carbon surface prior to use, enhanced removal efficiencies were obtained. At pH 7.0 removal efficiencies of 89% were achieved.

The electrosorption of strontium was also examined. A removal efficiency of 34.4% was achieved using “pelletized” carbon nanofibers. At pH 10.0 and using a coating of MnO_2 , removal efficiencies were improved to 68.0%.

The electrolytic removal of uranium was exceptional. For an inlet feed concentration of 100 ppm uranium, an effluent stream was obtained with uranium concentrations near or below 1 ppm. Long-term removal of uranium was accomplished using the smaller remediation cell. For a 42 hour period, excellent removal of uranium was achieved (99%). Drop-off in removal efficiency was observed beyond 42 hours due to clogging of the carbon material. Recovery and concentration of the uranium waste decreased the volume from 2 liters down to 95 ml and concentrated the uranium to 1543 ppm. This is equivalent to a capacity of $0.15 \frac{\text{g}_{\text{uranium}}}{\text{g}_{\text{carbon}}}$.

A scaled-up version of the prototype was constructed and tested to handle even greater flow rates of contaminated wastes. After several modifications, a removal efficiency of 99% was achieved for lead. A “real” sample obtained from the EPA’s cleanup process at Fort Benjamin Harrison was treated. Ninety five percent removal of lead was achieved for a single pass through the electrolytic cell.

A parametric study of removal efficiency versus cell variables of current, pH and flow rate was completed. Flow rate had the most significant effect on the removal of lead. The method worked well over the pH range of 3.5 to 7.0. At a pH below 3.5, the oxidation of the plated lead by the acid in solution became significant, thus decreasing the efficiency of the electrolytic cell. The scaled-up remediation cell was put to use treating 32.4 liters of a 100 ppm lead solution over a period of 54 hours. Removal efficiencies remained at 98% or greater for the study.

During the later years of support it was hoped that the process could be scaled up to allow its application to reasonably large volumes of metal laden waste waters. Unfortunately the scale up did not occur fast enough and the project ended with a device that was not large enough to be deployed except on a very small scale. Interest in the process still exists for small metal plating operations and discussions are also going on between WVU researchers and interested parties.

Microbial Enrichment for Enhancing *in-situ* Biodegradation of Hazardous Organic Wastes in Soil

Year/Task Number: 1994/MC-18
1995/1.3

PI: Alan J. Sexstone
Plant & Soil Science Division
College of Agriculture & Forestry
West Virginia University

Technical Summary

The purpose of this study was to develop a reliable assay to directly compare selected commercially available microbial inocula for bioaugmentation of mixed organic wastes in composted soil. Both surface and subsurface soil was excavated and amended for waste composting. Soils were artificially contaminated with either crude oil or a model mixed waste (AMOW) which contained hydrocarbons, solvents, and polynuclear aromatic compounds. Biodegradation of the pollutants was monitored in the presence and absence of inoculation. Monitoring was accomplished by use of the developed assay which monitored CO₂, an end-product of biological degradation or organic substrates.

Of the inocula tested, three (Sybron, Interbio, and Hydrobac) appeared to be the most effective. Microbiological analyses demonstrated that these inocula contained the highest number of hydrocarbon degrading bacteria. Beneficial results of inocula appeared to be most pronounced in subsurface compared with surface soils.

This project was successful in meeting its stated purpose. An assay was developed and used to measure the extent of biodegradation of the various contaminants. It was shown that bioaugmentation may be effectively employed to enhance rates of bioremediation in ex situ biopiles in which aeration and nutrition are non limiting. Furthermore, it was determined that the three mentioned inocula were the most effective at degrading the organic wastes.

Soil Decontamination with a Packed Flotation Column

Year/Task Number: 1994/MC-19

PI: Eung Ha Cho
Department of Chemical Engineering
West Virginia University

Technical Summary

The objective of this research was to investigate the removal, through a separation processes, of plutonium oxide from contaminated soils at DOE's Nevada Test Site. Experimentation was conducted using cerium dioxide as a surrogate waste amended to actual, uncontaminated soil from the DOE Nevada site.

Flotation tests were carried out with a Hallimond cell using collectors of emulsified oleic acid, petroleum sulfonate, and dodecylamine. Flotation tests using conventional flotation cells and a packed flotation column using only emulsified oleic acid were also performed.

This work produced interesting results from comparison of the flotation tests. It was found that the packed flotation column outperformed the conventional mechanical cell because the packed column minimized entrapment of non-floatable particles. It was also found that the cerium dioxide floated well from the study soil mix using all three collector solutions.

This research was successful in achieving its goals to emulate removal of plutonium oxide from site specific goals.

Treatment of Volatile Organic Compounds (VOCs) Using Biofilters

Year/Task Number: 1994/MC-20

PI: Patrick Carriere
Department of Civil & Environmental Engineering
West Virginia University

Technical Summary

The objective of this research was the investigation of efficiencies achieved using biofilters for removal of VOCs from gaseous waste streams. For this study, benzene and toluene were chosen as the contaminants for the gaseous waste stream. The two microorganisms selected as being capable of affecting degradation of the waste stream were 1) acinetobacter Sp. Genospecies 11 and 2) Nocardia Paraffinae Sp. In the study, removal efficiencies of benzene and toluene were studied and compared using both granular activated carbon and biologically activated carbon filters.

Evaluation of the results from the experiment indicated that the biologically activated carbon filter had better removal efficiencies (as high as 35%) of benzene and toluene than did the granular activated carbon filter.

This research was successful in achieving the project goals. It's results provide data for comparison of the two different systems which was not previously available.

Use of Granular Activated Carbon Columns for the Simultaneous Removal of Organics, Heavy Metals and Radionuclides

Year/Task Number: 1994/MC-21

PI: Brian Reed
Patrick Carriere
Department of Civil & Environmental Engineering
West Virginia University

Technical Summary

The goal of this research was to investigate the feasibility of using granular activated carbon (GAC) columns to treat an aqueous waste stream containing organic contaminants, heavy metals, and radionuclides. Results of this work demonstrated that the use of GAC columns to simultaneously remove organic and inorganic contaminants from an aqueous waste stream is technically viable. The research reports results in column pretreatment and regeneration of the carbon material after loading with lead and phenol contaminants. Experimentation into removal of strontium (Sr) and cesium (Cs) using GAC columns was performed. Removal of Sr by GAC columns appeared to be viable but the removal of Cs was not attained in sufficient quantities to warrant further research.

Overall this project was successful in completing its research objective and with producing usable results.

Compact Mercuric Iodide Detector Technology Development

Year/Task Number: 1994/MC-22

PI: Samuel Nandi
Department of Mechanical & Aerospace Engineering
West Virginia University

Technical Summary

This project investigated development of a compact mercuric-iodide based detector technology and a control strategy for the purpose of mobile robot navigation in radioactive exposure environments. The results of this work produced a mathematical model which enables a mobile robot to gain knowledge about its position and orientation with respect to the radiation source from readings of a sensory apparatus. A feedback control strategy was developed to navigate a mobile robot towards a radiation path.

The results of this work accomplished the planned goals.

Evaluation of IR and Mass Spectrometric Techniques for On-Site Monitoring of Volatile Organic Compounds

Year/Task Number: 1994/MC-23
1995/2.2

PI: Fred King
Department of Chemistry
West Virginia University

Technical Summary

The objective of this project was the identification of instrumental approaches for field determination of Volatile Organic Compounds (VOCs). Evaluation of current literature and available technologies identified the Open-Path Fourier Transform Infrared Spectroscopy as the best method for VOC detection.

The objective of the second years study was to develop an atmospheric monitoring ion trap mass spectrometry system and associated methods for the field determination of VOCs such as benzene, toluene, ethylbenzene and zylenees (BETX).

There was an attempt to employ selective ion storage software to enable the monitoring of the BETX components. This was attempted with a Gas Chromatograph inlet. However, the nature of the software precluded independent control of ionization, mass scanning, and detection. An additional problem was that the software for selected ion storage precluded the use of tandem mass spectrometry. This 1995 task produced no usable deliverables.

Socio-Economic Assessment of Alternative Environmental Restoration Techniques

Year/Task Number: 1994/MC-24

PI: Jerald J. Fletcher
Division of Resource Management
Agriculture & Resource Economics
College of Agriculture and Forestry
West Virginia University

Technical Summary

The primary objective of this research was to expand the amount of information on community concerns and costs included in the choice of clean-up technologies from a set of feasible alternatives. A survey instrument was developed through an iterative process of survey design, focus group discussions, and pretesting.

This project was successful. It not only expanded the amount of information on community concerns and costs, it also showed that current assessment methods typically used to evaluate alternative technologies do not include estimates of costs not paid by the responsible party or public agency. Consequently, current assessments used to choose the clean-up technology for a specific site are often not convincing to citizens.

This project resulted in a proposal for renewal that involved explicit recognition of the imposed costs to encourage citizen participation and lead to a more informed decision mechanism for final technology selection. More informed participation should both decrease the time involved in gaining acceptance of the alternative ultimately chosen and reduce the potential for gridlock.

The project was completed on budget and on schedule.

Waste Management, Education and Research Consortium (WERC) National Environmental Design

Year/Task Number: 1994/MC-25
1995/3.5

PI: Brian Reed
Department of Civil & Environmental Engineering
West Virginia University

Technical Summary

The purpose of WERC was to train students in the area of site remediation and restoration. The ultimate goal of WERC was to provide training for potential engineers and scientists for the DOE's remediation and restoration efforts.

A group of students, composed of both graduate and undergraduate students competed at the 4th and 5th Annual WERC for National Environmental Design held in Las Cruces, New Mexico.

WVU's participation in the design contest was an obvious success as in the 1995 contest the student group received the "Best Paper Award" and placed 5th overall. The students who participated in these programs were exposed to all aspects of the solution to a real-life environmental problem. Furthermore, several undergraduate students who participated in the program went on to graduate school at WVU due in part to their exposure to this program.

Development of Standard Test Protocols and Barrier Design Models for *in-situ* Formed Barriers

Year/Task Number: 1994/MC-26

PI:	S. Ameri	M. Gabr	D. Locke
	K. Aminian	B. Reed	BDM Federal
	Petroleum Eng. Dept.	Civil & Environ. Eng.	1199 Van Voorhis Road
	West Virginia Univ.	West Virginia Univ.	Morgantown, WV 26505
	Morgantown, WV	Morgantown, WV	

This research team was put together for the purpose of conducting research on physical barriers (mainly grouting) run by M. Gabr and desiccant barriers (circulating air barriers) headed by K. Aminian. The work was ultimately to be conducted on the Morgantown FETC site in building B-17 in hopes of gainfully using an underutilized building on the site. BDM Federal (Dave Locke and cohorts) was to provide technical advice on the barriers as well as provide site support in the B-17 building. This would allow the two research teams to conduct their research on site in the B-17 building with all of the proper permits, safety analysis reviews etc. The initial reporting on this project was to be as a team but it became readily apparent that for reporting purposes this was not a feasible operation. In order to straighten out the reporting mess the project in later years was divided into 3 projects. They were:

Chemical Grout Barriers Year/Task Number:	1995/1.5A 1996/1.3 1997/1.1
Circulating Air Barrier Year/Task Number:	1995/1.5B 1996/1.4 1997/1.2
Development of Standard Test Protocols	1995/1.5B 1996/1.4 1997/1/3

This technical summary will report only on the first year as Task MC-26.

Technical Summary

Chemical Grout Barriers:

- A prototype Large Diameter Column and Grout Injection System were manufactured for the testing of chemical grouts. Initial tests were began in January and refinements were made.
- Columns to conduct permeability testing of chemical grouts were constructed. Tests were begun immediately.
- A computer model to be used as grout injection simulator was identified and investigated.

Circulating Air Barriers:

- Tests were initiated to determine the effect of porous media on the air-water equilibrium that plays a critical role in the development of the CAB.
- Additional tests were designed by the CAB team to test the effect of dry air on an unconsolidated porous medium at irreducible water saturation. The experiments were conducted in B-17.

Development of Standard Test Protocols:

- The literature review was completed, reviewed by the research teams and delivered to FETC. BDM personnel compiled the three literature reviews (review of CAB, Chemical Grouts, and General Barrier Technologies) into one document and submitted to METC during January 1995.
- The Construction Permits for the small scale experiments for the Chemical Grouting and Circulating Air Barrier (CAB) was approved on December 23, 1994. Minor adjustments, as suggested by the METC SARS Review Committee, were made to the documents by the research teams. These documents were delivered to DOE/METC in January 1995. Construction and placement of the testing devices in B-17 commenced in January 1995.
- The research teams met as needed to keep informed of progress and problems associated with the project. WVU and BDM personnel moved into T-28, an office trailer located outside Building 17.

Contaminant Movement Prediction in Permeable Subsurface Soils

Year/Task Number: 1995/1.4

PI: H.I. Bilgesu
Sam Ameri
Department of Petroleum Engineering
West Virginia University

Technical Summary

The objective of this task was to investigate by modeling the effectiveness of prefabricated vertical drains (PVDs) in cleaning contaminated subsurface soils under saturated conditions. The work involved a numerical study to simulate the experimental work conducted with two different test setups, namely a smear tank and a contaminant recovery cell.

A software program was used to conduct runs with experimental data provided by research from other tasks. Additional runs were conducted to determine the effect of soil properties on the predicted drawdowns. The results from the numerical study were improved when the predicted drawdowns were matched with experimental data after modifying conductivity values for the soils.

The project was successful. A numerical model was selected and was successfully used to investigate the flow mechanisms in two different laboratory scale-test tanks. It was determined that high water flux rates between two boundaries define the flow paths and make it difficult to recover the contaminant. Also, PVDs were found to be ineffective for soils with high or very low conductivities. However, the model could not account for excess water accumulation above the soil as the results from the numerical studies under this condition were not comparable with experimental values.

Chemical Grout Barriers

Year/Task Number: 1995/1.5A Chemical Grout Barriers
1996/1.3 Performance and Characteristics Evaluation
of Acrylates as Grout Barriers
1997/ 1.1 Characteristics Evaluation of Grout Barriers
in Grout Testing Chamber

The three research projects shown above are related and the Tasks following 1.5A were logical extensions of the results of 1.5A. They are discussed here in totality as “Chemical Grout Barriers”.

The prelude to this project was “Development of Standard Test Protocols and Barrier Design Models for *in-situ* Formed Barriers done in 1994 as Task Number MC-26.

PI: Mohammed Gabr
Department of Civil & Environmental Engineering
West Virginia University

Technical Summary:

A significant effort in the U.S. and the world has been undertaken to develop remediation technologies for contaminated soils and waters. However, in some cases a permanent technology in response to some urgent environmental problems is yet to be developed. For this situation, a temporary barrier may be needed to retard the advancement of the plumes until a permanent remediation technology is implemented. As a result, extensive research is being conducted to evaluate the feasibility of using permeation grouts to develop subsurface containment/confinement systems to retard, or even prevent, the advancement of subsurface contaminant plumes.

A research program was conducted to assess the effectiveness of a urethane (Scotch-Seal (TM) Chemical Grout 5610 Gel manufactured by 3M Company) and a vinyl monomer (DurosealTM manufactured by Beton-Bau-Zubehor (BBZ) of Germany) grout in controlling the subsurface migration of waste. The study was carried out on the laboratory scale, and was intended to evaluate the chemical grouts ability to create a low-permeability barrier when injected into the soil. The development of standard grout evaluation and testing protocols was also a part of the program.

The experimental program was implemented in four phases: a) Grout Development, b) Performance Testing, c) Grout Testing Chamber, and d) Computer Modeling. The first phase included the evaluation of the grouts' properties and development of viable mix ratios. The second phase of the experimental program aimed at

examining the feasibility of injecting the urethane grout into a uniformly graded Ottawa sand (i.e., groutability) in large diameter (29.2cm), acrylic columns. Samples were collected from the resulting grout bulb and subjected to additional testing which yielded results on the grouted-sands hydraulic conductivity, compressive strength, and durability under permeation and immersion with various classes of chemicals. Phase 3 involved the design and construction of the Grout Testing Chamber (GTC) (essentially a 91.4 cm flexible-wall permeameter) and manufacture of a device to prepare uniform specimens for the GTC. The final phase evaluated the ability of the computer model BGROUT to accurately simulate the grout injections performed in Phase 2.

The first phase of the study resulted in four urethane mixes and one vinyl monomer mix being developed for the next phase. All the urethane mixes were 10:1 (activator:gel) ratios; however, the mix additives varied. The vinyl monomer mix was comprised of 50% water and 50% gel concentrate.

Results from the second phase indicated that two of the urethane grout mixes could be easily injected into the Ottawa sand at its porosity extremes. Additionally, the larger the perforation size and perforation length on the injection probe, the larger the resulting grout bulb and bulb radius. Samples collected from the injected bulbs yielded hydraulic conductivities (k) of 2.4×10^{-7} cm/s with water which significantly increased when using chemical permeants. Grouted-sand samples from both of the grout mixes swelled excessively and decreased in strength when immersed in water, bases and ethylene glycol solutions. Cupric sulfate, methanol, acetone, and acids appeared to have few observable affects on the samples.

The GTC was designed and sent out for construction. Additionally, a sand rain device was designed and manufactured to produce uniform density specimens for the GTC. Unfortunately, the grout testing chamber (GTC) was delayed many months during construction and did not arrive in time to be used. Consequently, that part of the project was canceled and the research using the GTC was never accomplished.

The results from Phase Four indicate that BGROUT can be used to formulate more efficient grout injection strategies. This model was relatively simple and easy to use. When comparing the results obtained from the Phase Two Injectability experiments and those predicted by the model, the margin of error was 5-19%. However, it was discovered that mass balance inconsistencies were encountered in nearly all the simulations.

Circulating Air Barriers or Development of Standard Test Protocols for Dessication Barriers

Year/Task Number: 1995/1.5b
1996/1.4
1997/1.2

PI: K. Aminian & S. Ameri
Petroleum and Natural Gas Eng.
West Virginia University

The prelude to this project was “Development of Standard Test Protocols and Barrier Design Models for *in-situ* Formed Barriers” done in 1994 as Task Number MC-26.

Technical Summary

This project aimed at developing and investigating containment/confinement technology using a “Circulating Air Barrier (CAB)”. The CAB utilizes the injection of dry air to create an ultra dry zone *in-situ*; beneath or adjacent to the zone of contamination to store contaminated fluids thus preventing their further migration. The CAB system can provide many advantages, however, there were no laboratory data or CAB field performance data available in the literature. There were however a number of issues that needed to be settled before it could be decided if the CAB technology was applicable. Key among these issues were the influence of the soil characteristics (such as porosity, permeability, water saturation, grain size distribution, and clay content) on the drying profile. This research was conducted using laboratory and meso-scale setups to evaluate the soil characteristics influence on CAB performance and to determine the effects of flow and sweep efficiency for fixed and mixed grain size soils. These experiments validated and/or improved model predictions of system behavior and drying profiles of different soil types.

Sand-packs were utilized for bench-scale testing to determine the relationship between soil characteristics and *in-situ* barrier quality. Sand-packs were calibrated to determine porosity, permeability, and saturation characteristics. The soil characteristics were varied by changing grain size and sorting of the pack materials. A detailed CAB vessel assembly was designed, approved for experimental studies at the B-17 facilities and constructed. Upon completion of the preliminary testing, the CAB vessel and the monitoring equipment was then assembled in Room 16 in FETC Building B-17. The developed protocols were found reasonable and repeatable. The results indicate that the procedures and instrumentation, with proper technique, generate highly accurate and quality data. The processes that take place during drying of an unsaturated thick porous media was studied and established. A large scale experimental setup was designed, constructed and tested.

Development of Standard Test Protocols and Barrier Design Models for *in-situ* Formed Barriers - Technology Support (BDM)

Year/Task Number: 1995/1.5b
1996/1.4
1997/1.3

PI: Dave Locke
William Overby
BDM Federal Inc.
1199 Van Voorhis Road
Morgantown, WV 26505

The prelude to this project was “Development of Standard Test Protocols and Barrier Design Models for *in-situ* Formed Barriers” done in 1994 as Task Number MC-26.

Technical Summary:

BDM Federal was to provide technical advice and assistance on the Circulating Air Barrier and Chemical Grout Barriers but more importantly they were to provide site support for the barrier projects allowing the research to be conducted in the B-17 building at FETC located in Morgantown WV. BDM was to draft, coordinate and obtain all of the proper permits, safety analysis reviews and other documents to allow research on both the circulating air barriers and chemical grouting barriers to be conducted in the B-17 building.

NEPA documentation for Phase I experiments was prepared by BDM and was submitted to FETC for review and approval. The NEPA documentation was accepted by FETC as an Appendix B Categorical Exclusion (CX-B). The project personnel completed “General Courses” and “Operation Safety” as per “1994 ES&H Training Courses for Short-Term Employees.” Training courses included HAZCOM I-IV, ES&H Awareness, RCRA Hazwaste 1, Chemical Hygiene, General Laboratory Safety 1 & 2, and General Safety Overview.

The Phase I experimental setup (CAB vessel assembly) and experimental procedures were designed and developed by BDM. The “Construction Permit Request” was prepared by BDM and was submitted to FETC SARS Committee for review and approval. The SARS committee approved the plan, with minor revisions, during its meeting on December 23, 1994. Detailed CAB vessel assembly drawings were submitted to FETC personnel for re-drawing as per FETC requirements. Detailed CAB vessel assembly drawings were submitted to EG&G personnel (as approved by FETC) for CAB fabrication. A substantial amount of interaction with EG&G personnel transpired in an attempt to produce a CAB vessel assembly which would not only produce

quality data but would also be extremely safe, durable, and easy to assemble, operate, and maintain. During the fabrication of the CAB vessel assembly, several minor design modifications were constituted in order to enhance the fundamental functions of the sand pack chambers, that is, enabling the repeatability of measuring sand pack properties. As a result of these modifications, the CAB vessel assembly component parts were re-drawn to scale.

A draft of the 'Operating Procedure' was completed and submitted as per the "Process Safety Committee Handbook, part 6. Operating Permit: New Request, subpart g. Operating Procedure." This included (g-1) Safety Precautions, (g-2) Material List, (g-3) Pre-Run Procedures, (g-4) Start-up Procedures, (g-5) Operating Procedures, (g-6) Shut-down Procedures, (g-7) Emergency Procedures, and (g-8) Training Plan. A draft of the 'Risk Assessment' was also completed and submitted as per the "process Safety Committee Handbook, part 6, Operating Permit: New Request, subpart I. Risk Assessment." The CAB vessel assembly component parts were re-drawn to scale and these drawings were submitted as per the "Process Safety Committee Handbook, part 6. Operating Permit: New Request, subpart p. Drawings." Several drawings were modified to reflect the space limitations in Room 16 in B-17 Building. The 'Operating Procedure' was then revised and submitted to METC for approval in preparation to begin conducting experiments in B-17 Building. The operating plan was approved and the operating permit was issued on September 15, 1996.

The 'Construction/Operating Permit' for Phase II experiments in METC Building B-17 was prepared by BDM and was submitted to FETC. Due to conditions of the designed Phase II experiments, there was no need for full SARS committee review. The plan was approved and the operating permit was to be issued upon completion of construction.

A comprehensive literature review was conducted. The literature review included the search of engineering and scientific journals and periodicals through CD-ROM available at the WVU library.

An effort was made to scale up the laboratory scale circulating air barrier to pilot scale. BDM had the lead to do this. The tanks were purchased as well as the instruments for completely instrumenting the pilot scale unit. The circulating air barrier vessel was completed, instrumented, tested and verified. Computer programs required to select the electrode for sampling and the frequency of sampling for data collection was completed. A random generator was used to select the electrode pairs out of the 36 pairs present for sampling to eliminate bias. The system was demonstrated for Dr. Kashiar Aminian of WVU-PNGE.

Testing indicated the vessel and instrumentation system would perform as designed and built. The project was halted at this point since additional funding was not forth coming to WVU from DOE. The PNGE may move the CATC to WVU campus for additional studies that may be funded by others.

Capture of Hazardous Waste Materials Utilizing Fluidization Coating Technology

Year/Task Number: 1995/2.3

AND

Treatment of Mixed Wastes via Steam Reforming

Year/Task Number: 1996/2.2

PI: Richard Turton
Department of Chemical Engineering
West Virginia University

Technical Summary:

The original purpose of this research was to investigate how fluidization coating technology can be utilized to capture and stabilize hazardous waste materials. In particular, the fate of aqueous solutions of heavy metal compounds was investigated. After initiation of this research an opportunity arose to work with one of the USDOE sponsored small businesses developing an innovative mixed waste treatment system using steam reforming. It was found that the laboratory scale fluidized bed reactor being used in the fluidization coating technology could with minor alterations be used to simulate the ThermoChem Steam Reforming Process developed by the Manufacturing and Technology Conversion International Inc.

Consequently, the research emphasis turned toward the investigation of the destruction efficiencies of RCRA organics and surrogates in a steam reforming atmosphere which tied in more closely with the ThermoChem research. The purpose of this new work was to simulate the second stage of the ThermoChem process, in which organic materials were to be destroyed in a high temperature steam reforming atmosphere.

[See "Remediation of Hazardous Sites with Steam Reforming" Task MC-11 during 1994 and Task 2.4 during 1995 by the Manufacturing and Technology Conversion International, Inc. (MTCI)]

The laboratory scale fluidized bed capable of operating at high temperatures was redesigned and constructed to simulate the Thermochem process. Toluene was taken as a test organic material and fed into the reactor with steam. The amount of toluene was approximately 1% by mole in the feed. The destruction efficiency at 1050°C exceeded 98%.

The project obtained its stated objectives and was completed on time and on budget.

A GIS Based Infrastructure for Site Characterization and Remediation

Year/Task Number: 1995/3.2
1996/2.1

PI: James Hooper, Director
Center for Environmental, Geotechnical & Applied Sciences
Marshall University
Huntington, WV

Technical Summary

The overall goal of this effort was to determine an effective geographic information system (GIS) based infrastructure for describing, characterizing, and remediating contaminated sites. Working closely with METC and the Army Corps of Engineers, during 1995 & 1996, the project was to (a) achieve actual on-site application of the system to a Corps project in Mason County, WV, (b) assess and augment the infrastructure for use in decontamination and decommissioning (D&D) efforts, and (c) develop a prototype interactive tutorial system to effectively transfer infrastructure concepts and skills to prospective users and managers.

The following achievements resulted from this research:

- Established a very productive working relationship with personnel of the Corps of Engineers Huntington district office.
- Completed the training on Intergraph MGE and PC ARC/INFO, the two major GIS systems under consideration.
- Configured, acquired, installed, and set up the necessary hardware and software including a server, workstation, color plotter, and color printer using an Ethernet network. Installed all the software components, including Intergraph MGE and PC ARC/INFO.
- Configured an integrated GIS, which allows data transfer from other software such as Microsoft Project and wordprocessors.
- Built the prototype interactive tutorial system using Director 4.0.
- Demonstrated the setup of the infrastructure of the GIS system, the preliminary data from WV Ordnance site, and the prototype tutorial system at the WVU Cooperative Agreement Program Review meeting on March 22, 1996 in Morgantown, WV.
- Developed a very effective GIS hardware/software capability, and widely applicable expertise in GIS at Marshall University. This will benefit DOE and the region for many years to come.

All objectives were successfully met and the project finished on time and on budget.

Small Business Technical Based Support

Year/Task Number: 1995/3.3
1996/3.2
1997/5.1

PI: Echol E. Cook
Department of Civil & Environmental Engineering
West Virginia University

Technical Summary:

The Small Business Support program was initiated to address problems that small businesses encounter during commercialization of innovative site remediation technologies that are developed by them and funded by FETC. Through FETC, a very large percentage of the USDOE's innovative remediation technologies are developed by small businesses. Small business owners are creative thinkers and are usually technically competent beyond their resource base. When they find technical problems, their lack of highly technical personnel creates an unsurpassable barrier for the small business to get their innovative technologies developed and commercialized. By ferreting out these problems, this program allowed teaming of a faculty member with the small business to solve the problem allowing further development of the innovative technology to occur.

By attending the kickoff meetings and other periodic meetings of the small businesses funded by FETC, an understanding of the project was obtained. During the presentations, potential small business and university research collaboration was evaluated. Interaction with program managers of the various projects was also pursued. Initiatives taken by DOE headquarters to bring together DOE, DOD and NASA commerce collaboration (with regards to site remediation capabilities and needs) increased opportunities for long term research projects. Attendance at the meetings and conferences furthered the understanding of research needs within the government. From these sources research projects were established and university faculty were employed as investigators.

Some examples of USDOE sponsored businesses and/or agencies that were assisted by this effort are: SpinTek Corporation, Vortec Corporation, West Virginia High Tech Consortium, Manufacturing and Technology Conversion International, Inc., GeneSyst, Inc. and RMI Environmental Services.

Approach for Assessing Potential Voluntary Environmental Protection, Kanawha Valley Area

Year/Task Number: 1995/3.4
1996/3.4

PI: Raymond J. Lovett
National Research Center for Coal & Energy
West Virginia University

Technical Summary:

The objective of this project was to first assess the interest and willingness of industry in the Kanawha River Valley to participate in discussions that would lead toward voluntary cleanup activities. The second objective was to implement the activities agreed upon by the interested parties. The project first involved individual discussions with the industry, government, and organized groups in the area. These discussions were used to determine the feasibility of organizing voluntary efforts.

The USDOE Morgantown Energy Technology Center (METC) was interested in sponsoring this project in hopes of obtaining some of the sites for demonstration of some of the innovative site remediation technologies developed through the sponsorship by METC.

Two organizations “Clean Sites” and “NICS” were in the forefront of the discussion. It was reported that a few discussions were conducted and a strategy was derived to have Paul Hill discuss the concept with selected individuals in the Kanawha Valley to determine the initial interest. These initial meetings led to a presentation before the Kanawha Valley Chemical Plant Manager group detailing the project. Individual meetings with four companies were also held. The “gist” of these meetings was that there was a continuing willingness of the companies to develop the issue and a definite interest in using new technologies in clean-ups. The PIs also met with the West Virginia Manufacturer’s Association regarding a Brownfields proposal. Furthermore, a meeting with Director of the West Virginia Division of Environmental Protection resulted in a commitment from him to assist the project “in any way” and a willingness to participate in any negotiations.

The project never really got started as the two primary organizations (Clean Sites and NICS) were in a continuous state of flux looking for directors and managers of their respective organizations. The project was eventually canceled.

Interagency Environmental Technology Office (IETO) Graduate Intern Program

Year/Task Number: 1995/3.6

PI: Echol E. Cook
Department of Civil & Environmental Engineering
West Virginia University

Technical Summary

The purpose of IETO was to foster private/public collaborations that stimulate environmental technology development, reduce regulatory barriers, and increase global market share. It was to be a one-stop shopping place for information on federal environmental technological programs. Through an interagency environmental technology office, experts could share information with individuals and organizations within and outside of the government arena. The purpose of the IETO Graduate Intern Program was to provide help to IETO and to provide a training opportunity for students from law, engineering and communications.

Over the 1995 time frame, interns assisted the executive director of IETO by conducting research, analysis, and documentation in the field of environmental technology development and commercialization. Depending on their background, experience, and interest, a number of opportunities were available to the interns. The interagency setting allowed the interns to experience governmental work from many different perspectives.

Overall, the IETO internships were a success for all of the WVU students involved. It gave students a first-hand experience of working in a highly political, high visibility area.

West Virginia High Tech Consortium (WVHTC) Environmental Technology Incubator Center (ETIC)

Year/Task Number: 1995/3.7
1996/3.1

PI: Jan Berkow
West Virginia High Tech Consortium Foundation
1000 Technology Drive, Suite 100
Fairmont, WV

Technical Summary

The WVHTC Foundation's mission was to create a high technology business sector in north central West Virginia. The mission was to be supported through the efforts of the new environmental support program. The new program was to enhance the development of growth of the environmental industry in the region. Further, the Foundation's Environmental Technology Support Program was to facilitate technology transfer and the commercialization of site remediation technologies developed by USDOE.

The WVHTC Foundation works with government, business, and educational entities to facilitate the pursuit of economic development. The Environmental Technology Incubator (ETI) fosters this effort in the area of environmental technology related business activity.

The ETI team took a very methodical approach towards determining its future beginning with the creation of a business plan that provided a foundation for its operation and an implementation statement. The second half of the year was devoted towards putting the implementation statement in motion.

The following year the first half of 1996 concluded with the creation of a business plan that focused on the commercialization service concept. During the second half of 1996, efforts were focused towards implementing key initiatives to support this new commercialization focus and to develop a track record in providing commercialization services as one means of obtaining future revenue.

While the concept was sound, the inability to find suitable environmental technologies in the state of West Virginia to participate greatly hampered the success of the effort.

Analysis of the Vortec Cyclone Melting System (VMS) for Remediation of PCB Contaminated Soils Using Computational Fluid Dynamics (CFD)

Year/Task Number: 1996/1.1
1997/2.1

PI: Ismail Celik
Department of Mechanical & Aerospace Engineering
West Virginia University

Technical Summary:

The primary objective of this project was to provide (via computer simulations) needed design information such as gas residence time, temperature distribution, species concentrations, and heat and pressure losses for refining the proposed design and/or validation of the assumptions made during the design of the sub-components of the cyclone melting system (CMS) that was under development by the Vortec Corporation. The focus of the analysis was for the remediation needs of PCB contaminated soils. A secondary objective was to develop and implement a global kinetic model for the formation and destruction of selected PCB's.

The computations for the simulations were performed using the commercial code FLUENT which is a general purpose, multidimensional computational fluid dynamics (CFD) code suitable for simulating flows in complex geometrics.

It was found that the gas residence time in the residence chamber (which provides reaction time for the destruction process of PCB's) calculated in several ways is greater than or equal to 2.0 seconds. The calculations with the FLUENT code confirmed a destruction time of 0.5 seconds for 99.9999% conversion of dichloromethane which was selected to represent all other PCB compounds in the flue gas. This selection was based on the kinetic model calculations which indicated the longest destruction time for dichloromethane among a dozen hydrocarbon and PCB compounds considered. Equilibrium calculations showed also that the equilibrium concentration of dichloromethane is less than one PPM which confirms the kinetic model calculations as well as the FLUENT calculations.

***in-situ* Bioremediation of Chlorinated Solvents**

Year/Task Number 1996/1.6

P.I.: Patrick E. Carriere & William A. Sack
Dept. Of Civil & Environmental Engineering
West Virginia University

Technical Summary

The purpose of the research was to evaluate biopolishing of contaminants at the USDOE site at Portsmouth, Ohio after surfactant flooding. The surfactant flood was to utilize an anionic surfactant and an alcohol such as isopropanol. Due to all unknown factors involved in the surfactant flood, it was not possible to develop a good estimate of the concentrations of contaminants and surfactant that would be left in the formation after the flood. Therefore a range of levels were to be evaluated in both columns and microcosms. It was possible that the isopropanol or perhaps other contaminants already present in the formation would serve as primary substrate for methanogenic and methanotrophic organisms. This possibility was to be evaluated by not adding a separate primary substrate (typically methanol) during the study. Both columns and microcosms were used to evaluate biopolishing at the PORTS facility and to evaluate the ability of methanotrophic, methanogenic, and other selected bacteria for cost-effective biotransformation of TCE and other volatile organic compounds (VOC's) found at the PORTS facility.

Two approaches were taken to simulate the site conditions and to predict the effectiveness of bioremediation at PORTS. Continuous flow column studies and anaerobic batch reactor (microcosm) studies were performed. Two column studies, a simultaneous anaerobic and aerobic column and a sequential anaerobic and aerobic column were utilized in addition to a second simultaneous column. Overall TCE removal was highest in the simultaneous column with percent removals for one pass as high as 96%, resulting in TCE removal from an initial concentration of 20 ppm to effluent TCE concentrations as low as 1.1 ppm. High vinyl chloride (VC) concentrations, averaging 844 ppb, remaining in the column effluent continued to be a problem with the simultaneous column but attempts to increase aerobic degradation via increased hydrogen peroxide addition and pH stabilization greatly improved VC destruction. Daughter product (DP) concentrations in the simultaneous column effluent were as low as 0.5 ppb for 1,1-DCE and trans-DCE, 7 ppb for VC, and 54 ppb for cis-DCE. The sequential column showed lower percent destruction, 85% at 20 ppm influent concentration and 70% removal at 50 ppm influent concentration. However, DP destruction appeared to be more complete in the sequential column with 1,1-DCE levels as low as 0.5 ppb, VC and trans-DCE levels below 2.5 ppb, and cis-DCE concentrations as low as 6 ppb.

Microcosm studies were performed to establish an experimental procedure for their use in this study. Factors such as head space volume, substrate addition, biomass concentrations, trace metal and nutrient concentrations, and possible agitation were considered. Initially testing was focused on comparisons between substrates and initial TCE concentrations. The substrates studied were methanol and the surfactant used in the surfactant flood.; initial TCE concentrations were between 20 and 100 ppm.

Anaerobic microcosm studies demonstrated the ability of methanogens to completely convert TCE to its daughter products from initial contaminant concentrations as high as 36 ppm. Kinetics were not developed due to equipment difficulties; but after an initial lag period of approximately two months for acclimation, TCE was removed to below the detection limit in a maximum of 70 days. The Aerosol MA80-I surfactant does not appear to support the biodegradation of TCE as a sole substrate for bioremediation. No data was collected on the effects of residual surfactant on TCE removal due to analytical problems.

During May 1997 a joint proposal with Intera, U.T. Austin, Texas and Radian Intration was submitted to FETC-Morgantown for remediation of chlorinated solvents at the USDOE site at Portsmouth, Ohio. West Virginia University was to do the biopolishing at the site. The proposal was not successful.

Development and Implementation of a Decision Support System for Management of the EM 50 Technology Development Program

Year/Task Number: 1996/1.7A

PI: Waste Policy Institute
Virginia Polytechnic Institute
Blacksburg, Virginia

Technical Summary:

The objective of this effort was to take a relational database system (implemented in Microsoft Access) that has an application front end written in Visual Basic and provide a useable product to the Department of Energy by October 15, 1996. The final product included the database system with its front end application fully populated with data from the Subsurface Contaminants Focus Area (SCFA). A decision tool process was provided to assist in analysis and prioritization of the technology development portfolio being sponsored by the DOE EM-50 program. The database was also to include data sets from the other four focus areas and cross-cutting programs by January 1997.

System demonstrations in November 1996 indicated that the system provided the functionality and flexibility requested by the customer, and hence, the customer approved expansion of the system to include the full SCFA data set. Therefore, the project was successful; it delivered a product that was acceptable to the customer.

Development of a Prototype Database and Decision Support System for Management of the EM 50 Technology Development Program

Year/Task Number: 1996/1.7B

PI: James W. Denton
College of Business & Economics
West Virginia University

Technical Summary:

The purpose of this project was to complete the work on the initial TechInvest project by validating and entering data to the database where required. In addition, decision support tools were added to aid in the process of prioritizing and selecting technologies to be applied to surface contamination problems. The finished product provided DOE with the capability to analyze funding decisions and justify their programs using sound analytical reasoning, minimizing decisions that may appear to be arbitrary or made on a ad-hoc basis.

The methodology consisted of examining the existing data set, revising data where applicable, and adding data to incomplete sections. The result of this preliminary action resulted in a database system populated with a significant subset of site-specific data and technology data from the Subsurface Contaminants focus area.

At the conclusion of the project, two on-line help systems were provided. The first was utilized by the database design team at Virginia Tech during their design of the EM-50 database. The second on-line help system effectively provided users of the EM50 database with on-line context-sensitive help.

Use of Centrifugal Membrane Technology With Novel Membranes to Treat Hazardous/Radioactive Wastes

Year/Task Number: 1996/2.3
1997/4.1

PI: Brian Reed
Roger Viadero, Jr.
Department of Civil & Environmental Engineering
West Virginia University

Technical Summary

Oily wastewaters, such as the extrusion press oil at the RMI Titanium Extrusion Plant in Ashtabula, Ohio, are encountered at many Department of Energy (DOE) decontamination and decommissioning (D&D) sites. Oily wastewaters are typically considered to be one of the most difficult waste streams to treat using conventional membrane filtration processes because it becomes difficult to maintain high cross-flow velocities to scour oil from the surface of the membrane as the feed stream is concentrated. However, it is possible to treat extremely concentrated wastes using a centrifugal membrane separation (CMS) system because the cleaning action is effectively decoupled from pressurization/feed recirculation by rotating the membrane surface at high speeds.

SpinTek, a California-based company, has developed and patented a cross-flow technology that improves upon conventional membrane separation processes. The *SpinTek* centrifugal membrane separation (CMS) system uses a series of flat, round membrane disk packs set on a hollow rotating shaft inside a cylindrical housing. The waste stream enters the membrane chamber under pressure and is distributed across the membrane surfaces by hydraulic action. Permeate is forced through the membranes and is collected in the hollow shaft and discharged. The concentrate exits at the edge of the membrane packs. The centrifugal action continuously cleans the membrane surface, thus decreasing cleaning chemical use and maintenance; increasing the volume of waste treated per area of membrane; and increasing the contaminant/solids concentration in the residual (i.e., increasing the volume reduction factor). *SpinTek's* CMS technology represents an improvement over conventional ultrafiltration technology and increases the number of waste streams that can be treated using membrane treatment.

In this study a solute gel layer concentration, OC_{gel} , of 39% oil was determined. OC_{gel} was constant with respect to pressure and membrane rotational speed, as anticipated from the thin-film model. The solute mass transfer coefficient, k_s , increased with membrane rotational speed due to a decrease in the solute boundary layer thickness at higher membrane rotational speeds. OC_{gel} and k_s were waste specific physico-chemical properties of the synthetic oily wastewater and therefore cannot be used directly as design parameters for full-

scale CMS systems. However, OC_{gel} and k_s determined in this study can be used as a basis to benchmark the performance of (1) other UF systems and (2) in future parametric studies of the CMS system.

Membrane rotation-induced hydraulic turbulence was determined to be an effective method of enhancing mass transfer conditions in the ultrafiltration of the synthetic oily wastewater. Additionally, permeate oil and grease (O/G) concentrations generally decreased as membrane rotational speed was increased due to a decrease in the thickness of the concentration boundary layer and thus fewer oil droplets to be passed through the membrane under convective forces.

The greater mass transfer properties in the CMS system can be used as a basis to broaden the application of the CMS system to waste and process streams which cannot be treated using conventional membrane separation systems or to concentrate waste and process streams to levels beyond those currently possible with conventional cross-flow membrane separation systems. Additionally, the results of this study can be applied more broadly to the treatment of other DOE wastes such as contaminated groundwater; mixed-waste process water; and existing waste residual (e.g., Hanford tank farm waste). However, it should be noted that the data presented in this study apply to the specific “worst case” scenario of an oily wastewater. Thus, bench-scale separation tests must be conducted when a new waste stream is proposed for treatment.

Development of Instrumental Methods for Characterization and Analysis of Nuclear Wastes and Environmental Contaminants

Year/Task Number: 1996/2.5

PI: Vincent T. Remcho
Department of Chemistry
West Virginia University

Technical Summary:

The focus of this research effort was the analysis of technetium 99 (^{99}Tc) and iodine 129 (^{129}I), common constituents of nuclear wastes at Hanford, Washington, and other DOE sites. These species are important target analytes in both the tank wastes themselves and in site aquifers. Characterization and chemical specification of both of these radionuclides in tank wastes and aquifers therefore represents an important DOE research goal.

This work focused on the development of new analytical strategies for the chemical specification and quantification of ^{99}Tc and ^{129}I in simulated nuclear waste tank and aquifer matrices. Capillary zone electrophoresis (CZE) and capillary electro kinetic chromatography (CEC) methods are being developed for each of the target ions. The CZE studies centered on the determination of optimum separation parameters including: selection of operating buffer composition and ionic strength, optimization of buffer pH, selecting of operating potential and injection conditions, and development of detection strategies (including UV, indirect fluorescence, and radiometric detection). In the first quarter, a reliable CZE method for separation of iodide (I^-) and iodate (IO_3^-) was developed. In the second quarter, a detector was developed for the indirect fluorescence measurement of iodide, iodate, and perrhenate (ReO_4^-) [a surrogate for pertechnetate (TcO_4^-)], and the CZE method previously developed was extended to include perrhenate.

In the third and fourth quarters of the project year, the CEC studies focused on the development of novel packed capillaries for anion exchange separations. This approach provided even higher loading capacities and therefore vastly improved detection limits. Here, the detection strategy employed was indirect fluorescence detection for the determination of small quantities of ^{99}Tc and ^{129}I .

These developments in the field of microelectrokinetic separations led to rugged, reproducible, cost-effective means for determining ^{99}Tc and ^{129}I forms and levels in various matrices. Ultimately, these newly developed tools may be applied in the analysis of other target analytes.

Production and Evaluation of Biosorbents and Cleaning Solutions for Use in Decontamination and Decommissioning

Year/Task Number: 1996/2.6A
1997/3.1

PI: John Kilbane
Institute of Gas Technology
1700 S. Mount Prospect Road
Des Plaines, Illinois 60018

Technical Summary

The objectives of this project were to prepare and to evaluate biosorbents and cleaning solutions that may be useful in the decontamination and decommissioning (D&D) of U.S. Department of Energy facilities. In this collaborative project, the Institute of Gas Technology made available to researchers at West Virginia University (WVU) biosorbents and cleaning solutions that are useful for D&D activities, but require filtration/liquid processing in order to be used in a practical process. Filtration tests were performed by WVU under FETC Task No. 1996/2.6B and 1997/3.1.

During this project biosorbent samples were prepared from several bacterial cultures and byproducts of the paper and food processing industries were obtained so that their possible use as biosorbents could be evaluated. The composition of wastewater streams typical of decontamination and decommissioning activities was determined and appropriate solutions were prepared for use in biosorbent testing. Test solutions contained the following metal species at 10 ppm each: Cd, Hg, La (this element serves as a surrogate for actinide radionuclides), Sr, U and Zn. Some test solutions also contained from 150 ppm to 10,000 ppm of potentially interfering ionic species: Fe, Na, NO₃, and SO₄. Additionally some tests were performed with radioactive wastewater obtained from the West Valley Nuclear facility. The chief radionuclide present in this wastewater was Sr.

Biosorbents prepared from bacterial cultures bound Cd, Hg, La and U and were achieving from 70% to 95% removal. However, the removal of Sr never exceeded 50% and removal efficiencies decreased significantly when interfering species were present. Similar results were obtained for biosorbents derived from byproducts of the paper and food industries. Significantly, lignin products were identified which exhibited metal binding efficiencies on a par with biosorbents prepared from bacterial cultures. Excellent removal of radioactivity was also obtained from West Valley Nuclear wastewater using lignin biosorbents. Two of the industrial byproduct samples in particular (Marasperse CBA-1 and Borresal HA-1) showed excellent removal of radioactivity from this wastewater (100% and 86% respectively) and offer real potential for use in conjunction with ultrafiltration for the treatment of wastewater. However, these same lignin products did

not exhibit good Sr removal efficiencies in further testing and the differences in performance observed with actual versus artificial wastewater is not currently understood. Nonetheless, the results obtained in this project regarding metal binding using biosorbents and industrial byproducts are highly encouraging. The ready availability and low cost of industrial byproducts make them attractive materials for use in commercial processes for metal removal, especially as some of these biosorbent materials were demonstrated by WVU to be easily removed from wastewater by ultrafiltration.

In other project activity, various surfactants were examined to identify commercially available products which can efficiently and effectively desorb hydrophobic contaminants from soil and other materials. Ultrafiltration testing of surfactant and surfactant/contaminant solutions were conducted by WVU. Surfactant solutions which are good for the desorption of polyaromatic hydrocarbons (PAHs) and total petroleum hydrocarbons (TPHs) from soils were identified. The surfactants that were studied focused on those which gave the best results for contaminant desorption, but those that are considered food grade surfactants are of particular interest as they should readily receive regulatory approval for use in environmental remediation applications. The surfactants studied included DXP135, DXP207, MA80-I, Rewoteric AMB14, Standapol ES2, Witconol 2722, and Witcamide 5085. Based on the contaminant desorption data obtained it was suggested that for PAH desorption DXP135, DXP207, and Witcamide 5085 show the best performance. However, of these only DXP135 can be classified as a food grade surfactant and is relatively inexpensive compared to the other products. Unfortunately, while Witcamide 5085 desorbs PAHs well it is considered to be relatively toxic. Witconol 2722 and MA80-I are also food grade surfactants. Additional contaminant desorption tests were performed to determine the ability of DXP135 and blends of DXP135 plus other surfactants to desorb PAHs and total petroleum hydrocarbons from several contaminated soils. DXP135 in ethanol-based solutions appears to yield the best performance for the desorption of PAHs from coal tar-contaminated soil from a former manufactured gas plant site, while Witconol 2722 in water based solutions yields the best performance for the desorption of petroleum hydrocarbons from soil.

Preliminary results of surfactant biodegradation tests indicate that surfactants present at high concentrations (500ppm) are generally inhibitory to microbial growth. Mixtures of two or more surfactants uniformly yields greater inhibition of bacterial growth. Enrichment culture techniques were used to obtain bacterial cultures which are adapted to utilize/tolerate high concentrations of surfactants. Bacterial cultures which can tolerate high concentrations of surfactants were used to examine the biodegradation of PAHs present in surfactant/contaminant mixtures. Excellent rates and extents of PAH biodegradation were obtained even in the presence of 2,000 ppm surfactant; however, the amount of surfactant biodegradation was minor. These results show that contaminants present in contaminant/surfactant mixtures can be efficiently biodegraded, but the biodegradation of surfactants is significantly slower and less complete. This would suggest the possible use of a biotreatment step to degrade contaminants in contaminant/surfactant mixtures so that the surfactant solution can be reused. These results also indicate that the biodegradation of residual surfactants used in environmental remediation processes could be problematic. Ultrafiltration tests of surfactant/contaminant mixtures performed by WVU indicated that efficient concentration/recovery of surfactant can be achieved; however, a significant amount of contaminant is present in the concentrated surfactant solution. This further supports the suggestion that a combined process involving biodegradation of contaminants and ultrafiltration to recover surfactants could be an effective treatment for surfactant/contaminant mixtures.

In summary, the project was successful in identifying low cost industrial byproduct materials that can be used as biosorbents and surfactant solutions which can be used, in conjunction with ultrafiltration, in decontamination and decommissioning activities.

Use of SpinTek Centrifugal Membrane Technology and Sorbents/Cleaning Solutions in the Decontamination and Decommissioning of DOE Facilities

Year/Task Number: 1996/2.6B
1997/3.2

PI: Brian Reed
Roger Viadero, Jr.
Department of Civil & Environmental Engineering
West Virginia University

Technical Summary

The use of sorbents (biosorbents, powdered activated carbon) and cleaning agents (surfactants, chelating agents) to decontaminate surfaces such as pipes and walls represents a unique and cost-effective method for remediating Department of Energy (DOE) facilities. As envisioned, the sorbent or cleaning agent would be added to a liquid (most likely water) and the solution would be contacted with the contaminated surface. For example, a pipe that is contaminated with inorganic and organic contaminants can be contacted with the contaminated surface. For example, a pipe that is contaminated with inorganic and organic contaminants can be contacted with a solution containing a surfactant (for organics) and a chelating agent (for inorganics). After removal of the surface-bound contamination by the cleaning agents, a solid sorbent can be added to the liquid to bind the cleaning agent-contaminant compound. A major problem associated with this approach is the efficient separation of the sorbent/cleaning agent from the liquid phase using conventional separation techniques.

SpinTek, a California-based company, has developed and patented a cross-flow technology that improves upon conventional membrane processes (e.g., tubular and hollow fiber modules). The *SpinTek* centrifugal membrane separation (CMS) system uses a series of flat, round membrane disks set on a hollow rotating shaft inside a cylindrical housing. The waste stream enters the membrane vessel under pressure and is distributed across the membrane surface by hydraulic action. Permeate is forced through the membrane, is collected in the hollow shaft, then discharged. The concentrate exits at the edge of the membrane packs. The centrifugal action continuously cleans the membrane surface, thus decreasing cleaning chemical use and maintenance and increasing the volume of waste treated per area of membrane.

The objective of this research was to investigate the feasibility of using centrifugal membrane technology to separate sorbents/cleaning agents (mainly developed and supplied by the Institute of Gas Technology) used in the decontamination/decommissioning (D&D) of DOE facilities. The result of this effort was the development of an efficient cost-effective method for remediation of DOE facilities. An additional benefit

of this research is the application of the experimental results to the treatment of other DOE wastes such as contaminated groundwater, mixed-waste process water, and existing waste residuals (e.g., Hanford Tank Farm Waste). Volume reduction factors for this technology were high and a relatively low amount of residual requiring additional treatment was produced.

In general, satisfactory permeate flux and sorbent/surfactant retention was maintained using the CMS system. Feed temperature, membrane rotational speed, and membrane pore size/molecular weight cut-off (MWCO) affected permeate flux and water quality in the biosorbent experiments. Permeate flux increased at elevated feed temperature and increasing membrane rotational speed. Permeate turbidity was higher at elevated temperature, though the average permeate turbidity in each run remained < 1 NTU. Lower permeate turbidity was observed at higher membrane rotational speed.

Polyvinylidene fluoride (PVDF) membranes were found to be suitable in the majority of sorbent/surfactant experiments. However, a ceramic membrane material was found to be more appropriate when treating a simulated zeolite sorbent in the CMS system, due to the membrane's high resistance to mechanical abrasion. In the treatment of the IGT FF52 amide-based surfactant, permeate flux was lower and permeate turbidity was higher in experiments conducted with a 10,000 MWCO PVDF membrane when compared to results obtained using a membrane with a 5,000 MWCO. It was hypothesized that since the molecular weight of the IGT FF52 micelle was close to the MWCO of 10,000 membrane, micelles tended to either pass through the membrane or become lodged in the pores. However, the micelles could not enter the pores of the 5,000 MWCO membrane because of the difference between the size of the surfactant micelles and the membrane pores. Thus, permeate turbidity was lower and permeate flux was higher for the 5,000 MWCO membrane. Consequently, the molecular weight of the surfactant and/or surfactant-contaminant complex must be known to ensure sufficient retention while not plugging the membrane pores.

A Hollow Fiber Membrane Separation (HFMS) system was able to treat an Aerosol MA80I solution to a final concentration of 12.9%. A surfactant rejection ranging from 49 to 89% was observed for the HFMS system, compared to an average of 13% in the CMS system. Although the permeate flux in the CMS system was ~3 times greater than the permeate flux in the HFMS system, the permeate flux advantage observed in the CMS system may be offset by the greater packing density of the hollow fiber module.

It should be noted that the data presented in this study apply to specific waste streams. Thus, bench-scale tests must be conducted to determine the physical/chemical characteristics of contaminants, sorbents, and/or surfactants prior to selecting a membrane material and pore size/MWCO when a new waste stream is proposed for treatment.

Technology Evaluation for Supercritical Water Oxidation (SCWO) Using a Supercritical Gravity Pressure Vessel (SGPV)

Year/Task Number 1996/3.3

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Technical Summary

Supercritical Water Oxidation (SCWO) is a low temperature thermal treatment technology (374 to 600°C) that holds the promise of high thermal destruction efficiencies (99.99+%). This treatment technology was well known to the U.S. Department of Energy and two (2) surface embodiments of Supercritical Water Oxidation (SCWO) had been tested at Idaho National Energy Laboratory (INEL).

The surface SCWO technologies have significant limitations with respect to solids loading and solids size. According to the Integrated Thermal Treatment Study (Cooley Report) surface SCWO is only applicable to 15-17% of DOE's Mixed Wastes, and therefore of limited usefulness.

This SCWO technology is a sub-surface embodiment for SCWO using a Supercritical Gravity Pressure Vessel (SPGV) which has been developed by GeneSyst International Inc. of Hudson, Ohio. The objective of this project was to increase the understanding of this sub-surface embodiment of SCWO, i.e., its advantages, disadvantages, its range of applicability for DOE's mixed waste and other wastes within DOE and DOD. This study also included a comparison with two (2) surface embodiments, MODEC and GA Atomics/MODAR.

The Supercritical Gravity Pressure Vessel (SGPV) was compared with surface SCWO embodiments and found to have a number of significant advantages:

- Applicable to more than 75% of DOE's Mixed Low-level Wastes;
- Reduced tendencies for erosion, corrosion, solids deposition and plugging;
- Reduced operational risks such as worker exposure to high temperatures;
- Due to its high volumetric capacity (150-600 gpm) it shows very significant cost savings of 70% (about \$1.7 billion) compared to the ITTS base case;
- Regulators like the SGPV configuration which includes a monitoring annulus for vessel integrity and secondary containment;
- Developmental needs have been identified and can all be addressed by planning for a pilot

- scale demonstration unit on surrogate and actual MLLW at a USDOE site;
The SGPV is also applicable to demilitarization of chemical weapons and energetic materials

While the SGPV appeared to have significant advantages over the surface SCWO embodiments, its initial cost (multimillions of dollars) was a major deterrent to the project being pursued to the pilot plant phase.

Laboratory Studies and Field Testing at the DOE/RMI Extrusion Plant

Year/Task Number: 1997/1.4

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Technical Summary

The RMI Titanium company (RMI) Extrusion Plant is located in Ashtabula County, Ohio. The facility consists of 25 buildings and occupies 7 acres of a 26 acre site. The facility is contaminated with both radiological and hazardous materials resulting from previous operations for the US Department of Energy. The primary function of RMI, since 1962, has been the extrusion and closed-die forging of metallic depleted, natural, and slightly enriched uranium (U) used in the production of nuclear fuel elements for defense production reactors, extrusion operations for other government agencies, and the private-sector. Extrusion operations ceased in 1990, since then the Nuclear Regulatory Commission (NRC) has required the facility to implement accelerated site clean-up pursuant to its Site Decommissioning Management Plan. The US Environmental Protection Agency has issued RMI a Resource Conservation Recovery Act (RCRA) Hazardous Waste Management Permit with conditions mandating clean-up of an existing Corrective Action Management Unit. DOE's office of Environmental Restoration and Waste Management (EM) has contracted RMI to conduct the RMI Decommissioning Project by removing all radiological and hazardous contaminants to levels which permit the facility and adjacent areas to be released for unrestricted use. The site provides numerous opportunities to demonstrate various site remediation technologies developed through the WVU Cooperative Agreement and the FETC-Morgantown EM 50 program.

The initial objectives of this project focused on information gathering and interpretation of site subsurface profile information in order to ascertain the applicability and potential success of performing a pilot-scale demonstration of the Prefabricated Vertical Drain (PVD) Enhanced Soil Flushing technology at the RMI facility. The proposed tasks for the project involved: 1) field investigation and site data evaluation, 2) predictive modeling, and 3) lab scale physical and chemical testing. Results from this work enabled researchers to understand the complexities of the site conditions, and to accurately portray subsurface conditions effecting the performance of the PVD system.

The goal of the work during Phase 0 efforts consisted of performing preliminary engineering studies necessary for subsequent design and installation of the Prefabricated Vertical Drain Enhanced Soil Flushing technology at the RMI facility located in Ashtabula, Ohio. The research included: an information review of

previous engineering studies/reports performed at the RMI facility regarding the site corrective measures; groundwater modeling to characterize the extent and magnitude of the trichloroethylene (TCE) contaminant plume; laboratory bench-scale testing to investigate performance requirements of the prefabricated vertical drains in site soil, and chemical laboratory analysis as part of a treatability study addressing the site contaminated soil. Specific results of this work are that the location of the PVD test pad (10' x 10' area) was completed. Understanding of the subsurface soil characteristics and properties, TCE contaminant migration behavior and extents, and results of surfactant influences on the site soil enabled subsequent experiments in Phase I to be properly planned and executed. Phase I was to install a pilot scale PVD system consisting of 8 PVDs to determine feasible extraction and injection rates of fluids from/to the subsurface. The treatment of the extracted fluids to federal/state release criteria was also included.

Pilot Scale Demonstration of TCE Flushing Through Prefabricated Vertical Drains (PVD's) at the RMI Extrusion Plant in Ashtabula, Ohio

Year/Task Number: 1997/1.6

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Technical Summary:

An innovative *in-situ* soil flushing technology incorporating Prefabricated Vertical Drains (PVDs) was implemented on a pilot scale at a site where soils and groundwater are contaminated with Trichloroethylene (TCE). The innovative soil flushing system implemented in this research was developed by Gabr et al (1994, 1995, 1996, 1997) and Quaranta and Gabr (1997, 1998) for the *in-situ* remediation of contaminated sites with fine fraction soils. The technique concept aims at enhancing the effectiveness of the flushing mechanism by providing for a shortened flow path as well as redundancy and wide coverage to capture the subsurface pollutants. The PVDs system has also been developed in such a way that allows for the ability to concentrate on a specific contaminated area where the need to capture the plume is urgent.

The test site is located at the RMI Titanium Company (RMI) in Ashtabula County, Ohio. The nature of work by the RMI Titanium Company was related to uranium metal extrusion and processing. The RMI work was conducted under contract with the US Atomic Energy Commission [currently the US Department of Energy (DOE)]. Under this contract, RMI extruded depleted, normal and slightly enriched, uranium (up to 2.1 weight percent U-235) for the DOE Defense Programs, from the early sixties until November 1990. The soil and groundwater at the site are contaminated with Trichloroethylene (TCE), Uranium, and Technetium 99 in limited areas of the site. The RMI site demonstration is being performed under DOE guidance and within the regulatory framework of the NRC regulations and guidelines. The current DOE mission at the RMI site consists of environmental restoration, decontamination, and decommissioning to terminate the NRC license so that the site may be returned to RMI for unrestricted use.

The clean-up of the facility is slated to continue for the next several years due to technology limitations related to remediation of soils with large percent fines. However, such a challenge is not unique to the RMI site. Recently, the United States Department of Energy (DOE) has evaluated more than 100 contaminated facilities in 36 states where the subsurface contamination included compounds that were generally disposed using past environmentally-improper practices. Several of these sites have soils containing high fractions of fine-grained particles which in most cases render the use of the conventional *in-situ* soil and groundwater

remediation technologies inadequate. Hence the need and motivation for the development of new remediation technology presented in this research. The research included field and laboratory investigations. The laboratory investigation was performed to provide data in support of the field testing program. Laboratory data provided information on soil characteristics, soil/contaminant interaction, and the compatibility of the soil/PVDs system. The field work was focused on implementing the PVDs technology on a pilot scale to investigate the feasibility of using the PVDs system for the flushing of TCE from the subsurface groundwater and soil. The field work was performed on a 10 ft x 10 ft pad installed on the fringe of the TCE plume. The pad consisted of 8 PVD's arranged in 3 rows on 3 foot centers. The outer rows contained 3 PVD's each for extraction and the inner row contained 2 PVD's for injection. The TCE concentration at the pad location ranged from approximately 8000 ppb at the up gradient to 200 ppb at the down gradient locations of the pad. Testing involved two main tasks; extraction only experiments and injection/extraction experiments. A third task related to the injection/extraction of a surfactant was performed on a limited basis. The surfactant study was primarily conducted by Dr. John Kilbane of the Institute of Gas Technology (IGT) and the reader is referred to IGT report for details on this task. However, data related to flow rates measured during the performance of the surfactant task is included in this report as such data are relevant to the physical characteristics of injection/extraction process. Because of the decrease experienced in injection/extraction rates while using the surfactant, its use was curtailed.

The results of this study successfully demonstrated the extraction and injection/extraction of liquids through the PVDs system as well as the subsurface flushing of the TCE. The extraction data showed a clear trend in flowrate with consistent values between 20 to 30 gal/hr at the onset of the extraction process to an average of 8-10 gal/hr by the end of the extraction cycle. Injection was introduced at 10 gal/hr under total head that varied from 6 ft to 3 ft. The injection process was normally continued for an 8-hour period while extraction was executed over a pulsing schedule. Results indicated that extraction flow rates as high as 45-50 gal/hr were obtained when extraction was performed in conjunction with injection. This rate represented approximately a 350% increase in extracted liquid as compared with the 10 gal/hr of extraction with no injection.

Effluent samples taken during testing indicated that the TCE plume was mobilized into the capturing grid along with phase-separated volatile organic in the gas phase. Volatilization of TCE in the saturated zone was observed to be on the order of 95%. Pulsing experiments were conducted to discern optimum system functionality for retrieval of TCE within the minimum amount of liquid. Results indicated that a flushing scheme of 1 hr on, 3 hr off, and 1 hr on yielded the most effective scheme in this case. Work is currently being conducted to implement the technology on the full scale at the same site.

Technical Support for Surfactant Flushing Through Prefabricated Vertical Drains (PVDs) at the RMI Extrusion Plant in Ashtabula, Ohio

Year/Task Number: 1997/1.7

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Technical Summary

A field experiment was performed to test the ability of prefabricated vertical drains (PVD's) to be used as a tool to deliver surfactant solutions to the subsurface for remediation of trichloroethylene (TCE) contamination at the DOE/RMI site in Ashtabula, Ohio. The objective of this project was to supply technical support for that field experiment in surfactant flooding by performing laboratory tests to select an appropriate surfactant product and the correct concentration of surfactant, obtain a sufficient quantity of the appropriate surfactant for use in the field experiment, assist in field operations, recruit industrial partners, and to provide field services for the biodegradation of residual TCE and surfactant.

The overall objective of the project was to demonstrate the use and versatility of PVD drains for the *in-situ* remediation of contaminated aquifers. The specific objective of this task was to identify and supply appropriate solutions for two remediation approaches: surfactant flooding, and *in-situ* biodegradation.

The project was completed as scheduled. Food grade surfactants which yield good TCE solubilization were identified and the composition of a surfactant formulation for use in preliminary field tests of surfactant flooding was determined: 2% MA-80, 0.5% Mazol GMOK, 0.3% NaCl, and 0.05% xanthan gum, and sufficient quantities of the materials to prepare 1,400 gallons of surfactant solution were obtained, shipped to Ashtabula, and used in surfactant flooding field tests. Ultrafiltration appears to be an appropriate technology for the removal of surfactant from solution. After extensive discussion with project personnel, commercial analytical labs, and regulators appropriate methods were identified. EPA SW846 Method 5030B/8260B will be used for the analysis of liquid samples, and 5035 for the analysis of soils containing surfactant/contaminant mixtures. Biodegradation with adapted cultures can be used to biodegrade the surfactant mixture used in this project.

Biodehalogenation and iron catalyzed dehalogenation of TCE in TCE/surfactant mixtures was demonstrated. The best results were obtained using a mixture of anaerobic microorganisms, zero valent iron, and surfactant.

It is interesting that the presence of this particular surfactant, MA-80, generally stimulated dehalogenation by both chemical and biological means. However, high surfactant concentrations of 1000 to 10,000 ppm could be inhibitory. It appears that a combined chemical/biological treatment option could be considered to treat residual TCE in surfactant contaminant mixtures; however, the inhibition of chemical and biological dehalogenation in the presence of Ashtabula site soil suggests that *in-situ* dehalogenation may not be an option at this site.

Activated charcoal and/or organoclay materials can be used to remove surfactant from solutions but the sorption capacities of these materials is somewhat low at about 20 mg per gram of sorbent.

All laboratory and field tests were successfully completed in support of the surfactant flushing through PVDs project at the RMI Ashtabula site.

Technical Support on Installation and Operation of the PVD System at the RMI Extrusion Plant in Ashtabula, Ohio

Year/Task Number: 1997/1.8A

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Technical Summary:

RMI Environmental Services (RMIES) worked cooperatively with US Department of Energy (DOE)-Federal Energy Technology Center (FETC), US DOE-Ashtabula Area Office-RMI Decommissioning Project, West Virginia University (WVU), North Carolina State University (NCSU), and the Institute of Gas Technology (IGT) to support development and deployment of a groundwater and soil remediation technology called Drain Enhanced Soil Flushing (DESF) utilizing Prefabricated Vertical Drains (PVD). RMIES's responsibilities included providing the site for the demonstration project, providing installation and operations support for the test pad area (Task 1.8A), and the design, construction, and operation of the wastewater treatment plant to treat the extracted groundwater (Task 1.8B). This final report summarizes Task 1.8A only.

The RMI Titanium Company Extrusion Plant site has a small soil and groundwater area which is contaminated with trichloroethylene, uranium, and technetium 99. The area has been designated by USEPA as a Corrective Action Management Unit (CAMU). To support development of the PVD technology, RMIES provided a 10' x 10' portion of this area for installation and operation of 8 PVD's. Initially RMIES coordinated installation of 8 PVD's and 2 monitoring wells through a local drilling contractor. The PVD's were networked together with polyvinyl chloride piping and connected to a portable Venturi vacuum system. Six PVD's were used as extraction drains and 2 PVD's were used as injection/extraction drains. A small temporary steel hoop building was constructed over the test pad area. Temporary utilities were also provided to the area. The system was operated intermittently in a combination of extraction and injection/extraction modes, part of which included injection/extraction of food grade surfactants to facilitate release of TCE from the subsurface soil. Approximately 10,500 gallons of groundwater was extracted from the test area between December, 1997 and June, 1998. Approximately 718 samples were collected and analyzed for various parameters including TCE, uranium, technetium 99, pH, specific conductance, surface tension, and solids. All data was forwarded to NCSU for evaluation and compilation into their final report. RMIES was successful in providing the area and appropriate installation and operational support for demonstration of this technology.

Design, Procurement, Installation and Operation of a Pilot Scale Wastewater Treatment System to Treat Extracted Fluids During Demonstration of the PVDs at the RMI Extrusion Plant in Ashtabula, Ohio

Year/Task Number: 1997/1.8B

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Technical Summary:

RMI Environmental Services (RMIES), working cooperatively with North Carolina State University (NCSU), West Virginia University (WVU), United States Department of Energy (US DOE)-Federal Energy Technology Center (FETC), US DOE Ashtabula Environmental Management Project (AEMP) Office and the Institute of Gas Technology (IGT) conducted a Drain Enhanced Soil Flushing (DESF) field study at the RMI Decommissioning Project (RMIDP) site. This field study focused on the development and deployment of a groundwater and soil remediation technology; Drain Enhanced Soil Flushing (DESF) using Prefabricated Vertical Drains (PVDs). This DESF PVD Field Demonstration Project included: 1) the testing of this technology for the clean-up of subsurface *in-situ* Trichloroethylene (TCE) contamination in the vicinity of a former evaporation pond and, 2) the successful treatment and disposal of the recovered ground water.

RMIES's responsibilities included the design, construction, operation and evaluation of a pilot waste water treatment plant (WWTP) for the treatment and disposal of the extracted groundwater solution.

The groundwater solution generated during the PVD/DESF Phase-I field demonstration was successfully treated for the removal of trichloroethylene (TCE), surfactants, and technetium-99 (Tc-99) using a packed column air stripper, biodegradation system and activated carbon. A TCE removal efficiency of >98.5% was obtained using a packed column air stripper. Surfactant removal of >98.9% was achieved within 7 to 10 days using a bioreactor inoculated with unspeciased *Pseudomonas*. Activated carbon, initially intended for final TCE polishing, exhibited 21.3% removal of Total Suspended Solids (TSS) and 99.8% removal of Total Dissolved Solids (TDS). Additionally, 97.5% Tc-99 removal was achieved.

In addition to waste water treatment, successful field trails were conducted for surfactant and Tc-99 removal by filtration. SpinTek Systems, of Huntington Beach, California, demonstrated 99.6% surfactant removal using their rotary membrane filtration unit and 97.3% surfactant removal by filtration with a spiral-wound nano filter. The 3M Company, of St. Paul, MN, achieved >98.8% removal of Tc-99 using their active

cartridge filtration apparatus (currently under development).

Design of Rotating Membrane Filtration System for Remediation Technologies

Year/Task Number: 1997/4.3

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Technical Summary:

This project involved the mechanical engineering design assessment of the rotary ultrafiltration system for water remediation developed by SpinTek™ Corp. SpinTek, Inc., a California-based company, has developed and patented a cross-flow membrane technology that improves upon the conventional membrane process. The SpinTek system uses a series of flat, round membrane disk packs, set on a hollow rotating shaft inside a cylindrical housing. The waste stream enters the membrane chamber under pressure and is distributed across the membrane surfaces by centrifugal and hydraulic action. Permeate is forced through the membrane and is collected in the hollow shaft and discharged. The centrifugal action continuously scours and cleans the membrane surface thereby decreasing cleaning, chemical use and maintenance, increasing the volume of waste treated per area of membrane, and increasing the contaminant/solids concentration in the residual (i.e., increases volume reduction factor). Various computer models were developed to analyze the various responses of interest during operation. Specifically, computer models for stress analysis, vibration analysis and for fluid dynamics were developed to assess the performance of the system. All the models developed were constructed based on geometric data provided by SpinTek™.

Two types of stress analyses were conducted on the filtration system. The first involved the stresses developed in the rotating elements. Specifically, the rotating disk develops radial and tangential stresses, which are directly related to the speeds of rotation. Shaft, disk and membrane were included in these analyses, which were conducted for the 8", 11" and 24" diameter configurations. Stresses were found to be in the safe range, considering that the von Misses index is relatively low compared with the yield strength of the disk.

A second set of stress analyses was conducted on the housing of the filtration chamber. The main concern was the housing expansions in the axial direction and the possible differential change of chamber depth above and below the membrane, which in turn, could give rise to a differential pressure and warping of the disk. This was verified and found to be not significant. This stress analysis was conducted for the 11" and 24" diameter configurations.

Vibration analysis models were constructed, for each of the rotor configurations, to study the modal

characteristics of each of them. These analyses were conducted in order to determine the instability characteristics (resonance conditions) and its relation to the operating speeds. Emphasis was placed on the shaft-disk arrangement, which exhibits flexural vibrations, as the speeds of operation are in the flexible-rotor range. The systems modeled perform in general at angular velocities, which fall in the range of some of the natural frequencies found for the disks. However, due to the fact that the disks are immersed in fluid, the harmonics involved are damped and the system is thus stable in the operating range.

A third set of models was developed to study the fluid dynamics within the filtration chamber. The main objective was to determine the effect of the turbulence promoters (wagon wheels) in terms of the fluid shear gradients on the membrane-rotating surface. Also, these models were used to determine the radial flow of the permeate through the membrane, considering the inflow pressure and the speeds of rotation. Parametric analyses were conducted to determine the response trends based on geometric changes of the wagon wheel design and its positioning with respect to the membrane.

It was verified that indeed the presence of the turbulence promoter increases the flow shear at the membrane surface, particularly underneath the spoke of the wagon-wheel. It was found that the amount of shear increases with the thickness of the spoke and as the spacing between spoke and membrane reduces. The angular velocity of the rotor seems to have the greatest effect on the flow shear, although that (angular velocity) is inversely related to the diameter of the disk for operation purposes. Conversely, rotor spacing had little effect if at all on increasing the flow shear at the membrane surface.

The rotational effects of the shaft and membrane were modeled by applying a radially-varying tangential velocity to the rotating wall and porous media cells. It was found that increasing the radial inlet velocity, while maintaining a constant rotor diameter and angular velocity, increased the axial, cross-membrane velocity and decreased back flow near the outer edge of the membrane. The “active” flow area of membrane, as a fraction of the total cross-membrane flow area, increased with decreased rotor diameter for cases with both maximum inlet velocity (0.77, 1.10, 2.47m/s) and decreased inlet velocity (0.25m/s). In these cases, the remaining membrane area was predicted to either experience negligible cross flow, or, at the outer edge, back flow. The ‘active’ flow area of membrane was predicted to remain approximately the same for each rotor diameter (consisting of the innermost 0.08-0.1m of radius in each case). The axial velocity through this section of “active” membrane increased with increased inlet velocity.

RESULTS AND DISCUSSION

SIGNIFICANT ACCOMPLISHMENTS FROM THE AGREEMENT

The Program was divided into the areas of Research, Industrial Participation and Small Business Support. The research was further divided into the following WVU Focus Areas: 1) Subsurface Contaminants, Containment and Remediation, 2) Mixed Waste Characterization, Treatment and Disposal, 3) Decontamination and Decommissioning, 4) Cross Cutting Innovative Technologies and 5) Outreach.

The program included a diversity of projects that brought together a cadre of investigators. Some of the key projects funded are listed below under their respective WVU focus area:

WVU Focus Area 1.0: Subsurface Contaminants, Containment and Remediation

Drain Enhanced Soil Flushing (DESF) using Prefabricated Vertical Drains (PVDs) - Dr. M.A. Gabr, WVU: DESF provides enhanced *in-situ* soil flushing using PVDs for remediation of contaminated sites where fine-grain soils are present. The research builds on the soil flushing process where remediation of contaminated aquifers using conventional pump-and-treat systems has shown to be ineffective and costly. The technology is being developed with **NILEX Corporation** and uses off the shelf equipment and supplies. Field demonstrations were performed and proven successful at an **Ashland Petroleum Corporation** gas station site in Weston, WV. The technology was demonstrated on a pilot scale at the RMI facility in Ashtabula, Ohio and is the focus of a future demonstration project.

Development of Standard Test Protocols and Barrier Design Models for Desiccation Barriers - B. Overbey & D. Locke, BDM Federal and Dr. K. Aminian & Dr. S. Ameri, WVU: The DOE/FETC B-17 building was used to test the viability of *in-situ* barriers for containing subsurface contaminants, such as those found under tanks at DOE's Hanford and Savannah River sites. BDM Federal, Inc. developed a circulating air barrier that used dry air injection to create a dry zone. Drying a soil layer increases its liquid storage capacity and so the soil will tend to retain rather than transmit the liquids. The technology uses commercially available oil and gas technologies and equipment. The WVU Petroleum Engineering Department provided technical and laboratory support.

Laboratory Studies and Field Testing at the DOE/RMI Extrusion Plant, Ashtabula, Ohio - Dr. J. Quaranta, WVU: RMI was involved with the production of nuclear fuel elements for defense production reactors. Extrusion operations ceased in 1990 and the Nuclear Regulatory Commission has required the facility to implement accelerated site clean up. WVU is supporting RMI's clean up challenges by focusing on the remediation of low hydraulic conductivity clay soil contaminated with trichloroethylene (TCE). A groundwater model was developed for predicting the extent of subsurface contaminant migration and chemical treatability studies were reviewed for *in-situ* remediation of TCE contaminated soil and

groundwater. WVU, DOE-Ashtabula, and RMI worked together in problem identification and with bringing WVU's technical resources in technology development to bear on this decontamination and decommissioning project.

Pilot Scale Demonstration of Trichloroethylene (TCE) Flushing Using Prefabricated Vertical Drains (PVDs) at RMI, Ashtabula Site - Dr. M. A. Gabr, WVU: Phase I of this work included proving the DESF technology at the pilot scale level at the RMI site where TCE contamination has been identified in the soil and groundwater. A small test pad consisting of eight PVDs was constructed and the major parameters affecting the efficiency of the system were studied. Water was first extracted and analyzed for TCE concentration changes with time and the required number of pore volumes of extracted fluid was determined. Surfactant flooding through the PVDs was conducted, along with studies on the potential for surfactant recycling. Phase II of this work will consider a larger area (1/10 acre) and constitutes most of the follow on work.

Technical Support for Surfactant Flushing Through PVDs at RMI, Ashtabula Site - Dr. J. Kilbane, Institute of Gas Technology (IGT): TCE is a highly recalcitrant environmental contaminant with low aqueous solubility and a density greater than water. It tends to sink and dissolve slowly serving as a source of groundwater contamination for decades. The goals of this work were to provide support services for the pilot scale PVD field tests being conducted at the RMI, Ashtabula site. This included selecting the appropriate surfactants, supplying the surfactants, and supplying nutrient solutions for possibly enhancing natural *in-situ* biodegradation of residual contaminants. Surfactant flooding evaluation considers the interfacial tension and phase behavior between surfactant solution and TCE. The ability to mobilize TCE, as indicated by interfacial tension measurements, was the chief criterion. This work was a crucial element in the future activities at RMI.

Treatment of Soil Flushing Solutions Produced During Demonstration of the PVDs at RMI, Ashtabula Site - E. Marsh, RMI Environmental Services: Once extracted from the PVDs, the soil flushing solutions needed to be treated, separated and re-injected, and/or properly disposed. The focus of this work was to identify the technologies available for separating the surfactant from the extraction water for re-injection, thus, significantly reducing costs. Several technologies were also tested on a pilot scale and evaluated for treatment and disposal of the remaining residuals and a waste water treatment facility was constructed. This work was a joint effort between WVU, RMI Environmental, and the Ohio EPA and will also be utilized in the larger scale demonstration proposed at RMI.

in-situ Bioremediation of Chlorinated Solvents - P. Carriere and W. Sack, WVU: This project researched the widespread problem of chlorinated aliphatic hydrocarbon contamination (CAH) in soil and groundwater at DOE sites. Studies were done to assess *in-situ* bioremediation as a polishing step following surfactant flushing. The technology was successfully implemented at the lab scale in aerobic and anaerobic column studies to determine the rates of contaminant and surfactant degradation, daughter product removal, and nutrient addition techniques.

Development and Implementation of a Decision Support System for Management of the EM-50 Technology Development Program - R. Malinovsky, WPI: The efforts of this project provided a means to organize and catalog various activities in the Office of Science and Technology Program so that the decision makers could take full advantage of the portfolio of USDOE R&D projects to meet the needs of the DOE Weapons Complex cleanup. The final product was a data base to be used as a decision tool to help in analysis and prioritization of the technology development portfolio being sponsored by the DOE EM-50 program. A joint effort between WVU, The Waste Policy Institute and Virginia Tech comprised this work.

A Prototype Database and Decision Support System (DDS) for Management of the EM-50 Technology Development Program - J. Denton, WVU: Decision support tools were developed in this task to aid in the process of prioritizing and selecting technologies consistent with the “Gate - Technology Maturity Levels” criterion used to evaluate projects for advancement to succeeding development phases, and considers costs, benefits and risks from the standpoint of the stakeholder. The finished project provided DOE assistance in funding decisions.

GIS - Based Infrastructure for Site Characterization and Remediation - J. Hooper and A. Lodgher, Marshall University: The primary goal of this work was to determine an effective Geographic Information System (GIS) based infrastructure for describing, characterizing, and remediating contaminated sites. Work was conducted with the **U.S. Army Corps of Engineers** at a large contaminated site (WV Ordnance site in Mason County, WV).

Focus Area 2.0: Mixed Waste Characterization, Treatment and Disposal

Analysis of Vortec Cyclone Melting System (CMSTM) for Remediation of PCB Contaminated Soils - Dr. I. Celik, WVU: This project combined WVU researchers with the **Vortec Corporation**. The research focused on providing information necessary for the design of retrofit components to an existing high temperature waste processing and recycling unit so the system can be used for remediating PCB (PolyChlorinated Biphenyls) contaminated soils via ex situ vitrification.

Instrumental Methods for Characterization and Analysis of Nuclear Wastes and Environmental Contaminants - V. Remcho, WVU: This research focused on novel detection strategies for the chemical specification and quantification of Technetium 99(⁹⁹Tc) and Iodine 129 (¹²⁹I) in simulated nuclear waste tanks and aquifer matrices. Direct interaction with the **Battelle Memorial Institute at the Pacific Northwest National Laboratory** facilitated this effort.

Focus Area 3.0: Decontamination and Decommissioning

Production and Evaluation of Biosorbents and Cleaning solutions for use in Decontamination and Decommissioning - Dr. J. Kilbane, IGT: The objectives of this research were to prepare and evaluate

biosorbents and cleaning solutions produced by **Institute of Gas Technology (IGT)** that may be useful in the decontamination and decommissioning of DOE facilities. The research was a joint effort between the CEE department at WVU and IGT that addressed the filtration/liquid processing to be used in practical applications.

Use of SpinTek Centrifugal Membrane Technology and Sorbents/Cleaning Solutions for D&D Work - Dr. B. Reed, WVU: The feasibility of using centrifugal membrane technology to separate sorbents/cleaning agents used in decontamination and decommissioning was investigated in this work. The project used the **SpinTek** Centrifugal Membrane system to filter the sorbents/cleaning agents developed through the efforts of the **IGT** Biosorbents project.

Focus Area 4.0: Cross Cutting Innovative Technologies

Use of Centrifugal Membrane Technology with Novel Membranes to Treat Hazardous/Radioactive Wastes - Dr. B. Reed, WVU: The objective of this research was to investigate the feasibility of using the **SpinTek** Centrifugal Membrane Technology coupled with innovative membranes for the treatment and/or separation of hazardous/radiological wastes. The results of this work proved a bench scale technology that can treat a variety of wastes, such as: contaminated groundwater, mixed-waste process water, waste residual, etc. The process can be used for both inorganic (radionuclides and heavy metals) and organic contaminants.

Environmental Pollution Control Devices Based on Novel Forms of Carbon - Dr. J. Zondlo, Dr. A. Brennsteiner and Dr. A. Stiller, WVU: The purpose of this research was to assess the feasibility of an electrochemical system that uses high surface area carbon devices to remove heavy metals from aqueous streams. Cathodic carbon materials were developed to maximize the conversion efficiency of the process. The system can be used to selectively remove and recover metal ions, and provides for a detailed quantitative analysis of the metal ions in solution down to the parts per billion range. The technology is also applicable for the removal of some radionuclides from water. Industrial tie-ins were made with the **Carbon Materials Group at Oak Ridge National Laboratory, Applied Sciences Inc., Concurrent Technologies Corporation and Swanson Plating Co.**

Design of a Rotating Membrane Filtration System for Remediation Technologies - Dr. V. Mucino, WVU: Support was provided by WVU's Mechanical & Aerospace Department to **SpinTek Corporation** for developing an optimum configuration to improve the capacity of the rotating filtration system with respect to energy consumption and cost. System optimization of the SpinTek unit required that a relationship between performance characteristics and the systems' parameters be established. Three mechanistic models were considered: 1) Stress Distribution Model, 2) The Dynamics Model, and 3) Fluid Dynamics Model. Various computer-aided design technologies were applied for developing these models including: the use of solid constructive geometry methods, finite element techniques and computation fluid dynamic codes.

Treatment of Mixed Wastes via Steam Reforming - R. Turton, WVU: This research investigated the destruction efficiency of RCRA organics occurring in a steam reforming atmosphere. The research directly addressed the optimization of the second stage of a small industrial scale prototype plant developed by ThermoChem Inc., Columbia, MD, a small business funded by FETC/DOE.

Evaluation of a Supercritical Gravity Pressure Vessel (SGPV) for Supercritical Water Oxidation (SCWO) - G. Rappe, Genesyst: The objectives of this research performed by **Genesyst International, Inc.**, were to perform a technology evaluation to determine the applicability of the Supercritical Gravity Pressure Vessel (SGPV) to waste streams in various DOE focus areas. The work determined the applicability of the SGPV technology to low level mixed wastes. Comparisons were made with two other SCWO technologies, as well as other thermal treatment systems.

Focus Area 5.0: Outreach

Small Business Technical-Based Support - Dr. E. Cook, WVU: This project was initiated to address problems with commercialization of innovative site remediation technologies developed by small businesses funded by DOE. Once a problem or opportunity was defined, researchers from WVU, or other sources were solicited to work with the small business in a research effort to solve the problem or remove the barrier to commercialization of the process.

West Virginia High Technology Consortium Foundation (WVHTC) Environmental Technology Support Program - J. Berkow, WVHTC: The goals of this program were to facilitate technology transfer and commercialization of environmental technologies by linking entrepreneurs, capital, market and general know-how through regional start-up companies launched through the Environmental Technology Incubator.

Approach for Assessing Potential Voluntary Environmental Protection, Kanawha Valley Area - R. Lovett, NRCCE: The objective of this project was to assess the interest and willingness of industry in the Kanawha River Valley, WV, to participate in discussions leading toward the voluntary cleanup of contaminated industrial sites using DOE developed technologies.

PROGRAM HIGHLIGHTS

The evolution of the WVU Cooperative Agreement Program over the past five years resulted in a slightly different direction being taken each year. Great strides were made in developing and demonstrating workable systems to fill gaps in current technologies.

Continuous funding was provided over the five years for developing the use of prefabricated vertical drains (PVDs) for subsurface cleaning of contaminated soils and aquifers. The PVDs can be placed, economically,

on 2-3 foot centers, 20-30 feet deep (or deeper) allowing a site to be completely matrixed. The installation of a 0.10 acre site with PVDs on a 3-foot spacing is estimated to take 3 days or less. Fluids can be vacuum extracted or injected (chemicals or surfactants) through adjacent PVDs. With this close spacing, the resulting short flow path (1.5 feet) for travel of the contaminant, very low permeability soils (like clays with $k=10^{-6}$, 10^{-7} cm/sec) can be remediated as well as the higher permeability granular soils. By extracting fluids from the PVDs, the location of the contaminant can be determined and one can then work with only those PVDs located in the exact contaminant area. This greatly reduces the volume of injected and extracted liquids to be addressed and allows complete control of the mobilized contaminants. Using the SpinTek Centrifugal Membrane System on the extracted liquids, the surfactant above the critical micelle concentration can be recovered for re-injection resulting in another cost savings. The crowning achievement of the WVU Cooperative Agreement has been in bringing together the PVD technology and centrifugal membrane technology. These two innovative technologies greatly enhance *in-situ* soil flushing and supplant pump and treat systems, thus, lowering expected remediation times from 20 years to 3-5 years.

RMI Titanium at Ashtabula, Ohio has provided a Trichloroethylene (TCE) contaminated site to demonstrate the PVD technology. Nilex Corporation provided the PVD materials and installation expertise over the past five years in conjunction with the CEE Department at WVU. The Institute of Gas Technology (IGT) accomplished studies to determine the surfactant and other chemicals required to release and tie up the TCE from the contaminated soil matrix. IGT also provided the expertise on mixing and injecting the various chemicals through the PVDs. RMI Environmental provided the treatment scheme and systems to treat the extracted fluids to standards allowing re-injection or release of the fluids to the local sewage treatment plant.

A number of other companies, though not supported by DOE/FETC, have collaborated through the WVU Cooperative Agreement. Ashland Oil Company provided a site for the preliminary testing of the PVDs at an abandoned gasoline station site in Weston, WV. Over the life of the WVU Cooperative Agreement, Nilex Corporation has provided all of the materials for the PVDs and in kind expertise for the work.

The "Environmental Pollution Control Devices Based on Novel Forms of Carbon" project has received widespread interest. This project investigates the electro-adsorption of heavy metals and transuranics from waste streams. The system can be used to selectively remove and recover metal ions and provides a detailed quantitative analysis of the metal ions in solution down to the parts per billion range. Applied Sciences Inc. has been providing nanofiber carbon materials for the project for past three years. Contacts have been established for applying this novel technology at the Swanson Plating Company in Morgantown, WV for the removal and recovery of chromium. The research group at the EPA Office in Cincinnati, Ohio, is working on the clean up of military ballistic and firing ranges. Enormous amounts of lead have been accumulating in the ground at these sites and the lead is now leaching through the soil and appearing in the ground water. The EPA has devised a scheme to remove the lead from the soil by dissolving it with a solution of acetic acid. Once in solution, the lead ions must be removed from the aqueous stream so that the acid can be recycled. Dr. Szlag of Cincinnati EPA is extremely interested in applying this technology and has already provided samples to WVU from the remediation of the Fort Benjamin Harrison Army Base that were successfully treated.

The WVU Cooperative Agreement has continually reached out to include any entity that may make a

contribution to the testing and development of innovative remediation technologies. As a result, efforts for bridging the gap in bringing other commercially viable technologies to the market has been demonstrated with great success.

TRACK RECORD FOR INNOVATION IN WORKING WITH INDUSTRY

Under the category of assisting small businesses the following successes resulted through interaction with some of the small remediation companies supported by DOE/FETC and other industrial collaborations.

RMI Environmental, Inc.: WVU, DOE-Ashtabula, and RMI worked together in problem identification and bringing WVU's technical resources in technology development to bear on this decontamination and decommissioning project. RMI Titanium at Ashtabula Ohio has provided a Trichloroethylene (TCE) contaminated site to demonstrate the Prefabricated Vertical Drain (PVD) technology. RMI Environmental provided the treatment scheme and system to treat the extracted fluids to standards allowing re-injection or release of the fluids to the local sewage treatment plant. **The Institute of Gas Technology (IGT)** did studies to determine the surfactant and other chemicals required to release and tie up the TCE from the contaminated soil matrix. IGT also provided the expertise on mixing and injecting of the various chemicals through the prefabricated vertical drains.

Institute of Gas Technology (IGT): IGT has been involved with the WVU Cooperative Agreement on several fronts. In addition to the current and proposed work at the RMI facility, IGT has worked with Dr. Reed of the CEE Department at WVU producing biosorbents and cleaning solutions for use with the SpinTek Centrifugal Membrane Technology. The potential for reusing these biosorbents and cleaning solutions in decontamination and decommissioning of DOE facilities has been successfully investigated. Reuse of these products will significantly reduce the costs of the DOE remediation efforts across its complex.

Nilex Corporation: Nilex Corporation has provided materials and in kind expertise over the past five years for applying the PVD technology to *in-situ* soil remediation efforts. **Ashland Oil and Refining Co.** provided an underground storage tank site (an abandoned service station) where the first demonstration on the use of the PVD technology for remediation of fine grained soils took place.

Thermo Chem Inc.: This small company supported by DOE developed a 2-stage steam reforming process that separated, removed and destroyed organic wastes by devolatilization via heating followed by high temperature destruction in a steam reforming atmosphere. Dr. Turton of the Chemical Engineering Department at WVU developed a high temperature experimental apparatus capable of simulating the conditions used in the prototype pilot scale process for treating mixed wastes. This equipment was used to assess the optimum conditions for the destruction of the organic material and to quantify the destruction efficiency of the process. The main focus of the work was to address the optimization of the second stage of the ThermoChem process. The experimental program (i.e., temperature, gas compositions and residence times) used in this work covered the range of operation of most interest and value to ThermoChem. As destruction efficiencies were evaluated in the WVU labs, ThermoChem's input was sought and changes in the experimental program were instituted to aid in the design of the prototype process.

Vortec, Inc.: Vortec Corporation's CMSTM is an ex-situ vitrification/remediation technology that involves high temperature process heating applications and treatment of hazardous waste and contaminated residuals by oxidizing organic contaminants and immobilizing inorganic contaminants within a glassy, vitrified matrix. An extensive research and development (R&D) program was implemented by the Vortec Corporation to modify their existing Cyclone Melting System (CMSTM) and retrofit it with appropriate units so that the system could be used for efficient remediation of polychlorinated biphenyl (PCB) contaminated soils. This task required determination of optimum design and operation parameters such as residence time, heat loss, pressure drop, and conversion and destruction (C&D) efficiencies. The computation and optimization of these parameters could best be accomplished via Computational Fluid Dynamics (CFD) codes to determine the flow field, temperature destruction, and species concentrations inside the units being considered. The calculated design parameters along with the detailed information and virtual flow visualization obtained from such computer simulations could greatly reduce the large cost of experimental testing and validation procedures.

The use of CFD in determining the optimum design parameters has benefits on several fronts. The C&D rates of contaminants is a strong function of the reactor temperature which, in turn, depends on the degree of turbulent mixing and the presence of recirculation zones. The gas flow residence time must be larger than typical C&D times. The usual practice of computing residence time from a plug flow reactor may lead to significant errors and unnecessary conservatism.

The use of CFD simulations provided by Dr. Celik in the Mechanical and Aerospace Engineering (MAE) Department at WVU not only provided detailed information about the nature of the flow, temperature, and concentration fields, but it also enabled engineers to calculate the required design parameters more accurately. This represented a great savings in both time and money in bringing this important technology to the market.

SpinTek, Inc.: SpinTek, Inc., a California-based company, has developed and patented a cross-flow membrane technology that improves upon the conventional membrane process. The SpinTek system uses a series of flat, round membrane disk packs, set on a hollow rotating shaft inside a cylindrical housing. The waste stream enters the membrane chamber under pressure and is distributed across the membrane surfaces by centrifugal and hydraulic action. Permeate is forced through the membrane and is collected in the hollow shaft and discharged. The centrifugal action continuously scours and cleans the membrane surface thereby decreasing cleaning chemical use and maintenance, increasing the volume of waste treated per area of membrane, and increasing the contaminant/solids concentration in the residual (i.e., increases volume reduction factor).

Dr. Reed from the CEE Department at WVU headed the investigation of various membrane materials and waste waters to determine the process applicability in numerous areas. The research team has been successful in marketing this product line to the DOE at Los Alamos Laboratory and also to private industry (**Ravenswood Aluminum**) for concentrating oily wastes to 50%. Being a novel separations process, the applicability of this technology throughout the DOE complex is unlimited.

As in any process, improvements can be made through modeling, redesign, optimization and consideration of new materials for construction. Dr. Mucino from the Mechanical and Aerospace Engineering (MAE)

Department at WVU took on the task of improving the SpinTek design. System optimization of the SpinTek filtration system required that a relationship between the performance characteristics (flow capacity and permeate quality) and the systems' parameters (geometry, material properties and operating conditions) be established. This involved the development of various mechanistic models to provide a description of various system responses. Three major models were developed that resulted in an optimum configuration of the filtration system that improved the capacity of the system for processing water. Also, they lead toward the study of options such as the trade off study of increasing disk diameter versus multiple disk arrangements and the study of performance of various membrane-disk materials.

The main overall benefit was improving the performance of the system and the associated characteristics that affected it the most. Capacity versus power assessments were studied, based on the aforementioned mechanistic models and a parametric sensitivity analysis conducted. The effective and improved performance of the filtration systems will allow greater capacity of water processing while maintaining the quality of the permeate.

This technology is presently being applied at Los Alamos National Lab as an innovative separations technology for oil and water streams and removal of uranium. This separation technology has great potential for application in numerous areas. The SpinTek technology is also being applied by WVU at the RMI facility in combination with PVDs for use in subsurface soil flushing operations to recover surfactants and contaminants from extracted ground water.

Applied Sciences Incorporated: Applied Sciences has provided novel carbon forms to the WVU Chemical Engineering Department for developing the electro-adsorption apparatus for the removal of radioactive materials from aqueous waste streams. Cathodic carbon materials were developed to maximize the conversion efficiency of the process. Dr. Alig, of Applied Sciences, was able to tailor the surface properties of the novel carbon fibers to help improve their ability to remove various metal ions.

Contact has been made and samples of carbon fibers obtained from Dr. Timothy Burchell at the **Carbon Materials Group at Oak Ridge National Laboratories**. Dr. Burchell's group has been developing activated carbon and graphite fibers with extremely high surface areas (up to 1000 m²/gram) and a monolithic structure that may be a perfect candidate for this application. Dr. Geoff Kimber of the **University of Kentucky, Center for Applied Energy Research** in Lexington, KY has become another source for highly conductive, high surface area carbon fiber monoliths. Contacts have been established for applying the novel carbon technology at the **Swanson Plating Company** in Morgantown, WV. It is proposed that the electrochemical methods developed in this research be applied to their chromium plating line for the removal and recovery of chromium. They have already supplied WVU's Department of Chemical Engineering with samples of an actual plating bath and waste water generated at their facility.

Dr. Szlag's research group at the **EPA Office in Cincinnati, Ohio**, is working for the DOD on cleaning up military ballistic and firing ranges. Enormous amounts of lead have been accumulating in the ground at these sites and the lead is now leaching through the soil and appearing in the ground water. The EPA has devised a scheme to remove the lead from the soil by dissolving it with a solution of acetic acid. Once in solution, the lead ions must be removed from the aqueous stream so that the acid can be recycled. Dr. Szlag is

extremely interested in applying this electroadsorption technology and has already provided samples to WVU from the remediation of the Fort Benjamin Harrison Army Base which were successfully treated.

The novel carbon project is also applicable for removing some radionuclides from water. Mr. Richard Crane, who is Sitting Secretary for the National Metal Platers Association, has identified potential applications for removing radionuclides from waste streams generated from decommissioning nuclear sites. Here, acid solutions are used to etch the coatings of radioactive material lining piping and valves from nuclear plants during decommissioning.

Graphite rods have been obtained from North American Carbon Products, Inc. (NAC) in Punxsutawney, PA. These rods will be used to replace the more expensive platinum wire as electrical contact to the anode side of the novel carbon beds.

Preliminary discussion with Dr. Hu Fleming of Zenon Environmental Systems, Inc. has identified a source for possible collaboration on the design and fabrication of the large-scale prototype cell. Dr. Fleming has extensive experience in waste water remediation and his contacts in the field may prove invaluable to the present effort.

The Waste Policy Institute (WPI): WPI collaborated through the Cooperative Agreement with the WVU School of Business and Economics and Virginia Tech to assist them in determining if DOE has supported the proper technologies for cleaning up the subsurface contaminants in the various weapon complexes. The efforts of this project provided a means to organize and catalog various activities in the Office of Science and Technology Program. Decision support tools were developed in this task to aid in the process of prioritizing and selecting technologies consistent with the “Gate - Technology Maturity Levels” criteria used by DOE to evaluate projects for advancement to succeeding development phases, and considers costs, benefits and risks from the standpoint of the stakeholder.

BDM Federal, Inc.: In cooperation with the WVU Department of Petroleum Engineering, has developed the B17 Building on the FETC-Morgantown site into a testing facility for demonstrating innovative *in-situ* subsurface barriers. Principally, the Circulating Air Barrier (CAB) has undergone further development at the pilot scale. The technology uses commercially available oil and gas technologies and equipment to address site remediation needs.

Discussions were conducted with RKK, Inc. who have successfully demonstrated the Freeze Barrier Technology at the Oakridge, TN site. RKK, Inc. is interested in conducting a pilot scale demonstration at the Hanford, CT site using the CAB as a backup barrier to prevent any contaminants from reaching the deep aquifer in the area. The effectiveness of using the CAB in this capacity first needs to be evaluated with the scaled up model proposed.

U.S. Army Corps of Engineers: The WV Ordnance site in Mason County, WV was provided by the U.S. Army Corps of Engineers to test the GIS system developed through the efforts of Marshall University. This infrastructure was successfully used to describe and characterize the site and suggest remediation strategies for its clean up efforts.

Battelle Memorial Institute at the Pacific Northwest National Laboratory: Scientists from this laboratory interacted with Dr. Remcho of the WVU Chemistry Department in simulating nuclear waste tanks and aquifer matrices for developing detection strategies for the chemical speciation and quantitation of Technetium 99 (^{99}Tc) and Iodine 129 (^{129}I).

GENESYST: This downhole supercritical water oxidation system has applications in many mixed waste scenarios. It can convert all organics to carbon dioxide and water including the hazardous components. Its initial costs are prohibitively expensive and siting a system requires several stakeholders, cooperation and funding.

Conclusions

This Cooperative Agreement funded more than 45 different projects over the five years plus period at cost of \$10,300,000. The Agreement also assisted a number of small businesses that work with the USDOE including Vortec, SpinTek Membrane Systems, Inc., and ThermoChem. Numerous contacts with other businesses occurred which resulted in many of them cooperating in the program by providing time, materials, etc. to the investigators at West Virginia University that were accomplishing the research.

The value of the WVU Cooperative Agreement was proved in the effort to fill the gaps in current remediation technologies. The Prefabricated Vertical Drain enhanced soil flushing has shown to be a very economical alternative to pump and treat. It can reduce soil clean up times to a three to five-year period rather than the 20 years typical of the pump and treat system. It also has the ability to clean fine grain *in-situ* contaminated soils (such as clays) having permeabilities on the order of 1×10^{-6} or 10^{-7} in which pump and treat systems are **not** applicable. The total cost, for five (5) years of research and development and two pilot plant studies, was approximately \$1,250,000. Articles featuring the Prefabricated Vertical Drain technology have been published in *Initiatives* and as a *FETC Success Story* on FETC's web site. The technology is presently being demonstrated on a larger scale at the former NRC site in Ashtabula, Ohio.

Another impressive technology developed and applied through the WVU Cooperative Agreement is the SpinTek Centrifugal Membrane System. Four projects were funded at WVU concerning this technology at a cost of \$500,000. Many articles throughout the USDOE have been written featuring this novel separation process technology. The technology has also been shown at the former NRC site in Ashtabula, Ohio for removing micelle and monomer surfactants from TCE contaminant-laden groundwater extracted from *in-situ* soil flushing operations through the prefabricated vertical drains. This surfactant recovery and recycle results in a significant reduction to surfactant costs and greatly reduces the costs to biodegrade the residual surfactant, prior to release to the environment. Due to the research done at West Virginia University, the technology has been adopted for use at the Los Alamos National Lab. The technology has also been adopted by an aluminum industry company to remove the oil from oily waste waters generated during the pressing and extruding of billet aluminum.

Considering their usefulness to the clean up effort and the cost to the USDOE for these two technologies, no other technologies provide or have the propensity to provide a greater return on investment. These technologies alone make the \$10.3 million investment made by the USDOE in the WVU Cooperative Agreement a tremendous success.

Other technologies, developed through the WVU Cooperative Agreement, such as the electroplating/adsorption of heavy metals and transuranics on novel forms of carbon have intense interest by the USDOE and various electroplating industries. While these technologies are not immediately usable to the USDOE due to scale-up problems, they will most likely further develop them.