Decontamination Systems Information and Research Program

Quarterly Report July - September 1995

October 1995

MASTER

Work Performed Under Contract No.: DE-FC21-92MC29467

U.S. Department of Energy
Office of Environmental Management
Office of Technology Development
Washington, DC

For

U.S. Department of Energy
Office of Fossil Energy
Morgantown Energy Technology Center
Morgantown, West Virginia

By
West Virginia University
Morgantown, West Virginia

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1000 Independence Avenue
Washington, DC 20585

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Office of Fossil Energy
Morgantown Energy Technology Center
P.O. Box 880
Morgantown, West Virginia 26507-0880

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October 1995

EXECUTIVE SUMMARY

The projects reported for the WVU Cooperative Agreement are categorized into the following three areas: 1.0 In Situ Remediation Process Development, 2.0 Advanced Product Applications Testing, and 3.0 Information Systems, Public Policy, Community Outreach, and Economics. Summaries of the significant accomplishments for the projects reported during the period 1 July 95 through 30 September 95 are presented in the following discussions.

1.0 IN SITU REMEDIATION PROCESS DEVELOPMENT

Task 1.1: Research on the Drain Enhanced Soil Flushing (DESF) for Organic Contaminants Removal project reported progress with the use of Prefabricated Vertical Drains (PVD) under vacuum conditions for soil flushing and remediation in study soils of 100% sand and a 80% sand/20% clay mixture. Data related to the performance of the PVD system for soil flushing are obtained from pilot-scale testing. Results show that for a 80% sand/20% clay, the areal extent of the zone of influence remained at approximately 15 cm or 30 times the effective diameter of the drain as the extraction vacuum increased from 2.48 kPa to 14.92 kPa. No such behavior was observed for the 100% sand specimens. Verification of the contaminant transport model showed favorable results in comparison with laboratory data using a 100% sand soil at unit weights of 1.57 and 1.67 g/cm³. The model predicted contaminant clean-up times that were consistent with actual experiment results for variations in soil properties, flushing flow rates, and dispersivity values.

Task 1.2: Work this period for the In Situ Bioremediation of Organic Contaminants project continued with anaerobic and aerobic column studies operated in a sequential mode. Parameters such as reducing agents and elevated TCE concentration were evaluated for the sequential column. The simultaneous column is operating and the lysimeter was constructed and is operating to evaluate the performance of Prefabricated Vertical Drains for amendments delivery. In the sequential column studies reducing agents and elevated TCE concentration were the principal variables investigated. Increases in TCE removal efficiency are reported. The sequential column is in a period of adjustment and no

conclusions are as yet available.

Task 1.3: Work performed on the Microbial Enrichment for Enhancing In Situ Biodegradation of Hazardous Organic Wastes in Soil this period focused on perfecting assays and performing bioremediation trials. Study soils were prepared with hexadecane, naphthalene, and anthracene hydrocarbons as the study contaminants. Data on the rates of the hydrocarbon mineralization are reported and discussed. A new staff member joined the project and has been productive in characterizing organisms and verifying their efficacy for degradation of waste oils and other organic compounds.

Task 1.4: Progress on the Contaminant Movement Prediction in Permeable Subsurface Soils project has consisted of verification of installed software and performing sample runs with model data. Data from experiments performed under Task 1.1 were input to the model and simulations of groundwater movement predicted based on a rectangular coordinate system. No progress was reported beyond the set-up and testing phase.

Task 1.5: Progress on Development of a Standard Protocol and Barrier Design Model for In Situ Formed Barriers is separated into Administrative Issues, Chemical Grouting (1.5a), and Circulating Air Barrier (CAB) (1.5b). Accomplishments made this period for each of these subtasks are discussed below.

Administrative Issues: Work accomplished by BDM Federal, Inc. included: Finalizing operating permits for CAB and the Chemical Grout testing at METC in B-17, and procurement of equipment and supplies for the Chemical Grouting research.

1.5a Chemical Grouting: Laboratory testing of the chemical (vinyl monomer) grout mix ratios continued with the addition of four new mix designs. Permeability tests are continuing to determine a near-optimum mix. Testing for the urethane grouts continued with column experiments focusing on seepage testing and compression testing of various grout mixes. The large diameter column and performance testing phase of the research showed progress with the 5610 Urethane for injectability, permeability, and durability/strength tests on the material. Construction of the large-scale sand rain device has progressed with manufacturing of a test cylinder

and procurement of a new laboratory to house the unit.

1.5b Circulating Air Barriers (CAB): Work in this area has included: 1) continued work on the Operating Plan for METC, 2) development of experimental protocols for the Sand-Pack testing, and 3) continued core testing for evaluating the influence of porous media on air-water equilibrium.

2.0 ADVANCED PRODUCT APPLICATIONS TESTING

Task 2.1: Work this period on the Chemical Destruction of Chlorinated Organic Compounds project continued with development of a procedure for the synthesis of a simple model polymer to function as an electron carrier for dechlorination. From this effort, two trimers were developed as models for the synthesis of higher molecular weight polymers.

Task 2.2: Progress on the Continued Development of an Atmospheric Monitoring Mass Spectrometry System project dealt with the molecular beam sampling interface construction. Several technical and staffing problems have hampered project progress. The research approach has been changed to focus on MS/MS experiments with the GC interface to permit the differentiation of ethylbenzene and xylenes.

Task 2.3: During this reporting period a change in the focus of the Capture of Hazardous Waste Materials Utilizing Fluidization Coating Technology project was performed. The current emphasis for the project is to investigate the destruction efficiencies of RCRA organics and surrogates in a steam reforming atmosphere. This new work will tie in closely with Task 2.4 Remediation of Hazardous Sites with Steam Reforming. During this period redesign of the equipment was made to include provisions for a dual gas feed system. Other modifications were made to incorporate gas detectors and a nitrogen dilution stream.

Task 2.4: The Remediation of Hazardous Sites with Steam Reforming project has reported that due to the consolidation of their corporation, the project has been delayed while all parts and equipment are packaged and shipped to the new test site in Baltimore. Work will resume during the next quarter.

Task 2.5: The Environmental Pollution Control Devices Based on Novel Forms of Carbon project reported completion of all objectives. Testing continued this quarter to determine long-term metal ion removal from feed water supplies using carbon nanofibers. Results showed that for a lead rich waste stream source after 72 hours of testing, an initial 100 ppm concentration was reduced to 10 ppm. All experimental data and discussions are included in the draft final report contained in this submittal.

3.0 INFORMATION SYSTEMS, PUBLIC POLICY, COMMUNITY OUTREACH, AND ECONOMICS

Task 3.1: The Winfield Lock and Dam Remediation project reported that air monitoring began at the end of August, and barring initial technical difficulties, has operated to obtain minute by minute air quality readings since 15 September. Air monitoring will continue with installation of a second unit around the first week of October. Development of the MS/MS unit was slowed due to numerous problems.

Task 3.2: Progress on the GIS-Based Infrastructure for Site Characterization and Remediation project this period saw personnel from Marshall Univ. and the Corps of Engineers traveling to the Corps' Nashville office to experiment with features of the GES software on actual data from a Hazardous, Toxic & Radioactive Waste data base. The project is reportedly on schedule and within budget.

Task 3.3: Efforts on the Small Business Support Program for this period dealt with: 1) initiating a pre-proposal call for development of the FY 96 WVU Cooperative Agreement; 2) development of a new task with Vortec Inc. to model development to maximize efficiency of an ex situ vitrification process. Two technical conferences were attended that dealt with decontamination and decommissioning, and hazardous waste management. Meetings with

General Electric Corp. have been scheduled to discuss a new approach using zero valent iron and iron sulfide for reductive dechlorination of ethylene chloride. The goal of this meeting is to explore the opportunity of coordinated research with General Electric. Finally, various meetings were held with the WV High Tech Consortium Foundation for development of the Environmental Technology Support Program.

Task 3.4 The Approach for Assessing Potential Voluntary Environmental Protection, Kanawha Valley Area project reported that two meetings were held with individuals from companies located in the Kanawha Valley. The discussions led to a presentation before the Kanawha Valley Chemical Plant managers group detailing the objectives of this project. Results are encouraging and subsequent meetings are planned for this next quarter.

Task 3.6 The Interagency Environmental Technologies Office (IETO) Graduate Intern Program project reports that five student interns were provided to IETO to assist in conducting research, analysis and documentation. Contracts with the students were extended to December 31, 1995.

Task 3.6 The West Virginia High Tech Consortium Foundation Environmental Technology Support Program began during this reporting period. Accomplishments to date are limited to establishing offices and identification of potential clients for recruitment.

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2.0 ADVANCED PRODUCT APPLICATIONS TESTING

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ENVIRONMENTAL TECHNOLOGY INCUBATOR CENTER (ETIC)

PROJECT TITLES WITH PRINCIPAL INVESTIGATORS

1.0 IN-SITU REMEDIATION PROCESS DEVELOPMENT

- 1.1 USE OF DRAIN ENHANCED SOIL FLUSHING (DESF)
FOR ORGANIC CONTAMINANTS REMOVAL

M. Gabr, Dept. of Civil & Environmental Eng.

- 1.2 IN-SITU BIOREMEDIATION OF CHLORINATED ORGANIC
SOLVENTS

W. Sack and P. Carriere,
Dept. of Civil & Environmental Eng.
A. Shiemke, Dept. of Biochemistry

- 1.3 MICROBIAL ENRICHMENT FOR ENHANCING IN-SITU
BIODEGRATION OF HAZARDOUS ORGANIC WASTES

A. Sexstone, Dept. of Plant & Soil Science

- 1.4 CONTAMINANT MOVEMENT PREDICTION IN PERMEABLE SUBSURFACE
SOILS

H. Bilgesu and S. Ameri, Dept. of Petroleum Eng.

- 1.5 DEVELOPMENT OF STANDARD TEST PROTOCOLS & BARRIER DESIGN
MODELS FOR IN-SITU FORMED BARRIERS

C. Black, NRCCE,
M. Gabr, Dept. of Civil & Environmental Eng.,
S. Ameri & K. Aminian, Dept. of Petroleum Eng.

2.0 ADVANCED PRODUCT APPLICATIONS TESTING

- 2.1 CHEMICAL DESTRUCTION OF CHLORINATED ORGANIC COMPOUNDS

K. Wang, Dept. of Chemistry

- 2.2 CONTINUED DEVELOPMENT OF AN ATMOSPHERIC MONITORING
MASS SPECTROMETRY SYSTEM

F. King, Dept. of Chemistry

2.3 CAPTURE OF HAZARDOUS CHEMICAL WASTE MATERIALS UTILIZING
FLUIDIZATION COATING TECHNOLOGY

R. Turton, Dept. of Chemical Eng.

2.4 SOIL DECONTAMINATION BY STEAM REFORMING

R. Lovett, NRCCE

2.5 CARBON PRODUCTS FOR WASTE STREAM CLEANUP

C. Irwin, NRCCE and J. Zondlo, Dept. of Chemical Eng.

3.0 INFORMATION SYSTEMS, PUBLIC POLICY,
COMMUNITY OUTREACH AND ECONOMICS

3.1 WINFIELD LOCK AND DAM ASSISTANCE PROGRAM

R. Lovett, NRCCE

3.2 A GIS BASED INFRASTRUCTURE FOR SITE CHARACTERIZATION
AND REMEDIATION

E. Cook, Dept. of Civil & Environmental Eng., and
J. Hooper, Marshall Univ.

3.3 SMALL BUSINESS SUPPORT PROGRAM

E. Cook, Dept. of Civil & Environmental Eng.

3.4 APPROACH FOR ASSESSING POTENTIAL VOLUNTARY
ENVIRONMENTAL PROTECTION - KANAWHA RIVER AREA

R. Lovett, NRCCE

3.5 WASTE-MANAGEMENT EDUCATION & RESEARCH CONSORTIUM
(WERC) NATIONAL ENVIRONMENTAL DESIGN

B. Reed, Dept. of Civil & Environmental Eng.

3.6 IETO GRADUATE INTERN PROGRAM

E. Cook, Dept. of Civil & Environmental Eng.

3.7 WV HIGH TECH CONSORTIUM (WVHTC)
ENVIRONMENTAL TECHNOLOGY INCUBATOR CENTER (ETIC)

K. Jones

ADMINISTRATIVE ISSUES

Administrative Summary

Background

West Virginia University (WVU) and the U.S. Department of Energy Morgantown Energy Technology Center (DOE/METC) entered into a Cooperative Agreement on August 29, 1992 titled "Decontamination Systems Information and Research Programs" (DOE Instrument No.:DE-FC21-92MC29467). Requirements stipulated by the Agreement require WVU to submit Technical Progress reports on a quarterly basis. This report contains the efforts of the fourteen research projects comprising the Agreement for the period July 1 to September 30, 1995.

Administrative Issues

The WVU College of Engineering, Department of Civil and Environmental Engineering has continued as the lead agency for administration of the Cooperative Agreement. All responsibilities for the Cooperative Agreement have been transferred to the Department of Civil and Environmental Engineering.

Project Variances, Accomplishments, and Problems

During this period a variance with the focus of Task 2.3, Capture of Hazardous Waste Materials Utilizing Fluidization Coating Technology. The project will now focus on a working relationship with ThermoChem Inc. Columbia, MD (Task 2.4) to modify and test the experimental equipment previously designed and constructed under Task 2.4.

Accounting Issues

An accrual accounting system is being used to represent actual spending. A cash basis has been used in the past which accounts for expenses as they are paid. An accrual accounting of expenditures will enable one to better compare actual expenses with progress schedules.

The NRCCE is not longer involved with the administration of the Cooperative Agreement. However, since this agreement is a multi year grant, all funds are cumulated. Information on previous activity reported under the direction of the NRCCE was obtained from the Controllers reports and is not detailed here. Due to this change in

responsibilities, the NRCCE administrative budget has been reduced and prepared for close out.

All extended budgets (designated by an "e" or represented by an old MC number) were also prepared for close out, and adjustments, where applicable, were made. These are shown on the attached graphs and noted on the budget spreadsheets. In cases where actual expenses were less than the planned budget, the budgeted amounts were reduced to obtain a zero balance. Budget adjustments were made on Task 1.2e, 1.3e, 1.5e, 1.5be, 2.4, 2.5e, MC-14 and NRCCE Administration. Any excess in funding resulting from close out procedures will be distributed to support research efforts.

There was an error in reporting the actual expenses for Task 1.2e and in reporting overhead and the application of overhead to subcontractor expenses in Task 3.4. Both reports were modified to correct these entries. Planned and actual spending were revised to reflect activity on projects where changes in the scope of work were realized and/or where increases in project budgets were approved.

Three new projects are being reported on this quarter. These include: Task 3.5 - WERC National Environmental Design Contest, Task 3.6 - Graduate Interns to IETO, and Task 3.7 - WV High Tech Consortium Environmental Technology.

Meetings will be scheduled in November with each Principal Investigator to predict close out activity for 31 December 95. This information will be summarized and included in our next quarterly report.

Scheduling Issues Discussion of the following projects is warranted:

Task 1.2 The project shows delays on three tasks which required substantial completion during the third quarter. Recovery is possible during the fourth quarter. The Principal Investigator has been notified of this discrepancy and the project will be monitored for progress.

Task 1.3 This project continues to lag the planned schedule by approximately 1.5 months. The researcher has been aware of this discrepancy and has indicated support to recover as much time as possible.

Task 1.5 The project shows a delay with testing of the Sand Rain device. This delay was due to acquiring a suitable facility for housing the equipment and since a facility has been found this issue is expected to be resolved during the next reporting period.

Task 2.2 This project shows a lag in work completed due to a series of staff and technical equipment problems. The Principal Investigator will be contacted to develop a recovery schedule during the fourth quarter reporting period.

Task 2.4 Schedule deviations with this project continue and are most recently due to a break-up of the company's California office and the dismantlement and transport of the experimental equipment. It does not appear that the original schedule is achievable and meetings have occurred to address the overall project goals and deliverables.

Task 3.1 The project shows a delay associated with the field monitoring. Field monitoring was begun during the last reporting period and is expected to continue through to the end of December.

BUDGET
&
SCHEDULE UPDATES

ACCRUED ACCOUNTING OF AWARDED FUNDS

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PERIOD COVERED 7/1 - 9/30/95

<u>OUTLAYS</u>		CASH VARIANCE notes
PREVIOUS OUTLAYS (Grant Start - 6/30/95)		
Cash outlays FUND 7631 - NRCCE	3,581,005	
Accrued outlays FUND 8527 - WVU	<u>1,384,515</u>	
TOTAL PREVIOUS OUTLAYS	4,965,520	
CURRENT OUTLAYS (7/1 - 9/30/95)		
Cash outlays - FUND 7631	37,724	
Accrued outlays - FUND 8527	<u>563,401</u>	
TOTAL CURRENT OUTLAYS	<u>601,125</u>	
<u>TOTAL OUTLAYS TO DATE 9/30/95</u>	5,566,645	* Note 1
<u>UNLIQUIDATED OBLIGATIONS</u>		
FUND 8527	<u>457,069</u>	* Note 2
<u>TOTAL SHARE OF OUTLAYS & UNLIQUIDATED OBLIGATIONS</u>	6,023,714	
<u>FUNDS AUTHORIZED</u>		
FUND 8731 (Prior to 1995)	<u>4,749,048</u>	4,749,048
FUND 8527	1,547,000	
Amendment No. A013	<u>75,950</u>	<u>1,622,950</u>
<u>TOTAL FUNDS AUTHORIZED TO DATE 9/30/95</u>	<u>6,371,998</u>	
<u>AMOUNT REMAINING</u>	<u>\$348,284</u>	

* Notes can be found on page 2

ACCRUED ACCOUNTING OF AWARDED FUNDS

Page 2 of 2

PERIOD COVERED 7/1 - 9/30/95

- * Note 1: Accrued outlays include those expenses "incurred" during the period covered. Differences in cash outlays reported by WVU controllers office will result due to the time required in obtaining the bill of sale from each college and the time needed to process and disburse the expense.

An accrual accounting system has been adopted to reflect a real time accounting of all disbursements made within the cooperative agreement under the direction of the Department of Civil and Environmental Engineering. The difference between the cash outlays reported by the controllers office and the accrued expenses reported herein will represent the expenditures in transit.

- * Note 2: Unliquidated obligations mainly include those amounts reserved for subcontractors and salaries. Additional obligations may include those recorded as an account payable, not yet disbursed. The unliquidated obligations may be less when when accounted for on an accrual basis because they are shown in part as an accrued expense.

General Note: Prior to the Department of Civil & Environmental Engineering's direction, The Cooperative agreement was administered by NRCCE. Because the grant is a multiyear grant, the cumulative amounts have been carried forward. Activity on FUND 7631 is not detailed here. The amounts shown were obtained from the controllers reports.

Overall SUMMARY - Planned Versus Actual Budgets

METC Task	PROJECT TITLE	PLANNED ACTUAL	PLANNED TOTALS	ACTUAL TOTALS	AMOUNT REMAINING	% of \$ EXPENDED	REMARKS
1.0 IN-SITU REMEDIATION PROCESS DEVELOPMENT							
1.1	Use of Drain Enhanced Soil Flushing for Organic Contaminants Removal	PLANNED ACTUAL	\$105,999	\$42,345	\$63,654	40%	
1.1e	Extended Budget	PLANNED ACTUAL	\$7,219	\$7,219	\$0	100%	Final Report
TOTAL TASK 1.1		PLANNED ACTUAL	\$113,218	\$49,564	\$63,654	44%	
1.2	In-Situ Bioremediation of Chlorinated Organic Solvents	PLANNED ACTUAL	\$95,690	\$72,425	\$23,265	76%	
1.2e	Extended Budget	PLANNED ACTUAL	\$10,924	\$10,925	(\$1)	100%	Budget & expense adjustment for close out
TOTAL TASK 1.2		PLANNED ACTUAL	\$106,614	\$83,350	\$23,264	78%	
1.3	Microbial Enrichment for Enhancing In Situ Biodegradation of Hazardous Organic Wastes	PLANNED ACTUAL	\$79,465	\$41,524	\$37,941	52%	
1.3e	Extended Budget	PLANNED ACTUAL	\$4,505	\$4,504	\$1	100%	Budget & expense adjustment for close out
TOTAL TASK 1.3		PLANNED ACTUAL	\$83,970	\$46,028	\$37,942	55%	
1.4	Contaminant Movement Prediction in Permeable Subsurface Soils	PLANNED ACTUAL	\$32,247	\$23,609	\$8,638	73%	
1.5	Development of Standard Test Protocols & Barrier Design Models for In-Situ Formed Barriers						Overall Budget Increase in regular budgets
1.5	NRCCE - Administration & BDM	PLANNED ACTUAL	\$395,225	\$314,430	\$80,795	80%	
1.5e	NRCCE - Extended Budget	PLANNED ACTUAL	\$15,386	\$15,389	(\$3)	100%	Budget adjustment for close out
1.5a	CIVIL ENGR - Chemical Grout Barriers	PLANNED ACTUAL	\$135,321	\$99,149	\$36,172	73%	
1.5ae	CIVIL ENGR - Extended Budget	PLANNED ACTUAL	\$35,003	\$35,002	\$1	100%	Budget adjustment for close out
1.5b	PET ENGR - Circulating Air Barriers	PLANNED ACTUAL	\$174,600	\$67,004	\$107,596	38%	
1.5b	PET ENGR - Circulating Air Barriers	PLANNED ACTUAL	\$36,480	\$36,476	\$4	100%	Budget adjustment for close out

CONTINUED

METC Task	PROJECT TITLE	PLANNED ACTUAL	PLANNED TOTALS	ACTUAL TOTALS	AMOUNT REMAINING	% of \$ EXPENDED	REMARKS
	TOTAL TASK 1.5	PLANNED ACTUAL	\$792,015	\$567,450	\$224,565	72%	
	TOTAL TASK 1.0	PLANNED ACTUAL	\$1,128,064	\$770,001	\$358,063	68%	

2.0 ADVANCED PRODUCT APPLICATIONS TESTING

2.1	Chemical Destruction of Chlorinated Organic Compounds	PLANNED ACTUAL	\$67,715	\$40,085	\$27,630	59%	
2.1e	Extended Budget	PLANNED ACTUAL	\$8,557	\$8,557	\$0	100%	Final Report
	TOTAL TASK 2.1	PLANNED ACTUAL	\$76,272	\$48,642	\$27,630	64%	
2.2	Continued Development - Atmospheric Monitoring Mass Spectrometry System	PLANNED ACTUAL	\$75,021	\$57,729	\$17,292	77%	
2.3	Capture of Haz Chemical Waste Materials Utilizing Fluidization Coating Technology	PLANNED ACTUAL	\$30,594	\$13,672	\$16,922	45%	
2.4	Soil Decontamination by Steam Reforming	PLANNED ACTUAL	\$293,882	\$277,869	\$16,013	95%	Budget modified
2.5	Carbon Products for Waste Stream Cleanup						
2.5	NRCCE - Administration & Penn State	PLANNED ACTUAL	\$158,463	\$152,299	\$6,164	96%	
2.5e	NRCCE - Extended Budget	PLANNED ACTUAL	\$16,278	\$16,280	(\$2)	100%	Budget Adjustment for close out
2.5	Chemical Engineering	PLANNED ACTUAL	\$75,300	\$67,619	\$7,681	90%	
2.5e	Chemical Engineering - Extended Budget	PLANNED ACTUAL	\$31,852	\$31,852	\$0	100%	Budget Adjustment for close out
	TOTAL TASK 2.5	PLANNED ACTUAL	\$281,893	\$268,050	\$13,843	95%	
	TOTAL TASK 2.0	PLANNED ACTUAL	\$757,662	\$665,962	\$91,700		

CONTINUED

MLC Task	PROJECT TITLE	PLANNED ACTUAL	PLANNED TOTALS	ACTUAL TOTALS	AMOUNT REMAINING	% of \$ EXPENDED	REMARKS
3.0 INFORMATION SYSTEMS, PUBLIC POLICY, COMMUNITY OUTREACH AND ECONOMICS							
3.1	Winfield Lock and Dam Assistance Program	PLANNED ACTUAL	\$81,269	\$46,032	\$35,237	57%	
3.2	A GIS Based Infrastructure for Site Characterization and Remediation	PLANNED ACTUAL	\$207,432	\$160,670	\$46,762	77%	
3.3	Small Business Support Program	PLANNED ACTUAL	\$94,860	\$67,821	\$27,039	71%	
3.4	Assessing Potential Voluntary Env. Protection - Kanawha River Area	PLANNED ACTUAL	\$90,097	\$43,811	\$46,286	49%	Budget and expense modification
3.5	WERC National Design Contest	PLANNED ACTUAL	\$5,965	\$4,532	\$1,433	76%	Initial Report
3.6	Graduate Interns to IETO	PLANNED ACTUAL	\$99,180	\$67,860	\$31,320	68%	Initial Report
3.7	WV High Tech Consortium Environmental Technology	PLANNED ACTUAL	\$68,001	\$2,770	\$65,231	4%	Initial Report
TOTAL TASK 3.0		PLANNED ACTUAL	\$646,804	\$393,496	\$253,308	61%	

OTHER EXTENDED BUDGETS

MC-7	Development of Organic Sensors	PLANNED ACTUAL	\$10,000	\$10,000	\$0	100%	Final Report
MC-14	Improved Computer Model to Predict VOC Recovery	PLANNED ACTUAL	\$2,342	\$2,341	\$1	100%	Budget Adjusted for Close out
TOTAL OTHER		PLANNED ACTUAL	\$12,342	\$12,341	\$1	100%	

continued

Task	PROJECT TITLE	PLANNED ACTUAL	PLANNED TOTALS	ACTUAL TOTALS	AMOUNT REMAINING	% of \$ EXPENDED	REMARKS
ADMINISTRATIVE PROJECT SET-UP							
4.1	General Administrative - WVU	PLANNED ACTUAL	\$114,347	\$71,140	\$43,207	62%	
4.2	Research Administration - NRCCE	PLANNED ACTUAL	\$26,457	\$26,457	\$0	100%	Budget Adjusted for close out
4.3	Confinement Administration - NRCCE	PLANNED ACTUAL	\$27,300	\$8,519	\$18,781	31%	
TOTAL ADMINISTRATION		PLANNED ACTUAL	\$168,104	\$106,116	\$61,988	63%	
=====							
GRAND TOTAL		PLANNED ACTUAL	\$2,712,976	\$1,947,916	\$765,060	72%	
=====							

METC Task	PROJECT TITLE	PLANNED ACTUAL	1 JAN	2 FEB	3 MARCH	4 APRIL	5 MAY	6 JUNE	7 JULY	8 AUG	9 SEPT	10 OCT	11 NOV	12 DEC	PLANNED TOTALS	ACTUAL TOTALS
1.0 IN-SITU REMEDIATION PROCESS DEVELOPMENT																
1.1	Use of Drain Enhanced Soil Flushing for Organic Contaminants Removal	PLANNED ACTUAL	5,434 665	6,864 1,350	8,864 0	6,863 1,618	6,863 1,607	8,794 11,308	19,004 14,392	8,136 5,774	12,426 5,631	7,836	7,636	7,279	\$105,999	\$42,345
1.1e	Extended Budget	PLANNED ACTUAL	243 305	243 0	1,015 1,060	243 62	4,016 4,083	1,459 1,572	0 137	0 0	0 0				\$7,219	\$7,219
TOTAL TASK 1.1		PLANNED ACTUAL	5,677 970	7,107 1,350	9,879 1,060	7,106 1,680	10,879 5,690	10,253 12,880	19,004 14,529	8,136 5,774	12,426 5,631	7,836	7,636	7,279	\$113,218	\$49,564
1.2	In-Situ Bioremediation of Chlorinated Organic Solvents	PLANNED ACTUAL	2,431 2,496	2,431 2,431	5,577 3,587	11,147 8,087	20,082 18,880	27,868 28,683	5,934 2,363	4,147 2,535	4,147 3,363	4,147	4,147	3,632	\$95,690	\$72,425
1.2e	Extended Budget	PLANNED ACTUAL	4,815 5,310	4,815 4,479	337 667	337 469	1,689 772	1,937 4,309	(3,006) (5,081)	0 0	0 0				\$10,924	\$10,925
TOTAL TASK 1.2		PLANNED ACTUAL	7,246 7,806	7,246 6,910	5,914 4,254	11,484 8,556	21,771 19,652	29,805 32,992	2,928 (2,718)	4,147 2,535	4,147 3,363	4,147	4,147	3,632	\$106,614	\$83,350
1.3	Microbial Enrichment for Enhancing In Situ Biodegradation of Hazardous Organic Wastes	PLANNED ACTUAL	3,536 0	3,536 0	4,108 0	4,108 3,536	4,108 3,536	20,930 6,291	4,354 13,294	4,354 9,036	10,788 5,831	9,216	6,073	4,354	\$79,465	\$41,524
1.3e	Extended Budget	PLANNED ACTUAL	0 0	0 0	1,250 0	1,250 526	1,250 2,369	1,250 1,650	(495) (41)	0 0	0 0				\$4,505	\$4,504
TOTAL TASK 1.3		PLANNED ACTUAL	3,536 0	3,536 0	5,358 0	5,358 4,062	5,358 5,905	22,180 7,941	3,859 13,253	4,354 9,036	10,788 5,831	9,216	6,073	4,354	\$83,970	\$46,028
1.4	Contaminant Movement Prediction in Permeable Subsurface Soils	PLANNED ACTUAL	0 0	0 0	0 0	0 0	5,065 4,959	14,984 9,999	1,115 0	1,859 10	1,859 8,641	3,218	2,431	1,716	\$32,247	\$23,609
1.5	Development of Standard Test Protocols & Barrier Design Models for In-Situ Formed Barriers															
1.5	NRCCE - Administration & BDM	PLANNED ACTUAL	45,922 42,749	45,922 42,749	45,922 43,767	45,922 42,749	45,922 49,686	45,922 44,342	26,243 8,217	32,380 8,231	32,380 31,940	28,690	0	0	\$395,225	\$314,430
1.5e	NRCCE - Extended Budget	PLANNED ACTUAL	2,737 0	5,948 3,212	8,148 3,212	8,148 3,212	8,148 3,212	2,737 829	2,737 0	4,440 1,712	(27,657) 0				\$15,386	\$15,389
1.5a	CIVIL ENGR - Chemical Grout Barriers	PLANNED ACTUAL	11,458 8,839	2,538 1,288	1,684 4,093	1,308 984	3,368 2,707	8,897 11,096	21,343 17,167	20,534 42,224	18,234 10,761	18,234	18,234	9,489	\$135,321	\$99,149
1.5ae	CIVIL ENGR - Extended Budget	PLANNED ACTUAL	5,411 4,513	3,266 2,516	5,182 5,360	2,708 2,547	5,982 7,722	5,552 5,367	2,408 3,126	2,122 3,096	2,372 755				\$35,003	\$35,002
1.5b	PET ENGR - Circulating Air Barriers	PLANNED ACTUAL	0 0	0 0	0 0	7,577 6,518	11,922 11,061	7,577 5,302	16,925 16,002	32,252 13,706	20,116 14,415	51,597	14,567	12,067	\$174,600	\$67,004
1.5be	PET ENGR - Circulating Air Barriers	PLANNED ACTUAL	0 0	0 0	5,926 4,920	5,926 5,882	729 973	3,429 4,646	13,614 10,057	7,445 9,998	(589) 0				\$35,480	\$36,476

CONTINUED

METC Task	PROJECT TITLE	PLANNED ACTUAL	1 JAN	2 FEB	3 MARCH	4 APRIL	5 MAY	6 JUNE	7 JULY	8 AUG	9 SEPT	10 OCT	11 NOV	12 DEC	PLANNED TOTALS	ACTUAL TOTALS
TOTAL TASK 1.5		PLANNED ACTUAL	65,528 56,101	57,674 49,765	66,862 61,362	71,589 61,892	76,071 75,361	74,114 71,582	83,270 54,559	99,173 78,967	44,866 57,871	98,521	32,801	21,556	\$792,015	\$567,450
TOTAL TASK 1.0		PLANNED ACTUAL	81,987 64,877	75,563 58,025	88,013 66,666	95,537 76,190	119,144 111,567	151,336 135,394	110,176 79,623	117,669 96,322	74,076 81,337	122,938	53,088	38,537	\$1,128,064	\$770,001
2.0 ADVANCED PRODUCT APPLICATIONS TESTING																
2.1	Chemical Destruction of Chlorinated Organic Compounds	PLANNED ACTUAL	2,074 0	2,074 0	2,789 0	2,789 6,127	8,395 7,919	11,754 9,551	8,221 5,347	7,595 4,853	6,506 6,288	5,506	5,506	5,506	\$67,715	\$40,085
2.1e	Extended Budget	PLANNED ACTUAL	0 0	0 0	3,392 86	5,165 5,165	0 0	0 3,306	0 0	0 0	0 0				\$8,557	\$8,557
TOTAL TASK 2.1		PLANNED ACTUAL	2,074 0	2,074 0	6,181 86	7,954 11,292	8,395 7,919	11,754 12,857	8,221 5,347	7,695 4,853	5,506 6,288	5,506	5,506	5,506	\$76,272	\$48,642
2.2	Continued Development - Atmospheric Monitoring Mass Spectrometry System	PLANNED ACTUAL	0 0	0 0	0 0	0 0	14,647 10,533	19,019 22,792	16,880 16,092	10,649 6,740	4,704 1,572	4,704	4,418	0	\$75,021	\$57,729
2.3	Capture of Haz Chemical Waste Materials Utilizing Fluidization Coating Technology	PLANNED ACTUAL	0 0	0 0	0 0	0 0	3,072 0	1,072 4,608	3,145 3,044	3,145 3,552	2,522 2,468	5,641	7,071	4,926	\$30,594	\$13,672
2.4	Soil Decontamination by Steam Reforming	PLANNED ACTUAL	53,844 38,532	53,844 63,475	53,844 37,716	53,844 35,436	53,844 51,699	64,594 31,154	1,452 9,133	1,452 10,724	(42,836) 0	0	0	0	\$293,882	\$277,869
2.5 Carbon Products for Waste Stream Cleanup																
2.5	NRCCE - Administration & Penn State	PLANNED ACTUAL	0 0	0 0	25,000 0	25,627 0	25,987 56,145	25,987 93,074	23,943 0	26,914 1,027	1,795 2,053	1,795	1,415	0	\$158,463	\$152,299
2.5e	NRCCE - Extended Budget	PLANNED ACTUAL	2,817 0	2,817 0	2,817 0	2,817 136	2,817 2,051	2,817 14,093	(624) 0	0 0	0 0				\$16,278	\$16,280
2.5	Chemical Engineering	PLANNED ACTUAL	0 0	0 0	3,414 2,673	10,635 9,425	10,635 10,096	10,545 11,752	19,502 9,846	10,158 11,913	10,158 11,914	153	0	0	\$75,300	\$67,619
2.5e	Chemical Engineering - Extended Budget	PLANNED ACTUAL	14,639 12,044	3,839 2,113	3,243 7,234	3,243 2,332	3,243 1,663	4,046 5,400	0 989	0 77	(401) 0				\$31,852	\$31,852
TOTAL TASK 2.5		PLANNED ACTUAL	17,456 12,044	6,656 2,113	34,474 9,907	42,322 11,893	42,682 69,955	43,395 124,319	42,921 10,835	37,072 13,017	11,652 13,967	1,948	1,415	0	\$281,893	\$268,050
TOTAL TASK 2.0		PLANNED ACTUAL	73,374 50,576	62,574 65,588	94,499 47,709	104,120 58,621	122,640 140,106	139,834 195,730	72,619 44,451	59,913 38,886	(18,552) 24,295	17,799	18,410	10,432	\$757,562	\$665,962

CONTINUED

METC Task	PROJECT TITLE	PLANNED ACTUAL	1 JAN	2 FEB	3 MARCH	4 APRIL	5 MAY	6 JUNE	7 JULY	8 AUG	9 SEPT	10 OCT	11 NOV	12 DEC	PLANNED TOTALS	ACTUAL TOTALS
3.0 INFORMATION SYSTEMS, PUBLIC POLICY, COMMUNITY OUTREACH AND ECONOMICS																
3.1	Winfield Lock and Dam Assistance Program	PLANNED ACTUAL	7,090 5,703	7,090 5,563	7,090 5,924	7,090 5,748	7,090 5,065	7,090 6,318	7,516 2,057	6,808 4,956	6,421 4,698	6,421	6,421	5,142	\$81,269	\$46,032
3.2	A GIS Based Infrastructure for Site Characterization and Remediation	PLANNED ACTUAL	3,602 2,570	9,690 10,691	4,886 3,834	17,342 10,943	15,072 8,580	47,083 60,090	26,219 23,451	26,893 18,746	18,213 21,765	13,290	11,908	13,234	\$207,432	\$160,670
3.3	Small Business Support Program	PLANNED ACTUAL	7,905 6,417	7,905 6,656	7,905 7,425	7,905 7,624	7,905 7,796	7,905 7,965	7,905 8,109	7,905 7,980	7,905 7,849	7,905	7,905	7,905	\$94,860	\$67,821
3.4	Assessing Potential Voluntary Env. Protection - Kanawha River Area	PLANNED ACTUAL	1,127 0	1,127 0	1,127 0	1,127 0	36,877 35,530	43,188 14,122	1,772 (6,000)	938 67	938 92	938	938	0	\$90,097	\$43,811
3.5	WERC National Design Contest	PLANNED ACTUAL	0 0	0 0	0 0	5,965 0	0 0	0 0	0 4,532	0 0	0 0	0	0	0	\$5,965	\$4,532
3.6	Graduate Interns to IETO	PLANNED ACTUAL	0 0	0 0	0 0	0 0	0 0	0 0	17,400 17,400	22,620 22,620	27,840 27,840	10,440	10,440	10,440	\$99,180	\$67,860
3.7	WV High Tech Consortium Environmental Technology	PLANNED ACTUAL	0 0	0 0	0 0	0 0	0 0	0 0	1,547 1,385	1,547 1,385	16,226 0	16,227	16,227	16,227	\$68,001	\$2,770
TOTAL TASK 3.0		PLANNED ACTUAL	19,724 14,690	25,812 22,910	21,008 17,183	39,429 24,315	66,944 56,971	105,266 88,495	62,359 50,934	66,711 55,754	77,543 62,244	55,221	53,839	52,948	\$646,804	\$393,496
OTHER EXTENDED BUDGETS																
MC-7	Development of Organic Sensors	PLANNED ACTUAL	2,500 0	2,500 0	2,500 1	2,500 2,860	0 7,139	0 0	0 0	0 0	0 0				\$10,000	\$10,000
MC-14	Improved Computer Model to Predict VOC Recovery	PLANNED ACTUAL	0 0	0 0	0 0	898 14	898 83	898 1,234	(352) 1,010	0 0	0 0				\$2,342	\$2,341
TOTAL OTHER		PLANNED ACTUAL	2,500 0	2,500 0	2,500 1	3,398 2,874	898 7,222	898 1,234	(352) 1,010	0 0	0 0	0	0	0	\$12,342	\$12,341

continued

METC Task	PROJECT TITLE	PLANNED ACTUAL	1 JAN	2 FEB	3 MARCH	4 APRIL	5 MAY	6 JUNE	7 JULY	8 AUG	9 SEPT	10 OCT	11 NOV	12 DEC	PLANNED TOTALS	ACTUAL TOTALS
ADMINISTRATIVE PROJECT SET-UP																
4.1	General Administrative - WVU	PLANNED ACTUAL	8,219 5,777	8,791 6,873	16,791 14,040	9,327 6,303	8,791 6,825	10,791 7,176	8,791 7,720	9,327 11,040	8,791 6,386	8,791	9,327	6,610	\$114,347	\$71,140
4.2	Research Administration - NRCCE	PLANNED ACTUAL	6,119 3,632	6,119 3,632	6,119 3,632	6,119 4,971	6,119 4,971	6,119 3,736	(10,257) 1,883	0 0	0 0				\$26,457	\$26,457
4.3	Confinement Administration - NRCCE	PLANNED ACTUAL	2,275 0	2,275 0	2,275 0	2,275 0	2,275 0	2,275 0	2,275 3,407	2,275 1,705	2,275 3,407	2,275	2,275	2,275	\$27,300	\$8,519
TOTAL ADMINISTRATION		PLANNED ACTUAL	16,613 9,409	17,185 9,505	25,185 17,672	17,721 11,274	17,185 11,796	19,185 10,912	809 13,010	11,602 12,745	11,066 9,793	11,066	11,602	8,885	\$168,104	\$106,116
GRAND TOTAL																
		PLANNED ACTUAL	194,198 139,552	183,634 156,028	231,205 149,231	260,205 173,274	326,811 327,662	416,519 431,765	245,611 189,028	255,895 203,707	144,133 177,669	207,024	136,939	110,802	\$2,712,976	\$1,947,916
CUMULATIVE TOTAL																
		PLANNED ACTUAL	194,198 139,552	377,832 295,580	609,037 444,811	869,242 618,085	1,196,053 945,747	1,612,572 1,377,512	1,858,183 1,566,540	2,114,078 1,770,247	2,258,211 1,947,916	2,465,235	2,602,174	2,712,976		
CUM BUDGET VARIANCE			54,646	82,252	164,226	251,157	250,306	235,060	291,643	343,831	310,295	2,465,235	2,602,174	2,712,976		

NOTE: Details of the above budgets can be found on the attached pages. These spreadsheets were formatted to round to the nearest dollar.
As a result, whole numbers were used in the above summary and minor differences may be noticed. In no case did these differences exceed \$5.

TASK 1.0
IN-SITU REMEDIATION
PROCESS DEVELOPMENT

METC TASK #1.1

#	Task Name	Dura	%Com	1995												1st		
				1st Quarter			2nd Quarter			3rd Quarter			4th Quarter					
				Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan		
1	EFFECTIVE DIAMETER	4.5M	85.00%															
2	SMEAR INFLUENCE	9.5M	80.00%															
3	WELL RESISTANCE	5M	60.00%															
4	MODEL VERIFICATION	7.5M	80.00%															
5	ECONOMIC EVALUATION & FIELD PLAN	6M	85.00%															
6	REPORTING	12.5M	75.00%

Critical	Noncritical	Complete	Summary	External
Critical Milestone	Noncritical Milestone	Complete Milestone	Summary Milestone	External Milestone
Free Float	Total Float (+)	Total Float (-)	Baseline	Non-Resource
Delay	Effort %Complete			

Drained Enhanced Soil Flushing for Organic Contaminants Removal

METC TASK 1.1 - PRINCIPAL INVESTIGATOR: M.A. Gabr

PROJECT: Drained Enhanced Soil Flushing (DESF) for Organic Contaminants Removal

METC TASK NO.: 1.1

WVU Act. No.: 8527-229-3243

PRINCIPAL INVESTIGATOR: M.A. Gabr

PERIOD ENGING: 9/30/95

DESCRIPTION	PLANNED ACTUAL	1 JAN	2 FEB	3 MARCH	4 APRIL	5 MAY	6 JUNE	7 JULY	8 AUG	9 SEPT	10 OCT	11 NOV	12 DEC	PROJECTED TOTALS	ACTUAL TOTALS	ATM REMAINING
SALARIES																
M.A. Gabr	planned actual	0 0	0 0	0 0	0 0	0 0	0 0	5,000 5,002	0 223	0 445	0 0	0 0	0 0	\$5,000	\$5,670	(670)
Post Doc.	planned actual	0 0	0 0	0 0	0 0	0 0	0 0	1,000 0	1,000 0	1,000 0	1,000 0	1,000 0	1,000 0	\$6,000	\$0	6,000
BENEFITS 29% of Salaries	planned actual	0 0	0 0	0 0	0 0	0 0	0 0	1,740 1,451	290 65	290 129	290 0	290 0	290 0	\$3,190	\$1,644	1,546
STUDENTS																
3 Graduate	planned actual	2,550 0	2,550 0	2,550 0	2,550 0	2,550 825	2,550 1,650	2,550 1,700	2,550 1,700	2,550 1,700	2,550 1,700	2,550 1,700	2,550 1,700	\$30,600	\$7,575	23,025
2 Undergraduates	planned actual	750 0	750 0	750 0	750 234	750 126	750 2,166	750 2,094	750 1,842	750 1,620	750 1,620	750 1,620	750 1,620	\$9,000	\$8,082	918
SUPPLIES	planned actual	500 465	500 0	500 0	500 30	500 173	2,000 2,211	500 0	250 0	250 44	250 44	250 44	0	\$6,000	\$2,923	3,077
OTHER - NRCCE Lab Analysis	planned actual	0 0	0 0	1,000 0	300 867	300 0	500 1,374	400 0	500 0	500 0	500 0	500 0	500 0	\$5,000	\$2,241	2,759
TRAVEL	planned actual	0 0	1,000 944	0 0	0 0	0 0	0 143	1,000 0	0 208	3,000 0	0 0	0 0	0 0	\$5,000	\$1,295	3,705
EQUIPMENT (Under 500)	planned actual	0 0	0 0	0 0	0 0	0 0	0 364	0 (182)	0 0	0 0	0 0	0 0	0 0	\$0	\$182	(182)
EQUIPMENT (Over 500)	planned actual	0 0	0 0	2,000 0	1,000 0	1,000 0	500 0	500 0	500 0	500 0	200 0	0 0	0 0	\$6,200	\$0	6,200
INDIRECT COSTS																
43% of expenses (exc equip>500)	planned actual	1,634 200	2,064 406	2,064 0	1,763 486	1,763 483	2,494 3,400	5,564 4,328	2,296 1,736	3,586 1,693	2,296 0	2,296 0	2,189 0	\$30,010	\$12,733	17,276
PLANNED TOTALS: PER MONTH																
		5,434	6,864	8,864	6,863	6,863	8,794	19,004	8,136	12,426	7,836	7,636	7,279	\$106,000		
ACTUAL TOTALS: PER MONTH																
		665	1,350	0	1,618	1,607	11,308	14,392	5,774	5,631	0	0	0		\$42,346	63,654
CUMULATIVE PLANNED TOTALS																
		5,434	12,298	21,162	28,025	34,888	43,682	62,686	70,822	83,249	91,085	98,721	106,000	\$106,000		
CUMULATIVE ACTUAL TOTALS																
		665	2,015	2,015	3,633	5,240	16,548	30,940	36,714	42,346	42,346	42,346	42,346		\$42,346	63,654
UNDER BUDGET																
		\$4,769	\$10,283	\$19,147	\$24,392	\$29,648	\$27,134	\$31,746	\$34,108	\$40,903	\$48,739	\$56,375	\$63,654			

TASK 1.1e: DESF for Organic Contaminants Removal

Drained Enhanced Soil Flushing *** EXTENDED BUDGET *** PRINCIPAL INVESTIGATOR: M.A. Gabr

NOTE: This will be the last budget report for this expended budget. It has expired.

PROJECT: Drained Enhanced Soil Flushing (DESF) for Organic Contaminants Removal

METC TASK NO.: 1.1e

WVU Act No.: 8527-229-3240

PRINCIPAL INVESTIGATOR: M.A. Gabr

*** EXTENDED BUDGET ***

PERIOD ENDING: 9/30/95

DESCRIPTION	PLANNED ACTUAL	1 JAN	2 FEB	3 MARCH	4 APRIL	5 MAY	6 JUNE	7 JULY	8 AUG	9 SEPT	10 OCT	11 NOV	12 DEC	PROJECTED TOTALS	ACTUAL TOTALS	AMT REMAINING
STUDENTS																
Graduate	planned	0	0	0	0	425	850	0	0	0				\$1,275		
	actual	0	0	0	0	425	850	0	0	0					\$1,275	\$0
Undergraduates	planned	0	0	540	0	0	0	0	0	0				\$540		
	actual	0	0	540	0	0	0	97	0	0					\$637	(\$97)
SUPPLIES	planned	170	170	170	170	1,000	170	0	0	0				\$1,850		
	actual	214	0	201	43	1,136	249	0	0	0					\$1,843	\$7
COMM/INFORM	planned	0	0	0	0	200	0	0	0	0				\$200		
	actual	0	0	0	0	190	0	0	0	0					\$190	\$10
EQUIPMENT (Under 500)	planned	0	0	0	0	0	0	0	0	0				\$0		
	actual	0	0	0	0	79	0	0	0	0					\$79	(\$79)
EQUIPMENT (Over 500)	planned	0	0	0	0	1,692	0	0	0	0				\$1,692		
	actual	0	0	0	0	1,466	0	0	0	0					\$1,466	\$226
INDIRECT COSTS																
43% of exp	planned	73	73	305	73	699	439	0	0	0				\$1,662		
Exc Equip	actual	92	0	319	19	787	473	42	0	0					\$1,730	(\$68)
PLANNED TOTALS: PER MONTH																
		243	243	1,015	243	4,016	1,459	0	0	0				\$7,219		
ACTUAL TOTALS: PER MONTH																
		305	0	1,060	62	4,083	1,572	139	0	0					\$7,220	(\$1)
CUMULATIVE PLANNED TOTALS																
		243	486	1,502	1,745	5,760	7,219	7,219	7,219	7,219				\$7,219		
CUMULATIVE ACTUAL TOTALS																
		305	305	1,365	1,427	5,510	7,082	7,220	7,220	7,220					\$7,220	(\$1)
CUMULATIVE BUDGET VARIANCE																
		(\$62)	\$181	\$136	\$318	\$250	\$137	(\$1)	(\$1)	(\$1)						

METC TASK #1.2

#	Task Name	Dura	%Com	1995												1st	
				1st Quarter			2nd Quarter			3rd Quarter			4th Quarter				
				Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec		
1	OPTIMIZATION OF SEQUENTIAL MINERALIZATI	11M	90.00%														
2	DESIGN & CONSTR. SIMULTANOUS COLUMN	2M	100.00%														
3	DEV & TESTING PROTOCOL TO LOCATE ZONES	4M	100.00%														
4	OPTIMIZATION OF SIMULTANEOUS MINERALIZ	7M	40.00%														
5	BIOREMEDIATION ASSESSMENT	4M	35.00%														
6	DESIGN & CONST. LYSIMITERS	8M	100.00%														
7	AMENDMENTS DELIVERY & CLOGGING	8M	10.00%														
8	REPORTING	12M	75.00%														

Critical	Noncritical	Complete	Summary	External
Critical Milestone	Noncritical Milestone	Complete Milestone	Summary Milestone	External Milestone
Free Float	Total Float (+)	Total Float (-)	Baseline	Non-Resource
Delay	Effort %Complete			

TASK 1.2: In-Situ Bioremediation of Chlorinated Organic Solvents

PRINCIPAL INVESTIGATORS: W. Sack, P. Carrier, A. Shiemke

PROJECT: In-Situ Bioremediation of Chlorinated Organic Solvents METC TASK NO.: 1.2

PRINCIPAL INVESTIGATOR(S): W. Sack, P. Carrier & A. Shiemke

WVU Act. No.: 8527-229-3244

PERIOD ENGING: 9/30/95

DESCRIPTION	PLANNED ACTUAL	1 JAN	2 FEB	3 MARCH	4 APRIL	5 MAY	6 JUNE	7 JULY	8 AUG	9 SEPT	10 OCT	11 NOV	12 DEC	PROJECTED TOTALS	ACTUAL TOTALS	AMT REMAINING
SALARIES																
W. Sack	planned	0	0	0	0	3,298	3,298	0	0	0	0	0	0	\$6,595		
	actual	0	0	0	0	3,298	3,298	0	0	0					\$6,595	\$0
P. Carriere	planned	0	0	0	0	2,836	2,836	0	0	0	0	0	0	\$5,671		
	actual	0	0	0	0	2,835	2,835	0	0	0					\$5,669	\$2
A. Shiemke	planned	0	0	0	0	1,150	1,150	0	0	0	0	0	0	\$2,300		
	actual	0	0	0	0	1,150	1,150	0	0	0					\$2,300	\$0
BENEFITS																
29% of Salaries	planned	0	0	0	0	2,112	2,112	0	0	0	0	0	0	\$4,224		
	actual	0	0	0	0	2,112	2,112	0	0	0	0	0	0		\$4,224	\$1
STUDENTS																
2 Graduate	planned	1,700	1,700	1,700	1,700	1,700	1,700	2,200	2,200	2,200	2,200	2,200	2,200	\$23,402		
	actual	1,700	1,700	1,700	1,700	1,700	1,700	1,700	1,700	1,700					\$15,300	\$8,102
OTHER	planned	0	0	0	0	0	200	50	0	0	0	0	0	\$250		
	actual	0	0	0	0	0	211	(47)	0	0					\$164	\$86
SUPPLIES	planned	0	0	2,000	1,000	1,000	1,000	1,000	500	500	500	500	140	\$8,140		
	actual	0	0	809	1,158	1,300	1,286	0	73	652					\$5,278	\$2,862
TRAVEL	planned	0	0	200	200	200	200	200	200	200	200	200	200	\$2,000		
	actual	0	0	0	0	0	0	0	0	0					\$0	\$2,000
EQUIPMENT (Under 500)	planned	0	0	0	0	0	0	0	0	0	0	0	0	\$0		
	actual	0	0	0	0	0	486	0	0	0					\$486	(\$486)
EQUIPMENT (*Over 500)	planned	0	0	0	7,000	2,500	10,000	1,000	0	0	0	0	0	\$20,500		
	actual	65	0	0	4,000	1,156	9,983	0	0	0					\$15,204	\$5,296
INDIRECT COSTS																
(43% of exp *exc/ Equip>500)	planned	731	731	1,677	1,247	5,287	5,373	1,484	1,247	1,247	1,247	1,247	1,092	\$22,610		
	actual	731	731	1,079	1,229	5,329	5,623	711	762	1,011	0	0	0		\$17,207	\$5,404
PLANNED TOTALS: PER MONTH																
		2,431	2,431	5,577	11,147	20,082	27,868	5,934	4,147	4,147	4,147	4,147	3,632	\$95,692		
ACTUAL TOTALS: PER MONTH																
		2,496	2,431	3,587	8,087	18,880	28,683	2,363	2,535	3,363	0	0	0		\$72,425	\$23,267
CUMULATIVE PLANNED TOTALS																
		2,431	4,863	10,440	21,588	41,670	69,539	75,472	79,619	83,766	87,913	92,060	95,692	\$95,692		
CUMULATIVE ACTUAL TOTALS																
		2,496	4,927	8,514	16,601	35,481	64,164	66,527	69,062	72,425	72,425	72,425	72,425		\$72,425	\$23,267
CUM BUDGET VARIANCE																
		(\$64)	(\$64)	\$1,926	\$4,987	\$6,189	\$5,375	\$8,945	\$10,557	\$11,341	\$15,488	\$19,635	\$23,267			

TASK 1.2e - In Situ Bioremediation of Chlorinated Organic Solvents

PRINCIPAL INVESTIGATORS: W. Sack & P. Carriere - EXTENDED Budget

NOTE: This will be the last report for this extended budget. It is now closed. Close out adjustments are noted below.

PROJECT: In-Situ Bioremediation of Chlorinated Organic Solvents

** Extended Budget **

PRINCIPAL INVESTIGATOR (S): W. Sack, P. Carriere & A. Shiemke

METC TASK NO.: 1.2e

WVU Act. No.: 8527-229-3241

PERIOD ENDING: 9/30/95

DESCRIPTION	PLANNED ACTUAL	1 JAN	2 FEB	3 MARCH	4 APRIL	5 MAY	6 JUNE	7 JULY	8 AUG	9 SEPT	adj	11 NOV	12 DEC	PROJECTED TOTALS	ACTUAL TOTALS	AMT Remaining
SALARIES																
P. Carrier	planned	2,428	2,428	0	0	0	0	0	0	0	0			\$4,856		
	actual	2,428	2,428	0	0	0	0	0	0	0	0				\$4,856	\$0
BENEFITS (29% of Salaries)	planned	704	704	0	0	0	0	0	0	0	0			\$1,408		
	actual	704	704	0	0	0	0	0	0	0	0				\$1,408	\$0
STUDENTS																
Graduate	planned	0	0	0	0	946	0	0	0	0	(946)			\$0		
	actual	0	0	0	0	540	1,275	0	0	0	(1,815)				\$0	\$0
SUPPLIES	planned	235	235	235	235	235	235	0	0	0	(37)			\$1,375		
	actual	582	0	466	328	0	468	0	0	0	(468)				\$1,375	(\$0)
COMM/INFO	planned	0	0	0	0	0	0	0	0	0	0			\$0		
	actual	0	0	0	0	0	190	0	0	0	(190)				\$0	\$0
EQUIPMENT	planned	0	0	0	0	0	1,600	0	0	0	(1,600)			\$0		
	actual	0	0	0	0	0	1,545	0	0	0	(1,545)				(\$0)	\$0
INDIRECT COSTS																
(43% of direct cost exc. equip & sub)	planned	1,448	1,448	101	101	508	101	0	0	0	(423)			\$3,285		\$0
	actual	1,597	1,347	200	141	232	831	0	0	0	(1,063)				\$3,285	(\$0)
PLANNED TOTALS: PER MONTH																
		4,815	4,815	337	337	1,689	1,937	0	0	0	(3,006)			\$10,924		
ACTUAL TOTALS: PER MONTH																
		5,310	4,479	667	469	772	4,309	0	0	0	(5,081)				\$10,924	(\$0)
CUMULATIVE PLANNED TOTALS																
		4,815	9,631	9,967	10,304	11,993	13,930	13,930	13,930	13,930	10,924			\$10,924		
CUMULATIVE ACTUAL TOTALS																
		5,310	9,789	10,456	10,925	11,697	16,006	16,006	16,006	16,006	10,924				\$10,924	(\$0)
CUMULATIVE BUDGET VARIANCE																
		(\$495)	(\$158)	(\$489)	(\$621)	\$296	(\$2,076)	(\$2,076)	(\$2,076)	(\$2,076)	(\$0)					

METC TASK #1.3

#	Task Name	Dura	%Com	1995													
				1st Quarter			2nd Quarter			3rd Quarter			4th Quarter				
				Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Ist
1	PRELIMINARY RESEARCH	1.5M	100.00%														
2	ANALYTICAL TECHNIQUES	4M	100.00%														
3	EVALUATE RADIORESPIROMETRY	2M	100.00%														
4	DEVELOP RADIORESPIROMETRIC ASSAY	2M	100.00%														
5	PREPARATION OF TRIALS	4M	37.50%														
6	SITE IDENTIFICATION	3M	100.00%														
7	CHARACTERIZE SOIL	3M	75.00%														
8	WASTE CHARACTERIZATION	3M	75.00%														
9	FINALIZE QA/QC	2M	75.00%														
10	BIOREMEDIATION TRIALS	5.5M	40.00%														
11	ANALYSIS & REPORTING	12M	60.00%														
12	ANALYZIZ & DATA REDUCTION	2M	20.00%														
13	REPORTS & MANUSCRIPTS	10M	75.00%														
14	OVERALL WORK COMPLETE	12M	70.00%														

Critical	Noncritical	Complete	Summary	External
Critical Milestone	Noncritical Milestone	Complete Milestone	Summary Milestone	External Milestone
Free Float	Total Float (+)	Total Float (-)	Baseline	Non-Resource
Delay	Effort %Complete			

TASK 1.3: Microbial Enrichment for Enhancing In Situ Biodegradation of Hazardous Organic Wastes - PRINCIPAL INVESTIGATOR: A. Sextone

PROJECT: Microbial Enrichment for Enhancing In-Situ Biodegradation of Hazardous Organic Wastes

PRINCIPAL INVESTIGATOR: Alan Sextone

METC TASK NO.: 1.3

WVU Act. No.: 8527-205-7526

PERIOD ENDING: 9/30/95

DESCRIPTION	PLANNED ACTUAL	1 JAN	2 FEB	3 MARCH	4 APRIL	5 MAY	6 JUNE	7 JULY	8 AUG	9 SEPT	10 OCT	11 NOV	12 DEC	PROJECTED TOTALS	ACTUAL TOTALS	AMT Remaining
SALARIES																
A. Sextone	planned actual	0 0	0 0	0 0	0 0	0 0	4,220 0	0 4,568	0 2,284	0 0	0 0	0 0	0 0	\$4,220	\$6,852	(\$2,632)
C. Atkinson	planned actual	0 0	0 0	0 0	0 0	0 0	4,899 0	0 0	0 0	0 0	0 0	0 0	0 0	\$4,899	\$0	\$4,899
Postdoctoral Associate	planned actual	1,917 0	1,917 0	1,917 0	1,917 1,917	1,917 1,917	1,917 1,917	2,050 2,050	2,050 2,050	2,050 2,050	2,050 2,050	2,050 2,050	2,050 2,050	\$23,802	\$11,901	\$11,901
BENEFITS (29% of Salaries)	planned actual	556 0	556 0	556 0	556 556	556 556	3,200 556	595 1,919	595 1,257	595 595	595 0	595 0	595 0	\$9,547	\$5,438	\$4,109
SUPPLIES	planned actual	0 0	0 0	400 0	400 0	400 0	400 1,798	400 769	400 352	400 1,433	400 400	400 400	400 400	\$4,000	\$4,342	(\$342)
TRAVEL	planned actual	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	900 0	900 0	0 0	\$1,800	\$0	\$1,800
OTHER Chemical Anal.	planned actual	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	3,101 0	2,500 0	302 0	0 0	\$5,903	\$0	\$5,903
EQUIPMENT (*Under 500)	planned actual	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 376	0 0	0 0	0 0	0 0	\$0	\$376	(\$376)
EQUIPMENT (*Over 500)	planned actual	0 0	0 0	0 0	0 0	0 0	0 184	0 0	0 0	2,000 0	0 0	0 0	0 0	\$2,000	\$184	\$1,816
INDIRECT COSTS																
(43% of direct cost *excl/ equip)	planned actual	1,063 0	1,063 0	1,235 0	1,235 1,063	1,235 1,063	6,294 1,836	1,309 3,997	1,309 2,717	2,643 1,753	2,771 0	1,826 0	1,309 0	\$23,294	\$12,431	\$10,863
PLANNED TOTALS: *PER MONTH		3,536	3,536	4,108	4,108	4,108	20,930	4,354	4,354	10,788	9,216	6,073	4,354	\$79,465		
ACTUAL TOTALS: PER MONTH		0	0	0	3,536	3,536	6,291	13,294	9,036	5,831	0	0	0		\$41,524	\$37,941
CUMULATIVE PLANNED TOTALS		3,536	7,073	11,181	15,289	19,397	40,328	44,681	49,035	59,823	69,039	75,111	79,465	\$79,465		
CUMULATIVE ACTUAL TOTALS		0	0	0	3,536	7,073	13,364	26,657	35,693	41,524	41,524	41,524	41,524		\$41,524	\$37,941
CUMULATIVE BUDGET VARIANCE		\$3,536	\$7,073	\$11,181	\$11,753	\$12,325	\$26,964	\$18,024	\$13,342	\$18,299	\$27,515	\$33,587	\$37,941			

TASK 1.3e: Microbial Enrichment for Enhancing In Situ Biodegradation of Hazardous Organic Wastes - PRINCIPAL INVESTIGATOR: A. Sextone - * Extended Budget *

NOTE: This will be the last report for this extended budget. It is now CLOSED. Close out adjustments are shown below.

PROJECT: Microbial Enrichment for Enhancing In-Situ Biodegradation of Hazardous
Organic Wastes - *Extended Budget*
PRINCIPAL INVESTIGATOR: Alan Sextone

METC TASK NO.: 1.3e
WVU Act. No.: 8527-205-7527
PERIOD ENDING: 9/30/95

DESCRIPTION	PLANNED ACTUAL	1 JAN	2 FEB	3 MARCH	4 APRIL	5 MAY	6 JUNE	7 JULY	8 AUG	9 SEPT	ADJ Budget Adjustment	PROJECTED TOTALS	ACTUAL TOTALS	AMT Remaining
SUPPLIES	planned actual	0 0	0 0	874 0	874 368	874 1,657	874 1,154	0 (29)	0 0	0 0	(346)	\$3,150	\$3,150	\$0
OTHER	planned actual	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0		\$0	\$0	\$0
INDIRECT COSTS														
(43% of direct cost *exc/ equip)	planned actual	0 0	0 0	376 0	376 168	376 712	376 496	0 (12)	0 0	0 0	(149)	\$1,355	\$1,354	\$0
PLANNED TOTALS: PER MONTH		0	0	1,250	1,250	1,250	1,250	0	0	0	(495)	\$4,505		
ACTUAL TOTALS: PER MONTH		0	0	0	526	2,369	1,650	(41)	0	0	0		\$4,504	\$1
CUMULATIVE PLANNED TOTALS		0	0	1,250	2,500	3,749	4,999	4,999	4,999	4,999	4,505	\$4,505		
CUMULATIVE ACTUAL TOTALS		0	0	0	526	2,895	4,545	4,504	4,504	4,504	4,504		\$4,504	\$1
CUMULATIVE														

METC TASK #1.4

#	Task Name	Dura	%Com	1995												1st	
				1st Quarter			2nd Quarter			3rd Quarter			4th Quarter				
				Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	
1	MODEL EVALUATION & ODERING	1M	100.00%														
2	SOFTWARE ACQUISITION & INSTALLATION	1M	100.00%														
3	MODEL CALIBRATION & DATA PREPARATION	1M	70.00%														
4	SENSITIVITY RUNS	3M	0.00%														
5	FINAL REPORT	1M	0.00%														

Critical	Noncritical	Complete	Summary	External
Critical Milestone	Noncritical Milestone	Complete Milestone	Summary Milestone	External Milestone
Free Float	Total Float (+)	Total Float (-)	Baseline	Non-Resource
Delay	Effort %Complete			

TASK 1.4: Contaminant Movement Prediction in Permeable Soils

PRINCIPAL INVESTIGATORS: H. Bilgesu and S. Ameri

PROJECT: Contaminant Movement Prediction in Permeable Subsurface Soils

METC TASK NO.: 1.4

WVU Act. No.: 8527-255-0434

PRINCIPAL INVESTIGATORS: H. Bilgesu and S. Ameri

PERIOD ENDING: 9/30/95

DESCRIPTION	PLANNED ACTUAL	1 JAN	2 FEB	3 MARCH	4 APRIL	5 MAY	6 JUNE	7 JULY	8 AUG	9 SEPT	10 OCT	11 NOV	12 DEC	PROJECTED TOTALS	ACTUAL TOTALS	AMT REMAINING
SALARIES																
H. Bilgesu	planned	0	0	0	0	2,668	5,335	330	0	0	0	0	0	\$8,333		
	actual	0	0	0	0	2,668	5,335	0	0	47					\$8,050	\$283
BENEFITS																
29% of	planned	0	0	0	0	774	1,547	96	0	0	0	0	0	\$2,417		
Salaries	actual	0	0	0	0	774	1,547	0	0	14	0	0	0		\$2,335	\$82
STUDENTS																
1 Graduate	planned	0	0	0	0	0	0	0	1,200	1,200	1,200	1,200	1,200	\$6,000		
	actual	0	0	0	0	0	0	0	0	2,000					\$2,000	\$4,000
SUPPLIES &	planned	0	0	0	0	50	50	50	50	50	1,000	500	0	\$1,750		
MISC.	actual	0	0	0	0	26	110	0	7	136					\$279	\$1,471
EQUIPMENT	planned	0	0	0	0	50	50	50	50	50	50	0	0	\$300		
<500	actual	0	0	0	0	0	0	0	0	199					\$199	\$101
EQUIPMENT	planned	0	0	0	0	0	5,000	363	0	0	0	0	0	\$5,363		
>500	actual					0	0	0	0	5,215					\$5,215	\$148
INDIRECT COSTS																
43% of exp	planned	0	0	0	0	1,523	3,002	226	559	559	968	731	516	\$8,084		
Exc Equip	actual	0	0	0	0	1,491	3,007	0	3	1,030	0	0	0		\$5,531	\$2,553
PLANNED TOTALS: PER MONTH																
		0	0	0	0	5,065	14,984	1,115	1,859	1,859	3,218	2,431	1,716	\$32,246		
ACTUAL TOTALS: PER MONTH																
		0	0	0	0	4,959	9,999	0	10	8,641	0	0	0		\$23,608	\$8,638
CUMULATIVE PLANNED TOTALS																
		0	0	0	0	5,065	20,049	21,164	23,023	24,882	28,099	30,530	32,246	\$32,246		
CUMULATIVE ACTUAL TOTALS																
		0	0	0	0	4,959	14,958	14,958	14,968	23,608	23,608	23,608	23,608		\$23,608	\$8,638
CUMULATIVE BUDGET VARIANCE																
		\$0	\$0	\$0	\$0	\$106	\$5,092	\$6,206	\$8,055	\$1,274	\$4,491	\$6,922	\$8,638			

Note: This budget has been slightly modified from that reported last quarter, however, the overall total did not change.

Project Name: Task 1.5

WBS	Task Name	Dura	%Compl	1995											
				Qtr2			Qtr3			Qtr4			Qtr1		
				Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar		
3.0	Lab Equip. & Prelim. Testing	1213h	57.00%												
3.1	Sand-Pack Tests (CAB)	870h	80.00%												
3.2	Core Tests (CAB)	520h	100.00%												
3.3	Testing of Sand Rain Device (CG)	520h	0.00%												
3.4	Testing of Chem. Barriers	870h	80.00%												
3.5	Phase I final Report Preparation	346h	50.00%												
3.6	Phase I Final Report	0h	0.00%												
4.0	GTC & CATC (Construction & Test	1213h	57.00%												
4.1	SARS Activities	520h	0.00%												
4.1.1	Develop Drawings for GTC	346h	100.00%												
4.1.2	Develop Drawings for CAB	346h	90.00%												
4.1.3	Construct GTC	520h	33.00%												
4.1.4	Develop Operating Plans for CAB	870h	80.00%												
4.1.5	Operating Permit for CAB	173h	0.00%												
4.1.6	Testing of GTC & CAB	173h	0.00%												
4.1.7	Construction Complete (CAB & GT	0h	0.00%												
4.2	Dev. Sample Prep. Protocols & QA	520h	0.00%												
4.2.1.1	Dev. Sample Prep. Protocol (GTC)	520h	0.00%												
4.2.1.2	Dev. QA/QC for Protocols (GTC)	520h	0.00%												
4.2.2.1	Dev. Sample Prep. Protocol (CAB)	520h	0.00%												
4.2.2.2	Dev. QA/QC for Protocols (CAB)	520h	0.00%												

TASK 1.5: In Situ Formed Barriers - NRCCE Reg. Budget

Development of Standard Test Protocols & Barrier Design Models

**PROJECT: Development of Standard Test Protocols and Barrier Design
for In Situ Formed Barriers
** NRCCE - Regular Budget ***

METC TASK NO.: 1.5
WVU Act. Nos.: 8527-224-1419
and 8527-224-1420
PERIOD ENDING: 9/30/95

PRINCIPAL INVESTIGATOR: C. Black

DESCRIPTION	PLANNED ACTUAL	1 JAN	2 FEB	3 MAR	4 APRIL	5 MAY	6 JUNE	7 JULY	8 AUG	9 SEPT	10 OCT	11 NOV	12 DEC	Projected TOTALS	Actual TOTALS	AMT Remaining
On Campus - WVU Account No.: 8527-224-1419																
SALARIES	planned	292	292	292	292	292	292	292	292	292	292	292	292	\$3,500		
C. Black	actual	0	0	0	0	0	0	0	0	0	0	0	0	\$0	\$0	\$3,500
BENEFITS	planned	85	85	85	85	85	85	85	85	85	85	85	85	\$1,015		
(29% of Salaries)	actual	0	0	0	0	0	0	0	0	0	0	0	0	\$0	\$0	\$1,015
SUPPLIES	planned	0	0	0	0	0	0	0	0	0	0	0	0	\$0		
	actual	0	0	0	0	303	70	0	0	0	0	0	0	\$373	\$373	(\$373)
TRAVEL	planned	0	0	0	0	0	0	0	0	0	0	0	0	\$0		
	actual	0	0	0	0	494	0	0	0	0	0	0	0	\$494	\$494	(\$494)
OTHER	planned	0	0	0	0	0	0	0	0	0	0	0	0	\$0		
Cont/Prof SV	actual	3,000	0	0	0	0	0	0	0	0	0	0	0	\$3,000	\$3,000	(\$3,000)
INDIRECT COSTS	planned	162	162	162	162	162	162	162	162	162	162	162	162	\$1,941		
(43% of direct cost)	actual	1,290	0	0	0	343	30	0	0	0	0	0	0	\$1,663	\$1,663	\$279
Planned Sub Totals		538	538	538	538	538	538	538	538	538	538	538	538	\$6,458		
Per Month - On Campus																
Actual Sub Totals		4,290	0	0	0	1,140	100	0	0	0	0	0	0	\$5,530	\$926	
Per Month - On Campus																

Off Campus - WVU Account No.: 8527-224-1420

GENERAL & MISC.	planned	475	475	475	475	475	475	189	0	0	0	0	0	\$3,039		
	actual	0	0	224	0	79	1,295	(139)	0	0	0	0	0	\$1,459	\$1,459	\$1,580
TRAVEL	planned	276	276	276	276	276	276	(1,050)	0	0	0	0	0	\$604		
	actual	0	0	604	0	0	0	0	0	0	0	0	0	\$604	\$604	(\$1)
CONT/PROF SV	planned	0	0	0	0	0	0	0	6,000	6,000	3,000	0	0	\$15,000		
	actual	0	0	0	0	0	0	0	6,225	5,642	3,000	0	0	\$11,867	\$11,867	\$3,133
EQUIPMENT	planned	2,250	2,250	2,250	2,250	2,250	2,250	2,302	0	0	0	0	0	\$15,802		
*(Over 500)	actual	0	0	0	0	6,840	0	8,388	574	0	0	0	0	\$15,802	\$15,802	\$0
Sub Contractor	planned	42,749	42,749	42,749	42,749	42,749	42,749	25,000	25,000	25,000	25,000	0	0	\$356,492		
*BDM	actual	42,749	42,749	42,749	42,749	42,749	42,749	0	0	25,000	25,000	0	0	\$281,492	\$281,492	\$75,000
INDIRECT COSTS	planned	173	173	173	173	173	173	(198)	1,380	1,380	690	0	0	\$4,288		
(23% of direct cost	actual	0	0	190	0	18	298	(32)	1,432	1,298	0	0	0	\$3,204	\$3,204	\$1,084
*excl equip & sub)																
Planned Sub-Totals		45,922	45,922	45,922	45,922	45,922	45,922	26,243	32,380	32,380	26,690	0	0	\$395,224		
Per Month - Off Campus																
Actual Sub-Totals		42,749	42,749	43,767	42,749	49,686	44,342	8,217	8,231	31,940	0	0	0	\$314,428	\$80,796	
Per Month - Off Campus																

MONTHLY GRAND TOTALS ON & OFF CAMPUS

PLANNED	46,460	46,460	46,460	46,460	46,460	46,460	46,460	26,781	32,918	32,918	29,228	538	538	401,681		
ACTUAL	47,039	42,749	43,767	42,749	50,828	44,442	8,217	8,231	31,940	0	0	0	0	319,958	\$81,723	

CUMULATIVE GRAND TOTALS ON & OFF CAMPUS

PLANNED	46,460	92,920	139,380	185,840	232,300	278,760	305,541	336,458	371,477	400,905	401,143	401,143	401,143	401,143		
ACTUAL	47,039	89,787	133,555	176,303	227,129	271,571	279,788	288,018	319,958	319,958	319,958	319,958	319,958	319,958	\$81,723	

1.5e: Standard Test Protocols & Design Models

In-Situ Formed Barriers - NRCCE * Extended Budget * - PI: C. Black

NOTE: This report will be the last report for this extended budget. It is now closed. Any funds that remained after the closeout date have been adjusted as noted below

**PROJECT: Development of Standard Test Protocols and Barrier Design Models
for In Situ Formed Barriers
** NRCCE - Extended Budget ***

**METC TASK NO.: 1.5e
WVU Act. No.: 8527-224-1423**

PRINCIPAL INVESTIGATOR: C. Black

PERIOD ENDING: 9/30/95

DESCRIPTION	PLANNED ACTUAL	1 JAN	2 FEB	3 MARCH	4 APRIL	5 MAY	6 JUNE	7 JULY	8 AUG	9 SEPT	BUDGET ADJUSTMENTS	PROJECTED TOTALS	ACTUAL TOTALS	AMT Remaining
SALARIES														
C. Black	planned	0	1,741	1,741	1,741	1,741	0	0	924	0		\$7,888		
	actual	0	1,741	1,741	1,741	1,741	0	0	924	0			\$7,888	(\$1)
BENEFITS (29% of Salaries)	planned	0	505	505	505	505	0	0	268	0		\$2,287		
	actual	0	505	505	505	505	0	0	268	0			\$2,288	(\$0)
SUPPLIES	planned	664	664	664	664	664	664	664	664	0	(5,306)	\$5		
	actual	0	0	0	0	0	0	0	5	0			\$5	\$0
TRAVEL	planned	1,250	1,250	1,250	1,250	1,250	1,250	1,250	1,250	0	(9,420)	\$580		
	actual	0	0	0	0	0	580	0	0	0			\$580	\$0
EQUIPMENT (OVER 500)	planned	0	0	2,200	2,200	2,200	0	0	0	0	(6,599)	\$0		
	actual	0	0	0	0	0	0	0	0	0			\$0	\$0
INDIRECT COSTS														
(43% of direct cost *exc/ equip & sub)	planned	823	1,789	1,789	1,789	1,789	823	823	1,335	0	(6,332)	\$4,627		
	actual	0	966	966	966	966	249	0	515	0			\$4,627	(\$0)
PLANNED TOTALS:														
PER MONTH		2,737	5,948	8,148	8,148	8,148	2,737	2,737	4,440	0	(27,657)	\$15,387		
ACTUAL TOTALS:														
PER MONTH		0	3,212	3,212	3,212	3,212	829	0	1,712	0	0		\$15,387	(\$1)
CUMULATIVE														
PLANNED TOTALS		2,737	8,685	16,833	24,982	33,130	35,867	38,603	43,044	43,044	15,387	\$15,387		
CUMULATIVE														
ACTUAL TOTALS		0	3,212	6,423	9,635	12,846	13,676	13,676	16,387	16,387	15,387		\$15,387	(\$1)
CUMULATIVE														
BUDGET VARIANCE		\$2,737	\$5,474	\$10,410	\$15,347	\$20,283	\$22,191	\$24,928	\$27,656	\$27,656	(\$1)			

TASK 1.5a: CHEMICAL GROUT - IN-SITU FORMED BARRIERS

PRINCIPAL INVESTIGATOR: M. A. Gabr

PROJECT: Development of Standard Test Protocols and Barrier Design Models
for In-Situ Formed Barriers
CIVIL & ENVIRONMENTAL ENGINEERING - DETAILED BUDGET
PRINCIPAL INVESTIGATOR(S): M. Gabr & B. Reed

METC TASK NO.: 1.5a
WVU Act. Nos.: 8527-229-3236 & 3239
PERIOD ENDING: 9/30/95

DESCRIPTION	PLANNED ACTUAL	1 JAN	2 FEB	3 MARCH	4 APRIL	5 MAY	6 JUNE	7 JULY	8 AUG	9 SEPT	10 OCT	11 NOV	12 DEC	PROJECTED TOTALS	ACTUAL TOTALS	AMT REMAINING
***** ON-CAMPUS ***** WVU Act. No.: 8527-229-3236																
SALARIES																
Faculty	planned actual	0 0	0 0	0 0	0 0	0 0	0 0	1,500 0	1,500 3,062	1,500 1,122	1,500	1,500	1,500	\$9,000	\$4,184	\$4,816
Secretary	planned actual	0 0	0 0	0 0	0 0	0 0	0 0	362 0	362 0	362 0	362	362	362	\$2,173	\$0	\$2,173
BENEFITS 29% of Salaries	planned actual	0 0	0 0	0 0	0 0	0 0	0 0	540 0	540 888	540 325	540 0	540 0	540 0	3,240	\$1,213	\$2,027
STUDENTS	planned actual	0 0	0 0	0 0	0 0	200 200	900 900	2,060 1,700	1,455 1,275	850 850	850	850	850	\$8,015	\$4,925	\$3,090
INDIRECT COSTS @ 43%	planned actual	0 0	0 0	0 0	0 0	86 86	387 387	1,919 731	1,659 2,247	1,398 988	1,398 0	1,398 0	1,398 0	\$9,644	\$4,439	\$5,205
SUB-TOTAL ON-CAMPUS	planned actual	0 0	0 0	0 0	0 0	286 286	1,287 1,287	6,381 2,431	5,516 7,472	4,651 3,285	4,651 0	4,651 0	4,651 0	\$32,072	\$14,761	\$17,311
***** OFF-CAMPUS ***** WVU Act. No.: 8527-229-3239																
SALARIES																
	planned actual	0 0	0 0	0 0	0 0	0 0	0 0	1,301 874	2,240 437	2,240 0	2,240	2,240	2,240	\$12,501	\$1,311	\$11,190
BENEFITS 29% of Salaries	planned actual	0 0	0 0	0 0	0 0	0 0	0 0	377 253	850 127	850 0	850 0	850 0	850 0	\$3,625	\$380	\$3,245
STUDENTS	planned actual	0 0	0 0	0 0	0 0	1,675 1,675	5,870 5,870	8,314 8,008	6,444 10,650	4,575 6,744	4,575	4,575	4,575	\$40,603	\$32,947	\$7,656
SUPPLIES & COMM/INFO	planned actual	5,000 4,839	1,000 1,047	308 2,875	0 800	0 528	300 3,095	1,419 808	1,419 0	1,419 0	1,419	1,419	0	\$13,701	\$13,789	(\$88)
TRAVEL	planned actual	250 0	250 0	250 0	250 0	250 0	250 0	250 0	250 539	250 0	250	250	250	\$3,000	\$539	\$2,462
EQUIP < 500 & REFERENCES	planned actual	0 0	0 0	0 0	0 0	0 0	0 0	0 363	0 0	0 0	0	0	0	\$0	\$363	(\$363)
EQUIP > 500	planned actual	5,000 3,133	1,000 0	1,000 557	1,000 0	1,000 0	1,000 70	7,000 4,481	7,000 27,769	7,000 2,466	7,000	7,000	0	\$45,000	\$38,475	\$6,525
INDIRECT COSTS 23% of exp	planned actual	1,208 1,067	288 241	128 661	58 184	443 508	1,477 2,062	2,682 2,370	2,531 2,703	2,101 1,551	2,101 0	2,101 0	1,774 0	\$16,889	\$11,345	\$5,543
SUB-TOTAL OFF-CAMPUS	planned actual	11,458 8,839	2,538 1,288	1,684 4,093	1,308 984	3,368 2,707	8,897 11,096	21,343 17,157	20,534 42,224	18,234 10,761	18,234 0	18,234 0	9,489 0	\$135,319	\$99,149	\$36,170
PLANNED TOTALS: PER MONTH		11,458	2,538	1,684	1,308	3,654	10,184	27,724	26,049	22,885	22,885	22,885	14,140	167,392		
ACTUAL TOTALS: PER MONTH		8,839	1,288	4,093	984	2,993	12,383	19,588	49,696	14,046	0	0	0		113,910	\$53,482
CUMULATIVE PLANNED TOTALS		11,458	13,996	15,679	16,986	20,640	30,824	58,548	84,597	107,482	130,367	153,252	167,392	\$167,392		
CUMULATIVE ACTUAL TOTALS		8,839	10,127	14,219	15,203	18,196	30,579	50,168	99,863	113,910	113,910	113,910	113,910		\$113,910	\$53,482

TASK 1.5ae: CHEMICAL GROUT- IN SITU FORMED BARRIERS

PRINCIPAL INVESTIGATORS: M. Gabr and B. Reed - *Extende Budget*

■ PLANNED SPENDING ◇ — ACTUAL SPENDING

NOTE: This will be the last report for this extended budget. It is now Closed.

**PROJECT: Development of Standard Test Protocols and Barrier Design Models
for In-Situ Formed Barriers - CHEMICAL GROUT**

METC TASK NO.: 1.5ae
WVU Act. No.: 8527-229-3238

CIVIL & ENVIRONMENTAL ENGINEERING - DETAILED **EXTENDEDBUDGET
PRINCIPAL INVESTIGATORS): M. Gabr & B. Reed**

PERIOD ENDING: 9/30/95

DESCRIPTION	PLANNED ACTUAL	1 JAN	2 FEB	3 MARCH	4 APRIL	5 MAY	6 JUNE	7 JULY	8 AUG	9 SEPT	10 OCT	11 NOV	12 DEC	PROJECTED TOTALS	ACTUAL TOTALS	AMT REMAINING
***** ON-CAMPUS *****																
STUDENTS	planned actual	1,484 860	1,484 1,000	1,484 1,369	1,484 1,677	1,484 2,557	1,484 1,330	1,484 1,990	1,484 2,165	1,659 528				\$13,529	\$13,466	\$64
SUPPLIES	planned actual	2,300 1,862	800 760	2,000 2,179	200 105	2,000 2,199	1,000 996	200 196	0 0	0 0				\$8,600	\$8,296	\$204
EQUIPMENT (Under \$500)	planned actual	0 444	0 0	0 200	0 0	0 0	0 315	0 0	0 0	0 0				\$0	\$959	(\$959)
EQUIPMENT (Over \$500)	planned actual	0 0	0 0	200 0	300 0	1,000 921	2,000 1,590	0 0	0 0	0 0				\$3,600	\$2,511	\$989
INDIRECT COSTS 43% of exp	planned actual	1,627 1,367	982 767	1,498 1,612	724 766	1,498 2,045	1,068 1,136	724 940	638 931	713 227				\$9,472	\$9,770	(\$297)
PLANNED TOTALS: PER MONTH		5,411	3,266	5,182	2,708	5,982	5,552	2,408	2,122	2,372				35,001		
ACTUAL TOTALS: PER MONTH		4,513	2,516	5,360	2,547	7,722	5,367	3,126	3,096	755					35,002	(\$0)
CUMULATIVE PLANNED TOTALS		5,411	8,677	13,858	16,566	22,548	28,100	30,507	32,629	35,001				\$35,001		
CUMULATIVE ACTUAL TOTALS		4,513	7,029	12,389	14,936	22,658	28,026	31,161	34,247	35,002					\$35,002	(\$0)
CUMULATIVE BUDGET VARIANCE		\$898	\$1,647	\$1,469	\$1,630	(\$110)	\$75	(\$643)	(\$1,617)	(\$0)						

TASK 1.5b: CIRCULATING AIR BARRIERS

PRINCIPAL INVESTIGATORS: S. Ameri, K. Aminian and D. Molnar

Task 1.5: Development of Standard Test Protocols and Barrier Design Models for In-Situ Formed Barriers

PROJECT: Development of Standard Test Protocols and Barrier Design Models
for In-Situ Formed Barriers

METC TASK NO.: 1.5b

ORGS: 0416 & 0433

PETROLEUM ENGINEERING - DETAILED *Regular* BUDGET for CIRCULATING AIR BARRIERS

PRINCIPAL INVESTIGATOR (S): S. Ameri, K. Amnian and D. Molnar

PERIOD ENDING: 9/30/95

DESCRIPTION	PLANNED ACTUAL	1 JAN	2 FEB	3 MARCH	4 APRIL	5 MAY	6 JUNE	7 JULY	8 AUG	9 SEPT	10 OCT	11 NOV	12 DEC	PROJECTED TOTALS	ACTUAL TOTALS	AMT REMAINING
***** ON-CAMPUS ***** WVU Act. No.: 8527-255-0416																
SALARIES																
K. Aminian	planned	0	0	0	0	0	0	2,457	7,852	3,158	2,219	2,219	2,219	\$20,122		
	actual	0	0	0	0	0	0	4,254	2,908	1,562					\$8,724	\$11,398
S. Mohaghegh	planned	0	0	0	0	2,355	0	0	0	0	0	0	0	\$2,355		
	actual	0	0	0	0	2,355	0	0	0	0					\$2,355	\$0
S. Ameri	planned	0	0	0	0	0	0	0	2,914	2,752	0	0	0	\$5,666		
	actual	0	0	0	0	0	0	636	1,271	1,271					\$3,178	\$2,488
BENEFITS	planned	0	0	0	0	683	0	713	3,122	1,713	644	644	644	\$8,161		
29% of Salaries	actual	0	0	0	0	683	0	1,418	1,212	822	0	0	0		\$4,135	\$4,027
INDIRECT COSTS	planned	0	0	0	0	1,306	0	1,363	5,972	3,277	1,231	1,231	1,231	\$15,611		
43% of exp	actual	0	0	0	0	1,306	0	2,712	2,318	1,571	0	0	0		\$7,908	\$7,703
SUB-TOTAL	planned	0	0	0	0	4,344	0	4,532	19,860	10,898	4,093	4,093	4,093	\$51,915		
ON-CAMPUS	actual	0	0	0	0	4,344	0	9,021	7,709	5,226	0	0	0		\$26,300	\$25,616
***** OFF-CAMPUS ***** WVU Act. No.: 8527-255-0433																
SALARIES	planned	0	0	0	2,450	2,450	2,450	2,617	2,617	614	2,700	2,700	2,700	\$21,298		
D. Molnar	actual	0	0	0	2,325	2,450	2,450	2,617	2,617	2,617					\$15,076	\$6,222
BENEFITS	planned	0	0	0	711	711	711	759	759	178	783	783	783	\$6,176		
29% of Salaries	actual	0	0	0	674	711	711	759	759	759	0	0	0		\$4,372	\$1,804
STUDENTS	planned	0	0	0	3,000	3,000	3,000	3,000	3,000	3,003	3,000	3,000	3,000	\$27,003		
3 Graduate	actual	0	0	0	2,300	2,300	1,150	2,300	1,500	4,095					\$13,645	\$13,358
TRAVEL	planned	0	0	0	0	0	0	1,667	1,667	1,667	0	0	0	\$5,000		
	actual	0	0	0	0	0	0	0	0	0					\$0	\$5,000
OTHER	planned	0	0	0	0	0	0	0	0	0	0	0	0	\$0		
	actual	0	0	0	0	0	0	0	0	0					\$0	\$0
EQUIPMENT	planned	0	0	0	0	0	0	2,500	2,500	2,500	39,530	2,500	0	\$49,530		
(No Overhead)	actual	0	0	0	0	0	0	0	0	0					\$0	\$49,530
INDIRECT COSTS	planned	0	0	0	1,417	1,417	1,417	1,850	1,850	1,256	1,491	1,491	1,491	\$13,680		
23% of exp	actual	0	0	0	1,219	1,256	991	1,305	1,121	1,718	0	0	0		\$7,611	\$6,068
SUB-TOTAL	planned	0	0	0	7,577	7,577	7,577	12,392	12,392	9,218	47,504	10,474	7,974	\$122,687		
OFF-CAMPUS	actual	0	0	0	6,518	6,716	5,302	6,981	5,997	9,189	0	0	0		\$40,704	\$81,983
PLANNED TOTALS:		0	0	0	7,577	11,922	7,577	18,925	32,252	20,116	51,597	14,567	12,087	174,603		
PER MONTH																
*** OVERALL ***																
ACTUAL TOTALS:		0	0	0	6,518	11,061	5,302	16,002	13,706	14,415	0	0	0		67,004	\$107,598
PER MONTH																
CUMULATIVE																
PLANNED TOTALS		0	0	0	7,577	19,499	27,077	44,001	76,254	96,370	147,968	162,535	174,603	\$174,603		
*** OVERALL ***																
CUMULATIVE																
ACTUAL TOTALS		0	0	0	6,518	17,579	22,881	38,883	52,589	67,004	67,004	67,004	67,004		\$67,004	\$107,598
CUMULATIVE																
BUDGET VARIANCE		\$0	\$0	\$0	\$1,059	\$1,920	\$4,196	\$5,119	\$23,665	\$29,366	\$80,963	\$95,531	\$107,598			

NOTE: This budget has been increased since the last quarterly report, due to an increase in the scope of work.

TASK 1.5be: CIRCULATING AIR BARRIERS

PRINCIPAL INVESTIGATORS: S. Ameri, K. Aminian and D. Molnar - *Extended Budget

NOTE: This will be the last report for this extended budget. It is now CLOSED. Close out adjustments are shown below.

**PROJECT: Development of Standard Test Protocols and Barrier Design Models
for In-Situ Formed Barriers - Circulating Air Barriers**

METC TASK NO.: 1.5be

WVU Act. No.: 8527-255-0427

PETROLEUM ENGINEERING - Detailed ** EXTENDED Budget
PRINCIPAL INVESTIGATORS): S. Ameri, K. Amnian and D. Molnar**

PERIOD ENDING: 9/30/95

DESCRIPTION	PLANNED ACTUAL	1 JAN	2 FEB	3 MARCH	4 APRIL	5 MAY	6 JUNE	7 JULY	8 AUG	9 SEPT	ADJ Budget Adjustments	PROJECTED TOTALS	ACTUAL TOTALS	AMT REMAINING
***** ON-CAMPUS *****														
SALARIES														
S. Ameri	planned	0	0	0	0	0	0	6,878	3,964	0		\$10,842		
	actual	0	0	0	0	0	0	5,420	5,420	0			\$10,840	\$2
S. Mohaghegh	planned	0	0	2,980	2,980	0	0	0	0	0		\$6,960		
	actual	0	0	2,667	2,980	312	0	0	0	0			\$5,959	\$1
BENEFITS	planned	0	0	864	864	0	0	1,995	1,150	0		\$4,873		
29% of Salaries	actual	0	0	773	864	90	0	1,572	1,572	0			\$4,872	\$1
GENERAL	planned	0	0	300	300	300	300	300	93	0	(813)	\$780		
	actual	0	0	0	269	0	480	31	0	0			\$780	(\$0)
EQUIPMENT	planned	0	0	0	0	0	0	0	0	0	278	\$278		
(Under \$500)	actual	0	0	0	0	278	0	0	0	0			\$278	(\$0)
EQUIPMENT	planned	0	0	0	0	300	3,000	497	0	0	177	\$3,974		
(Over \$500)	actual	0	0	0	0	0	3,960	14	0	0			\$3,974	\$0
INDIRECT COSTS	planned	0	0	1,782	1,782	129	129	3,944	2,239	0	(231)	\$9,774		
43% of exp	actual	0	0	1,479	1,769	293	206	3,020	3,006	0			\$9,774	\$0
PLANNED TOTALS:		0	0	5,926	5,926	729	3,429	13,614	7,445	0	(589)	36,481		
PER MONTH														
ACTUAL TOTALS:		0	0	4,920	5,882	973	4,646	10,057	9,998	0	0		36,477	\$4
PER MONTH														
CUMULATIVE														
PLANNED TOTALS		0	0	5,926	11,852	12,581	16,010	29,624	37,070	37,070	36,481	\$36,481		

TASK 2.0
ADVANCED PRODUCT
APPLICATIONS TESTING

METC TASK #2.1

#	Task Name	Dura	%Com	1995												1st	
				1st Quarter			2nd Quarter			3rd Quarter			4th Quarter				
				Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	
1	SYNTHESIS OF MONOMERS	3M	100.00%														
2	SYNTHESIS OF POLYMERS	3M	85.00%														
3	SURVEY DECHLORINATION TECHNOLOGY	3M	100.00%														
4	PCBs ANALYSIS PROCEDURE	1M	100.00%														
5	DECHLORINATION BY CHEMICAL PROCESS	4M	0.00%														
6	REPORTS	12M	75.00%														

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Critical	Noncritical	Complete	Summary	External
Critical Milestone	Noncritical Milestone	Complete Milestone	Summary Milestone	External Milestone
Free Float	Total Float (+)	Total Float (-)	Baseline	Non-Resource
Delay	Effort %Complete			

TASK 2.1: Chemical Destruction of Chlorinated Organic Compounds

PRINCIPAL INVESTIGATOR: Kung Wang

PROJECT: Chemical Destruction of Chlorinated Organic Compounds

METC TASK NO.: 2.1

WVU Act. No.: 8527-211-0625

PRINCIPAL INVESTIGATOR: Kung Wang

PERIOD ENDING: 9/30/95

DESCRIPTION	PLANNED ACTUAL	1 JAN	2 FEB	3 MARCH	4 APRIL	5 MAY	6 JUNE	7 JULY	8 AUG	9 SEPT	10 OCT	11 NOV	12 DEC	PROJECTED TOTALS	ACTUAL TOTALS	AMT REMAININ
SALARIES																
K. Wang	planned	0	0	0	0	2,303	2,303	0	0	0	0	0	0	\$4,606		
	actual	0	0	0	0	2,303	2,303	0	0	0	0	0	0		\$4,606	\$0
BENEFITS																
29% of Salaries	planned	0	0	0	0	668	668	0	0	0	0	0	0	\$1,336		
	actual	0	0	0	0	668	668	0	0	0	0	0	0		\$1,336	\$0
STUDENTS																
3 Graduates	planned	950	950	950	950	1,900	2,850	2,850	2,850	2,850	2,850	2,850	2,850	\$25,650		
	actual	0	0	0	3,800	1,900	2,850	2,850	2,850	2,850	2,850	2,850	2,850		\$17,100	\$8,550
SUPPLIES & ANALYSIS	planned	500	500	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	\$11,000		
	actual	0	0	0	484	667	858	889	544	698	0	0	0		\$4,140	\$6,860
TRAVEL	planned	0	0	0	0	0	0	500	500	0	0	0	0	\$1,000		
	actual	0	0	0	0	0	0	0	0	849	0	0	0		\$849	\$151
EQUIPMENT	planned	0	0	0	0	0	2,000	2,000	1,374	0	0	0	0	\$5,374		
	actual	0	0	0	0	0	0	0	0	0	0	0	0		\$0	\$5,374
INDIRECT COSTS																
43% of exp Exc Equip	planned	624	624	839	839	2,524	2,933	1,871	1,871	1,656	1,656	1,656	1,656	\$18,744		
	actual	0	0	0	1,842	2,381	2,872	1,608	1,459	1,891	0	0	0		\$12,053	\$6,691
PLANNED TOTALS: PER MONTH																
		2,074	2,074	2,789	2,789	8,395	11,754	8,221	7,595	5,506	5,506	5,506	5,506	\$67,710		
ACTUAL TOTALS: PER MONTH																
		0	0	0	6,127	7,919	9,551	5,347	4,853	6,288	0	0	0		\$40,084	\$27,626
CUMULATIVE PLANNED TOTALS																
		2,074	4,147	6,936	9,724	18,119	29,873	38,094	45,688	51,194	56,699	62,205	67,710	\$67,710		
CUMULATIVE ACTUAL TOTALS																
		0	0	0	6,127	14,045	23,596	28,943	33,796	40,084	40,084	40,084	40,084		\$40,084	\$27,626
CUMULATIVE BUDGET VARIANCE																
		\$2,074	\$4,147	\$6,936	\$3,597	\$4,074	\$6,277	\$9,151	\$11,892	\$11,110	\$16,615	\$22,121	\$27,626			

Task 2.1e: Chemical Destruction of Chlorinated Organic Compounds

PRINCIPAL INVESTIGATOR: Kung Wang - EXTENDED BUDGET

NOTE: This will be the last report under WVU Account No.: 8527-211-0622 - Account closed

PROJECT: Chemical Destruction of Chlorinated Organic Compounds

METC TASK NO.: 2.1e

**** Extended Budget ****

PRINCIPAL INVESTIGATOR): Kung Wang

PERIOD ENDING: 9-29-95

DESCRIPTION	PLANNED ACTUAL	1 JAN	2 FEB	3 MARCH	4 APRIL	5 MAY	6 JUNE	7 JULY	8 AUG	9 SEPT	10 OCT	11 NOV	12 DEC	PROJECTED TOTALS	ACTUAL TOTALS	AMOUNT REMAINING
SALARIES																
K. Wang	planned	0	0	0	2,800	0	0	0	0	0				\$2,800		
	actual	0	0	0	2,800	0	0	0	0	0					\$2,800	\$0
BENEFITS																
29% of	planned	0	0	0	812	0	0	0	0	0				\$812		
Salaries	actual	0	0	0	812	0	0	0	0	0					\$812	\$0
GENERAL	planned	0	0	0	0	0	0	0	0	0				\$0		
	actual	0	0	60	0	0	(60)	0	0	0					\$0	\$0
TRAVEL	planned	0	0	0	0	0	0	0	0	0				\$0		
	actual	0	0	0	0	0	0	0	0	0					\$0	\$0
EQUIPMENT	planned	0	0	3,392	0	0	0	0	0	0				\$3,392		
	actual	0	0	0	0	0	3,392	0	0	0					\$3,392	\$0
INDIRECT COSTS																
43% of exp	planned	0	0	0	1,553	0	0	0	0	0				\$1,553		
Exc Equip	actual	0	0	26	1,553	0	(26)	0	0	0					\$1,553	\$0
PLANNED TOTALS:																
PER MONTH		0	0	3,392	5,165	0	0	0	0	0				\$8,557		
ACTUAL TOTALS:																
PER MONTH		0	0	86	5,165	0	3,306	0	0	0					\$8,557	\$0
CUMULATIVE																
PLANNED TOTALS		0	0	3,392	8,557	8,557	8,557	8,557	8,557	8,557				\$8,557		
CUMULATIVE																
ACTUAL TOTALS		0	0	86	5,251	5,251	8,557	8,557	8,557	8,557					\$8,557	\$0
CUMULATIVE																
BUDGET VARIANCE		\$0	\$0	\$3,306	\$3,306	\$3,306	\$0	\$0	\$0	\$0						

METC TASK #2.2

#	Task Name	Dura	%Com	1995												Ist	
				1st Quarter			2nd Quarter			3rd Quarter			4th Quarter				
				Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	
1	PURCHASE STANDARDS	1M	100.00%	██████													
2	HYDROCARBON DETERMINATION	5M	50.00%		████████████████████												
3	ETHYLBENZENE/XYLENES	2M	50.00%		████████												
4	IONIZATION OPTIMIZATION	3M	60.00%				████████████████										
5	ENVIRONMENTAL INTERFERENCES	2M	10.00%					████████									
6	WINFIELD DEMONSTRATION	1M	0.00%	.....	.....	.....	.....	██████									
7	HALOGENATED HYDROCARBON DETERMINATIO	6M	25.00%						██								
8	IONIZATION OPPTIMIZATION	3M	60.00%						████████████████								
9	INTERFERENCE EVALUATION	3M	50.00%							████████████████							
10	INTERFERENCE AMELIORATION	4M	0.00%	.....	.....	.....	.....	.....	.....	████████████████████							
11	REPORTS	12M	75.00%	██													

■ Critical

◇ Critical Milestone

▨ Free Float

..... Delay

■ Noncritical

◇ Noncritical Milestone

▨ Total Float (+)

▲ Effort %Complete

■ Complete

◇ Complete Milestone

▨ Total Float (-)

▬ Summary

◇ Summary Milestone

▬ Baseline

■ External

◇ External Milestone

..... Non-Resource

TASK 2.2: Atmospheric Monitoring Mass Spectrometry

PRINCIPAL INVESTIGATOR: Fred King

PROJECT: Continued Development of an Atmospheric Monitoring Mass Spectrometry

METC TASK NO.: 2.2

WVU Act. No.: 8527-211-0623

PRINCIPAL INVESTIGATOR: Fred King

PERIOD ENDING: 9/30/95

DESCRIPTION	PLANNED ACTUAL	1 JAN	2 FEB	3 MARCH	4 APRIL	5 MAY	6 JUNE	7 JULY	8 AUG	9 SEPT	10 OCT	11 NOV	12 DEC	PROJECTED TOTALS	ACTUAL TOTALS	AMT REMAINING
SALARIES																
Fred King	planned	0	0	0	0	2,060	4,120	4,120	2,060	0	0	0	0	\$12,360		
	actual	0	0	0	0	2,060	4,120	4,120	2,060	0					\$12,360	\$0
Technician	planned	0	0	0	0	1,771	1,771	1,771	1,771	1,771	1,771	1,771	0	\$12,400		
	actual	0	0	0	0	814	1,393	787	97	214					\$3,305	\$9,095
BENEFITS																
29% of Salaries	planned	0	0	0	0	1,111	1,709	1,709	1,111	514	514	514	0	\$7,180		
	actual	0	0	0	0	833	1,599	1,423	626	62	0	0	0		\$4,543	\$2,637
STUDENTS and NON-BENEFIT SALARIES																
2 Graduate Students	planned	0	0	0	0	1,100	2,200	2,200	1,100	0	0	0	0	\$6,600		
	actual	0	0	0	0	1,100	2,200	2,200	1,100	0					\$6,600	\$0
Technicians	planned	0	0	0	0	1,600	2,400	800	400	0	0	0	0	\$5,200		
	actual	0	0	0	0	2,558	4,379	2,499	303	672					\$10,411	(\$5,211)
SUPPLIES	planned	0	0	0	0	1,100	1,100	804	804	804	804	804	0	\$6,220		
	actual	0	0	0	0	0	1,139	224	0	151					\$1,514	\$4,707
RENT	planned	0	0	0	0	0	0	0	0	0	0	0	0	\$0		
	actual	0	0	0	0	0	0	0	528	0					\$528	(\$528)
TRAVEL	planned	0	0	0	0	1,500	0	400	200	200	200	0	0	\$2,500		
	actual	0	0	0	0	0	1,109	0	0	0					\$1,109	\$1,391
INDIRECT COSTS																
43% of exp	planned	0	0	0	0	4,404	5,719	5,076	3,202	1,414	1,414	1,328	0	\$22,558		
Exc Equip	actual	0	0	0	0	3,167	6,854	4,839	2,027	473	0	0	0		\$17,359	\$5,199
PLANNED TOTALS:																
PER MONTH		0	0	0	0	14,647	19,019	16,880	10,649	4,704	4,704	4,418	0	\$75,019		
ACTUAL TOTALS:																
PER MONTH		0	0	0	0	10,533	22,792	16,092	6,740	1,572	0	0	0		\$57,729	\$17,290
CUMULATIVE																
PLANNED TOTALS		0	0	0	0	14,647	33,666	50,545	61,194	65,898	70,601	75,019	75,019	\$75,019		
CUMULATIVE																
ACTUAL TOTALS		0	0	0	0	10,533	33,325	49,417	56,157	57,729	57,729	57,729	57,729		\$57,729	\$17,290
CUMULATIVE																
BUDGET VARIANCE		\$0	\$0	\$0	\$0	\$4,114	\$341	\$1,129	\$5,037	\$8,169	\$12,872	\$17,290	\$17,290			

METC TASK #2.3

#	Task Name	Dura	%Com	1995											
				Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	DESIGN OF FLUID BED SYSTEM	4M	100.00%												
2	CONSTRUCTION OF FLUID BED	4M	85.00%												
3	CHOSE MODEL CHEMS & PARAMS	2M	100.00%												
4	DESIGN & MFG. NEW DISTRIBUTOR PLATE	4M	50.00%												
5	DESIGN & MFG. FEED GAS SYS	4M	50.00%												
6	SAFETY REVIEW	1M	30.00%												
7	DESIGN GAS SAMPLING EQUIP	4M	0.00%												

Critical

Critical Milestone

Free Float

Delay

Noncritical

Noncritical Milestone

Total Float (+)

Effort %Complete

Complete

Complete Milestone

Total Float (-)

Complete Milestone

Summary

Summary Milestone

External

External Milestone

Non-Resource

Non-Resource

Task 2.3: Capture of Hazardous Materials Utilizing Fluidization Coating

PRINCIPAL INVESTIGATORS: Richard Turton

■ PLANNED SPENDING ◇ — ACTUAL SPENDING

PROJECT: Capture of Hazardous Waste Materials Utilizing Fluidization Coating Technology

METC TASK NO.: 2.3

WVU Act. No.: 8527-229-1792

PRINCIPAL INVESTIGATORS): Richard Turton

PERIOD ENDING: 9/30/95

DESCRIPTION	PLANNED ACTUAL	1 JAN	2 FEB	3 MARCH	4 APRIL	5 MAY	6 JUNE	7 JULY	8 AUG	9 SEPT	10 OCT	11 NOV	12 DEC	PROJECTED TOTALS	ACTUAL TOTALS	AMT REMAINING
SALARIES																
R. Turton	planned	0	0	0	0	0	0	1,046	1,046	1,046	2,427	2,427	2,427	\$10,418		
	actual	0	0	0	0	0	0	1,046	1,046	1,046					\$3,139	7,280
BENEFITS																
29% of Salaries	planned	0	0	0	0	0	0	303	303	303	704	704	704	\$3,021		
	actual	0	0	0	0	0	0	303	303	303	0	0	0		\$910	2,111
STUDENTS																
1 Graduate	planned	0	0	0	0	0	0	100	100	115	115	115	115	\$658		
	actual	0	0	0	0	0	0	60	60	108					\$228	431
SUPPLIES																
	planned	0	0	0	0	400	400	400	400	300	300	300	0	\$2,600		
	actual	0	0	0	0	0	997	559	1,075	269					\$2,900	(400)
TRAVEL																
	planned	0	0	0	0	0	0	0	0	0	0	1,000	0	\$1,000		
	actual	0	0	0	0	0	0	160	0	0					\$160	840
SUBCONTRACT																
	planned	0	0	0	0	0	0	0	0	0	400	400	200	\$1,000		
	actual	0	0	0	0	0	0	0	0	0					\$0	1,000
EQUIPMENT (No Overhead)																
	planned	0	0	0	0	2,500	500	500	500	0	0	0	0	\$4,000		
	actual	0	0	0	0	0	3,182	0	0	0					\$3,182	818
INDIRECT COSTS																
43% of exp	planned	0	0	0	0	172	172	795	795	758	1,696	2,126	1,481	\$7,997		
Exc Equip	actual	0	0	0	0	0	429	915	1,068	742	0	0	0		\$3,155	4,842
PLANNED TOTALS: PER MONTH																
		0	0	0	0	3,072	1,072	3,145	3,145	2,522	5,641	7,071	4,926	\$30,594		
ACTUAL TOTALS: PER MONTH																
		0	0	0	0	0	4,608	3,044	3,552	2,468	0	0	0		\$13,673	\$16,921
CUMULATIVE PLANNED TOTALS																
		0	0	0	0	3,072	4,144	7,289	10,433	12,955	18,597	25,668	30,594	\$30,594		
CUMULATIVE ACTUAL TOTALS																
		0	0	0	0	0	4,608	7,653	11,205	13,673	13,673	13,673	13,673		\$13,673	16,921
CUMULATIVE BUDGET VARIANCE																
		\$0	\$0	\$0	\$0	\$3,072	(\$464)	(\$364)	(\$772)	(\$718)	\$4,924	\$11,995	\$16,921			

Note: The planned budget has been revised from last quarter to reflect a change in the scope of work. Changes were made between salary classifications. The overall budget did not change.

U.S. DEPARTMENT OF ENERGY
FEDERAL ASSISTANCE MANAGEMENT SUMMARY REPORT

FORM APPROVED
OMS No. 1900-0127
Page of

[1] Program/Project Identification No. DE-FC21-90MC29467	[2] Program/Project Title Decontamination Systems Information and Research Program	[3] Reporting Period July - September 1995
[4] Name and Address Manufacturing and Technology Conversion International, Inc. P.O. Box 21, Columbia, MD 21045		[5] Program/Project Start Date June 17, 1993
		[6] Completion Date December 31, 1995

[11] Major Milestone Status		Units Planned	Units Complete
Task 1: System Modification	P	100%	
	A	90%	
	C		
Task 2: Testing & Analysis	P	0%	
	A		
	C		
Task 3: Scale-Up Design & Final Report	P	0%	
	A		
	C		
	P		
	A		
	C		
	P		
	A		
	C		
	P		
	A		
	C		
	P		
	A		
	C		

[12] Remarks

[13] Signature of Recipient and Date James C. Wiseloh 10/5/95	[14] Signature of DOE Reviewing Representative and Date
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TASK 2.4: Soil Decontamination by Steam Reforming

PRINCIPAL INVESTIGATOR (S): R. Lovette transferred to J. Quaranta

NOTE: This budget has been adjusted to reflect the change in administration from NRCCE to WVU. MTCI is completing their report and may incur additional charges
However, the subcontractor amounts were adjusted to reflect all charges > \$25,000.

PROJECT: Soil Decontamination by Steam Reforming

METC TASK NO.: 2.4
WVU Act. No.: 8527-224-1427
PERIOD ENDING: 9/30/95

PRINCIPAL INVESTIGATOR: R. Lovette

DESCRIPTION	PLANNED ACTUAL	1 JAN	2 FEB	3 MARCH	4 APRIL	5 MAY	6 JUNE	7 JULY	8 AUG	9 SEPT	ADJ adjustments	10 OCT	11 NOV	12 DEC	PROJECTED TOTALS	ACTUAL TOTALS	AMT Remaining
SALARIES	planned actual	432 0	432 0	432 0	432 0	432 0	432 0	432 0	432 0	432 0	(3,887)				(\$1)	\$0	(\$1)
BENEFITS (29% of Salaries)	planned actual	125 0	125 0	125 0	125 0	125 0	125 0	125 0	125 0	125 0	(1,127) 0				(\$0)	\$0	(\$0)
SUPPLIES	planned actual	42 65	42 292	42 677	42 0	42 0	42 0	42 0	42 0	42 0	659				\$1,034	\$1,034	\$0
TRAVEL	planned actual	417 0	417 0	417 0	417 0	417 0	417 0	417 0	417 0	417 0	(3,750)				\$0	\$0	\$0
SUB-CONTRACT (Under 25K)	planned actual	0 0	0 0	0 0	0 0	0 0	25,000 0	0 0	0 0	0 0	(25,000)				\$0	\$0	\$0
SUB-CONTRACT (Over 25K)	planned actual	52,392 38,439	52,392 63,057	52,392 36,748	52,392 35,436	52,392 51,699	27,392 31,154	0 9,133	0 10,724	0 0	3,052				\$292,404	\$276,390	\$16,014
INDIRECT COSTS																	
(43% of direct cost *exc/ equip & sub)	planned actual	437 28	437 126	437 291	437 0	437 0	11,187 0	437 0	437 0	437 0	(14,235) 0	0 0	0 0	0 0	\$444	\$445	(\$0)
PLANNED TOTALS: PER MONTH		53,844	53,844	53,844	53,844	53,844	64,594	1,452	1,452	1,452	(44,288)	0	0	0	\$293,882		
ACTUAL TOTALS: PER MONTH		38,532	63,476	37,716	35,436	51,699	31,154	9,133	10,724	0	0	0	0	0		\$277,868	\$16,013
CUMULATIVE PLANNED TOTALS		53,844	107,688	161,532	215,376	269,220	333,814	335,266	336,718	338,170	293,882	293,882	293,882	293,882	\$293,882		
CUMULATIVE ACTUAL TOTALS		38,532	102,007	139,723	175,159	226,858	258,011	267,144	277,868	277,868	277,868	277,868	277,868	277,868		\$277,868	\$16,013
CUMULATIVE BUDGET VARIANCE		\$15,312	\$5,681	\$21,809	\$40,217	\$42,362	\$75,803	\$68,122	\$58,850	\$60,302	\$16,013	\$16,013	\$16,013	\$16,013			

METC TASK #2.5

#	Task Name	Dura	%Com	1995												1st	
				1st Quarter			2nd Quarter			3rd Quarter			4th Quarter				
				Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	
1	Preliminary Research	3M	100.00%														
2	Electrochemical Remediation	3M	100.00%														
3	Technical Evaluation	2M	100.00%														
4	Analytical Techniques	7.24M	100.00%									◇					
5	Preparation for Trials	6M	100.00%									◇					
6	Characterize Carbon Samples	5M	100.00%														
7	Testing	8M	100.00%														
8	Analysis & Reporting	8.95M	100.00%														
9	Data Reduction	3.95M	100.00%														

■ Critical

◇ Critical Milestone

▨ Free Float

..... Delay

■ Noncritical

◇ Noncritical Milestone

▨ Total Float (+)

▲ Effort %Complete

■ Complete

◆ Complete Milestone

▨ Total Float (-)

▨ Summary

◇ Summary Milestone

— Baseline

■ External

◆ External Milestone

..... Non-Resource

TASK 2.5: Carbon Products for Waste Stream Clean-up

PRINCIPAL INVESTIGATOR: C. Invin - NRCCE Budget

PROJECT: Carbon Products for Waste Stream Clean up
 NRCCE - Detail of Regular Budget
 PRINCIPAL INVESTIGATOR: C. Irwin

METC TASK NO.: 2.5
 WVU Act. No.: 8527-224-1428
 PERIOD ENDING: 9/30/95

DESCRIPTION	PLANNED ACTUAL	1 JAN	2 FEB	3 MARCH	4 APRIL	5 MAY	6 JUNE	7 JULY	8 AUG	9 SEPT	10 OCT	11 NOV	12 DEC	PROJECTED TOTALS	ACTUAL TOTALS	AMT Remaining
SALARIES																
C. Irwin	planned actual	0 0	0 0	0 0	0 0	0 0	0 0	0 0	1,014 288	528 576	526 526	526 526	0 0	\$2,592	\$864	\$1,728
M. Reda	planned actual	0 0	0 0	0 0	0 0	108 0	108 0	241 0	241 158	241 316	241 241	241 241	0 0	\$1,422	\$474	\$948
Staff	planned actual	0 0	0 0	0 0	0 0	87 0	87 0	206 0	206 111	206 221	206 206	0 0	0 0	\$997	\$332	\$665
BENEFITS (29% of Salaries)	planned actual	0 0	0 0	0 0	0 0	57 0	57 0	130 0	424 162	282 323	282 282	222 0	0 0	\$1,453	\$484	\$969
SUPPLIES	planned actual	0 0	0 0	0 0	439 0	439 0	439 0	(1,316) 0	0 0	0 0	0 0	0 0	0 0	\$0	\$0	\$0
Sub-Contract *Penn State	planned actual	0 0	0 0	25,000 0	25,000 0	25,000 56,145	25,000 93,074	25,000 0	24,219 0	0 0	0 0	0 0	0 0	\$149,219	\$149,219	\$0
INDIRECT COSTS																
(43% of direct cost *exc sub contract)	planned actual	0 0	0 0	0 0	189 0	297 0	297 0	(318) 0	810 309	540 617	540 540	425 0	0 0	\$2,779	\$926	\$1,853
PLANNED TOTALS: PER MONTH		0	0	25,000	25,627	25,987	25,987	23,943	26,914	1,795	1,795	1,415	0	\$158,462		
ACTUAL TOTALS: PER MONTH		0	0	0	0	56,145	93,074	0	1,027	2,053	0	0	0		\$152,299	\$6,163
CUMULATIVE PLANNED TOTALS		0	0	25,000	50,627	76,614	102,601	128,544	153,458	155,253	157,047	158,462	158,462	\$158,462		
CUMULATIVE ACTUAL TOTALS		0	0	0	0	56,145	149,219	149,219	150,246	152,299	152,299	152,299	152,299		\$152,299	\$6,163
CUMULATIVE BUDGET VARIANCE		\$0	\$0	\$25,000	\$50,627	\$20,469	(\$46,618)	(\$22,675)	\$3,212	\$2,953	\$4,748	\$6,163	\$6,163			

TASK 2.5e: Carbon Products for Waste Steam Clean up

PRINCIPAL INVESTIGATOR: C. Irwin - NRCCE * Extended Budget *

NOTE: This will be the last report for this extended budget. It is now closed. Any funds remaining were adjusted as noted below.

PROJECT: Carbon Products for Waste Stream Clean up
NRCCE - **Extended Budget
PRINCIPAL INVESTIGATOR: C. Irwin

METC TASK NO.: 2.5e
WVU Act. No.: 8527-224-1428
PERIOD ENDING: 9/30/95

DESCRIPTION	PLANNED ACTUAL	1 JAN	2 FEB	3 MARCH	4 APRIL	5 MAY	6 JUNE	7 JULY	8 AUG	9 SEPT	BUDGET ADJUSTMENTS	PROJECTED TOTALS	ACTUAL TOTALS	AMT Remaining
SALARIES														
C. Irwin	planned actual	980 0	980 0	980 0	980 0	980 0	980 5,879	0 0	0 0	0 0		\$5,879	\$5,879	\$0
M. Reda	planned actual	315 0	315 0	315 0	315 0	315 1,112	315 778	0 0	0 0	0 0		\$1,890	\$1,890	(\$0)
Staff	planned actual	161 0	161 0	161 0	161 0	161 0	161 983	0 0	0 0	0 0		\$966	\$983	(\$17)
BENEFITS (29% of Salaries)	planned actual	422 0	422 0	422 0	422 0	422 322	422 2,216	0 0	0 0	0 0		\$2,533	\$2,538	(\$5)
SUPPLIES	planned actual	0 0	0 0	0 0	0 46	0 0	0 0	0 0	0 0	0 0		\$0	\$46	(\$46)
TRAVEL	planned actual	92 0	92 0	92 0	92 50	92 0	92 0	0 0	0 0	0 0	(504)	\$50	\$50	\$0
INDIRECT COSTS														
(43% of direct cost *exc sub contract)	planned actual	847 0	847 0	847 0	847 41	847 617	847 4,238	0 0	0 0	0 0	(120)	\$4,963	\$4,896	\$68
PLANNED TOTALS: PER MONTH		2,817	2,817	2,817	2,817	2,817	2,817	0	0	0	(624)	\$16,281		
ACTUAL TOTALS: PER MONTH		0	0	0	136	2,051	14,093	0	0	0	0		\$16,281	\$0
CUMULATIVE PLANNED TOTALS		2,817	5,635	8,452	11,270	14,087	16,905	16,905	16,905	16,905	16,281	\$16,281		
CUMULATIVE ACTUAL TOTALS		0	0	0	136	2,187	16,281	16,281	16,281	16,281	16,281		\$16,281	\$0
CUMULATIVE BUDGET VARIANCE		\$2,817	\$5,635	\$8,452	\$11,134	\$11,900	\$624	\$624	\$624	\$624	\$0	\$0	\$0	

TASK 2.5: Carbon Products for Waste Stream Clean-up

** DETAILED REPORT FOR CHEMICAL ENGINEERING - Regular Budget - Pt: John Zondlo

PROJECT: Carbon Products for Waste Stream Clean-up
Chemical Engineering - Detailed REGULAR Budget
PRINCIPAL INVESTIGATOR: John Zondolo

METC TASK NO.: 2.5
WVU Act. No.: 8527-229-1793
PERIOD ENDING: 9/30/95

DESCRIPTION	PLANNED ACTUAL	1 JAN	2 FEB	3 MARCH	4 APRIL	5 MAY	6 JUNE	7 JULY	8 AUG	9 SEPT	10 OCT	11 NOV	12 DEC	PROJECTED TOTALS	ACTUAL TOTALS	AMT REMAINING
SALARIES																
Stiller/Zondolo	planned actual	0 0	0 0	0 0	0 0	0 0	0 0	5,161 0	0 1,301	0 1,301	0 0	0 0	0 0	\$5,161	\$2,602	\$2,559
Brennstener	planned actual	0 0	0 0	0 0	2,292 2,292	2,292 2,292	2,292 2,292	2,292 2,333	2,292 2,333	2,292 2,333	0 0	0 0	0 0	\$13,752	\$13,876	(\$124)
Finklea (PT @ 7% Benf)	planned actual	0 0	0 0	50 51	50 0	50 0	50 0	50 459	100 0	100 0	100 0	0 0	0 0	\$550	\$510	\$40
Technician	planned actual	0 0	0 0	0 0	1,670 1,670	1,670 1,670	1,670 1,670	1,670 1,670	1,670 1,670	1,670 1,670	0 0	0 0	0 0	\$10,020	\$10,020	\$0
Clerical/Misc	planned actual	0 0	0 0	1,200 1,136	300 0	300 0	251 915	0 0	0 0	0 0	0 0	0 0	0 0	\$2,051	\$2,051	\$0
BENEFITS																
29% of Salaries	planned actual	0 0	0 0	352 333	1,239 1,149	1,239 1,149	1,226 1,414	2,649 1,193	1,156 1,538	1,156 1,538	7 0	0 0	0 0	\$9,024	\$8,315	\$709
STUDENTS																
Graduate Assistant	planned actual	0 0	0 0	0 0	1,100 1,010	1,100 1,100	1,100 1,100	1,100 1,100	1,100 1,100	1,100 1,100	0 0	0 0	0 0	\$6,600	\$6,610	\$90
SUPPLIES	planned actual	0 0	0 0	786 349	786 470	786 849	786 827	786 130	786 388	786 389	0 0	0 0	0 0	\$5,499	\$3,402	\$2,097
INDIRECT COSTS																
43% of exp Exc Equip	planned actual	0 0	0 0	1,026 804	3,198 2,834	3,198 3,036	3,171 3,534	5,894 2,961	3,055 3,582	3,055 3,583	46 0	0 0	0 0	\$22,642	\$20,333	\$2,310
PLANNED TOTALS: PER MONTH		0	0	3,414	10,635	10,635	10,545	19,602	10,158	10,158	153	0	0	\$76,299		
ACTUAL TOTALS: PER MONTH		0	0	2,673	9,426	10,096	11,752	9,846	11,913	11,914	0	0	0		\$67,619	\$7,681
CUMULATIVE PLANNED TOTALS		0	0	3,414	14,048	24,683	35,228	54,830	64,988	75,146	75,299	75,299	75,299	\$75,299		
CUMULATIVE ACTUAL TOTALS		0	0	2,673	12,098	22,194	33,946	43,792	55,705	67,619	67,619	67,619	67,619		\$67,619	\$7,681
CUMULATIVE BUDGET VARIANCE		\$0	\$0	\$741	\$1,951	\$2,490	\$1,282	\$11,038	\$9,284	\$7,528	\$7,681	\$7,681	\$7,681			

TASK 2.5E: Carbon Products for Waste Stream Clean-up

** DETAILED REPORT FOR CHEMICAL ENGINEERING - ** Extended Budget ** Pl: John Zondlo

NOTE: This will be the last report for this extended budget. It is now closed. The transactions necessary to close out the account are recorded below.

PROJECT: Carbon Products for Waste Stream Clean-up
Chemical Engineering - Detailed EXTENDED Budget
PRINCIPAL INVESTIGATOR: John Zondolo

METC TASK NO.: 2.5E
WVU Act. No.: 8527-229-1791
PERIOD ENDING: 9/30/95

DESCRIPTION	PLANNED ACTUAL	1 JAN	2 FEB	3 MARCH	4 APRIL	5 MAY	6 JUNE	7 JULY	8 AUG	9 SEPT	Adj Adjustments for Close out	PROJECTED TOTALS	ACTUAL TOTALS	ATM REMAINING
SALARIES														
Brennstelner	planned actual	2,300 2,291	1,137 1,146	0 0	0 0	0 0	0 0	0 268	0 0	0 0	268 0	\$3,705	\$3,705	\$1
Technician	planned actual	1,670 1,670	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	\$1,670	\$1,670	\$0
Clerical/Misc	planned actual	2,000 1,750	200 0	200 0	200 0	200 0	635 1,685	0 0	0 0	0 0	0 0	\$3,435	\$3,435	\$0
BENEFITS														
29% of Salaries	planned actual	1,731 1,656	388 332	58 0	58 0	58 0	184 489	0 78	0 0	0 0	78 0	\$2,655	\$2,655	\$0
STUDENTS														
Graduate Assistant	planned actual	640 550	0 0	1,050 1,050	1,050 1,140	1,050 1,050	1,050 1,050	0 (550)	0 0	0 0	(550) 0	\$4,290	\$4,290	\$0
SUPPLIES	planned actual	962 0	960 0	960 4,009	960 491	960 113	960 553	0 896	0 54	0 0	363 0	\$6,115	\$6,115	(\$0)
TRAVEL	planned actual	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	\$0	\$0	\$0
EQUIPMENT	planned actual	1,335 722	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	(613) 0	\$722	\$722	\$0
INDIRECT COSTS														
43% of exp Exc Equip	planned actual	4,000 3,404	1,154 635	975 2,175	975 701	975 500	1,217 1,624	0 297	0 23	0 0	64 0	\$9,361	\$9,361	\$0
PLANNED TOTALS: PER MONTH														
		14,639	3,839	3,243	3,243	3,243	4,046	0	0	0	(400)	\$31,853		
ACTUAL TOTALS: PER MONTH														
		12,044	2,113	7,234	2,332	1,663	5,400	989	77	0	0		\$31,852	\$1
CUMULATIVE PLANNED TOTALS														
		14,639	18,478	21,721	24,964	28,208	32,253	32,253	32,253	32,253	31,853	\$31,853		
CUMULATIVE ACTUAL TOTALS														
		12,044	14,157	21,391	23,723	25,386	30,786	31,775	31,852	31,852	31,852		\$31,852	\$1
CUMULATIVE BUDGET VARIANCE														
		\$2,595	\$4,321	\$330	\$1,241	\$2,821	\$1,467	\$478	\$401	\$401	\$1			

TASK 3.0
INFORMATION SYSTEMS,
PUBLIC POLICY,
COMMUNITY OUTREACH,
AND ECONOMICS

METC TASK #3.1

#	Task Name	Dura	%Com	1995												1st	
				1st Quarter			2nd Quarter			3rd Quarter			4th Quarter				
				Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	
1	Evaluate Remedial Work	1M	100.00%														
2	Develop MS/MS Monitor	7M	80.00%														
3	Implement Monitor	3M	100.00%														
4	Monitor Site	7M	0.00%														
5	Reports	0M	0.00%														

Critical	Noncritical	Complete	Summary	External
Critical Milestone	Noncritical Milestone	Complete Milestone	Summary Milestone	External Milestone
Free Float	Total Float (+)	Total Float (-)	Baseline	Non-Resource
Delay	Effort %Complete			

TASK 3.1 - WINFIELD LOCK AND DAM ASSISTANCE PROGRAM

PRINCIPAL INVESTIGATOR: R. Lovette

PROJECT: Winfield Lock and Dam Assistance Program

METC TASK NO.: 3.1

WVU Act. No.: 8527-224-1426

PRINCIPAL INVESTIGATOR: Raymond Lovette

PERIOD ENDING: 9/30/95

DESCRIPTION	PLANNED ACTUAL	1 JAN	2 FEB	3 MARCH	4 APRIL	5 MAY	6 JUNE	7 JULY	8 AUG	9 SEPT	10 OCT	11 NOV	12 DEC	PROJECTED TOTALS	ACTUAL TOTALS	AMT Remaining
SALARIES	planned actual	3,039 2,776	3,039 2,776	3,039 2,776	3,039 2,776	3,039 2,776	3,039 2,776	2,891 1375	3,143 2567	2,891 2390	2,891	2,891	2,833	\$35,771	\$22,988	\$12,783
BENEFITS (29% of Salaries)	planned actual	881 805	881 805	881 805	881 805	881 805	881 805	838 399	911 744	838 693	838 0	838 0	822 0	\$10,374	\$6,667	\$3,707
STUDENTS	planned actual	343 456	343 270	343 213	343 306	343 384	343 54	343 (868)	0 0	0 0	0	0	0	\$2,400	\$815	\$1,585
SUPPLIES	planned actual	667 756	667 756	667 756	667 797	667 62	667 606	667 29	667 0	667 0	667	667	667	\$8,000	\$3,762	\$4,238
COMM/INFO	planned actual	0 0	0 0	0 0	0 0	0 0	0 0	300 659	300 292	300 320	300	300	0	\$1,500	\$1,271	\$229
EQUIP < 500	planned actual	0 0	0 0	0 0	0 0	0 0	0 0	320 0	320 561	320 53	320	320	0	\$1,600	\$614	\$986
REFERENCE MATERIALS	planned actual	0 0	0 0	0 0	0 0	0 0	0 0	380 57	380 0	380 0	380	380	0	\$1,900	\$57	\$1,843
MAINTENANCE CONTRACTOR	planned actual	0 0	0 0	0 0	0 0	0 0	0 780	0 0	0 0	0 0	0	0	0	\$0	\$780	(\$780)
TRAVEL	planned actual	1,029 0	1,029 69	1,029 428	1,029 146	1,029 230	1,029 288	577 78	0 0	0 492	0	0	0	\$8,748	\$1,731	\$5,017
INDIRECT COSTS																
(19% of direct cost *exc/ equip & sub)	planned actual	1,132 911	1,132 888	1,132 946	1,132 918	1,132 809	1,132 1,009	1,200 328	1,087 781	1,025 750	1,025 0	1,025 0	821	\$12,978	7,350	\$5,628
PLANNED TOTALS: PER MONTH		7,090	7,090	7,090	7,090	7,090	7,090	7,518	8,808	6,421	6,421	6,421	6,142	\$48,289		
ACTUAL TOTALS: PER MONTH		5,704	5,564	5,924	5,749	5,066	6,318	2,057	4,956	4,698	0	0	0		\$46,036	\$35,233
CUMULATIVE PLANNED TOTALS		7,090	14,179	21,269	28,359	35,449	42,538	50,054	58,862	63,284	69,705	76,126	81,269	\$81,269		
CUMULATIVE ACTUAL TOTALS		5,704	11,267	17,192	22,940	28,006	34,324	36,382	41,337	46,036	46,036	46,036	46,036		\$46,036	\$35,233
CUMULATIVE BUDGET VARIANCE		\$1,386	\$2,912	\$4,078	\$5,419	\$7,443	\$8,214	\$13,673	\$15,525	\$17,248	\$23,670	\$30,091	\$35,233			

METC TASK #3.2

#	Task Name	Dura	%Com	1995													
				1st Quarter			2nd Quarter			3rd Quarter			4th Quarter				
				Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	
1	NEPA Documentation	3.5M	100.00%														
2	System Requirements	3M	100.00%														
3	Devise & Specify System Requirements	11M	80.00%														
4	Determine Operating Procedures	2M	0.00%														
5	Develop materials for Technology Transfer	2M	0.00%														

..... Non-Resource

Task 3.2: A GIS Infrastructure for Characterization & Remediation

PRINCIPAL INVESTIGATOR: E. Cook - * Overall Budget

PROJECT: A GIS Based Infrastructure for Site Characterization

** OVERALL Budget **

PRINCIPAL INVESTIGATOR: E. Cook

METC TASK NO.: 3.2

WVU Act. No.: 8527-229-3245

PERIOD ENDING: 9/30/95

DESCRIPTION	PLANNED ACTUAL	1 JAN	2 FEB	3 MARCH	4 APRIL	5 MAY	6 JUNE	7 JULY	8 AUG	9 SEPT	10 OCT	11 NOV	12 DEC	PROJECTED TOTALS	ACTUAL TOTALS	AMT Remaining
SALARIES																
E. Cook	planned actual	222 212	222 212	222 212	222 212	222 226	222 240	222 240	222 216	222 190	222	222	222	\$2,661	\$1,959	\$702
Secretary	planned actual	83 0	83 0	83 0	83 0	83 0	83 0	83 0	83 0	83 0	83	83	83	\$995	\$0	\$995
BENEFITS (29% of Salaries)	planned actual	88 61	88 61	88 61	88 61	88 66	88 70	88 70	88 62	88 55	88 0	88 0	88 0	\$1,060	\$568	\$492
*SUB-CONTRACT Marshall Univ	planned actual	3,040 2,179	9,128 10,300	4,324 3,443	16,780 10,552	14,510 8,163	46,521 59,647	25,657 23,008	26,331 18,349	17,651 21,415	12,728	11,346	12,672	\$200,688	\$167,056	\$43,632
INDIRECT COSTS																
(43% of direct cost *exc/ equip & sub)	planned actual	169 118	169 118	169 118	169 118	169 125	169 133	169 133	169 119	169 105	169 0	169 0	169 0	\$2,028	\$1,087	\$941
PLANNED TOTALS: PER MONTH		3,602	9,690	4,886	17,342	15,072	47,083	26,219	26,893	18,213	13,290	11,908	13,234	\$207,432		
ACTUAL TOTALS: PER MONTH		2,570	10,691	3,834	10,943	8,680	60,090	23,451	18,746	21,765	0	0	0		\$160,670	\$46,762
CUMULATIVE PLANNED TOTALS		3,602	13,292	18,178	35,520	50,592	97,675	123,894	150,797	169,000	182,290	194,198	207,432	\$207,432		
CUMULATIVE ACTUAL TOTALS		2,570	13,261	17,095	28,038	36,618	96,708	120,159	138,904	160,670	160,670	160,670	160,670		\$160,670	\$46,762
CUMULATIVE BUDGET VARIANCE		\$1,032	\$31	\$1,083	\$7,482	\$13,974	\$967	\$3,735	\$11,883	\$8,330	\$21,620	\$33,528	\$46,762			

*Note: A detailed accounting of the Sub Contractors expenses follows

A GIS Based Infrastructure for Site Characterization and Remediation

PRINCIPAL INVESTIGATOR: James Hooper/Marshall University

PROJECT: A GIS Based Infrastructure for Site Characterization and Remediation

MECT TASK NO.: 3.2

PERIOD ENDING: 9/30/95

PRINCIPAL INVESTIGATOR: James Hooper

*** MARSHALL UNIVERSITY - DETAILED REPORT ***

DESCRIPTION	PLANNED	JAN 1	FEB 2	MARCH 3	APRIL 4	MAY 5	JUNE 6	JULY 7	AUGUST 8	SEPT 9	OCT 10	NOV 11	DEC 12	PROJECTED TOTALS	ACTUAL TOTALS	AMOUNT REMAINING
LABOR COST																
Personal	planned	1,300	1,225	1,800	6,000	4,500	15,708	14,296	10,703	6,162	6,568	5,806	6,480	\$82,594	\$69,628	23,966
	actual	1,300	1,225	1,788	6,173	4,569	15,708	14,296	10,889	4,935	6,568	5,806	6,480	\$82,594	\$69,628	23,966
Clerical	planned	150	250	350	400	450	650	450	400	450	400	350	500	\$4,800	\$4,800	\$0.00
	actual	140	260	350	380	450	670	450	400	450	400	350	500	\$4,800	\$4,800	\$0.00
Student	planned	0	0	0	0	0	1,026	980	1,200	480	480	480	480	\$5,106	\$3,386	1,711
	actual	0	0	0	0	0	1,026	980	1,008	828	480	480	480	\$5,106	\$3,386	1,711
BENEFITS (Variable per class)	planned	228	539	357	984	778	2,537	1,848	1,064	1,064	1,108	884	1,123	\$9,719	\$9,890	3,826
	actual	214	539	357	984	778	2,537	1,848	1,064	1,064	1,108	884	1,123	\$9,719	\$9,890	3,826
EQUIPMENT																
1 - Computers, Printers, ect	planned	0	0	0	0	0	14,000	0	6,000	5,500	0	0	0	\$25,500	\$25,048	452
	actual	0	0	0	0	0	13,884	0	6,000	5,500	0	0	0	\$25,500	\$25,048	452
2 - Software	planned	0	0	0	2,500	2,500	1,350	6,350	0	0	0	0	0	\$6,350	\$6,350	\$0.00
	actual	0	0	0	2,500	2,500	1,350	6,350	0	0	0	0	0	\$6,350	\$6,350	\$0.00
OTHER																
Training	planned	525	525	525	2,159	2,159	2,159	6,478	0	0	0	0	0	\$8,053	\$7,703	350
	actual	525	525	525	2,159	2,159	2,159	6,478	0	0	0	0	0	\$8,053	\$7,703	350
Travel	planned	0	2,000	0	100	100	89	550	550	550	500	500	500	\$5,598	\$5,598	\$0.00
	actual	0	2,210	0	100	109	384	825	550	550	500	500	500	\$5,598	\$5,598	\$0.00
Telephone, Misc.	planned	0	0	0	36	37	37	100	100	100	100	100	100	\$730	\$1,199	(469)
	actual	0	0	0	36	37	37	100	100	100	100	100	100	\$730	\$1,199	(469)
INDIRECT COSTS																
38% of exp	planned	837	2,513	1,881	4,621	3,985	8,853	17,085	4,588	3,249	3,505	3,124	3,484	\$48,240	\$48,240	\$0.00
	actual	800	2,338	1,881	4,621	3,985	8,853	17,085	4,588	3,249	3,505	3,124	3,484	\$48,240	\$48,240	\$0.00
Exc Equip-1	planned	0	0	0	0	0	12,574	6,335	6,033	2,850	0	0	0	\$28,759	\$28,759	\$0.00
	actual	0	0	0	0	0	12,574	6,335	6,033	2,850	0	0	0	\$28,759	\$28,759	\$0.00
PLANNED TOTALS PER MONTH		3,040	9,128	4,324	16,780	14,510	46,521	25,657	26,331	17,051	0	0	0	\$200,000	\$200,000	\$0.00
ACTUAL TOTALS PER MONTH		2,179	10,300	3,443	10,552	8,163	59,647	23,008	18,349	21,415	0	0	0	\$157,055	\$157,055	\$43,633
CUMULATIVE PLANNED TOTALS		3,040	12,168	16,492	33,272	47,781	94,302	119,859	146,290	163,941	179,870	189,015	190,000	\$200,000	\$200,000	\$0.00
CUMULATIVE ACTUAL TOTALS		2,179	12,478	15,921	26,473	34,636	94,283	117,291	135,640	157,055	157,055	157,055	157,055	\$157,055	\$157,055	\$43,633
BUDGET VARIANCE		\$861	(\$311)	\$571	\$6,799	\$13,145	\$19	\$2,068	\$10,650	\$6,887	\$19,815	\$30,961	\$43,633			

METC TASK #3.3

#	Task Name	Dura	%Com	1995												1st	
				1st Quarter			2nd Quarter			3rd Quarter			4th Quarter				
				Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	
1	Interact w/ METC on Business Needs	11M	85.00%														
2	Meet w/ Small Businesses	10M	69.00%														
3	Develop Proposals w/ Small Businesses	11M	72.00%														

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Critical	Noncritical	Complete	Summary	External
Critical Milestone	Noncritical Milestone	Complete Milestone	Summary Milestone	External Milestone
Free Float	Total Float (+)	Total Float (-)	Baseline	Non-Resource
Delay	Effort %Complete			

TASK 3.3: SMALL BUSINESS SUPPORT PROGRAM

PRINCIPAL INVESTIGATOR: E. Cook

PROJECT: Small Business Program - Administrative Budget

METC TASK NO.: 3.3

PRINCIPAL INVESTIGATOR: E. Cook

WVU Act. No.: 8527-229-3242

PERIOD ENDING: 9/30/95

DESCRIPTION	PLANNED ACTUAL	1 JAN	2 FEB	3 MARCH	4 APRIL	5 MAY	6 JUNE	7 JULY	8 AUG	9 SEPT	10 OCT	11 NOV	12 DEC	PROJECTED TOTALS	ACTUAL TOTALS	AMT Remaining
SALARIES																
Director	planned actual	1,535 1,475	1,535 1,475	1,535 1,475	1,535 1,475	1,535 1,569	1,535 1,661	1,535 1,661	1,535 1,591	1,535 1,520	1,535	1,535	1,535	\$18,414	\$13,905	\$4,509
Technical Assistant	planned actual	2,334 0	2,334 0	2,334 1,854	2,334 2,334	2,334 2,334	2,334 2,334	2,334 2,380	2,334 2,380	2,334 2,380	2,334	2,334	2,334	\$28,008	\$16,996	\$12,012
Secretary	planned actual	417 323	417 323	417 323	417 323	417 323	417 323	417 355	417 355	417 355	417	417	417	\$5,000	\$3,003	\$1,997
BENEFITS (29% of Salaries)	planned actual	1,243 521	1,243 522	1,243 1,059	1,243 1,199	1,243 1,226	1,243 1,252	1,243 1,275	1,243 1,255	1,243 1,234	1,243	1,243	1,243	\$14,912	\$9,542	\$5,370
STUDENTS	planned actual	0 2,168	0 2,334	0 480	0 0	0 0	0 0	0 0	0 0	0 0	0	0	0	\$0	\$4,982	(\$4,982)
INDIRECT COSTS																
(43% of direct cost *exc/ equip & sub)	planned actual	2,377 1,930	2,377 2,002	2,377 2,233	2,377 2,293	2,377 2,344	2,377 2,395	2,377 2,438	2,377 2,400	2,377 2,360	2,377	2,377	2,377	\$28,524	\$20,394	\$8,130
PLANNED TOTALS:																
PER MONTH:		7,905	7,905	7,905	7,905	7,905	7,905	7,905	7,905	7,905	7,905	7,905	7,905	\$94,858		
ACTUAL TOTALS:																
PER MONTH		6,417	6,656	7,425	7,624	7,798	7,965	8,109	7,980	7,849	0	0	0		\$67,822	\$27,036
CUMULATIVE																
PLANNED TOTALS		7,905	15,810	23,715	31,619	39,524	47,429	55,334	63,239	71,144	79,048	86,953	94,858	\$94,858		
CUMULATIVE																
ACTUAL TOTALS		6,417	13,073	20,498	28,122	35,918	43,884	51,993	59,973	67,822	67,822	67,822	67,822		\$67,822	\$27,036
CUMULATIVE																
BUDGET VARIANCE		\$1,488	\$2,736	\$3,216	\$3,497	\$3,606	\$3,545	\$3,341	\$3,286	\$3,321	\$11,226	\$19,131	\$27,036			

METC TASK #3.4

#	Task Name	Dura %Com	1995											
			1st Quarter			2nd Quarter			3rd Quarter			4th Quarter		
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	Initial Contact of Parties	1M 100.00%												
2	Conduct Meetings with Parties	1M 50.00%												
3	Scoping meetings with USEPA and WDEQ	2M 0.00%												
4	Prepare summary of meetings	0.5M 0.00%												
5	Group Meeting	1M 0.00%												

Critical Milestone

Free Float

Delay

Noncritical Milestone

Total Float (+)

Effort %Complete

 Complete

 Complete Milestone

 Total Float (-)

 Summary

 Summary Milestone

 Baseline

 External Milestone

 External Milestone

 Non-Resource

TASK 3.4: Approach for Assessing Voluntary Environmental Protection

Kanawaha River Area - Principal Investigator: R. Lovette

PROJECT: Approach for Assessing Potential Voluntary Environmental
Protection - Kanawha River Area
PRINCIPAL INVESTIGATOR: R. Lovette

METC TASK NO.: 3.4
WVU Act. No.: 8527-224-1422
PERIOD ENDING: 9/30/95

DESCRIPTION	PLANNED ACTUAL	1 JAN	2 FEB	3 MARCH	4 APRIL	5 MAY	6 JUNE	OH Adj	7 JULY	8 AUG	9 SEPT	10 OCT	11 NOV	12 DEC	PROJECTED TOTALS	ACTUAL TOTALS	AMT Remaining
SUPPLIES	planned actual	71 0	71 0	71 0	71 0	71 0	71 0		71 0	71 0	71 0	71 0	71 0	0	\$785	\$0	\$785
TRAVEL	planned actual	717 0	717 0	717 0	717 0	717 0	717 0		717 0	717 68	717 77	717 0	717 0	0	\$7,888	\$133	\$7,755
SUB-CONTRACT (2 - Under 25K)	planned actual	0 0	0 0	0 0	0 0	25,000 24,848	0 154	25,000 (2,385)	0 0	0 0	0 0	0 0	0 0	0	\$50,000	\$25,000	\$25,000
SUB-CONTRACT (1 - Over 25K)	planned actual	0 0	0 0	0 0	0 0	0 0	42,061 13,902	(21,781)	0 0	0 0	0 0	0 0	0 0	0	\$20,280	\$13,902	\$6,378
INDIRECT COSTS																	
(19% of direct cost *exc/ equip & sub)	planned actual	339 0	339 0	339 0	339 0	11,089 10,684	339 68	(2,385) (6,000)	150 0	150 11	150 15	150 0	150 0	0	\$11,148	\$4,775	\$6,373
PLANNED TOTALS: PER MONTH		1,127	1,127	1,127	1,127	36,877	43,188	834	938	938	938	938	938	0	\$90,101		
ACTUAL TOTALS PER MONTH		0	0	0	0	35,530	14,122	(6,000)	0	87	92	0	0	0		\$43,810	\$48,291
CUMULATIVE PLANNED TOTALS		1,127	2,255	3,382	4,510	41,387	84,576	85,410	88,348	88,286	88,225	88,163	90,101	90,101	90,101		
CUMULATIVE ACTUAL TOTALS		0	0	0	0	35,530	49,652	43,652	43,652	43,719	43,810	43,810	43,810	43,810		\$43,810	\$48,291
CUMULATIVE BUDGET VARIANCE		1,127	2,255	3,382	4,510	5,858	34,924	41,758	42,698	43,568	44,414	45,353	46,291	46,291			

NOTE: There was an error in reporting the overhead rate and the application of overhead to subcontractors.
This report has been modified to correct these errors.
The majority of work on this project is now anticipated to occur during the last quarter of 1995

TASK 3.5 - WERC National Environmental Design Contest

PRINCIPAL INVESTIGATOR: B. Reed

PROJECT: WERC National Design Contest

METC TASK NO.: 3.5
WVU Act. No.: 8527-090-3205
PERIOD ENDING: 9/30/95

PRINCIPAL INVESTIGATOR: B. Reed

DESCRIPTION	PLANNED	JAN 1	FEB 2	MARCH 3	APRIL 4	MAY 5	JUNE 6	JULY 7	AUG 8	SEPT 9	OCT 10	NOV 11	DEC 12	PROJECTED TOTALS	ACTUAL TOTALS	AMT Remaining
TRAVEL																
Airline	planned	3,600							2,996					\$3,600	\$2,996	\$604
	actual															
Dormitories	planned	613												\$613	\$0	\$613
	actual															
Hotel	planned	300							234					\$300	\$234	\$66
	actual															
Van Rental	planned			500					64					\$500	\$64	\$436
	actual															
Meals	planned								182					\$0	\$182	(\$182)
	actual															
Other	planned								342					\$0	\$342	(\$342)
	actual															
INDIRECT COSTS																
(18% of direct cost	planned	0	0	0	0	0	0	0	0	0	0	0	0		\$724	\$724
exc/ equip & sub)	actual	0	0	0	0	0	0	0	0	0	0	0	0			
PLANNED TOTALS PER MONTH																
		0	0	0	0	0	0	4,532	0	0	0	0	0		\$4,532	\$1,434
ACTUAL TOTALS PER MONTH																
		0	0	0	0	0	0	4,532	0	0	0	0	0		\$4,532	\$1,434
CUMULATIVE PLANNED TOTALS																
		0	0	0	0	0	0	4,532	4,532	4,532	4,532	4,532	4,532		\$4,532	\$1,434
CUMULATIVE ACTUAL TOTALS																
		0	0	0	0	0	0	4,532	4,532	4,532	4,532	4,532	4,532		\$4,532	\$1,434
CUMULATIVE BUDGET VARIANCE																
		\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0		\$0	\$0

TASK 3.6 - Graduate Interns to IETO

PRINCIPAL INVESTIGATOR: S. Kiger

PROJECT: Graduate Interns to IETO

METC TASK NO.: 3.6

WVU Act. No.: 8527-090-3203

PRINCIPAL INVESTIGATOR: S. Kiger

PERIOD ENDING: 9/30/95

DESCRIPTION	PLANNED ACTUAL	1 JAN	2 FEB	3 MARCH	4 APRIL	5 MAY	6 JUNE	7 JULY	8 AUG	9 SEPT	10 OCT	11 NOV	12 DEC	PROJECTED TOTALS	ACTUAL TOTALS	AMT Remaining
STUDENTS																
5 @ \$3,000/Mth for 3 Months	planned actual							15,000 15,000	15,000 15,000	15,000 15,000				\$45,000	\$45,000	\$0
3 @ \$3,000/Mth for 4.5 months	planned actual								4,500 4,500	9,000 9,000	9,000	9,000	9,000	\$40,500	\$13,500	\$27,000
INDIRECT COSTS																
(16% of direct cost *excl/ equip & sub)	planned actual	0 0	0 0	0 0	0 0	0 0	0 0	2,400 2,400	3,120 3,120	3,840 3,840	1,440 0	1,440 0	1,440 0	\$13,680	\$9,360	\$4,320
PLANNED TOTALS: PER MONTH		0	0	0	0	0	0	17,400	22,620	27,840	10,440	10,440	10,440	\$99,180		
ACTUAL TOTALS: PER MONTH		0	0	0	0	0	0	17,400	22,620	27,840	0	0	0		\$67,860	\$31,320
CUMULATIVE PLANNED TOTALS		0	0	0	0	0	0	17,400	40,020	67,860	78,300	88,740	99,180	\$99,180		
CUMULATIVE ACTUAL TOTALS		0	0	0	0	0	0	17,400	40,020	67,860	67,860	67,860	67,860		\$67,860	\$31,320
CUMULATIVE BUDGET VARIANCE		\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$10,440	\$20,880	\$31,320			

TASK 3.7 - WV High Tech Consortium Environmental Technology

PRINCIPAL INVESTIGATOR:

PROJECT: WV High Tech Consortium Environmental Technology

METC TASK NO.: 3.7

WVU Act. No.: 8527-090-3206

PRINCIPAL INVESTIGATOR: Karen Jones

PERIOD ENDING: 9/30/95

DESCRIPTION	PLANNED ACTUAL	1 JAN	2 FEB	3 MARCH	4 APRIL	5 MAY	6 JUNE	7 JULY	8 AUG	9 SEPT	10 OCT	11 NOV	12 DEC	PROJECTED TOTALS	ACTUAL TOTALS	AMT Remaining
SALARIES																
Project Director	planned actual	0 0	0 0	0 0	0 0	0 0	0 0	800 724	800 724	4,600 0	4,600 0	4,600 0	4,600 0	\$20,000 \$16,168	\$1,449	\$18,551
BENEFITS (29% of Salaries)	planned actual	0 0	0 0	0 0	0 0	0 0	0 0	647 586	647 586	3,719 0	3,719 0	3,719 0	3,719 0	\$16,168 \$1,171	\$1,171	\$14,997
STUDENTS	planned actual	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	500 0	500 0	500 0	500 0	\$2,000 \$0	\$0	\$2,000
TECHNICAL/ FACILITIES	planned actual	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	4,500 0	4,500 0	4,500 0	4,500 0	\$18,000 \$0	\$0	\$18,000
SUPPLIES	planned actual	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	750 0	750 0	750 0	750 0	\$3,000 \$0	\$0	\$3,000
PUBLIC INFO SERVICES	planned actual	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	625 0	625 0	625 0	625 0	\$2,500 \$0	\$0	\$2,500
TRAVEL	planned actual	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	659 0	659 0	659 0	659 0	\$2,635 \$0	\$0	\$2,635
GENERAL ADM	planned actual	0 0	0 0	0 0	0 0	0 0	0 0	100 76	100 76	874 0	874 0	874 0	874 0	\$3,697 \$151	\$151	\$3,546
SUB-TOTAL	planned actual	0 0	0 0	0 0	0 0	0 0	0 0	1,547 1,385	1,547 1,385	16,228 0	16,227 0	16,227 0	16,227 0	\$68,000 \$2,770	\$2,770	\$65,229
INDIRECT COSTS																
(23% of first \$25,000)	planned actual	0 0	0 0	0 0	0 0	0 0	0 0	356 319	356 319	3,732 0	1,308 0	0 0	0 0	\$5,750 \$637	\$637	\$5,113
PLANNED TOTALS: PER MONTH		0	0	0	0	0	0	1,902	1,902	19,958	17,533	16,227	16,227	\$73,750		
ACTUAL TOTALS: PER MONTH		0	0	0	0	0	0	1,704	1,704	0	0	0	0		\$3,408	\$70,342
CUMULATIVE PLANNED TOTALS		0	0	0	0	0	0	1,902	3,804	23,763	41,296	57,523	73,750	\$73,750		
CUMULATIVE ACTUAL TOTALS		0	0	0	0	0	0	1,704	3,408	3,408	3,408	3,408	3,408		\$3,408	\$70,342
CUMULATIVE BUDGET VARIANCE		\$0	\$0	\$0	\$0	\$0	\$0	\$199	\$397	\$20,358	\$37,889	\$54,115	\$70,342			

Development of Organic Sensors - Extended Budget (MC-7)

PRINCIPAL INVESTIGATOR: H.O. Finklea

Note: This will be the last budget report for this project

PROJECT: Development of Organic Sensors

Old Project No.: MC-7

** Extended Budget **

WVU Act. No.: 8527-211-0624

PRINCIPAL INVESTIGATOR: H.O. Finklea

PERIOD ENDING: 6/30/95

DESCRIPTION	PLANNED ACTUAL	1 JAN	2 FEB	3 MARCH	4 APRIL	5 MAY	6 JUNE	7 JULY	8 AUG	9 SEPT	10 OCT	11 NOV	12 DEC	PROJECTED TOTALS	ACTUAL TOTALS	AMT REMAININ
STUDENTS																
2 Graduate	planned	1,748	1,748	1,748	1,748	0	0	0	0					\$6,993		
	actual	0	0	0	2,000	4,992	0	0	0						\$6,992	\$1
GENERAL EXP	planned	0	0	0	0	0	0	0	0					\$0		
	actual	0	0	1	0	0	0	0	0						\$1	(\$1)
EQUIPMENT	planned	0	0	0	0	0	0	0	0					\$0		
	actual	0	0	0	0	0	0	0	0						\$0	\$0
INDIRECT COSTS																
43% of exp	planned	752	752	752	752	0	0	0	0					\$3,007		
Exc Equip	actual	0	0	0	860	2,147	0	0	0						\$3,007	\$0
PLANNED TOTALS:																
PER MONTH		2,500	2,500	2,500	2,500	0	0	0	0					\$10,000		
ACTUAL TOTALS:																
PER MONTH		0	0	1	2,860	7,139	0	0	0						\$10,000	\$0
CUMULATIVE																
PLANNED TOTALS		2,500	5,000	7,500	10,000	10,000	10,000	10,000	10,000					\$10,000		
CUMULATIVE																
ACTUAL TOTALS		0	0	1	2,861	10,000	10,000	10,000	10,000						\$10,000	\$0
CUM BUDGET																
VARIANCE		\$2,500	\$5,000	\$7,499	\$7,139	\$0	\$0	\$0	\$0							

Improved Computer Model to Predict VOC Recovery

OLD NO. MC-14 - Extended Budget - PRINCIPAL INVESTIGATOR: S. Ameri

Note: This will be the last report for this extended budget. It is now closed. Any funds remaining were adjusted as noted below.

PROJECT: Improved Computer Model to Predict VOC Recovery
Extended Budget

Old Project MC-14
WVU Act. No.: 8527-255-0432

PRINCIPAL INVESTIGATOR: S. Ameri

PERIOD ENDING: 9/29/95

DESCRIPTION	PLANNED ACTUAL	1 JAN	2 FEB	3 MARCH	4 APRIL	5 MAY	6 JUNE	7 JULY	8 AUG	9 SEPT	BUDGET ADJUSTMENTS	PROJECTED TOTALS	ACTUAL TOTALS	AMT REMAINING
SUPPLIES	planned actual	0 0	0 0	0 0	344 10	344 68	344 863	0 26	0 0	0 0	(76)	\$957	\$957	\$0
TRAVEL	planned actual	0 0	0 0	0 0	283 0	283 0	283 0	0 680	0 0	0 0	(170)	\$680	\$680	\$0
INDIRECT COSTS														
43% of exp Exc Equip	planned actual	0 0	0 0	0 0	270 4	270 25	270 371	0 304	0 0	0 0	(106)	\$704	\$704	\$0
PLANNED TOTALS: PER MONTH		0	0	0	898	898	898	0	0	0	(352)	2,341		
ACTUAL TOTALS: PER MONTH		0	0	0	14	83	1,234	1,010	0	0	0		2,341	\$0
CUMULATIVE PLANNED TOTALS		0	0	0	898	1,795	2,693	2,693	2,693	2,693	2,341	\$2,341		
CUMULATIVE ACTUAL TOTALS		0	0	0	14	97	1,331	2,341	2,341	2,341	2,341		\$2,341	\$0
CUM BUDGET VARIANCE		\$0	\$0	\$0	\$883	\$1,698	\$1,362	\$352	\$352	\$352	\$0			

ADMINISTRATIVE BUDGETS

Dept. of Civil & Environmental Engineering - Administrative Budget

PRINCIPAL INVESTIGATOR: E. Cook

PROJECT: WVU General Administrative Budget

WVU Act. No.: 8527-229-3237

PRINCIPAL INVESTIGATOR: E.E. Cook

PERIOD ENDING: 9/30/95

DESCRIPTION	PLANNED ACTUAL	1 JAN	2 FEB	3 MARCH	4 APRIL	5 MAY	6 JUNE	7 JULY	8 AUG	9 SEPT	10 OCT	11 NOV	12 DEC	PROJECTED TOTALS	ACTUAL TOTALS	AMT Remaining
SALARIES																
Director	planned actual	2,084 2,002	2,084 2,002	2,084 2,002	2,084 2,002	2,084 2,128	2,084 2,280	2,084 2,250	2,084 2,128	2,084 2,005	2,084	2,084	2,084	\$25,000	\$18,767	\$6,237
Engineering Scientist	planned actual	666 0	666 0	666 639	666 666	666 666	666 666	666 666	666 666	666 666	666	666	666	\$7,997	\$4,636	\$3,462
Secretary	planned actual	833 666	833 666	833 666	833 666	833 666	833 666	833 721	833 721	833 721	833	833	833	\$9,999	\$6,099	\$3,900
BENEFITS (29% of Salaries)	planned actual	1,039 771	1,039 771	1,039 927	1,039 964	1,039 1,000	1,039 1,038	1,039 1,055	1,039 1,019	1,039 984	1,039	1,039	1,039	\$12,470	\$8,626	\$3,844
STUDENTS	planned actual	0 611	0 666	0 127	0 0	0 0	0 0	0 0	0 0	0 0	0	0	0	\$0	\$1,404	(\$1,404)
SUPPLIES	planned actual	1,125 0	1,125 12	1,125 421	1,500 120	1,125 325	1,125 410	1,125 622	1,500 279	1,125 90	1,125	1,125	1,125	\$18,500	\$2,179	\$11,321
TRAVEL	planned actual	0 0	250 0	250 0	250 0	250 0	250 0	250 0	250 1,782	250 0	250	250	250	\$2,500	\$1,782	\$718
EQUIP < 500	planned actual	0 0	150 0	150 601	150 0	150 0	150 0	150 185	150 0	150 0	150	150	150	\$1,500	\$687	\$813
EQUIP > 500	planned actual	0 0	0 0	8,000 6,642	0 0	0 0	12,000 0	0 0	0 1,609	0 0	0	0	0	\$10,000	\$8,251	\$1,749
INDIRECT COSTS (43% of direct cost *excl/ equip & sub)	planned actual	2,471 1,737	2,643 1,766	2,643 2,225	2,605 1,886	2,643 2,062	2,643 2,158	2,643 2,321	2,605 2,836	2,643 1,920	2,643	2,605	2,605	\$17,088	\$18,911	\$12,466
PLANNED TOTALS		8,219	8,791	16,791	9,327	8,791	10,791	9,791	9,327	8,791	8,791	8,791	8,791			
ACTUAL TOTALS: PER MONTH		5,777	5,873	14,040	6,303	6,825	7,176	7,720	11,040	6,386	0	0	0		\$71,140	\$43,206
CUMULATIVE																
PLANNED TOTALS		8,219	17,010	33,801	43,127	51,918	62,709	71,500	80,827	89,617	98,408	107,199	114,990			
CUMULATIVE ACTUAL TOTALS		5,777	11,650	25,690	31,993	38,818	45,994	53,714	64,754	71,140	71,140	71,140	71,140		\$71,140	\$43,206
CUMULATIVE BUDGET VARIANCE		\$2,442	\$5,360	\$8,111	\$11,134	\$13,100	\$16,715	\$17,785	\$16,073	\$18,478	\$27,268	\$36,598	\$43,206			

NRCCE ADMINISTRATIVE BUDGET

PRINCIPAL INVESTIGATOR: P. Ziemkiewicz

■ PLANNED SPENDING ♦ -- ACTUAL SPENDING

NOTE: This budget has been adjusted to reflect the change in administration from NRCCE to WVU Dept. of Civil & Environmental Engineering.

PROJECT: NRCCE ADMINISTRATIVE BUDGET

WVU Act. No.: 8527-224-1424

PRINCIPAL INVESTIGATOR: P. Ziemkiewicz

PERIOD ENDING: 9/30/95

DESCRIPTION	PLANNED ACTUAL	1 JAN	2 FEB	3 MARCH	4 APRIL	5 MAY	6 JUNE	7 JULY	8 AUG	9 SEPT	3 Mth Proj Oct - Dec.	Adj BUDGET Adjustments	PROJECTED TOTAL	ACTUAL TOTALS	AMT Remaining
SALARIES															
R. Lovette	planned actual	917 738	917 738	917 738	917 738	917 738	917 738	917 369	917 0	917 0	2,750	(6,208)	\$4,784	\$4,784	(\$0)
N. Reese	planned actual	1,267 1,232	1,267 1,232	1,267 1,232	1,267 1,232	1,267 1,232	1,267 1,234	1,267 652	1,267 0	1,267 0	3,800	(7,159)	\$8,043	\$8,043	(\$0)
P. Ziemkiewicz	planned actual	334 0	334 0	334 0	334 0	334 0	334 0	334 0	334 0	334 0	1,001	(4,008)	(\$0)	\$0	(\$0)
Staff	planned actual	541 0	541 0	541 0	541 726	541 726	541 0	541 0	541 0	541 0	1,624	(5,045)	\$1,451	\$1,451	(\$0)
BENEFITS (29% of Salaries)		887 571	887 571	887 571	887 781	887 781	887 572	887 286	887 0	887 0	2,661	(6,501)	\$4,144	\$4,144	\$0
SUPPLIES	planned actual	125 0	125 0	125 0	125 0	125 0	125 70	125 0	125 0	125 0	375	(1,430)	\$70	\$70	\$0
TRAVEL	planned actual	208 0	208 0	208 0	208 0	208 0	208 0	208 0	208 0	208 0	625	(2,500)	\$0	\$0	\$0
INDIRECT COSTS															
(43% of direct cost *exc/ equip & sub)	planned actual	1,840 1,092	1,840 1,092	1,840 1,092	1,840 1,495	1,840 1,495	1,840 1,123	1,840 566	1,840 0	1,840 0	5,520	(14,125)	\$7,956	\$7,956	\$0
PLANNED TOTALS PER MONTH		6,119	6,119	6,119	6,119	6,119	6,119	6,119	6,119	6,119	19,358	(46,973)			
ACTUAL TOTALS: PER MONTH		3,632	3,632	3,632	4,971	4,971	3,736	1,883	0	0	0	0	0	\$26,457	\$0
CUMULATIVE PLANNED TOTALS		6,119	12,239	18,358	24,477	30,596	36,715	42,835	48,954	55,074	74,431	26,457	26,457	26,457	
CUMULATIVE ACTUAL TOTALS		3,632	7,264	10,897	15,867	20,838	24,574	26,457	26,457	26,457	26,457	26,457	26,457	\$26,457	\$0
CUMULATIVE BUDGET VARIANCE		\$2,487	\$4,974	\$7,461	\$8,610	\$9,759	\$12,142	\$16,378	\$22,497	\$28,617	\$46,974	\$0	\$0	\$0	

NRCCE - CONFINEMENT ADMINISTRATION

PRINCIPAL INVESTIGATOR: C. Black

PROJECT: Confinement Administration

WVU Account No.: 8527-224-1425

PRINCIPAL INVESTIGATOR(S): Courtney Black

PERIOD ENDING: 9/30/95

DESCRIPTION	PLANNED ACTUAL	1 JAN	2 FEB	3 MARCH	4 APRIL	5 MAY	6 JUNE	7 JULY	8 AUG	9 SEPT	10 OCT	11 NOV	12 DEC	PROJECTED TOTALS	ACTUAL TOTALS	Amount Remaining
SALARIES																
Black	planned	1,239	1,239	1,239	1,239	1,239	1,239	1,239	1,239	1,239	1,239	1,239	1,239	\$14,700		
	actual	0	0	0	0	0	0	1,847	924	1,847					\$4,618	10,181
BENEFITS																
29% of Salaries	planned	358	358	358	358	358	358	358	358	358	358	358	358	\$4,292		
	actual	0	0	0	0	0	0	536	268	536	0	0	0		\$1,339	2,952
INDIRECT COSTS																
43% of expenses	planned	684	684	684	684	684	684	684	684	684	684	684	684	\$8,200		
	actual	0	0	0	0	0	0	1,025	513	1,025	0	0	0		\$2,562	5,647
PLANNED TOTALS PER MONTH																
		2,275	2,275	2,275	2,275	2,275	2,275	2,275	2,275	2,275	2,275	2,275	2,275	\$27,300		
ACTUAL TOTALS PER MONTH																
		0	0	0	0	0	0	3,407	1,705	3,407	0	0	0		\$8,519	18,781
CUMULATIVE PLANNED TOTALS																
		2,275	4,550	6,825	9,100	11,375	13,650	15,925	18,200	20,475	22,750	25,025	27,300	\$27,300		
CUMULATIVE ACTUAL TOTALS																
		0	0	0	0	0	0	3,407	5,112	8,519	8,519	8,519	8,519		\$8,519	18,781
UNDER BUDGET																
		\$2,275	\$4,550	\$6,825	\$9,100	\$11,375	\$13,650	\$12,518	\$13,088	\$11,956	\$14,231	\$16,506	\$18,781			

QUARTERLY TECHNICAL PROGRESS REPORTS

TASK 1.0
IN-SITU REMEDIATION
PROCESS DEVELOPMENT

SITE REMEDIATION TECHNOLOGIES

DRAIN-ENHANCED SOIL FLUSHING (DESF) FOR ORGANIC CONTAMINANTS REMOVAL

TASK 1.1

Quarterly Report XII for Period
July 1 through September 30, 1995

Work Performed Under Contract
No.:DE-FC21-92MC29467

For
U.S. Department of Energy
Office of Fossil Energy
Morgantown Energy Technology Center
Morgantown, West Virginia

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OCTOBER 1995

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1.0 INTRODUCTION

This project researches the use of Prefabricated Vertical Drain (PVD) systems for remediation of contaminated sites with fine grained soils. PVD systems are relatively simple in operation and installation. They require no drilling rig equipment and are expected to significantly reduce remediation costs while at the same time increase the efficiency of the remediation effort.

The use of PVDs in the current state of practice has been in the area of soil improvement. Other than the work performed in the first phase of this project, no research work has been conducted to investigate the feasibility of using PVDs for soil flushing.

2.0 PURPOSE

The main objective of this research phase is to investigate major parameters influencing the efficiency of contaminant extraction using PVD systems. Research focused on conducting bench-scale tests with soils for simulation of in situ conditions. Specific objectives are as follows:

1. a) Development of the effective diameter for in situ characterization of the PVDs; b) Effect of smear and well resistance on the hydraulic efficiency of the PVDs, and c) Effect of the method of installation on the recovery efficiency of the PVD system.
2. Full development and Beta testing of the PVDs' contaminant transport model developed in Phase I.
3. Field demonstration program and testing, cost analysis, and performance of the recovery process using the PVDs.

3.0 BACKGROUND

The PVD system is used to shorten the drainage path of the groundwater flow and therefore promote subsurface liquid movement and expedite the soil flushing process in low permeability soils. Proved technologies exist for the in situ soil flushing for sites with granular soils (hydraulic conductivity approximately 1×10^{-2} cm/s). However in the case of sites where the soil is predominantly clay with corresponding hydraulic conductivity ranging 1×10^{-3} to 1×10^{-7} cm/s, implementation of the traditional soil flushing technology is ineffective and cost prohibitive.

In the previous phase of this project progress was advanced along the following three fronts:

1. Contaminant and Soil Characterization: A study soil was developed and categorized in accordance with ASTM standards. The testing program included column and batch studies on contaminated soils with the study surfactant being anionic aqueous solution of sodium dodecylsulfate.
2. Injection/Extraction Flushing Concept: Several pilot scale Contaminant Recovery Cells (CRCs) were used to evaluate the flow characteristics of the soils sampled and the concept of using PVDs. Soil samples were prepared in the CRCs and PVDs were installed in rectangular and circular configurations.
3. A predictive model for PVD enhanced soil flushing was developed. The model was developed assuming full saturation and no diffusion or decay. Parameter studies were performed to predict soil flushing rates using a PVD system.

4.0 WORK PERFORMED THIS PERIOD

Work performed during this reporting period included the following tasks:

1. Continued experimentation on the Effective Diameter and Smear Effects.
2. Experimentation on the influence of PVD layout on chloride capture efficiency.
3. Set-up for the PVD Head Loss experiment.

During this reporting period, for the Smear Effects and Contaminant Recovery experiments the study soil was changed from a 100% Ottawa sand to a mix of 80% Ottawa sand and 20% Kaolinite soil. A detailed report covering the work for this period is contained in Attachment A.

5.0 CONCLUSIONS: The results of the experiments are contained in Attachment A.

6.0 WORK PLANNED FOR NEXT PERIOD:

The following tasks are planned for the next reporting period.

1. Development of the draft Site Demonstration proposal.
2. Continue testing with 80/20 study soils.
3. Begin testing for the PVD Head Loss experiment.

ATTACHMENT A

TOPICAL REPORT

for

CHARACTERISTICS and PERFORMANCE

of PREFABRICATED VERTICAL DRAINS

for ENHANCED SOIL FLUSHING

ABSTRACT

The innovative concept of using prefabricated vertical drains (PVD) for remediation of contaminated sites where fine-grained soils are present is examined. The use of PVD under vacuum conditions for soil flushing and remediation is investigated in study soils of 100% sand and a 80% sand/20% clay mixture. Data related to the performance of the PVD system for soil flushing are obtained from pilot-scale testing. Results show that for a 80% sand/20% clay, the areal extent of the zone of influence remained at approximately 15 cm or 30 times the effective diameter of the drain as the extraction vacuum increased from 2.48 kPa to 14.92 kPa. No such behavior was observed for the 100% sand specimens. A contaminant transport model developed for the PVD flushing system is verified using experimental data. Verification of the contaminant transport model showed favorable results in comparison with laboratory data using a 100% sand soil at unit weights of 1.57 and 1.67 g/cm³. The model predicted contaminant clean-up times that were consistent with actual experiment results for variations in soil properties, flushing flow rates, and dispersivity values. The experimental program is described in detail and results are presented and discussed.

INTRODUCTION

There are a number of approaches to in situ remediation of contaminated soil whereby contaminants are removed without excavating the soil. These include soil flushing, dual phase extraction, soil vapor extraction, and bioremediation. Of these techniques, soil flushing is the focus of the investigation in this research. Soil flushing is a treatment technology that is used to flush-out contaminated soils beneath the ground surface with the aid of solutions. The technology uses drilled injection and extraction wells located within the contaminated zone. Pumping equipment is used to inject a flushing solution under a positive pressure into the injection wells. The solution permeates through the contaminated soil, desorbing and mobilizing the contaminants towards the extraction wells. The extraction wells are used to collect the contaminated groundwater where it is removed for subsequent treatment. This technology is illustrated in Figure #1 (1).

In the case of fine-grained soils that are electrochemically and non-electrochemically active, both the extraction of the contaminant from the soil and movement of the flushing solution are less than that observed for the relatively inert large grained soils (i.e., coarse sands). In the former case, both the extraction of the contaminant from the soil and movement of the flushing solution are restricted due to the low permeability and adsorption characteristics of the fine-grained soils. Conventional soil flushing is not always effective for remediating contaminated soils in this case and the use of "pump and treat systems" on long term basis is often required.

The purpose of this research effort is to study the use of PVD, a typical cross-section is shown in Figure #2, as a viable and cost effective remediation method at contaminated sites having fine-grained soils.

Many challenges need to be addressed before the successful implementation of this technology in a field application. Research in this paper addresses two key issues related to the use of PVDs in soil flushing: 1) characterization of the PVD zone of influence, and 2) use of pilot-scale test results to verify the contaminant transport model developed for the PVD enhanced soil flushing process. Verification of the contaminant transport model will be performed using data obtained from the CRC pilot-scale testing. The tests were designed to obtain data for the development of optimum PVD field installation configurations for contaminant recovery. Resource constraints prohibit the experimental evaluation of the proposed approach under all geochemical and physical conditions. Given a particular physical configuration (i.e.; number and placement of drains, hydraulic and chemical loadings) data will be obtained and compared to model predictions of the contaminant transport occurring within the soil.

PVD CONCEPT

The idea behind using the PVD system is to shorten the drainage path of the groundwater flow and promote subsurface liquid movement which expedites the soil flushing process. The application concept incorporates the PVDs as a component in the "treatment-train" of the flushing process. The PVDs in this case are used for injection of a flushing solution into the in situ soil and groundwater, and for the removal and treatment of the contaminated flushing solution.

Figure #3 shows a conceptual layout of a field installation using a triangular grid with alternating off-set rows of injection and extraction PVDs. The PVDs are tied into collector piping for application of the vacuum and introduction of the flushing fluid. After installation of the PVDs and collector piping, the entire site is covered with a flexible pvc sheeting to minimize air infiltration and vacuum losses. The in situ soil is intended to be maintained in a saturated condition for minimizing soil compression (consolidation) and the corresponding reduction in hydraulic conductivity.

In comparison with conventional well fields and drains, the use of Prefabricated Vertical Drains may expedite the contaminant recovery and reduce both labor and material costs. Installation of the PVD system is relatively simple and inexpensive with no drilling required, and the fluid extraction process may prove to be practical and cost effective.

The PVD is constructed of a composite system consisting of a inner core and an outer filter jacket. Figure #2 shows a typical PVD which measures 100 mm in width x 4 mm in thickness. The flexible core is constructed of extruded polypropylene with formed flow path grooves on both sides along its length. The jacket serves as an outer skin to maintain the core's cross-sectional shape and hydraulic capacity of the flow path grooves. The jacket is constructed of a durable, non-woven polypropylene geotextile which functions as a filter to allow passage of groundwater into the drain core while preventing piping of fines from the adjoining soil.

PVD ZONE OF INFLUENCE

Evaluation of the zone of influence is critical for the field design of the PVD flushing system. Past developments of the PVD zone of influence were based on the consolidation theory where the consolidation rate was found to be proportional the square of the drainage path. The drainage path was represented by a circular cylindrical soil column having the same length as the PVD, see Figure #4, where d_c = PVD zone of influence. The cylinder contains a set volume of soil and water, assuming fully saturated conditions (zero air voids). The water within this cylinder was to be removed, applying surface surcharge for squeezing the water through the drains (2).

Past analysis for evaluating PVDs focused on consolidation and accelerating the rate of settlement in soft soils. Contrary to soil improvement applications, inducing a volume change in the case of soil flushing is undesirable since such action will retard the movement of the subsurface liquid.

The usual layout patterns are either a square or triangular arrangement. For this research, a triangular layout was selected as shown in Figure #5. This layout pattern optimizes the area covered to minimize contaminated zones where the flushing fluid would not penetrate. By overlapping the zones of influence for the injection and extraction PVDs, complete coverage of the right of way is possible.

CONTAMINANT TRANSPORT MODEL

Work by Gabr et. al(3) dealt with the feasibility and efficiency of liquid extraction using a vacuum enhanced PVD injection and extraction system. Gabr investigated PVD performance on bench-scale and pilot-scale levels. The pilot-scale experimentation included testing PVD extraction systems using soil specimens measuring 0.67m x 0.67m x 1.0m, (width/depth /length). The testing apparatus was termed a Contaminant Recovery Cell (CRC) and is shown in Figure #6.

The Contaminant Transport Model developed by Gabr et al.(3) is a tool to predict the efficiency of contaminant recovery and fluid migration in soil using the PVD enhanced system. The model was developed assuming axisymmetric conditions to approximate the three dimensional flushing process. The model accounts for

advection with miscible transport having provisions for dispersion, and adsorption/desorption processes. The model is only applicable to transport.

The final form of the contaminant transport model developed by Gabr et al.(3) is as follows:

$$\frac{C(z,r,t)}{C_0} = \frac{1}{2} \left[\operatorname{erf}\left(\frac{T_z+1}{2\sqrt{T_z/P_z}}\right) - \operatorname{erf}\left(\frac{T_z-1}{2\sqrt{T_z/P_z}}\right) \right] \operatorname{erfc}\left(\frac{3M_r N_r}{8\pi R_d}\right) \quad (1)$$

where:

$$T_z = \frac{v_z t}{nR_d z} \quad (2)$$

$$P_z = \frac{z}{\alpha_z} \quad (3)$$

$$M_r = \frac{Q_0 t}{(r-r_0)^3} \quad (4)$$

$$N_r = \frac{\alpha_r r^2}{nH(r-r_0)^2} \quad (5)$$

and the retardation factor is expressed as:

$$R_d = 1 + \frac{\phi K_d}{n} \quad (6)$$

EXPERIMENTAL PROGRAM

MATERIALS

PVD: The PVDs used were fabricated with final measurements of 2.54 cm wide x 4 mm thick. Table 1 shows the manufacturer's product specifications for the PVDs used in this study.

Soil: Two study soils were used: 1) 100% Ottawa sand, and 2) a 80% Ottawa sand and 20% Kaolin mix. The Ottawa sand was obtained from the U.S. Silica Company, Ottawa, IL, and the Kaolin was DB Float supplied from the Georgia Kaolin Company, New Jersey. The Ottawa sand showed a uniform grain size distribution between 1.0 and 0.1 mm, with 90% passing a #20 sieve, and the Kaolin showed a grain size distribution between 0.01 and 0.001 mm (3).

ZONE OF INFLUENCE TESTS

The testing apparatus used for determining the PVD zone of influence was termed a Smear Cell and is shown schematically in Figures #7 (cross-section) and #8 (plan). For this testing, the PVDs were held in place within the cells prior to the placement of the study soil. This method of locating the PVDs prior to placing the soil was intended to eliminate the soil disturbance effect, either smear for the clay mix or densification for the sand.

Preparation of the Smear Cell using 100% Ottawa sand consisted of the following steps which were performed on duplicate samples: 1) the PVD was secured to the bottom center of the Smear Cell; 2) a sand raining device was used to place the sand around the PVD, the device was held at 40 cm above the soil; 3) between each lift, the sand was densified by dropping a standard proctor hammer 25 times onto a plywood plate (42 cm in diameter x 1.9 cm thick); and 4) The actual soil density was computed from information recorded on the weight of each soil lift and final height of the soil in the Smear Cell.

For preparation of the 80% Ottawa sand / 20% Kaolin mix, the procedure was similar with the exception that the soil was placed in 10.5 cm lifts and compacted using a 8.76 kg weight, dropped 50 times from a 61 cm height. The sample properties are shown in Table #2, where e = void ratio, n = porosity, D_r = relative density, and k = hydraulic conductivity.

After construction of the soil/PVD specimen, piezometers were installed at the locations shown in Figure #8. The soil surface was covered with a plastic barrier to minimize vacuum losses and prevent short-circuiting. The fluid in the Smear Cell was extracted through the PVD using a vacuum line inserted in the first 4 cm of the PVD core; the PVD was sealed at the top with silicone and duct tape. All PVDs were fabricated with closed end bottoms.

The vacuum was supplied via a cyclone set-up that was regulated using a valve and pressure control panel system. The Smear Cell was under a constant head and had a water injection supply located at its perimeter. After the vacuum was applied, the drawdown was recorded by use of an ohm-meter. The ohm-meter leads were used to measure the elevation of the piezometers from an established datum.

CRC TESTS

Two series of tracer tests were performed in the CRC's using 100% Ottawa sand. The samples were constructed with a sand raining device for soil placement. For the CRC having a dry density of 1.57 g/cm^3 , the sand was rained maintaining a constant height between the raining device and sand surface of 20 cm; and for a dry density of 1.67 g/cm^3 , the sand was rained at a height of 61 cm. Table 3 lists the soil properties obtained from the CRCs for this testing. All experiments were performed under a constant temperature of 27° Celsius . The PVDs were arranged in the CRC's in off-set rows as shown in Figures #5 & #6; where the center row used two PVDs for fluid injection and six perimeter PVDs for the fluid extraction.

The Contaminant Recovery Cells (CRC) used a 100 and 1,000 mg/l sodium chloride (NaCl) tracer for verifying the contaminant transport model. The experimental procedure was to first saturate the soil with the desired tracer concentration. Next, potable water was injected into the center two PVDs and vacuum pressure was applied to the six perimeter PVDs. Grab samples of the sodium chloride tracer were taken from the extracted fluid during set time increments for subsequent chemical analysis.

The grab samples were analyzed for chloride ion concentration using a standard chloride ion probe. Chloride ion standards were prepared from known concentrations in order to obtain the ion

concentration from the milli-volt readings for each sample.

RESULTS & DISCUSSION

ZONE OF INFLUENCE

100% Sand: Figure #9 shows the average fluid drawdown versus piezometer spacing distance for various extraction vacuum pressures at constant head conditions. The data are averages of the 3, 6, 9, and 12 minute drawdowns for the indicated vacuum pressure. For piezometer 1-4, a comparison of the 2.48 kPa vacuum with the 19.0 kPa vacuum shows that as the vacuum increases, the quantity of extracted fluid increases, the drawdown between PVD 1 and PVD 4 is the same at approximately 13 cm. A prominent drawdown is evident for piezometers 5-8 and 13-16, but not for piezometers 9-12. This may indicate a non-uniform distribution of the vacuum within the PVD zone of influence may have existed. Figure #10 is a graph of the extracted fluid flow rate plotted versus time for the baseline sand. The plot shows the extracted flowrate varied less than 1 ml/s for the 19.0 kPa vacuum pressures over the testing duration of 12 minutes, and that the PVD developed approximately a constant extraction rate of 8.5 ml/s for the 2.48 kPa vacuum pressure.

80%Sand/20%Kaolin Mix: Figure #11 shows a graph of the average fluid drawdown versus piezometer spacing distance for various extraction vacuum pressures at constant head conditions. The data are averages of the 3, 6, 9, and 12 minute drawdowns for the indicated vacuum pressure. This plot shows the clear development of a cone of depression which was not as easily observed for the baseline 100% sand. This observation may be explained in the difference in hydraulic conductivity (k) between the two soils, where for the sand k was approximately 4×10^{-2} cm/s, compared with the 80/20 mix where k was approximately 1×10^{-4} cm/s. The difference in k may have produced sufficient resistance to fluid flow to develop the cone of depression.

Surface contours are shown in Figure #12 for the two different vacuum pressures. The areal extent of the cone of depression appears to increase slightly as the vacuum is distributed throughout the test cell. This is evidenced from Figure 12(a) where the zone of influence extends approximately 10 cm on the +Y axis at a vacuum pressure of 2.48 kPa compared with over a 20 cm

distance on the same axis for a vacuum pressure of 14.92 kPa. This is compared with the retrieved flow rate which increases significantly from approximately 3.9 ml/s at 2.48 kPa to approximately 6.4 ml/s at 14.92 kPa over the 12 minute interval.

From Figure #12, it appears that there may not be significant benefit with increasing the vacuum beyond the desired depth of the fluid to be extracted (PVD embedment depth), because the zone of influence does not correspondingly increase as the vacuum is increased. This is evidenced by the zone of influence remaining between 15 to 20 cm on the +X axis, and at an approximately constant value of 15 cm on -Y axis.

Figure #13 is a graph of the extracted fluid flow rate plotted versus time for the 80/20 mix. This plot shows that after the vacuum is distributed throughout the cell, the extracted flowrate varies with less than 0.5 ml/s at a vacuum of 14.92 kPa for the 12 minute duration. This variation was less than approximately 0.25 ml/s at 2.48 kPa for the same time period. This observation of the initial distribution of the vacuum pressure within the cell is consistent with that occurring in the baseline sand. This plot shows that there is no significant reduction in flowrate as evidenced by the small fluctuations in the extraction rates for each of the associated vacuum pressures, supporting the requirement that maintaining soil saturation using the PVDs is feasible in order to minimize compression of the soil sample.

CONTAMINANT TRANSPORT MODEL VERIFICATION

Application of the PVD Contaminant Transport Model was performed using the soil parameters and contaminant (tracer) properties from the CRC pilot-scale testing. These parameters are listed in Table 4.

The value of the Partition Coefficient was $K_d = 1 \times 10^{-6} \text{ m}^3/\text{Kg}$, based on the non-reactivity of the Ottawa sand for absorption of the Na^+ ion. This value produced a retardation factor (R_d) of 1.00. Shackelford and Redmond (5) report a value of $2.4 \times 10^{-3} \text{ m}^3/\text{Kg}$ for the Na^+ ion in a study soil consisting of 100% Kaolin.

An equation for the Cl^- ion concentration as a function of the detected Cl^- ion millivolt reading was developed and used to determine the Cl^- ion concentration in ppm units for the extracted samples. The Cl^- ion concentrations were divided by

the initial concentration (C/C_0) and plotted versus the sampling time increment. Graphs of Extracted Cumulative Volume versus Time and C/C_0 versus Time are shown in Figures #14, and Figures #15 through #18, respectively.

Figure #14 is a graph of the Extracted Cumulative Volume versus Time for each of the extraction PVDs associated with Figure #15. This graph shows a consistently increasing flow occurring during the test and flowrates used to determine Q_0 and V_z for input into the model.

The data for Figures #15 through #18, show the chloride ion concentration obtained from the pilot-scale experiments as symbols and the lines are the results of the concentration ratio (C/C_0) computed by the contaminant transport model. These figures were developed for various values of the radial and vertical dispersivity coefficients (α_r, α_z): (0.10, 0.01), (0.30, 0.03), and (0.50, 0.05). An order of magnitude difference of 10 was assumed between the dispersivity coefficients. This difference takes into consideration a larger dispersivity of the tracer occurring in the direction of the fluid flow paths, and less dispersivity perpendicular to the flow paths.

Figures #15 through #17, show favorable results predicted by the model for values of $\alpha_r=0.30$ and 0.50, with corresponding $\alpha_z=0.03$ and 0.05. While Figure #18 shows a best curve fit using $\alpha_r=0.10$ and 0.30, with corresponding $\alpha_z=0.01$ and 0.03. The model shows the significant influences between the fluid flowrates and velocities with changes in the soil's properties and corresponding dispersivity. This is evidenced where the higher dispersivity values ($\alpha_r=0.30$ and 0.50, with $\alpha_z=0.03$ and 0.05) in Figure #16 ($V_z=0.167$ m/hr and $Q_0=0.012$ m³/hr) showed the best fit compared with the lower dispersivity values ($\alpha_r=0.10$ and 0.30, with $\alpha_z=0.01$ and 0.03) for the larger fluid velocity ($V_z=0.468$ m/hr and $Q_0=0.03$ m³/hr) shown in Figure #18. Both of these experiments were performed at a tracer concentration of 1,000 ppm NaCl.

SUMMARY & CONCLUSIONS

Characterization of the PVD Zone of Influence for two study soils was performed. Based on the experiment results and model predictions, the following conclusions may be drawn:

- 1) No significant benefit was observed when increasing the vacuum beyond the desired depth of the fluid to be extracted (PVD embedment depth), because the zone of influence does not correspondingly increase as the vacuum is increased. As shown in Figure 12(a) where the zone of influence extends approximately 10 cm on the +Y axis at a vacuum pressure of 2.48 kPa compared with over a 20 cm distance on the same axis for a vacuum pressure of 14.92 kPa. This is compared with the drawdown which increases significantly from approximately 3.9 ml/s at 2.48 kPa to approximately 6.4 ml/s at 14.92 kPa over the 12 minute interval.
- 2) Under approximately constant vacuum pressures the PVDs maintained steady extraction flow rates for two different soils. Figure #10 shows the extracted flowrate for sand varied less than 1 ml/s for the 19.0 kPa vacuum pressures over the testing duration, and that the PVD developed approximately a constant extraction rate of 8.5 ml/s for the 2.48 kPa vacuum pressure. Similarly for the 80/20 mix, Figure #13 shows the vacuum is distributed throughout the cell and the extracted flowrate varies less than 0.5 ml/s at a vacuum of 14.92 kPa for the 12 minute duration, and less than approximately 0.25 ml/s at 2.48 kPa for the same time period.
- 3) The Contaminant Transport Model accurately reflected the influences of higher fluid flushing flowrates, velocities, and soil properties on the dispersivity. This is evidenced where the higher dispersivity values ($\alpha_x=0.30$ and 0.50 , with $\alpha_z=0.03$ and 0.05) in Figure #16 ($V_z=0.167$ m/hr, $Q_o=0.012$ m³/hr) showed the best fit; Compared with the lower dispersivity values ($\alpha_x=0.10$ and 0.30 , with $\alpha_z=0.01$ and 0.03) for the larger fluid velocity ($V_z=0.468$ m/hr, $Q_o=0.03$ m³/hr) shown in Figure #18.

- 4) The model showed contaminant clean-up times consistent with the results from the lab testing. This is shown in Figure #15 where the tracer was removed from the CRC in approximately 49 minutes, and the model predicted clean-up time of 47 minutes with $\alpha_x=0.30$ and $\alpha_z=0.03$; and a clean-up time of 39 minutes with $\alpha_x=0.50$ and $\alpha_z=0.05$.

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REFERENCES

1. US EPA (1992) A Citizen's Guide to In Situ Soil Flushing, U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, EPA/542/F-92/007.
2. Hansbo, S., *Ground Engineering*, Vol. 12, No. 5, July 1979, pp. 16-25.
3. M.A. Gabr, J.J. Bowders, J. Wang, and J. Quaranta. In Situ Soil Flushing Using Prefabricated Vertical Drains. *Canadian Geotechnical Journal*, To be published in February 1996 issue.
4. MEBRA Wick Drain Product Literature, NILEX Corporation, Englewood, CO. 1993. Personal communication
5. Shackelford C.D. and Redmond, P.L. (1995) "Solute Breakthrough Curves for Processed Kaolin at Low Flow Rates.", *J. Geotech. Engrg.*, ASCE, 121(1), 17-32.

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Table 1	PVD Properties
Table 2	Smear Cell Soil Properties
Table 3	CRC Soil Properties
Table 4	Model Parameters

Table 1 - PVD Properties

Property	Reference	Value
Drain body material (MD-88)	Product Information ^a	Polypropylene
Filter material	Product Information ^a	Polypropylene
Pore Size Opening	Product Information ^a	0.110
AOS (Sieve #)	Product Information ^a	120/140
Filter Permeability	Product Information ^a	0.45

^a NILEX MEBRA® WICK DRAIN, Nixel Corp. Englewood, CO (4)

Table 2 - Smear Cell Soil Properties

Soil Specimen	Dry Density (γ_d), g/cm ³	Moisture Content (w)	e	n	D_r	k cm/s
100% Sand	1.72		0.54	0.35	79%	4×10^{-2}
80% / 20% mix	1.74	5%	0.52	0.34		1×10^{-4}

Table 3 CRC Soil Properties

CRC #	Dry Density	k (cm/s) (in situ)	e	n
1	1.68 g/cm ³	6.88 x 10 ⁻²	0.57	0.37
2	1.57 g/cm ³	4.14 x 10 ⁻²	0.69	0.41

Table 4 - Model Parameters

Figure #	C_o (mg/L)	H m	n	ρ_b Kg/m ³	V_z m/hr	K_d m ³ /Kg	Q_o m ³ /hr
15	100	0.457	0.37	1670	0.308	$1 \cdot 10^{-6}$	0.02
16	1000	0.457	0.41	1570	0.167	$1 \cdot 10^{-6}$	0.012
17	100	0.457	0.41	1570	0.208	$1 \cdot 10^{-6}$	0.015
18	1000	0.457	0.37	1670	0.468	$1 \cdot 10^{-6}$	0.03

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Figure #8: Smear Cell - Plan View

NOTE:

① PIEZOMETER NUMBER TYP.

TYPICAL PIEZOMETER:
0.476 cm I.D. TYP.

Figure #9:

**Average Drawdown for 3, 6, 9, and 12 Minutes
vs. Piezometer Distances for Various Vacuum
Pressures on 100% Ottawa Sand ($\gamma_d = 1.72 \text{ g/cm}^3$)**

Figure #10: PVD Flowrate vs. Time for Various Vacuum Pressures
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(a)

(b)

Figure #13: PVD Flowrate vs. Time for Various Vacuum Pressures
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SITE REMEDIATION TECHNOLOGIES
IN SITU BIOREMEDIATION OF ORGANIC CONTAMINANTS
METC TASK No. 1.2

Quarterly Technical Progress Report
for Period July 1 through September 30, 1995

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Abstract

In situ bioremediation offers a number of advantages over other processes for destruction of organics in groundwater. Advantages include the potential for complete or near complete destruction of contaminants in place, avoidance of transfer of pollutants to another medium, less risk of health hazards due to human exposure and cost-effectiveness in many cases. This research seeks to exploit the natural symbiotic relationship between methanogenic and methanotropic microorganisms. The methanogens are able to carry out the anaerobic reductive dehalogenation (RD) of highly chlorinated solvents producing methane. The methanotrophs, in turn, utilize the end products of the methanogens, including methane, to aerobically degrade the residual compounds to environmentally acceptable end products. Both groups of organisms work cometabolically and require a primary substrate.

The project is divided into two main tasks and a number of subtasks. Under task 1, controlled testing will be performed in columns to find optimum conditions for the complete mineralization of trichloroethylene (TCE) to innocuous end products. Columns will be set up to examine both sequential and simultaneous mineralization. In the sequential columns, RD will be accomplished first with conditions that favor methanogens followed by aerobic conditions that favor methanotrophs. In the simultaneous column, an attempt will be made to set up conditions which promote anaerobic microzones within the columns so that RD and aerobic oxidation take place almost continuously along the column. It is planned to use hydrogen peroxide as an electron acceptor for the methanotrophs.

In task 2, delivery of amendments (such as the primary substrate and electron acceptor) to low permeability soils using prefabricated wick drains (PVD's) will be evaluated using a box lysimeter. Use of wick drains for delivery of amendments and possible ground water recirculation is a unique application of this technology and offers significant improvement over existing methods which require a large number of wells in "tight" soils.

Executive Summary

In situ bioremediation offers a number of advantages over other processes for destruction of organics in groundwater. Advantages include the potential for complete or near complete destruction of contaminants in place, avoidance of transfer of the pollutants to another medium, less risk of health hazards due to human exposure and cost-effectiveness in many cases. The objective of this research is to evaluate and optimize the ability of methanotrophic, methanogenic, and other selected bacteria for cost-effective biotransformation of a mixture of chlorinated solvents as are often found at DOE sites. A five phase workplan is utilized which involves the systematic manipulation of environmental conditions to enhance the rate and extent of biodegradation of the candidate VOC's. It is planned to take advantage of the natural symbiotic relationship between the methanogenic and methanotrophic bacteria so as to promote sequential anaerobic/aerobic mineralization of the chlorinated solvents.

The anaerobic and aerobic columns were joined together near the end of last the quarter with the aerobic column receiving the effluent from the anaerobic column and continued to operate during this quarter. First, the effect of reducing agents was investigated from 7/1 to 9/13. As the quarter began, only L-cysteine at a concentration of 5 mg/L was added to the groundwater feed. Later, on July 21, 1995, sodium sulfide at a concentration of 20 mg/L ($\text{Na}_2\text{S} \cdot 9\text{H}_2\text{O}$) was also added to the feed. Overall TCE removal increased by 34.6% (from 32.8 to 44.2 %). An increase in daughter product formation was also noted. Cis-DCE increased by 29.2%, trans-DCE by 8.7%, 1,1-DCE by 19.8%, and VC by 53.3%. The changes in daughter products were more pronounced towards the end of this period. On August 11, the $\text{Na}_2\text{S} \cdot 9\text{H}_2\text{O}$ was increased from 20 to 25 mg/L, while the L-cysteine was increased from 5 to 25 mg/L. As a result, the percent removal of TCE increased by 11.21% (from 44 to 49 %). A very significant increase in the formation of daughter products was observed. Cis-DCE increased from 33.8 to 112.4 ug/L (233 %). The concentrations of the other DP's also greatly increased as follows: trans-DCE by 188.7%, 1,1-DCE by 4.32%, and VC by 280.3%. However, the increase in $\text{Na}_2\text{S} \cdot 9\text{H}_2\text{O}$ concentration caused a decrease in the redox potential (ORP) in both the anaerobic and aerobic sections of the column. The ORP value in the aerobic bottom port decreased to -26.4 mV and the dissolved oxygen (DO) concentration fell to 0 mg/L. The DO had been holding about 1 to 2 mg/L in the aerobic portion of the column. To raise the DO concentration and keep methanotroph activity, the hydrogen peroxide (H_2O_2) concentration was increased from 75 mg/L to 85 mg/L on August 25. The addition of 85 mg/L of H_2O_2 made only a slight improvement in the DO from 0 to 0.93 mg/L. The H_2O_2 concentration was further increased to 150 mg/L on September 6 which resulted in an effluent DO concentration of 2 mg/L. In addition, the effect of elevated TCE concentration was also investigated. In the anaerobic column, the TCE concentration was increased from 5 to a target level of 25 mg/L to study the extent of dehalogenation occurring under elevated TCE concentration. It may be seen that TCE removal reached 56 % (had been about 49 % at the 5 mg/L TCE feed. It should also be noted that a small concentration of Vitamin B-12 was added to the groundwater on 9/3 and may have contributed somewhat to the increased TCE removal. The production of daughter products was increased significantly when the TCE concentration was increased. The following increases in DP's were noted: cis-DCE; from 112 to 245 ug/L (up 54 %), trans-DCE; from 32 to 59 ug/L (up 46 %), 1,1-DCE; from 43 to 70 ug/L (up 39 %), and from 65 to 72 ug/L (up 11 %) for the VC. As the TCE level was increased, the ORP became less negative and fell from -198 mV to about -100 mV (Table 6). This was possibly due to the highly oxidized nature of the TCE molecule.

A 24-inch simultaneous column was setup near the end of the previous quarter. The feed has the same groundwater composition as for the sequential column experiment and the influent TCE concentration was maintained at 5mg/L throughout the quarter. An integrity test was performed from August 10-23 to ensure no leaks in

the column. The test was stopped on August 23 when more than 95% of the influent TCE was recovered at the effluent port. The column was inoculated with 420mL (one pore volume) of anaerobic bacteria from the maintenance reactor effluent from August 23-25. Almost immediately after the inoculation, traces of the daughter products (VC, 1,1-, and cis-DCE) were detected. After ensuring substantial anaerobic bacterial growth, a concentration of 25mg/L of H_2O_2 was added at different locations in the column to create oxidative conditions prior to the addition of methanotrophs. On September 12 the column was inoculated with 330 mL of methanotrophs and the H_2O_2 concentration was increased to 50mg/L. It can be seen that as methanotrophs were added, the mass flowrate of DPs dropped up the column indicating that the methanotrophs are removing the DPs. It will take some time to adjust the column so as to optimize the symbiotic activity desired. It may be seen that H_2O_2 is added just before ports 3 and 5. Hence, it is planned to encourage methanotrophs at in these areas. Thus, anaerobic growth will take place at the beginning of the column (from port 1 to where the peroxide is put in just below port 3) with RD. Anaerobic activity is again encourage in the region between ports 3 and 5 after the added oxygen (peroxide) has been used up to some extent. Aerobic activity will be encouraged in the two zones above the H_2O_2 addition and the effluent should leave with a positive dissolved oxygen concentration at port 7. While the column is still in a period of adjustment and it is too soon to make any conclusions, it may be noted that total organic carbon removal is taking place as expected. It may also be noted that the ORP generally becomes more positive after H_2O_2 addition just below ports 3 and 5.

The lysimeter has been constructed and is running. The purpose of the lysimeter is to evaluate prefabricated vertical drains (PVD's) for delivery of ammendments and to evaluate potential clogging of the drains. Data has not yet been collected. The present lysimeter is operating in an aerobic mode. It is innoculated with activated sludge from the aeration basin of the Morgantown WWTP. The lysimeter has a one-inch wide prefabricated vertical drain (PVD) for nutrient and ground water delivery. The system is being fed with brain heart infusion (BHI) media which is an excellent and complete growth media at an initial concentration of 20 mg/L. Six liters are made up daily and added to a sump (6-L flask). The solution is pumped from there with a peristaltic pump into a constant head tank. This tank can be moved up or down depending on the needed head. The pump is set-up to pump 4 mL/min to the tank while the lysimeter is fed at an initial rate of about 3.47 ml/min (5 L/d). The excess flow simply overflows back to the feed sump. At the bottom of the tank there is a clamp in order to control flow. Eighteen piezometers are located in the lysimeter to monitor the clogging in the PVD due to bacteria growth. Water elevation in the piezometers will be evaluated using an ohm meter.

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1.0 INTRODUCTION

A variety of toxic organic contaminants are found at DOE sites including fuel hydrocarbons, polychlorinated biphenyls (PCB's) and volatile organic solvents such as trichloroethylene (TCE), perchloroethylene, and carbon tetrachloride. These compounds may occur as single contaminants, but are often found in conjunction with heavy metals or in mixed wastes containing radioactive components.

In-situ bioremediation has a number of advantages for destruction of organic contaminants in groundwater. Other processes such as sorption and volatilization do not destroy contaminants, but rather just concentrate them or transfer them to another medium. Abiotic (chemical) transformation is not normally cost-effective in groundwaters and may even result in production of more toxic chemical species.

Clean-up methods often involve soil flushing to mobilize the contaminants for transport to the surface for treatment. However, because many organic contaminants sorb to soils, they are not readily leached from the soils often leaving toxic residuals in place even after flushing. Furthermore, bringing the contaminants to the surface increases the risk of health hazards due to human exposure. There is increasing recognition that bacteria are present and active in the subsurface and that *in situ* biotransformation offers a potentially more effective and economical method of contaminant destruction.

2.0 PURPOSE

The purpose of the research is to evaluate and optimize the ability of methanotrophic, methanogenic, and other selected bacteria for cost-effective biotransformation of TCE and other volatile organic compounds (VOC's) found at DOE sites. The approach outlined involves the systematic manipulation of environmental conditions in the subsurface for the purpose of enhancing the rate and extent of biodegradation of candidate (VOC's). This approach takes advantage of the ubiquity of methanotrophic and methanogenic bacteria and introduction of non-native organisms should not be necessary. Also, only relatively benign enhancing compounds will be added in non-toxic concentrations. It is envisioned to take advantage of the natural symbiotic relationship between the methanogenic and methanotrophic bacteria so as to promote sequential anaerobic/aerobic mineralization of the chlorinated solvent contaminants.

3.0 BACKGROUND

A number of exciting developments are occurring in the field of environmental biotechnology (engineering applications of microbial ecology). For example, while trace concentrations of some organic contaminants cannot support microbial growth as the sole electron donor, they can still be biotransformed by engineering the system so that the microbial population obtains the majority of its energy and carbon from a different compound that serves as the primary substrate. This is sometimes referred to as *secondary utilization*. There are also many organic contaminants that are biotransformed in the environment for which no microorganisms have been found which are able to use them as sole carbon source. This is a special case of secondary metabolism often termed *cometabolism*. Cometabolism has been defined (Dalton, 1982) as the "transformation of a non-growth substrate in the obligate presence of a growth substrate or another transformable compound". As an example, halogenated methanes, ethanes, and ethylenes are poor growth substrates for bacterial growth but may be degraded by

methanotrophs growing aerobically on methane (Henson et al., 1988).

4.0 METHODOLOGY

The principal focus of the investigation is to develop methods which will enhance bacterial metabolism of organic contaminants in sub-surface environments in order to increase the rate and extent of biodegradation. Our original proposal was organized into five phases, as follows:

Phase 1: Literature Review.

Phase 2: Batch Studies to Evaluate Optimum Concentration of Growth Enhancing Agents in Both Liquid and Soil Cultures.

Phase 3: Column Studies to Evaluate the Rate and Extent of Degradation of Candidate VOC's.

Phase 4: Comparison of TCE Biotransformation by Particulate and Soluble Methane Monooxygenase.

Phase 5: Investigation of the Utilization of the Symbiotic Relationship Between Methanogenic and Methanotrophic Bacteria for VOC Degradation Without Addition of Exogenous Methane.

A comprehensive literature review of biodegradation of chlorinated solvents was completed and submitted as part of the second quarterly report. As a result of this review we realized the potential for developing the relationship between the methanotrophs (aerobic) and the methanogens (anaerobic) for mineralization of both highly chlorinated and less chlorinated compounds. Emphasis was given to this approach in subsequent phases of the workplan.

The methanotrophs have an obligate requirement for methane, which is complemented by the methane production of methanogenic organisms. Furthermore, the methanogens ability to dehalogenate more oxidized (more halogenated) pollutants, generating vinyl chloride, is complemented by the ability of the methanotrophs to mineralize vinyl chloride and other small mono-chlorinated hydrocarbons. The rate limiting step of mineralization under anaerobic conditions is the dehalogenation of vinyl chloride. Thus, it might be advantageous to induce methanotrophic growth at the point where all (or most) of the more chlorinated compounds have been dehalogenated to vinyl chloride. The number of chlorines dramatically effects the rate of anaerobic degradation: the more chlorines the faster the rate of degradation (Sims et al., 1990). A higher number of halogen substituents results in a more oxidized compound making it more susceptible to biological reduction.

Although methanogenic bacteria will not grow in the presence of oxygen, the reductive dehalogenation reaction is somewhat oxygen tolerant. The rate of TCE degradation is reduced under micro-aerophilic conditions, but not completely blocked (Freedman and Gossett, 1989). Under these conditions a suitable source of reducing equivalents must be provided (eg. methanol, hydrogen, acetate, and formate). It is interesting to note in this regard that Kastner (1991) reported that an aerobic enrichment culture's ability to dechlorinate cis-1,2-dichloroethylene was shown to be dependent on a cyclic transition from aerobic to anaerobic conditions and limited oxygen supply. It may also be possible to increase biodegradation rates by alternating methanogenic and methanotrophic growth conditions, thus limiting the accumulation of potentially toxic byproducts, as well as optimizing the alternating production of methane rich and oxygen rich conditions.

5.0 WORK PERFORMED THIS PERIOD

This quarter, the columns were combined to operate in a sequential mode. Parameters such as reducing agents and elevated TCE concentration were evaluated for the sequential column. The simultaneous column is operating this quarter and the lysimeter was constructed and is running to evaluate the performance of PVD drains for amendments delivery.

A brief summary of progress on the tasks is presented below.

1.1 Optimization of Sequential Mineralization--90 % Complete

This task was continued this quarter in the combined columns by investigating the influence of a variety of variables on performance.

1.2 Design and Construction of Simultaneous Mineralization Column-100% Complete

This task was completed last quarter when the funds became available (in March).

1.3 Development and Testing of Protocol to Locate Zones--100 % Complete

A microsystem was located that allows measurement of the oxidation reduction potential (ORP) externally and measurements were carried out on both the anaerobic and aerobic columns. The system allows the use of ORP measurements to locate the anaerobic and aerobic zones.

1.4 Optimization of Simultaneous Mineralization--40 % Complete

The system is now constructed and running.

1.5 Assessment of Potential Bioremediation of High Concentrations of CAH Compounds --35 % Complete

The effect of elevated TCE influent concentration was investigated this quarter.

2.1 Design and Construction of Lysimeters Equipped with PVD's--100 % Complete

The lysimeters were designed this quarter and are operating to evaluate the performance of PVD for amendment delivery.

2.2 Amendments Delivery and Potential Clogging--10 % Complete

3.0 Preparation and Submission of Quarterly and Final Reports--75 % Complete

Assuming equal weight for each of the 8 project tasks noted above, it is estimated that the overall project is 68.75% complete.

6.0 RESULTS AND DISCUSSION

6.1 Sequential Column.

The anaerobic and aerobic columns were joined together near the end of the last quarter. A schematic diagram of the sequential setup is given Figure 1. The column has been operating in a continuous upflow mode under a variety of

conditions. Reducing agents and elevated TCE concentration were the principal variables investigated this quarter. Table 1 shows the substrate and inorganic concentrations entering the anaerobic column for various time periods.

As noted in earlier reports, anaerobic decomposition of chlorinated solvents is accomplished through reductive dehalogenation (RD) where a primary substrate is needed. During RD, the halogenated compound becomes an electron acceptor and chlorine atoms are sequentially replaced by hydrogen atoms. Reduction of TCE proceeds via the formation of one of three isomers of dichloroethene (trans-, cis-, or 1,1-DCE), then vinyl chloride, and finally ethene.

In the aerobic decomposition of chlorinated solvents, the methanotrophic bacteria produce methane monooxygenase (MMO) to begin oxidation of methane (primary substrate). The MMO is relatively non-specific and the enzyme is also active (cometabolically) in transforming TCE to TCE epoxide, which is eventually mineralized to CO₂ and H₂O. While the MMO enzyme is responsible for the initial epoxidation of TCE, other enzymes are responsible for further metabolism for biomass assimilation or energy production.

The degradation of chlorinated ethenes may be efficiently accomplished during sequential anaerobic/aerobic biological treatment. The methane produced by the anaerobes can then be used as primary substrate by the methanotrophs. Also, reductive dehalogenation is most effective for very oxidated compounds (CAHs with high chlorine content), while methanotrophic cometabolism is more effective for more reduced compounds. Therefore, the anaerobic organisms reduce the highly oxidated compounds down into less halogenated homologues, which can then be more easily transformed by methanotrophic bacteria.

Table 1. Changes in Sequential Anaerobic Column Feed Conditions

Concentration (mg/L)

Chemical	7/1 - 7/20	7/21 - 8/10	8/11 - 9/2	9/3 - 9/13	9/14 - 9/30
NH ₄ Cl	56.5	56.65	56.65	56.65	56.65
K ₂ HPO ₄	2.92	2.92	2.92	2.92	2.92
KH ₂ PO ₄	2.11	2.11	2.11	2.11	2.11
MgCl ₂ · 6H ₂ O	0	5.76	5.76	5.76	5.76
MgSO ₄ · 7H ₂ O	5.76	0	0	0	0
MnCl ₂ · 4H ₂ O	1.92	1.92	1.92	1.92	1.92
CoCl ₂ · 6H ₂ O	3.84	3.84	3.84	3.84	3.84
ZnCl ₂	1.92	1.92	1.92	1.92	1.92
CaCl ₂ · 2H ₂ O	6.34	6.34	6.34	6.34	6.34
H ₃ BO ₃	0.58	0.58	0.58	0.58	0.58
NiCl ₂ · 6H ₂ O	1.92	1.92	1.92	1.92	1.92

Chemical	7/1 - 7/20	7/21 - 8/10	8/11 - 9/2	9/3 - 9/13	9/14 - 9/30
Na ₂ MoO ₄ ·2H ₂ O	0.768	0.768	0.768	0.768	0.768
L-Cysteine ¹	5.0	5.0	25	25	25
Na ₂ S·9H ₂ O ¹	0	20	25	25	25
NaHCO ₃	76.8	76.8	76.8	76.8	76.8
Yeast Extract ²	1.92	5	5.0	5.0	5.0
FeCl ₂ ·4H ₂ O ³	1.15	1.15	1.15	6	6
Vitamin B-12 ⁴	0	0	0	5	5
Methanol	750	750	750	750	750
Acetic Acid ⁵	185.4	185.4	185.4	185.4	0
TCE	5	5	5	5	25

¹ For reduction in ORP

² To ensure sufficient vitamins for both columns.

³ Increased after a sample for Fe was low after sulfide addition

⁴ Found to be coenzyme used in RD

⁵ Provided in methanogenesis

6.1.1 Effect of Reducing Agents

Reducing agents are necessary to keep the sequential column anaerobic and provide low redox potential needed for methanogenesis (Ljungdahl, 1986). Haddad (1990) stated that it is impossible to get the redox potential below 0 mV without the addition of a reducing agent. The two reducing agents used in this study are sodium sulfide (Na₂S) and L-cysteine (C₃H₇NO₂S·HCl·H₂O). Sodium sulfide is alkaline in nature with a redox potential (E_s) of -571 mV and is normally added as 0.01-0.025% in the media. L-cysteine is an organic reducing agent which is acidic in nature with an E_s of -210 mV and is normally added as 0.02-0.08% in the media. For pH control, these two reducing agents have been used together with a concentration of 0.025% each in the media giving an E_s of -571 mV (Ljungdahl, 1986).

Tables 2 through 7 and Figures 2 through 12 summarize the results obtained. As the quarter began, only L-cysteine at a concentration of 5 mg/L was added to the groundwater feed. Later, on July 21, 1995, sodium sulfide at a concentration of 20 mg/L (Na₂S·9H₂O) was also added to the feed. Table 2 shows that overall TCE removal increased by 34.6% (from 32.8 to 44.2 %). From Tables 3 and 4, an increase in daughter product formation was also noted. Cis-DCE increased by 29.2%, trans-DCE by 8.7%, 1,1-DCE by 19.8%, and VC by 53.3%. The changes in daughter products were more pronounced towards the end of this period.

Table 2. Percent Removal throughout the Sequential Column.

	7/1-7/20	7/21-8/10	8/11-9/2	9/3-9/13	9/14-9/30
TCE					
Over all	32.8	44.15	49.1	62.87	na
Anaerobic Top wrt Influent	28.9	43.81	47.47	63.3	55.72
Aerobic Top wrt Anaerobic Top	4.0	2.6	3.11	-0.8	na
cis-DCE	7.1	16.08	9.47	18.67	na
trans-DCE	27.54	0	7.61	23.17	na
1,1 DCE	10.15	14.92	15.1	18.89	na
VC	46.67	28.1	66.25	76.96	na

Table 3. Concentration (ug/L) and Mass flowrate (ug/hr) in the Sequential Column (7/1-7/20)

Port	TCE		Cis		Trans		1,1		VC	
	Conc	MF	Conc	MF	Conc	MF	Conc	MF	Conc	MF
Aerobic Top	3499	17.89	28	0.143	10.7	0.05	36.2	0.186	8.22	0.04
Aerobic Bottom	3569	18.21	28	0.143	9.7	0.049	37.3	0.191	11.1	0.057
Anaerobic Top	3716	18.93	30.4	0.154	14	0.069	41.0	0.207	14.8	0.075
Anaerobic Bottom	3654	18.64	26.1	0.132	8.1	.040	39.1	0.197	14.9	0.075
Influent	5245	26.63								

Table 4. Concentration (ug/L) and Mass flowrate (ug/hr) in the Sequential Column (7/21-8/10)

Port	TCE		Cis		Trans		1,1		VC	
	Conc	MF	Conc	MF	Conc	MF	Conc	MF	Conc	MF
Aerobic Top	2942	16.7	26.3	0.167	10.68	0.076	34.14	0.211	13.89	0.11
Aerobic Bottom	2986	16.9	34.4	0.226	11.14	0.080	36.6	0.223	15.19	0.105
Anaerobic Top	3028	16.8	33.8	0.199	11.25	0.075	41.18	0.248	19.3	0.115
Anaerobic Bottom	3066	17.1	16.4	0.096	11.33	0.078	40.99	0.242	17.13	0.101
Influent	5955	29.9								

On August 11, the $\text{Na}_2\text{S} \cdot 9\text{H}_2\text{O}$ was increased from 20 to 25 mg/L, while the L-cysteine was increased from 5 to 25 mg/L. As a result, the percent removal of TCE increased by 11.21% (from 44 to 49 %). Comparing the values in Tables 4 & 5 shows a very significant increase in the formation of daughter products. It may be noted that cis-DCE increased from 33.8 to 112.4 ug/L (233 %). The concentrations of the other DP's also greatly increased as follows: trans-DCE by 188.7%, 1,1-DCE by 4.32%, and VC by 280.3%.

Table 5. Concentration (ug/L) and Mass Flowrate (ug/hr) in the Sequential Column (8/11-9/2)

Port	TCE		Cis		Trans		1,1		VC	
	Conc	MF	Conc	MF	Conc	MF	Conc	MF	Conc	MF
Aerobic Top	3279	26.2	105.3	0.882	28.76	0.255	35	0.298	22.27	0.187
Aerobic Bottom	3267	26.08	102.1	0.855	30.27	0.261	37	0.310	24.04	0.201
Anaerobic Top	3486	27.04	112.4	0.908	32.48	0.276	42.96	0.351	65.15	0.554
Anaerobic Bottom	3707	28.22	17.1	0.137	16.45	0.139	38.47	0.316	68.10	0.134
Influent	6965	51.47								

However, the increase in $\text{Na}_2\text{S} \cdot 9\text{H}_2\text{O}$ concentration caused a decrease in the redox potential (ORP) in both the anaerobic and aerobic sections of the column. As observed in Table 6 and Figure 12, the ORP value in the aerobic bottom port decreased to -26.4 mV and the dissolved oxygen (DO) concentration fell to 0 mg/L. The DO had been holding about 1 to 2 mg/L in the aerobic portion of the

column. To raise the DO concentration and keep methanotroph activity, the hydrogen peroxide (H_2O_2) concentration was increased from 75 mg/L to 85 mg/L on August 25 as noted in Table 7. The addition of 85 mg/L of H_2O_2 made only a slight improvement in the DO from 0 to 0.93 mg/L. The H_2O_2 concentration was further increased to 150 mg/L on September 6 which resulted in an effluent DO concentration of 2 mg/L.

Table 6. Average ORP Values in mV

	7/1-7/20	7/21-8/10	8/11-9/2	9/3-9/13	9/14-9/30
Aerobic Top	172.5	136.1	-23.8	-49.6	-23.7
Aerobic Bottom	186.2	142.8	-26.4	-28.4	-16.5
Anaerobic top	-179.3	-146	-182.8	-188.5	-125.4
Anaerobic Bottom	-171.1	-134.6	-192.3	-190.5	-100.6

Table 7. Changes in Sequential Aerobic Column Conditions

Concentration (mg/L) % Time [HRT] (hours)

Chemical	7/1 -8/15	8/16 - 8/24	8/25 - 9/5	9/6 - 9/10	9/11-9/13	9/15-9/22	9/23-
H_2O_2	75	75	85	150	40 ¹	60	80
CH ₃ OH	32	32	32	32	32	12.6 ²	25.1 ²
NaNO ₃	85	85	85	85	850	850	850
HRT	48	24	24	24	24	24	24

¹Column taken off-line and refed with methanotrophs

²Stoichiometric Concentration

6.1.2 Effect of Elevated TCE Concentration

At the beginning of the quarter, the sequential column was operating with an influent concentration of TCE of 5 mg/L corresponding to a TCE loading rate of 0.031 mg/d·cm² or 1.02 mg/d·L and an HRT of 96 hours. On August 10, the HRT was decreased from 96 to 48 hours. The corresponding loading rate was then increased to 0.062 mg/d·cm² or 2.04 mg/d·L. This increase in TCE loading did not

affect the TCE removal rate as the % removal at 48 hours HRT remained about the same as was noted at 96 hours. This is not surprising since most of the removal of TCE has been noted in the first quarter of the column. It is likely that the HRT could be decreased further.

On September 11, the aerobic column was taken off-line to inoculate the column with additional methanotrophs (250 mL). This was done as the low DO and ORP conditions might have had an adverse effect on the bacterial growth in the column due to the increase of sodium sulfide which was added to increase RD in the anaerobic portion of the column. Thus, beginning on 9/11, both columns were operated independently for a period of time. In order to avoid toxic shock to the new methanotrophs, the H_2O_2 concentration was decreased from 85 to 40 mg/L before the addition of the methanotrophs and was later gradually increased in increment of 20 mg/L to 80 mg/L.

In the anaerobic column, the TCE concentration was increased from 5 to a target level of 25 mg/L to study the extent of dehalogenation occurring under elevated TCE concentration. This concentration corresponds to a TCE loading rate of 3.1 mg/d·cm² or 10.2 mg/d·L. The effect of elevated TCE concentration on TCE removal and daughter products production is presented in Table 8 and Figures 13 to 22 for the period of 9/14 to 9/30. It may be seen that TCE removal (Table 8) reached 56 % (had been about 49 % at the 5 mg/L TCE feed. It should also be noted that a small concentration of Vitamin B-12 was added to the groundwater on 9/3 and may have contributed somewhat to the increased TCE removal. As may be noted in Table 8, the production of daughter products was increased significantly when the TCE concentration was increased. The following increases in DP's were noted: cis-DCE; from 112 to 245 ug/L (up 54 %), trans-DCE; from 32 to 59 ug/L (up 46 %), 1,1-DCE; from 43 to 70 ug/L (up 39 %), and from 65 to 72 ug/L (up 11 %) for the VC. As the TCE level was increased, the ORP became less negative and fell from -198 mV to about -100 mV (Table 6). This was possibly due to the highly oxidized nature of the TCE molecule.

Table 8. Concentration (ug/L) and Mass flowrate (ug/hr) in the Anaerobic Column (9/14-9/30)

Port	TCE		Cis		Trans		1,1		VC	
	Conc	MF	Conc	MF	Conc	MF	Conc	MF	Conc	MF
Anaerobic Top	8785	86.84	245.6	2.49	58.63	0.607	70.53	0.739	71.75	0.708
Anaerobic Bottom	10051	106.1	15.9	0.17	14.4	0.150	77.63	0.811	14.13	0.148
Influent	19346	196.1								
% Removal	55	56								

6.1.3 Mass Balances

Two separate types of mass balances were performed to relate TCE removed to daughter products formed. For a better description, the balances are termed "kinetic" and "stoichiometric". Neither type of mass balance is complete for reasons noted below. Details on the approach of each balance along with an

example are given in the Appendix. The first mass balance (kinetic) was based on the relationship between the rates of DCE production from the rate of TCE degradation (VC production was not taken into account). The second mass balance was based on simple stoichiometric relationships of TCE reduction and the DP's formed.

Table 9 shows the ratio of TCE consumed to daughter products formed.

Table 9. Mass Balances to Estimate the Percent of influent TCE Consumed based on Daughter Product Formation *

Time Period	Kinetic(%)	Stoichiometric (%)
7/1-7/20	16.9	5.6
8/11-9/2	16.4	15.0
9/14-9/30	15.9	18.1

* balance is not complete for reasons described in text

The relatively low amount of TCE accounted for is most likely due to the fact that the gas is not sampled for ethene or ethane and the vinyl chloride produced could be lost into the gas phase due to its high volatility. Peaks determined as 1,2-dichloroethane (DCA) and chloroethane have been found in the column. As noted earlier, these gases are not sampled as they leave the anaerobic as this would interfere with operation of the aerobic section of the treatment process.

6.2 Simultaneous Column

A 24-inch simultaneous column was setup near the end of the previous quarter. The schematic is shown in Figure 23. The influent ground water composition is the same as for the sequential column and the influent TCE concentration was maintained at 5mg/L throughout the quarter.

6.2.1 Column Integrity Test: An integrity test was performed from August 10-23 to ensure no leaks in the column. Table 10 and Figure 24 give an overview of the test. The test was stopped on August 23 when more than 95% of the influent TCE was recovered at the effluent port.

Table 10. Simultaneous Column Integrity Test.

Port	Mass Flowrate (ug/h)	% TCE removed
Influent	31.3	Final 3 day average 4.46
Effluent	29.4	
Influent	38.39	Seven day average 3.89
Effluent	36.9	

6.2.2 Biodegradation Studies

The column was inoculated with 420mL (one pore volume) of anaerobic bacteria from the maintenance reactor effluent from August 23-25. Almost immediately after the inoculation, traces of the daughter products (VC, 1,1-, and cis-DCE) were detected (Figures 25-33), indicating reductive dehalogenation. After ensuring substantial anaerobic bacterial growth, H_2O_2 was added at different locations in the column (see Figure 23) at a concentration of 25mg/L to create oxidative conditions prior to the addition of methanotrophs. On September 12 the column was inoculated with 330 mL of methanotrophs and the H_2O_2 concentration was increased to 50mg/L. From Table 12, it can be seen that after methanotrophs were added, the mass flowrate of DPs generally fell as the waste moved up the column. In each case, port 4 (see Figure 23) is about the middle of the column while the effluent is at port 7 (top of column). For example, the mass flow rate of cis-DCE fell from 0.0577 to 0.044 ug/hr as it moved from port 4 to 7 respectively indicating that the methanotrophs are removing the DP.

Table 11. Changes in Simultaneous Column Conditions

Concentration (mg/L)				
Chemical	8/30-9/11	9/12-9/18 (Inoculated on 9/12)	9/23-9/24	9/25-9/30
H_2O_2	25	50	50	75
CH_3OH	32	32	32	32
$NaNO_3$	0	0	850	850
HRT	48	48	48	48

¹After Inoculating Column with methanotrophs

Table 12. Daughter Product Concentration (ug/L) and Mass Flowrate (ug/hr) in Simultaneous Column.

	Before Methanotroph Inoculation		After Methanotroph Inoculation	
	Conc	MF	Conc	MF
cis-DCE in Column Effluent	4.16	0.039	4.84	0.044
cis-DCE at Port 4	3.76	0.030	6.86	0.0577
trans-DCE in Column Effluent	13.45	0.0126	14.01	0.122
trans-DCE at Port 4	12.31	0.012	13.47	0.122

	Before Methanotroph Inoculation		After Methanotroph Inoculation	
VC in Column Effluent	4.98	0.043	3.09	0.279
VC at Port 4	3.09	0.027	4.43	0.381

Figures 25 to 33 present changes in TCE and DP concentration and mass flow rate during the start-up period as the column was developing cultures of anaerobic and aerobic organisms. As discussed in earlier reports, the goal of the simultaneous column is to transition from anaerobic to aerobic growth to allow recycling of methane and cooperative removal of intermediates by each group of organism. The dissolved oxygen level will be raised just enough to encourage methanotrophs (using hydrogen peroxide) but not enough to stop all anaerobic activity. It is theorized that the symbiotic activity between the two groups will result in more efficient mineralization of the TCE. It will take some time to adjust the column so as to optimize the symbiotic activity desired. Referring to Figure 23, it may be seen that H_2O_2 is added just before ports 3 and 5. Hence, it is planned to encourage methanotrophs at in these areas. Thus, anaerobic growth will take place at the beginning of the column (from port 1 to where the peroxide is put in just below port 3) with RD. Anaerobic activity is again encourage in the region between ports 3 and 5 after the added oxygen (peroxide) has been used up to some extent. Aerobic activity will be encouraged in the two zones above the H_2O_2 addition and the effluent should leave with a positive dissolved oxygen concentration at port 7.

Figures 34-35 show the changes in ORP and TOC throughout the column for different periods (before and after methanotroph addition). While the column is still in a period of adjustment and it is too soon to make any conclusions, it may be noted that total organic carbon removal is taking place as expected. It may also be noted that the ORP generally becomes more positive after H_2O_2 addition just below ports 3 and 5.

6.3 Lysimeter Set-up

The lysimeter has been constructed and is running. The purpose of the lysimeter is to evaluate prefabricated vertical drains (PVD's) for delivery of ammendments and to evaluate potential clogging of the drains. Data has not yet been collected. A schematic of the lysimeter is presented in Figure 36. Both aerobic and anerobic systems will be set up. The present lysimeter will be operated in an aerobic mode. It is innoculated with activated sludge from the aeration basin of the Morgantown WWTP. The lysimeter has a one-inch wide prefabricated vertical drain (PVD) for nutrient and ground water delivery. The system is being fed with brain heart infusion (BHI) media which is an excellent and complete growth media at an initial concentration of 20 mg/L. Six liters are made up daily and added to a sump (6-L flask). The solution is pumped from there with a peristaltic pump into a constant head tank. This tank can be moved up or down depending on the needed head. The pump is set-up to pump 4 mL/min to the tank while the lysimeter is fed at an initial rate of about 3.47 ml/min (5 L/d). The excess flow simply overflows back to the feed sump. At the bottom of the tank there is a clamp in order to control flow. Eighteen piezometers are located in the lysimeter to monitor the clogging in the PVD due to bacteria growth. Water elevation in the piezometers will be evaluated using an ohm meter.

7.0 CONCLUSIONS

The anaerobic and aerobic columns were joined together near the end of last the quarter with the aerobic column receiving the effluent from the anaerobic column and continued to operate during this quarter. First, the effect of reducing agents was investigated from 7/1 to 9/13. As the quarter began, only L-cysteine at a concentration of 5 mg/L was added to the groundwater feed. Later, on July 21, 1995, sodium sulfide at a concentration of 20 mg/L ($\text{Na}_2\text{S} \cdot 9\text{H}_2\text{O}$) was also added to the feed. Overall TCE removal increased by 34.6% (from 32.8 to 44.2 %). An increase in daughter product formation was also noted. Cis-DCE increased by 29.2%, trans-DCE by 8.7%, 1,1-DCE by 19.8%, and VC by 53.3%. The changes in daughter products were more pronounced towards the end of this period. On August 11, the $\text{Na}_2\text{S} \cdot 9\text{H}_2\text{O}$ was increased from 20 to 25 mg/L, while the L-cysteine was increased from 5 to 25 mg/L. As a result, the percent removal of TCE increased by 11.21% (from 44 to 49 %). A very significant increase in the formation of daughter products was observed. Cis-DCE increased from 33.8 to 112.4 ug/L (233 %). The concentrations of the other DP's also greatly increased as follows: trans-DCE by 188.7%, 1,1-DCE by 4.32%, and VC by 280.3%. However, the increase in $\text{Na}_2\text{S} \cdot 9\text{H}_2\text{O}$ concentration caused a decrease in the redox potential (ORP) in both the anaerobic and aerobic sections of the column. The ORP value in the aerobic bottom port decreased to -26.4 mV and the dissolved oxygen (DO) concentration fell to 0 mg/L. The DO had been holding about 1 to 2 mg/L in the aerobic portion of the column. To raise the DO concentration and keep methanotroph activity, the hydrogen peroxide (H_2O_2) concentration was increased from 75 mg/L to 85 mg/L on August 25. The addition of 85 mg/L of H_2O_2 made only a slight improvement in the DO from 0 to 0.93 mg/L. The H_2O_2 concentration was further increased to 150 mg/L on September 6 which resulted in an effluent DO concentration of 2 mg/L. In addition, the effect of elevated TCE concentration was also investigated. In the anaerobic column, the TCE concentration was increased from 5 to a target level of 25 mg/L to study the extent of dehalogenation occurring under elevated TCE concentration. It may be seen that TCE removal reached 56 % (had been about 49 % at the 5 mg/L TCE feed. It should also be noted that a small concentration of Vitamin B-12 was added to the groundwater on 9/3 and may have contributed somewhat to the increased TCE removal. The production of daughter products was increased significantly when the TCE concentration was increased. The following increases in DP's were noted: cis-DCE; from 112 to 245 ug/L (up 54 %), trans-DCE; from 32 to 59 ug/L (up 46 %), 1,1-DCE; from 43 to 70 ug/L (up 39 %), and from 65 to 72 ug/L (up 11 %) for the VC. As the TCE level was increased, the ORP became less negative and fell from -198 mV to about -100 mV (Table 6). This was possibly due to the highly oxidized nature of the TCE molecule.

A 24-inch simultaneous column was setup near the end of the previous quarter. An integrity test was performed from August 10-23 to ensure no leaks in the column. More than 95% of the influent TCE was recovered at the effluent port. It will take some time to adjust the column so as to optimize the symbiotic activity desired. It may be seen that H_2O_2 is added just before ports 3 and 5. Hence, it is planned to encourage methanotrophs at in these areas. Thus, anaerobic growth will take place at the beginning of the column (from port 1 to where the peroxide is put in just below port 3) with RD. Anaerobic activity is again encourage in the region between ports 3 and 5 after the added oxygen (peroxide) has been used up to some extent. Aerobic activity will be encouraged in the two zones above the H_2O_2 addition and the effluent should leave with a positive dissolved oxygen concentration at port 7. While the column is still in a period of adjustment and it is too soon to make any conclusions, it may be noted that total organic carbon removal is taking place as expected. It may also be noted that the ORP generally becomes more positive after H_2O_2 addition just below ports 3 and 5.

The lysimeter has been constructed and is running. Data has not yet been

collected. The present lysimeter is operating in an aerobic mode. It is inoculated with activated sludge from the aeration basin of the Morgantown WWTP. The lysimeter has a one-inch wide prefabricated vertical drain (PVD) for nutrient and ground water delivery. The system is being fed with brain heart infusion (BHI) media which is an excellent and complete growth media at an initial concentration of 20 mg/L. Six liters are made up daily and added to a sump (6-L flask). The solution is pumped from there with a peristaltic pump into a constant head tank. This tank can be moved up or down depending on the needed head. The pump is set-up to pump 4 mL/min to the tank while the lysimeter is fed at an initial rate of about 3.47 mL/min (5 L/d). The excess flow simply overflows back to the feed sump. At the bottom of the tank there is a clamp in order to control flow. Eighteen piezometers are located in the lysimeter to monitor the clogging in the PVD due to bacteria growth. Water elevation in the piezometers will be evaluated using an ohm meter.

8.0 WORK PLANNED FOR NEXT QUARTER

The existing anaerobic and aerobic columns have already been joined together to evaluate sequential mineralization (Subtask 1.1) and investigate the influence of a variety of variables on performance in order to optimize mineralization of TCE. Data collection will continue with respect to ORP and CAH concentration. In addition, mass balance calculations will be performed.

As noted earlier, the simultaneous system (Subtask 1.2) will continue to operate next quarter. Data will be collected to evaluate simultaneous mineralization based on which parameters like influent nutrient concentration, influent primary substrate concentration, and anaerobic and aerobic zones to optimize the system.

Both sequential and simultaneous columns will initially be operated at a detention time of 48 hours and a TCE feed of 5.0 mg/L. Assessment of bioremediation of elevated concentrations of TCE will continue to be evaluated next quarter (Subtask 1.5) in both systems. Ports have been constructed to add a high concentration shock load of TCE to the columns.

Evaluation of prefabricated vertical drains (PVDs) for field application of amendments using lysimeters (Task 2) will continue next quarter to evaluate potential clogging of the drains.

9.0 TECHNICAL/ADMINISTRATIVE DIFFICULTIES

Technical difficulties were experienced this quarter when the gas chromatometer (GC) malfunctioned. GC measurements are vital in determining the amount of TCE that occurs in the influent and throughout the column.

10.0 REFERENCES

Dalton, H. and D.E. Stirling (1982) "Cometabolism", Philos. Trans. R. Soc. Lond., 297, pp 481-496.

Freedman, D.L. and J.M. Gossett (1989) "Biological Reductive Dechlorination of Tetrachlorethylene and Trichlorethylene to Ethylene Under Methanogenic Conditions", Appl. and Env. Microbiol., pp 2144-2151.

Haddad, Bassem I. (1990) "Methane Recovery and Suppression in Simulated Sanitary Landfills." Ph.D. Dissertation, West Virginia University.

Henson, J.M. et al. (1988) "Microbial Removal of Halogenated Methanes, Ethanes and Ethylene in an Aerobic Soil Exposed to Methane", FEMS Microbiology Ecology, 53 (3/4), pp 193-201.

Kaster, M. (1991) "Reductive Dechlorination of Tri- and Tetrachloroethylenes Depends on Transition from Aerobic to Anaerobic Conditions", Appl. and Environ. Microbiology, Vol 57, No. 7, pp. 2039-46.

Ljungdahl, Lars G. And Juergen Wiegel (1986) "Working with Anaerobic Bacteria." Manual of Industrial Microbiology and Technology, pp 84-87.

Sims, J.L., R.C. Sims, and J.E. Mathews (1990) "Approach to Bioremediation of Contaminated Soil", Hazardous Waste and Hazardous Materials, V. 7, pp 117-149.

Tandoi, V. et al. (1994) "Reductive Dehalogenation of Chlorinated Ethenes and Halogenated Ethanes by a High Rate Anaerobic Enrichment Culture", Env. Sci. and Tech., Vol. 28, # 5, pp. 973-979.

Vira, A., Byrnes, J., and Fogel, S. (1992) "Technological Requirements for the Maintenance of Specialized Cultures in the Subsurface Environment: Complete Biodegradation of PCE." 85th Annual Meeting & Exhibition of the Air & Waste Management Association, Kansas City, MO.

11.0 APPENDIX 1

Period from 7/21 to 8/10

Kinetic Method (First-Order)

Concentration of TCE = 5 mg/L

$$B/A_o = (1-x) [1 / (1 - \beta)] [(1 - x)^{\beta-1} - 1]$$

where B/A_o = production of initial TCE going to DCE

$$\beta = k_{TCE} / k_{DCE}$$

x = percent removal

From Tandoi, et al (1994) each step in reductive dechlorination of TCE is greater than ten times slower than the preceding step. Therefore, choose $\beta = 0.09$.

For x = 50%;

$$\begin{aligned} B/A_o &= (1 - 0.5) [1 / (1 - 0.09)] [(1 - 0.5)^{0.09-1} - 1] \\ &= 0.482 \end{aligned}$$

Rates of DCE in anaerobic top port:

$$\text{cis-1,2-DCE} = 0.90 \text{ } \mu\text{g/h}$$

$$\text{trans-1,2-DCE} = 0.27 \text{ } \mu\text{g/h}$$

$$\text{1,1-DCE} = 0.39 \text{ } \mu\text{g/h}$$

$$\text{Total DCE} = 1.56 \text{ } \mu\text{g/h}$$

$$(B/A_o)_{wt} = 0.482 (0.74) = 0.356$$

$$\text{Expected DCE production} = 53.68 (0.356) (0.5) = 9.54 \text{ } \mu\text{g DCE/h}$$

$$\% \text{ of daughter products produced to TCE destroyed} = 1.56 / 9.54 \times 100\% = 16.4\%.$$

Period from 7/21 to 8/10

Stoichiometric calculations

TCE concentration = 5 ppm

Flowrate of TCE in influent = 53.68 µg/h

Flowrates in top port: TCE = 30.84 µg/h
 cis-DCE = 0.90 µg/h
 trans-DCE = 0.27 µg/h
 1,1-DCE = 0.39 µg/h
 VC = 0.51 µg/h

Mole Balance across the whole column:

Amt TCE removed = 53.68 - 30.84 = 22.84 µg/h

Amt DCE created and not destroyed = cis + trans + 1,1
 = 0.90 + 0.27 + 0.39
 = 1.56 µg/h

Amt VC created and not destroyed = 0.51 µg/h

Mol TCE removed = 22.84 µg/h (1 µmol / 131.5 µg) = 0.174 µmol TCE / h

Amt TCE going to DCE:
 = 1.56 µg DCE/h (1 µmol DCE / 97.0 µg DCE) (1 µmol TCE / 1 µmol DCE)
 = 0.016 µmol TCE / h

Amt TCE going to VC:
 = 0.51 µg VC / h (1 µmol VC / 62.5 µg VC) (1 µmol TCE / 1 µmol VC)
 = 0.0097 µmol TCE / h

Amt TCE removed not going to daughter products:
 = 0.174 - (0.016 + 0.0097)
 = 0.1493

% TCE going to daughter products:
 = [1 - (0.1493 / 0.174)] × 100%
 = 15% Percent (%) of TCE going to daughter products.

Period	Kinetic Method	Stoichiometric Method
7/7 - 7/20 ¹	16.9	5.6
7/21 - 8/10 ²	16.4	15
8/11 - 9/2 ³	15.9	18.1

¹L-cysteine concentration 5 ppm and TCE at 5 ppm

²Na₂S added at 20 ppm and L-cysteine 5 ppm with TCE conc. of 5 ppm

³TCE concentration increased to 25 ppm with 25 ppm Na₂S and L-cysteine

Figure 1: Sequential Columns

Figure 2. Seq. Col. Concentration of TCE

Figure 3. Seq. Col. Mass Flowrate of TCE

Figure 4. Seq. Col. Concentration cis-1,2-DCE

Figure 5. Seq. Col. Mass Flowrate cis-1,2-DCE

Figure 6. Seq. Col. Concentration trans-1,2-DCE

Figure 7. Seq. Col. Mass Flowrate trans-1,2-DCE

Figure 8. Seq. Col. Concentration 1,1-DCE

Figure 9. Seq. Col. Mass Flowrate 1,1-DCE

Figure 10. Seq. Col. Concentration Vinyl Chloride

Figure 11. Seq. Col. Mass Flowrate Vinyl Chloride

Figure 12. Seq. Col. ORP Values

Figure 13. An. Col. Concentration TCE for Increase in TCE

Figure 14. An. Col. Mass Flowrate TCE for Increase in TCE

Figure 15. An. Col. Concentration cis-1,2-DCE for Increase in TCE

Figure 16. An. Col. Mass Flowrate cis-1,2-DCE for Increase in TCE

Figure 17. An. Col. Concentration trans-1,2-DCE for Increase in TCE

Figure 18. An. Col. Mass Flowrate trans-1,2-DCE for Increase in TCE

Figure 19. An. Col. Concentration 1,1-DCE for Increase in TCE

Figure 20. An. Col. Mass Flowrate 1,1-DCE for Increase in TCE

Figure 21. An. Col. Concentration Vinyl Chloride for Increase in TCE

Figure 22. An. Col. Mass Flowrate Vinyl Chloride for Increase in TCE

Figure 23. Simultaneous Column

Figure 24. Sim. Col. Integrity Test

Figure 25. Sim. Col. Concentration TCE

Figure 26. Sim. Col. Mass Flowrate TCE

Figure 27. Sim. Col. Concentration cis-1,2-DCE

Figure 28. Sim. Col. Mass Flowrate cis-1,2-DCE

Figure 29. Sim. Col. Concentration 1,1-DCE

Figure 32. Sim. Col. Mass Flowrate Vinyl Chloride

Figure 30. Sim. Col. Mass Flowrate 1,1-DCE

Figure 31. Sim. Col. Concentration Vinyl Chloride

Figure 33. Sim. Col. ORP

Figure 34. Sim. Col. ORP and TOC before Methanotroph Addition

Figure 35. ORP and TOC throughout Sim. Col. after Methanotroph Addition

Figure 36. Lysimeter Setup with PVD

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

**WVU / METC / DOE COOPERATIVE AGREEMENT
Contract No: DE-FC21-92NC29467**

METC TASK No. 1.3

QUARTERLY REPORT: July-September, 1995

For:

**U.S. Department of Energy
Office of Fossil Energy
Morgantown Energy Technology Center
Morgantown, West Virginia**

By:

**Dr. Alan J. Sexstone and Dr. Pradeep Saini
Division of Plant & Soil Sciences
College of Agriculture and Forestry
West Virginia University
Morgantown, WV 26506-6057**

INTRODUCTION AND PURPOSE

Superfund and RCRA regulations have mandated the restoration of millions of cubic yards of contaminated soils nationwide. The cost of excavation and hauling large volumes of soil, combined with the tighter environmental regulation of landfills has severely restricted this cleanup option. Both industry and government are actively seeking additional innovative organic waste cleanup technologies to remedy this problem. Bioremediation is often proposed as a cost-effective treatment option for on-site hazardous waste clean-up, particularly where large soil volumes are involved and incineration is not considered feasible. However, biodegradation results are influenced by local site conditions making effective remediation difficult to predict and insure. We have been investigating the effectiveness of commercially available microbial inocula for use in bioaugmented remediation of hazardous mixed organic wastes in soil. At present, we are examining *ex-situ* remediation and surface composting, a process ideally suited to incorporation of a microbial inoculant. Bioaugmentation holds great promise for degradation of compounds which are now recalcitrant in soil, however efficacy of available microbial inocula must first be critically evaluated. We are developing a generalized testing procedure and expertise, which we can employ to examine bioaugmentation / biodegradation of a variety of wastes and / or waste sites (Figure 1).

During the 1994 we concentrated on identification of superior commercially available microbial inocula for bioremediation of organic wastes. Inocula were screened for biodegradation kinetics in surface and subsurface soil samples artificially contaminated with a chemically defined model mixed organic waste. During the coming year we propose that superior products selected by our screening procedure must next be tested for effectiveness in the variety of mixed organic wastes and soils expected in real world conditions. Therefore, we will obtain soil samples from waste contaminated sites, return them to the laboratory, and quantify the effectiveness of selected inocula for bioaugmented soil remediation. We will assess effectiveness of biodegradation by monitoring substrate disappearance of parent organic compounds following their extraction from soil. To facilitate screening of a large number of soils we will also develop and apply a rapid radiorespirometric technique based on the ability of microorganisms to biodegrade ^{14}C labeled recalcitrant compounds directly injected into the mixed waste milieu of the contaminated sample. Identification of suitable inocula and development of rapid screening methods for waste biodegradation represent the next necessary step prior to large-scale deployment of bioaugmentation technology in the field.

Objectives

The overall research objective is delineation of conditions under which bioremediation can effectively be employed to enhance remediation of hazardous organic wastes. Specific objectives for the 1995 work are: 1) Verify the effectiveness of bioaugmentation in soils collected from sites previously contaminated with hazardous mixed organic wastes. Superior commercially available microbial inocula selected during our year one laboratory trials will be utilized. 2) Develop and apply a radiorespirometric

technique for the rapid screening of bioaugmentation effectiveness in soil samples previously contaminated with hazardous mixed organic wastes.

(3.0-4.0)

BACKGROUND AND METHODOLOGY

The 1995 study will be performed by researchers in WVU's Division of Plant & Soil Sciences . Contaminated soils for the study will be obtained from industrial and government sites as well as from existing production sites identified by regional oil and gas cooperatives with whom we cooperate (IOGA / WVONGA). We will concentrate on soils contaminated with hydrocarbons and solvents and will study five sites.

Waste contaminated bulk soil will be returned to the laboratory and stored at 4°C prior to use. Soils will be amended with NH_4NO_3 and K_2HPO_4 to fall within C:N:P:K ratios determined as optimum for waste degradation. Soil samples (10 g wet weight) will be distributed to replicate 250-ml Erlenmeyer flasks and adjusted to 25 % gravimetric moisture content (approximately 60 % water filled porosity, a level optimum for aerobic microbial activity in soil). Sterile control soils will be prepared by autoclaving flasks at 121°C and 103 kPa for 20 minutes on 2 consecutive days. The waste contaminated soil will be then mixed 1:1 with glass beads to improve porosity and aeration, a typical procedure for soil composting. Soils will also be amended with a water soluble dispersant chosen from the EPA/ NCPPS to enhance release of the waste from soil particles and maximize contact with the soil microflora. Half of the treated soils will be amended with the commercial microbial inocula at rates recommended by the manufacturer. Inocula selected are produced by Sybron, Interbio, and Hydrobac.

Radiorespirometry will be employed to follow mineralization of individual compounds within the mixed waste. Individual ^{14}C labeled compounds will be added to the contaminated soil at 1.0 uCi per 10 gram soil. The working assumption is that the added radiolabeled compound does not significantly increase the pool size of the component within the mixed waste, thus does not affect the mineralization rate of the compound. ^{14}C - CO_2 will be trapped into sodium hydroxide and aliquots counted in a Scintiverse cocktail using a Wallac 1409 Scintillation counter. Direct injection of a known radiolabeled hydrocarbon or solvent into the mixed waste milieu of the soil should allow rapid assessment of relative biodegradation potential. If successfully developed, this technique will allow us to rapidly screen a larger number of soil samples for effectiveness of bioaugmentation.

(5.0-7.0)

PROGRESS THIS PERIOD (July-September, 1995) RESULTS, DISCUSSION, CONCLUSIONS

During the first quarter of 1995 (Jan. to March) we monitored cumulative AMOW mineralization in the presence and absence of inocula. Inoculum addition significantly increased soil respiration compared with uninoculated soil and soil amended with sterile inocula. Addition of waste to inoculated soil inhibited soil respiration compared to non-waste amended soil. These data emphasized that use of ^{14}C labeled

substrates in a radiorespirometric assay was necessary to monitor specific organic pollutants.

The second quarter (March to June) was spent in methods development. We examined a variety of assay configurations for optimum soil incubation and subsequent CO₂ trapping. We decided to use a passive base trap as illustrated in Figure 1, rather than an active gas train setup. Our rationale for this decision was ease of use and increased experimental replication. This configuration allowed us to measure mineralization of the labeled substrate by LSC as well as total mineralization by titration of the base trap.

The third quarter (July-September) was spent perfecting the assay as well as performing bioremediation trials. At our meeting at METC on April 27, we agreed to concentrate on model contaminants in a variety of soils including contaminated soils from industrial production sites. The soil used for the initial work was the previously described Guernsey silt loam. Bulk soil was obtained from the surface A horizon, air dried and ground to pass through 2mm sieve. Soils were amended to fall within C:N of 60:1 and C:P of 400:1. Replicate soil samples (10 g wet wt.) were added to 250 mL Erlenmeyer glass flasks and were mixed with glass beads (10 g) to promote aeration. The treatments were soil + inoculum + waste (S+I+W), soil + Waste (S+W), and sterile soil + sterile inoculum + waste (SS+SI+W). The hydrocarbons used in the study were hexadecane (a long chain aliphatic hydrocarbon), naphthalene (aromatic hydrocarbon containing two benzene rings) and anthracene (aromatic hydrocarbon containing three benzene rings). The individual hydrocarbons were dissolved in toluene (except for hexadecane) and were added to the flasks at a rate of 1% w/w. Because the solubility of anthracene is very low (1 g anthracene dissolves in 125 mL toluene), it was dissolved in toluene, added to the empty flasks and volatilized under a stream of nitrogen gas. The treatment mixtures were added immediately following the volatilization. In addition to the ¹²C waste compounds, ¹⁴C labeled anthracene (2.51X10⁶ DPM), hexadecane (2.26X10⁶ DPM), and naphthalene (2.78X10⁶ DPM) were also added to the flasks. Treated soils was adjusted to the field capacity and amended with commercially available microbial inoculum (ABR Hydrocarbon 9583) at a rate of 10% w/w (Sybron Chemicals Inc., 111 Kesler Mill Road, Salem, VA 24153) which was found to perform well in previous tests.

A 20 mL glass scintillation vial containing 1N NaOH to trap the CO₂ produced was suspended in each flask. The flasks were closed airtight with #8 neoprene rubber stoppers. The schematics of flasks set up is shown in Figure 1. The flasks were incubated at 25±2°C and sampled weekly. More frequent sampling at 3-4 days intervals was required for the treatments receiving inoculum in order to compensate for high CO₂ production due to mineralization of the bran based carrier of the inoculum. At the given sampling period, the traps were removed from the flasks and a portion (0.5 mL) was used for the scintillation counting on a Wallace liquid scintillation counter. Barium chloride was added to the remaining NaOH to precipitate dissolved CO₂ as BaCO₃. Amount of dissolved CO₂ was calculated after titrating the excess NaOH against 1N HCl to an endpoint of pH 7.0. Since nonlabeled compound degradation was similar to ¹⁴C labeled compound, the amount of ¹⁴CO₂ produced was directly proportional to the ¹²CO₂ produced. Thus, On the basis of ¹⁴CO₂ produced, we were able to quantify the kinetics of nonlabeled waste degradation in a system where it is impossible to distinguish between the CO₂ produced by the compound of concern and CO₂ produced by bran based inoculum.

Initial rates of ^{12}C and ^{14}C hexadecane, naphthalene, and anthracene mineralization are presented in Figures 2-4. ^{12}C mineralization was similar in both the hexadecane and anthracene treatments. Much higher CO_2 production was observed in the inoculated treatment, probably due to microbial utilization of the bran inoculum carrier. After 14 days hexadecane was mineralized in uninoculated, but not inoculated soil suggesting that the inoculum carrier was acting as a competing substrate. Neither anthracene or naphthalene was mineralized after 14 days. Naphthalene inhibited ^{12}C mineralization when compared with other hydrocarbon additions.

Ms Payal Malhotra, M.Sc., joined our lab as a visiting scientist. She has isolated 10 microbial strains from the commercial inoculants used in the study. She currently is characterizing these organisms using the Biolog system, and is verifying their efficacy for degradation of waste oils and other organic compounds.

We plan to extend our experiment to the soils obtained from contaminated industrial sites. We have received three representative soils from three different crude oil production sites. We are currently characterizing the pollutants and initiating radiorespirometric experiments with these soils.

(8.0) WORK PLANNED FOR NEXT PERIOD

During the coming quarter we will complete the radiorespirometric assay / bioremediation trials as discussed in our 1995 milestones chart (see attached).

(9.0) DIFFICULTIES: None.

Percentage of Project Completion, MC-18, METC Task 1.3, Year 2 (1995)

1.0	Preliminary Research	8w	100
2.0	Analytical Techniques		
2.1	Evaluate Radiorespirometry	8w	100
2.2	Develop Radiorespirometric Assay	8w	100
3.0	Preparation of Trials		
3.1	Site Identification	12w	100
3.2	Site Characterization	12w	75
3.3	Waste Characterization	12w	75
3.4	Finalize QA/QC	8w	
4.0	Bioremediation Trials		
4.1	Trial 1	6w	50
4.2	Trial 2	6w	50
4.3	Trial 3	6w	5
4.4	Trial 4	6w	5
4.5	Trial 5	6w	5
5.0	Trial Repeats (concurrent)		40
6.0	Analysis and Reporting		60
6.1	Analysis and Data Reduction	8w	20
6.2	Reports and Manuscripts	40w	75
7.0	Overall Work Complete	50w	75

Fig. 1. CO₂/¹⁴CO₂ *In vitro* rapid mineralization assay : Passive base trap method.

Fig. 4. Initial rates of *in vitro* anthracene biodegradation in the presence or absence of microbial inoculum.

S = Soil; I = Inoculum; W = Waste; SS = sterile soil; SI = Sterile inoculum.

Fig. 2. Initial rates of *in vitro* hexadecane biodegradation in the presence or absence of microbial inoculum.

S = Soil; I = Inoculum; W = Waste; SS = sterile soil; SI = Sterile inoculum.

Fig. 3. Initial rates of *in vitro* naphthalene biodegradation in the presence or absence of microbial inoculum.

S = Soil; I = Inoculum; W = Waste; SS = sterile soil; SI = Sterile inoculum.

CONTAMINANT MOVEMENT PREDICTION IN PERMEABLE SUBSURFACE SOILS

METC Task No. 1.4

Quarterly Technical Progress Report
Reporting Period: July 1, 1995 - September 30, 1995

Work Performed Under Contract
No: DE-FC21-92MC29467

For:
U.S. Department of Energy
Office of Fossil Energy
Morgantown Energy Technology Center
Morgantown, West Virginia

By:
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October 1995

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ABSTRACT

Contaminations of the subsurface soils are problems encountered in many areas and especially locations with various underground and surface tanks used for storage of hazardous materials. The subsurface conditions vary at a site and the prediction of contaminant movement is a difficult task. This work focuses on the flow behavior of fluids in the porous media where drainage with prefabricated vertical drains (PVD) are used to flush the soils.

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EXECUTIVE SUMMARY

This subtask was funded for the initial 60% of the requested amount in mid March 1995 and subsequently the remaining 40% were funded in May 1995. Presently, experimental data from smear tests, and the drawdown tests conducted with tank model are used to assign soil and operational parameters for the numerical model. Runs are conducted with the model using published data. Preliminary runs are conducted using the unsteady state data from smear tests.

INTRODUCTION

Contaminations of the subsurface soils are problems encountered in many areas and especially locations with various underground and surface tanks used for storage of hazardous materials. Environmentally hazardous conditions are experienced when an existing container leaks or ruptures due to natural or man caused actions. As a result, the contents, defined as hazardous to health and attributed mainly to hydrocarbon derivatives, leak from their environment.

The subsurface conditions vary at a site and the prediction of contaminant movement is a difficult task. The plumes can partially be absorbed by soils as well as changing from one state to another through condensation or vaporization. The prediction of movements of these contaminants as a liquid or gas is a very difficult task due to the nature of the formations involved at a particular site. Additional difficulty results from the need for a knowledge of multiphase transport process that describes the movement of these chemicals.

PURPOSE

The purpose of this study is to investigate the flow mechanisms through different numerical models and to select at an existing model to study the subsurface flow mechanisms. The selected model will be used to predict the behavior of fluids in a laboratory scale contaminant recovery cell.

BACKGROUND

Fresh water aquifers are subject to contamination from a variety of activities such as spills of hazardous materials. When a spill occurs the fate of the contamination depends on many factors. The most important factor is the transmissibility property of the soils or permeable media. Proper knowledge and understanding of the heterogeneity of subsurface can provide a useful tool in understanding the fate and remediation of the contamination.

METHODOLOGY

A commercially available numerical model will be selected for the investigation of prefabricated vertical drains (PVD) on both laboratory and field scale investigation. Different grid designs will be considered for the representation of the experimental setup presently available in the West Virginia University's Civil Engineering laboratories. Some important soil properties that will be considered are porosity, thickness and conductivity of the porous medium, injection rates and subsurface fluid velocities, spacing between PVD's.

WORK PERFORMED THIS PERIOD

Work continued with the verification of the installed software. Some difficulties were experienced with sample runs because of low memory in the personal computer. Special setups were needed to conduct runs with the model selected for the project. A different configuration was used with the computer for conducting model studies.

Information about a new version of the existing model was received. The new version is a self-contained package with an interactive graphical interface for data input and analysis of results. The existing program does not have a post-processor for the visualization of the results.

The data from tests conducted with the smear experiment were used to design the first set of runs. Initial design is consisted of 25 by 25 single layer system. Each square block has a side of 2-cm resulting in a total of 50 cm by 50 cm system. The simulation of a circular system was not possible with existing software. Other software considered for this study also did not use a radial coordinate system. The representation of the experimental system in the model is shown in Figure 1. In this experiment, one prefabricated vertical drain was used. Sixteen piezometers were used with a group of four on separate radial directions. The heads were recorded at 3, 6, 9, 12, and 15 minutes.

The transient operational parameters from the experimental data are converted to field units. Presently, work is continued with the preparation of unsteady state input parameters for the tank model.

WORK PLANNED FOR NEXT PERIOD

The followings are planned for the next quarterly period:

1. The runs will continue with installed software using data published in the manual.
2. Work will continue with the assignment of soil properties to the selected grid system for the drawdown tests.
3. Runs will be conducted using different operating conditions representing the experiments conducted with smear tests.
4. Runs will be conducted using different soil and operating conditions representing the drawdown experiments conducted with tank models.

0 = Inactive cell
1 = Variable head cell
-1 = Boundary cell
2 = Location of drain

REFERENCES

USEPA, "Determining Soil Response Action Levels Based on Potential Contaminant Migration to Ground Water: A Compendium of Examples," October 1989, EPA/540/2-89/057, Office of Emergency and Remedial Response, Washington, D.C. 20460.

USEPA, "Handbook on In-Situ Treatment of Hazardous Waste-Contaminated Soils," January 1990, EPA/540/2-90/002, Office of Research and Development, Cincinnati, OH 45628.

Amirebrahimi, A.M., and Herrmann, L.R., "Continuum Model and Analysis of Wick-Drained Systems," Journal for Numerical and Analytical Methods in Geomechanics, vol. 17, p. 827-847, 1993.

Guido, V.A., and Ludewig, N.M., "A Comparative Laboratory Evaluation of Band-Shaped Prefabricated Drains," Consolidation of Soils: Testing and Evaluation, ASTM Technical publication 892, Philadelphia, PA., p. 642-662, 1985.

Scientific Software Group, "VISUAL MODFLOW," Washington, DC.

**DEVELOPMENT OF A STANDARD PROTOCOL AND BARRIER
DESIGN MODEL FOR IN-SITU FORMED BARRIERS**

Task 1.5 (Administration Task)

Quarterly Technical Progress Report
for the Period of July 1, 1995 to September 30, 1995

Work Performed Under
Contract Number: DE-FC21-92MC29467

For
U.S. Department of Energy
Morgantown Energy Technology Center
PO Box 880, 3610 Collins Ferry Road
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G. Johnson, Ph.D.

Executive Summary

The report for this project is divided into three major sections. The first section (1.5) reports on the Administration of the Project. The second section (1.5a) reports on the progress of the Chemical Grouting research being conducted by the West Virginia University Department of Civil and Environmental Engineering. This research team is headed by Drs. Mohammed Gabr and Brian Reed. The Chemical Grout section is subdivided into four sections on which the graduate research assistants report separately. The third major section (1.5b) reports on progress of the Circulating Air Barrier (CAB) team. The CAB team consists of Drs. Sam Ameri, Khashayar Aminian and Shahob Mohaghegh of the WVU Petroleum and Natural Gas Engineering (PNGE) department and David Locke, William Overby and Dr. Greg Johnson of BDM Federal, Inc.

During this period of performance, work on the project has progressed at West Virginia University. Members of the Chemical Grout team initiated Safety Documentation to conduct testing of the Sand Rain Device in the High Bay area of the National Research Center for Coal and Energy. The team is also considering moving some experiments to the COMER Building until Building 17 at METC is completed. The grout testing columns and circulating air barrier testing cells were constructed this quarter by EG&G Technical Services of West Virginia. All fabrication work by EG&G will be completed early next quarter. The columns will be used to conduct the bench-scale testing of the barriers. Initially this testing will take place at West Virginia University and move to the B-17 facility when the facility is ready.

BDM Federal, Inc. received funding in September to prepare the B-17 facility. Work to be completed includes:

- Finalize operating permits for CAB and Chemical Grout (bench and large scale),
- Design and Supervise utility installations,
- Supervise installation of laboratory equipment, and
- Ensure safety procedures and laboratory protocols are followed by all researchers using facility.

Under the administration task of this project, much time this quarter was spent procuring equipment and supplies for the Chemical Grout team. Several large pieces of equipment were procured to aid in the laboratory development of this barrier. Follow-up contact was also made with the U.S. DOE Focus Area Groups to update them of progress and to aid in the development of future strategies for the project. A detailed account of technical progress on the project can be found in Report 1.5a and 1.5b.

Work Planned for next quarter:

Work with BDM on ensuring that the B-17 facility is complete and ready for testing to commence.

Continue dialogue with Focus Area Groups and other laboratories.

Close-out contract with NRCCE as Civil Engineering will assume administrative duties after next quarter.

DEVELOPMENT of STANDARD TEST PROTOCOLS and BARRIER DESIGN MODELS
for
IN SITU BARRIERS
METC Task No. 1.5a
(Chemical Grout Barriers)

Quarterly Technical Progress Report
Reporting Period: 07/1/95 - 09/31/95

Work Performed Under Contract
No.: DE-FC21-92MC29467

For:
U.S. Department of Energy
Office of Fossil Energy
Morgantown Energy Technology Center
Morgantown, WV

By:
Department of Civil and Environmental Engineering
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1.0 PROJECT INTRODUCTION

There is a significant effort in the U.S. and the world to develop remediation technologies for contaminated soils and waters. In parallel to these efforts, confinement and containment technologies are needed to retard, or even prevent, the advancement of contaminant plumes into the environment until the development of appropriate remediation techniques are identified and implemented.

This research aims at investigating and developing containment/confinement technologies using chemical grouts for in-situ formation of plume barriers. Two types of chemical grouts are being evaluated for barrier use: Duraseal™ (a vinyl monomer compound from Germany) and Chemical Grout 5610™ (a urethane product from 3M). These grouts are being evaluated on ability to form in-situ barriers (i.e., injectability/viscosity), toxicity, resistance to chemical degradation, strength properties, and permeability.

The research work has been divided into the following tasks:

- A. Grout Development
- B. Performance Testing
- C. Grout Testing Chamber (GTC)
- D. Computer Modeling

Grout Development involves the identification of the grout mix ratio that exhibits optimum properties for use as a subsurface barrier. The hydraulic properties of the developed grout will then be tested as a function of time using rigid wall columns. In addition, physical, chemical, and engineering properties of the grout will be determined.

Performance Testing utilizes large diameter acrylic columns (11.5" I.D.) to investigate the injectability of the grout into sand and the structural and hydraulic performance of the formed barrier. Long-term performance of the barrier system formed using the grouts will be studied utilizing different types of permeant fluids.

The selected design mixes will be tested in the Grout Testing Chamber (GTC). The GTC is essentially a large scale flexible wall permeameter (3 ft. diameter specimen). It is capable of simulating in-situ stress conditions and eliminates the influence of boundary effects on the performance of the barrier. This device will evaluate the effectiveness of the barrier system to control contaminant transport. A sub-task is the development of a method and device to form uniform specimens. This will be accomplished through the use of a sand rain device.

The final task is the development of a computer model to predict the subsurface characteristics (i.e., bulbs size, barrier thickness, etc.) of the barrier utilizing different injection strategies. The modeling output will then be compared and verified with the results obtained from the large diameter column testing and GTC.

The current status, testing methodologies, and results of this research is found in the following report.

2.0 CHEMICAL GROUTS TO CONTROL LEACHATE

Research Objectives:

- Choose and evaluate various chemical grouts which exhibit properties making their use feasible in the development of a bottom seal at hazardous waste sites.
- Determine the physical properties of the grouts selected for further study.
- Characterize and develop the chemical grouts as a low permeability barrier to various chemicals and water.
- Conduct performance testing and establish a systematic test protocol

2:1: VINYL MONOMER TO CONTROL LEACHATE

Graduate Research Assistant: David A. Bolten

Project Status:

Four mix ratios have completed immersion testing, and three additional ratios are currently being evaluated. The data collected from immersion testing of the four initial mix designs have been reduced and compared, and are now being subjected to further evaluation (i.e., compressive strength, viscosity, etc.). Because of the permeability test's time requirements, permeability determination has been delayed until a "near-optimum" grout mix is developed. Once determined, rigid wall permeability tests will be conducted.

Grout Ratios

The vinyl monomer grout is formed from two components, each having two ingredients. Component A is a combination of gel concentrate activated with an accelerator. Component B is produced by dissolving a hardening agent in water. Although the amount of accelerator in component A is primarily responsible for the gel time of the grout, it has been found that varying the amount of hardening agent in component B will also affect the gel time. The ratios tested and the percent of component A and component B of each ratio are presented in Table 1.

Table 1. Ratios of Grout Tested

COMPONENT A	COMPONENT B	RATIO OF COMP A / COMP B
% Accelerator	Water/Hardener Mix Solution	
2%	5%	1/1
2%	10%	1/1
2%	5%	3/1
2%	10%	3/1
6%	5%	1/3
4%	5%	½
4%	10%	½

Immersion Testing

The original immersion test, consisting of a period of soaking followed by a equal period of drying, has been expanded to include constant immersion on the grout plugs in the waste solution. After five soaking and drying periods the grout plugs are left immersed in the waste solution and checked weekly for weight and volume change. The grout plugs are left in the waste solution until the grout becomes stable (no change in weight or volume), or the grout plugs lose physical and chemical structure.

In every immersion test conducted thus far, the sodium hydroxide solutions have the most detrimental effect on the grout. Also constant throughout every immersion test, once left immersed, water eventually destroys the integrity of the grout..

Compression Testing

Unconfined compression tests are currently being conducted on four grout ratios. After being immersed in various waste solutions for 1, 7, 14, and 21 days, the grout molds are tested following the procedures previously mentioned. This procedure is followed to determine the rate at which various waste solutions affected the compressive strength of the sand and grout molds at different time intervals.

For each ratio of grout tested, cupric sulfate has the most dramatic increase in strength between intervals. All other waste solution results change for each ratio.

PART 2.2: URETHANE GROUTS TO CONTROL LEACHATE

Graduate Research Assistant: Tara D. Judy

Project Status:

Currently, column experiments are being conducted to determine the hydraulic conductivity of the urethane grout. The experimental setup is described below. The grout specimens were permeated under a constant head of the permeant solution for approximately 2 months. Because none of the solution permeated through the specimens, it was decided that the test columns would be pressurized. For the last month, all the test columns have been pressurized to 15 psi and again no fluids have permeated the grout specimens. Additionally, unconfined compression tests have been conducted using the following gel:extender ratios: 1:14, 1:12, 1:10, and 1:8. For each ratio, unconfined compression tests were conducted for curing times of 24 hours, 7 days, 14 days, and 21 days. The experimental procedures for the column experiments and the unconfined compression tests are described below, respectively.

Column Experiments

Four inch diameter acrylic columns were employed in the column experiments to test for hydraulic conductivity. On both ends of the each column, threaded end caps were glued. Wooden stands were constructed to hold the columns. Underneath the stand, a secondary liquid confinement box was built out of wood and plastic sheets. First, the column was made water-tight using a four inch diameter acrylic plug, which was held in place after the clean-out was screwed on.

Pressurizing Columns

The air compressor nozzle was replaced with a plug valve having a nipple on the end to connect to 1/4 " tubing. The tubing runs from the nipple into a regulator (controls air pressure), and then into a manifold having fifteen outlets. Fifteen brass connection tubes were placed in the threaded outlets. Union tees were ordered so that more columns can be pressurized from one manifold. Therefore, if one union tee is added to each manifold outlet, up to thirty columns can be pressurized. Tubing runs from the manifold into an on-line air regulator (controls air flow rate). Attached to the on-line air regulator is a 1 1/2 " pressure gage. This gage can read pressures ranging from 0-60 psi. From the on-line air regulator, the tubing is then connected to a 1/4" plastic plug valve. This valve is necessary so that air flow can be shut off to any one column. The top clean-out was complete with a brass connection tube and a 1/4 air release valve (used mostly during grout application to sand). The top clean-out had nonhardening putty applied around threads, then screwed tightly in with a pipe wrench. The tubing was then connected from the plastic plug valve to the brass connection tube on the male top

cap. To further ensure air tightness, silicon has been placed around top end of cap and around threaded connections. Currently, a pressure of 15 psi is being applied to the columns. Sixteen columns are now being tested using the following grout to extender ratios: 1:14, 1:12, 1:10, and 1:8. Two columns with distilled water as the head solution are being tested for each ratio, along with two columns with NaOH solution having a pH of 13.

Grout Specimen Design and Preparation

A mass of sand equal to 1705 g at a height of 5 and 7/16 inches resulted in a minimum density of 95 lb/ft³ when placed in the 4 inch diameter columns. A pore volume of grout was then poured into the column through a long funnel so as to not disturb the sand lift. Pressure was then added to force the grout through the sand pores. The grout/sand mixture was then allowed to cure 1-2 hours. After curing, the bottom clean-out was taken off and the acrylic plug was replaced with a 4 inch porous corundum stone, that had been previously saturated with water. A No. 4 filter paper was placed on the porous stone to prevent clogging of the stone with fines. An O-ring was placed around the stone to ensure water tightness. The clean-out was then screwed back on. In the center of the bottom clean-out, a stainless steel 1/4 inch connection tube was placed. Tubing went from bottom of end cap into a 500 ml graduated cylinder which was covered with parafilm wax to minimize evaporation of solution. After letting the urethane grout sit with 5 L for 1 day, all the columns were pressurized.

Unconfined Compression Tests

Compression tests were conducted following ASTM standard D2166. For each grout mix design, three specimens were molded and tested. Compression tests were conducted for the following curing periods: after 1 hour in the mold, 24 hours exposed to air, 7 days exposed to air, 14 days exposed to air, and 21 days exposed to air. For example, the 24 hour curing period included 1 hour of mold curing after which the specimen was taken out of mold and exposed to air for 24 hours. This same procedure applied for the 7, 14, and 21 days of curing.

Results

Column Experiments:

Diffusion appears to be the predominate seepage mechanism.

Unconfined Compression Tests:

An increase in strength with respect to time was noted up to the 14 day compression tests. However, there was little difference between the 14 day compression tests and the 21 day compression tests. It appears that a 14 day curing period ensures maximum curing. Also, surprisingly, the 1:12 (gel:extender) has a higher strength than the 1:8. After 14 days of curing, the 1:12 specimens had a strength of 20 psi, compared to the 1:8 specimens which only attained a strength of 14 psi.

3.0 LARGE DIAMETER COLUMN AND PERFORMANCE TESTING

Graduate Research Assistant: Jacob S. Freshwater

Research Objectives:

- Establish and develop a testing protocol for evaluation of various chemical compounds as a permeation grout for forming in-situ barriers.
- Evaluate the performance of the grouts as a barrier to plume migration.
- Determine the durability of the grouts when exposed to chemical agents.
- Determine the structural integrity of the grout by simulating in-situ stress conditions.

Project Status:

Numerous laboratory studies were conducted during this project period. All efforts to date have focused on the 5610 Urethane. The following sections will discuss the results obtained from these studies.

Mix Design

Because the results of the other phases of this research are not complete, grout mixes selected for this phase of the project were developed based on preliminary testing and evaluation methods (i.e., gel time, viscosity testing, economic feasibility). After testing numerous grout mixes, two 10:1 (activator:5610 gel) mixes were selected for further testing. One mix utilized 10 parts gel time extender (GTE) to one part gel in hopes of maximizing the gel time, while the other investigated the effects of other additives (i.e., water substitution, gel reinforcing agent (GR)). The second mix contains a 60% water, 30% GTE, and 10% GR mixture of the additives. The physical properties of the two mixes is summarized in Table 1

Table 1: Grout Mixes Chosen For Further Testing

Grout Mix	Initial Viscosity (cP)	Gel Time (min)
10:1 (GTE:Gel)	400	25
10:1 (60%W/30%GTE/10%GR)	200	21

To increase the gel time, the activator components were chilled to approximately 10°C prior to mixing with the gel.

Injectability Testing

Most of the injectability testing completed in this quarter investigated the 10:1 (60/30/10) mix. These experiments (12 total) studied the effects of varying soil densities (i.e., porosity) and well design (1.5", 3", & 6: perforation length). Injectability testing was conducted using Ottawa sand at three densities (minimum, maximum, and an intermediate prepared in methods previously developed and discussed) with the same well design. A similar set of tests was then conducted using a different well design. The final series of testing varied the wells perforation hole size. During each experiment, the injection pressure, time to injection completion, and bulb characteristics were recorded. The variation between the bulbs was quantified using a bulb dimension ratio (simply the bulb length divided by bulb diameter). For the 1.5 in. well this ratio was nearly constant for all the densities tested; however, it was found to slightly increase for the 3 in. and 6 in. well designs. Additionally, changing the perforation size of the wells resulted in no change in the bulb dimension ratio.

Future experiments will investigate the effects of injection into saturated (w/ water and chemicals) medias.

Permeability Testing

The permeability testing completed has also utilized the 10:1 (60/30/10) mix. The values for the other mix are currently being obtained. The samples were permeated with seven permeants: deionized (DI) water, 0.01M HCl, 0.1M HCl, 1.0M HCl, 0.01M NaOH, 0.1M NaOH, and 1.0M NaOH. In brief, none of the permeabilities obtained from any of the permeants meet the EPA's landfill liner requirements ($<10^{-7}$ cm/s). Furthermore, as the concentration of the permeant solution increased, the coefficient of permeability increased. To simulate actual field conditions, future experiments will be conducted on both mixes using the EPA's Toxicity Characteristic Leaching Procedure (TCLP) extract solutions.

Durability/Strength Testing

This phase of the experimental program is nearly complete. Samples were collected from each of the grout mixes and immersed in various chemical solutions at different concentrations. The solutions utilized have been discussed in previous reports. Samples were immersed for 1 day, 7 day, and 14 days. After the immersion period, the sample was removed from the solution and subjected to unconfined compression testing. By comparing the results obtained from the two mixes, the effect of the gel reinforcing agent can be quantified.

Samples from both grout mixes are severely degraded and altered by water and all concentrations of NaOH and ethylene glycol. Low concentrations of all the solutions resulted in excessive swelling and strength loss. 1M and 2M HCl and yielded different results. The HCl immersed samples were unaffected, while the

HNO₃ immersed samples were totally destroyed. Acetone and cupric sulfate immersed samples were also unaffected. Based on the results obtained from this phase of testing, there is no definitive variation between the strength/durability of the mix containing the gel reinforcer and that without.

Problems

The permeability tests often yield varying results which results in the need for multiple tests to be performed. Additionally, the permeants and grout deteriorate the latex membrane used in the flex-wall testing. As a preventative measure, the samples have been wrapped in Teflon tape; however, occasionally a test needs to be discontinued, resulting in a loss of substantial time.

4.0 SAND RAIN DEVICE

Graduate Research Assistant: James Moseley

Research Objectives:

- Construct a device that will produce a uniformly dense sand sample for large-scale grout testing.

Project Status:

There are three phases to the sand rain device portion of the barrier design project. They are design, construction, and testing. The construction portion of the project has been completed since mid-July. A lab facility was finally secured on September 22. The apparatus now needs moved from the storage room, assembled, and calibrated for the eventual testing. Afterward, devising standard tests to insure desired and uniform densities are both possible and consistently formed can commence.

Results

Although work on the device itself has slowed somewhat (see below), the following items have been completed in the meantime:

- ▶ As noted above, a high bay area in the COMER building has been secured and cleared for use in testing the device for at least a year.
- ▶ Enough sand for several months of testing has been ordered and should arrive during the first week in October.
- ▶ A plexi-glass cylinder has been ordered for use during the tests as a sample mold in place of the GTC. It is identical to the one used as the reservoir in the device itself so the reservoir can conceivably be replaced if the need arises.
- ▶ The paperwork for the GTC has been processed and Trautwein Soil Testing Equipment

in Houston has begun construction of that apparatus.

- ▶ Standard methods for testing the capabilities and limitations of the machine as well as measuring the relative densities achievable have all been established although they will likely undergo some revision as testing progresses.

Problems

The past several months have been filled with exercises in frustration. The sand rain device has sat in storage since its completion while waiting for lab space in which to set it up. When it became apparent that B17 was not available for use, I attempted to secure an area inside the NRCCE building on the Evansdale campus. It later became apparent that the process of being granted permission was only a seemingly endless series of questions and paperwork. The overall impression was the director there wasn't interested in permitting use of the facility considering the length of the applications and the extraordinary time it took to receive replies from him.

While waiting for replies from the director, I pursued other possibilities and with the much help from Dr. Gabr and the Chairman of the CEE department, Dr. Sam Kiger, I was finally granted space in the COMER building. Unfortunately this has caused an unforeseen delay in testing the apparatus.

5.0: COMPUTER MODELING

Graduate Research Assistant: Edward L. Hakala

Research Objectives:

- Personalize BGROUT to model specific meso-scale grout injection experiments.
- Effectively use COLORGRID in analyzing output created by BGROUT.
- Investigate grout injection strategies.

Project Status:

The computer modeling has been slow but consistent with most of the time spent on history matching and mass balance error problems. Three-dimensional results have been obtained that resemble current small-scale grout injection experiments. These results are only possible when injection rates are significantly increased to compensate for the material balance error that is reoccurring.

The literature reveals that material balance errors may be caused by numerical dispersion and by altering a few parameters the error may be reduced. This is currently being worked on, along with other options in dealing with the material balance errors that are prevalent in BGROUT's 2 and 3-dimensional simulations.

Thorough examination of BGROUT's one-dimensional modeling capabilities reveals that accurate and usable results may be obtained. Mass balance errors can consistently be reduced to less than 5 percent, depending on the type of grid used. Radial one-dimensional grids are highly inaccurate, while horizontal grids are the contrary.

Problems:

The material balance errors are generally between 50 and 70 percent when using a 3-dimensional model. This error is reduced slightly when simulating 2-dimensional models and is usually negligible when simulating 1-dimensional problems. These results are in agreement with those found by Walter K. Sawyer, the developer of BGROUT.

So far it appears that little can be done to significantly reduce the 3-dimensional grout injection simulations. Other ways of dealing with this problem must be sought after and examined.

DEVELOPMENT of STANDARD TEST PROTOCOLS and BARRIER DESIGN MODELS
for
IN SITU BARRIERS
METC Task No. 1.5
(Circulating Air Barrier)

Quarterly Technical Progress Report
Reporting Period: 07/01/95 - 09/31/95

Work Performed Under Contract
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For:
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Office of Fossil Energy
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ABSTRACT

Significant research effort is currently being conducted in the United States and the world for remediation of contaminated soils and groundwater. In parallel to remediation efforts, confinement technologies are needed to retard, or even prevent, the advancement of contamination plumes into the environment until the implementation of remediation efforts is completed. Research proposed herein aims at developing and investigating containment/confinement technology using desiccation for in situ formation of barriers.

The desiccant barrier proposed to be investigated will be the recently developed circulating air barrier (CAB). The CAB utilizes the injection of dry gas (air, nitrogen, CO₂, etc.) to create an ultra dry zone in situ; beneath or adjacent to the zone of contamination. The CAB relies on the removal (drying) of in situ liquids (water) so that any contaminating liquids entering the zone of desiccation must replace the previously removed liquids before the contaminants can migrate further. In field application, the CAB may be established by means of specific patterns of vertical or horizontal (or a combination of vertical and horizontal) injection and withdrawal wells which enable the injected dry gas to travel through and dry the formation prior to exiting via a withdrawal well.

This research will be conducted using laboratory and meso-scale setups. In addition to conventional laboratory equipment proposed research will utilize a large scale reactor for simulating in situ conditions. Conducting the research based on a meso-scale setup will minimize problems associated with scale effects. Such problems are usually encountered when a method is developed in the laboratory with no considerations given to correlation of laboratory scale results to field implementation. The B-17 facility in METC with its infrastructure will be utilized to conduct the proposed work. The proposed experimental methodologies will simulate field conditions and should provide laboratory data to test and enhance predictions of CAB performance made by existing models and computer simulations.

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EXECUTIVE SUMMARY

This study aims 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. The CAB system can provide many advantages, however, there are no laboratory data or CAB field performance data available in the literature. There are however are a number of issues that must be settled before it can be decided if CAB technology is applicable. Key among these issues are the influence of the soil characteristics (such as porosity, permeability, water saturation, grain size distribution, and clay content) on the drying profile. This research will be conducted using laboratory and meso-scale setups to evaluate the soil characteristics influence on CAB performance and will determine the effects of flow and sweep efficiency for fixed and mixed grain size soils. These experiments will validate and/or improve model predictions of system behavior and drying profiles of different soil types.

Sand-packs are being utilized for bench-scale testing to determine the relationship between soil characteristics and in situ barrier quality. Sand-packs are being calibrated to determine porosity, permeability, and saturation characteristics. The soil characteristics will be varied by changing grain size and sorting of the pack materials. A detailed CAB vessel assembly has been designed and been approved for experimental studies at B-17 facilities. The procurement of materials and fabrication of the assembly is in progress by EG&G at METC. Additional laboratory tests on core samples have been undertaken to evaluate the influence of porous media on air-water equilibrium and mass transfer.

1.0 INTRODUCTION

Many contaminated subsurface sites can not be economically decontaminated because of the limitations in technologies for decontamination. In such cases, containment becomes the primary technology for environmental protection. For non-excavatable sites, in situ containment is the most viable approach for preventing further spread of contamination. Different approaches for achieving in situ containment have been proposed, however, the study herein is focused on the evaluation of in situ barriers created by soil desiccation.

The desiccant barrier proposed to be investigated is the recently developed (1,2) Circulating Air Barrier (CAB). The CAB utilizes the injection of dry gas into a porous media to create an ultra dry zone in situ by removing water and reducing the water saturation below the level required for liquids to flow in order to prevent migration of underground contaminants. The CAB, once established, will also provide a means of monitoring and removing contaminants entering the zone. The proposed experimental methodology should provide laboratory data to test and enhance predictions of CAB performance made by existing models and computer simulations.

2.0 PURPOSE

The concept of the Circulating Air Barrier was conceived (1,2) to solve the subsurface contamination problems at the Hanford site used by the former Atomic Energy Commission. The references to CAB (1,2,3) are mainly related to CAB as a concept, and no field or laboratory data is available in the literature. The previous studies (1,2) concluded that a CAB system provided many advantages, however, the concept needs to be demonstrated to develop data necessary for scale-up and regulatory acceptance.

Among issues that must be settled before it can be decided if CAB technology is applicable to all DOE sites are the influence of the soil characteristics (such as, porosity, permeability, water saturation, grain size distribution, and clay content) on the drying profile and CAB performance. The laboratory study to be undertaken will evaluate the soil characteristics influence on CAB performance and will determine the effects of flow and sweep efficiency for fixed and mixed grain size soils. These experiments will validate and/or improve model predictions of system behavior and drying profiles of different soil types.

3.0 BACKGROUND

The Circulating Air Barrier (CAB) system is a desiccant-type barrier designed to prevent the movement of liquid contaminants toward groundwater, using air circulation and a processing system to lower water saturation in a targeted subsurface zone. The concept of Circulating Air Barrier was introduced in a study (1) that evaluated the barrier systems that could be installed beneath and around the tank farms with a minimum of excavation at DOE's Hanford Site. The CAB can be installed using either vertical or horizontal wells, establishing a pattern of air injection and extraction wells. The moving air vaporizes water in the zone and carries the water vapor to an extraction well. In time, circulation of the air reduces the water saturation in the swept interval, and continues to remove, by evaporation, liquids that move into the zone such as a leaked plume. No liquids can flow through this interval until a critical saturation is achieved, a saturation level that is well above the initial saturation. In the event that a leak occurs, the CAB system serves as a tool for early leak detection and provides a means to withdraw volatile contaminants for surface treatment. The study concluded that CAB system provided many advantages including non-physical confinement, active monitoring and leak detection, commercially available oil and gas technologies and equipment, emergency response and rapid deployment capability, and high potential for integration with other remediation technologies. However, the concept needs to be demonstrated to develop data needed for scale-up and regulatory acceptance.

A follow up study by K&M/BDM (2) which addressed modeling, cold test design, and surface processing and control design for the CAB demonstration at Hanford concluded that several issues must be settled before it can be decided if CAB technology is applicable to all DOE sites. Key among these issues is the influence of the soil characteristics such as porosity, permeability, water saturation, grain size-distribution, and clay content on the drying profile and CAB performance. This report further recommended a laboratory study to be undertaken to evaluate the soil characteristics influence on CAB performance and to find out the effects of flow and sweep efficiency for fixed grain-size and mixed grain-size soils. This would also serve to validate and/or improve model predictions of system behavior and drying profiles of different soil types. In addition, a range of geologic and climatic environments within which the CAB could successfully operate, baseline equilibrium moisture curve for a specific grain-size, and relative humidity for a specific temperature could be determined.

4.0 METHODOLOGY

Experimental procedures will be developed to address the problem of evaluating a desiccant barrier, i.e., a barrier based on creation of a dry zone of earth beneath a contaminated zone to store contaminating liquids, thus preventing their further migration. Two phases of experimental research are proposed in this study. The B-17 facility in METC with its infrastructure will be utilized to conduct the proposed work. The first phase deals with bench-scale experiments using laboratory setups. The second phase will deal with a meso-scale setup that will utilize large tanks for simulations of in situ conditions in order to minimize problems associated with scale effects.

Bench-scale testing of the CAB process parameters will utilize sand packs to determine the relationship between soil characteristics and in situ barrier quality. Sand packs will be calibrated to determine porosity, permeability, and saturation characteristics. The soil characteristics will be varied by changing grain size and sorting of the pack materials. Residual water saturation of the pack will be established by first saturating the pack with water and then desaturating the pack by injection of water-saturated air. The pack will then be dried at various rates of air injection to determine drying characteristics as a function of rate, remaining water saturation, and soil characteristics. The final phase of sand pack testing will be to resaturate the packs with simulated contaminant fluids injected at low pressure (near atmospheric) at the top while monitoring any effluent at the bottom. This will allow determination of contaminants migration rate as well as total storage capacity of the packs.

Meso-scale performance testing will be used to investigate the effectiveness of the CAB system in containment/confinement of the study waste under simulated field conditions. The meso-scale tests of the CAB system will utilize large rectangular tanks in DOE/METC's B-17 building to create a three-dimensional test bed to verify, refine, and extrapolate the results of sand pack experiments to field like conditions. The tanks will be filled to a desired depth by slurring sand of predetermined grain size range into the tanks with water. All or part of bed will then be desaturated, dried, and "contaminated" with a safe liquid to simulate the CAB process on the meso-scale. Instrumentation and sampling ports and tubes will be placed in strategic locations in or at the tanks to monitor the status of the CAB.

5.0 WORK PERFORMED THIS PERIOD

5.1 Task 1: SARS Activity

Detailed CAB vessel assembly drawings were submitted to EG&G personnel (as approved by METC) for CAB fabrication and the machine work for the CAB vessel assembly component parts is near completion. A substantial amount of interaction with EG&G personnel has transpired in an attempt to produce a CAB vessel assembly which will not only produce quality data but will also be extremely safe, durable, and easy to assemble, operate, and maintain.

A draft of the 'Operating Plan' (prior to preparation of the draft of the 'Operating Permit') requirements has been completed, however, its editing and consummation is dependent upon final CAB vessel assembly construction because the actual machining of the various components and their integration necessitated some minor design modifications. These modifications generally improved the safety and operational efficiency of the CAB vessel assembly while also adhering to original METC design requirements.

5.2 Task 2.1: Literature Review

A comprehensive literature review relative to CAB was conducted and completed during previous quarters and reported earlier. A presentation relative to the results of the literature review was given on 03/30/95.

Additional literature searches relative to procedures and instrumentation for measuring and monitoring air humidity, soil moisture, and permeability have been continued during this quarter. The key issues in the selection of the instruments are those relative to the accuracy necessary for acceptable measurement and data acquisition while minimizing intrusion in the sand-pack or CAB bed.

Based on an in depth investigation of instrumentation manufacturers products and cost effectiveness; sensors, electronic packages, and data acquisition systems have been selected which should adequately provide accurate data and should also have application in the larger scaled experiments to be performed in the METC building B-17.

5.3 Task 3: Laboratory Equipment and Preliminary Testing

The air-water equilibrium plays a critical role in the CAB design and development. While there are published data for air-water equilibrium, they are not obtained in the porous media. Consequently, it is important to investigate the influence of porous media on both gas-water equilibrium and mass transfer in porous media. Two sets of preliminary experiments have been designed. These experiments are described below.

5.3.1 Sand-pack Tests

The effect of dry air on an unconsolidated porous medium at irreducible water saturation will be investigated during these sets of experiments. The main portions of these experiments will be conducted at the B-17 Building at METC utilizing the CAB vessel assembly. However, a series of preliminary experiments have been designed to evaluate the protocols for determining sand pack properties.

The procedure and experimental setups for determining sand-pack porosity and permeability have been developed (see Figures 1 and 2). The measured porosity values based on the developed protocols have been found reasonable and repeatable. The permeability measurement instrumentation and protocols have been evaluated for accuracy and repeatability.

A series of experiments to determine the effect of an unconsolidated porous media on air-water equilibrium have been completed using a similar, yet experientially modified (see Figure 3) sand-pack test chamber. The methodology of experimental procedures and instrumentation has been utilized in a similar fashion such as those in the previously reported air-water equilibrium tests with Berea sandstone core.

5.3.2 Core Tests

The effect of porous media on air-water equilibrium has been investigated utilizing Berea sandstone core samples. It should be noted that a consolidated porous media, such as a Berea sandstone core sample, does not represent the typical soils at DOE Sites. However, these series of experiments will provide a foundation for evaluating the influence of porous media on air-water equilibrium when the media is at irreducible water saturation. Also, these experiments will provide a lower limit for sand-pack experiments while the

published air-water equilibrium will serve as an upper limit.

The experiments have been completed in terms of a static state, the results of which have been previously reported.

6.0 RESULTS AND DISCUSSION

6.1 SARS Activity

The draft form of the 'Operating Plan' and 'Operating Permit' have been completed and should be finalized and submitted for METC approval during the next quarter. This process has been contingent upon completion of the CAB vessel assembly fabrication due to minor design modifications.

Upon receipt of the completed CAB vessel assembly, the drawings of the assembly and the operating procedures for the 'Operating Plan' will be finalized which will enable submission of a "finalized" draft of the 'Operating Permit' to METC perusal and modification prior approval.

6.2 Sand-Pack Tests

A series of air-water equilibrium experiments have been performed on the sand packs at optimum compaction water saturation. The results (Figure 4) are deemed inconclusive in comparison with the published data and the problems associated with the measurement of data and subsequent calculations have been attributed to the physical design of the preliminary experimental chambers. Experimental data collection will begin with one chamber of the completed CAB vessel assembly with which it is anticipated that these problems (associated with un-occupied volume) will be resolved. At the same time, attempts are continuing to solve these problems with the existing experimental chambers.

6.3 Core Tests

The core saturation, desaturation, and air-water equilibrium experiments have been successfully performed and a comparison of the published and experimental air-water equilibrium data has been previously reported (see Figure 5). Equipment problems have prevented initiation of mass transfer experimentation.

7.0 CONCLUSIONS

7.1 SARS Activity

The next phase of SARS activity is completion of the preliminary form of the 'Operating Permit' and presentation to METC for approval. The completion of this document was contingent upon design and fabrication modifications of the CAB vessel assembly in order to complete the drawings and operating procedures relative to the requirements of the 'Operating Plan'. This SARS activity should be completed within the next quarter.

7.2 Sand-Pack Tests

The sand-pack tests have been useful in establishing experimental protocols and identifying the necessary instrumentation for the CAB vessel assembly experimentation. The experimental results indicate that accurate air-water equilibrium measurements will not be generated until an actual CAB vessel chamber is used for experimentation. However, the experimental test chambers will continue to be modified in an attempt to procure fundamental data prior to calibration and use of the CAB vessel assembly.

7.3 Core Tests

The core tests have provided a foundation for evaluating the influence of porous media on air-water equilibrium. As is illustrated in Figure 5, it would appear that the effect of a porous media on air-water equilibrium is one of enhancement. This enhancement can be attributed to the increased surface area (contact area) in the pore space of the porous media which seems to dominate the effects of surface tension between the two phases.

8.0 WORK PLANNED FOR NEXT PERIOD

8.1 SARS Activity

Upon completion of the fabrication of the CAB vessel assembly, finalize drawings and 'Operating Plan' for 'Operating Permit'. Submit 'Operating Permit' for METC

approval.

8.2 Sand-Pack Tests

Calibrate CAB vessel assembly components and initiate experimentation based on previously determined protocols. Continue determining and acquiring appropriate instrumentation for CAB vessel assembly.

Continue packing sand as per modified 'Standard Ordinary Compaction Test', measuring porosity and permeability, and continue static air-water equilibrium experiments. Perform similar experimentation using a sand of a different grain size.

9.0 TECHNICAL/ADMINISTRATIVE DIFFICULTIES

After meeting with John Rotunda, METC's lead instrumentation technician, on May 25, 1995 determination of the accuracy of necessary instrumentation was accomplished.

10. REFERENCES

1. K&M/BDM: "Evaluation of Alternative Drilling Technologies and Subsurface Barriers for Single Shell Tanks at Hanford", Report Prepared for USDOE/METC under Contract No. DE-AC21-90MC27346, Phase I: Feasibility Assessment Jan. 1993 and Phase II: Implementation Plan Development Nov. 1993.
2. K&M/BDM: "Design of Circulating Air Barrier System for Cold Tests at Hanford", Volume I - Draft Report Prepared for USDOE/METC under Contract No. DE-AC21-90MC27346, Task 23, July 30, 1994.
3. Thompson, B.M., C.E. Morris, J. Stormont, M.D. Anesky: "Development of Dry Barrier for Containment and Remediation of Waste Sites", Proceedings of Waste Management 94 Symposia, Vol. III, pp. 2193-2198.
4. Robert E. Treybal: Mass Transfer Operations, Second Edition, McGraw-Hill Book Company, 1968.
5. H.C. Slider: Worldwide Practical Petroleum Reservoir Engineering, PennWell Books, 1982.
6. C.H. Ikoku: Natural Gas Production Engineering, McGraw-Hill Book Company, 1983.
7. Katz and Coats: Underground Storage of Fluids, Ulrichs Books Inc., Ann Arbor, Mich., 1975.
8. Katz et al: Handbook of Natural Gas Engineering, McGraw-Hill Book Company, 1959.
9. "Compaction Tests", Chapter 6: Manual of Soil Laboratory Testing, Vol. 1, John Wiley and Sons, 1978.
10. ASTM Committee D-18: "Standard Test Methods for Moisture-Density Relations of Soil, Rock, and Soil-Aggregate Mixtures using 5.5 lb Rammer and 12-inch Drop", from Annual Book of ASTM Standards, Section 4, Vol. 04.08, 1991.
11. ASTM Committee D-18: "Test Methods for Moisture-Density Relations of Soil (D698)", Proceeding for Testing Soils, Fourth Edition, December 1964.
12. ASTM Committee D-18: "Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures", from Annual Book of ASTM Standards, Section 4, Vol. 04.08, 1991.

13. ASTM Committee D-18: "Standard Test Method for Permeability of Granular Soils (Constant Head)", from Annual Book of ASTM Standards, section 4, Vol. 04.08, 1991.
14. Alsono, M., M. Satoh, and K. Miiynami: "Void-Size Distribution in Two-Dimensional Random Packings of Equal-Sized Disks", The Canadian Journal of Chemical Engineering, Vol. 70, February 1992, pp. 28-32.
15. Ouchlyama, N.: "Porosity Estimation from Particle Size Distribution", Ind. Eng. Chem. Fundam., Vol. 25, No. 1, 1986, pp. 125-129.
16. Aberg, B.: "Hydraulic Conductivity of Noncohesive Soils", Journal of Geotechnical Engineering, Vol. 118, No. 9, September 1992, pp. 1335-1347.
17. Ameri, S., T.P. Meloy, and K. Aminian: "Permeable Rock Model Using an Array of Pores", Powder Technology, Vol. 75, 1993, pp. 107-112.

Sand Pack Porosity Measurement

Figure 1: The experimental setup for porosity measurements

Sand Pack Permeability Measurement

Figure 2: The experimental setup for permeability measurements

Sand Pack Air-Water Equilibrium Measurement

Figure 3: The experimental setup for sand-pack air-water equilibrium

SAND PACK AIR-WATER EQUILIBRIUM DATA

Figure 4: Sand-pack air-water equilibrium data comparison

BEREA SANDSTONE AIR-WATER EQUILIBRIUM DATA

Figure 5: Berea sandstone air-water equilibrium data comparison

TASK 2.0
ADVANCED PRODUCT
APPLICATIONS TESTING

Chemical Destruction of Chlorinated Organic Compounds

METC TASK NUMBER: 2.1

Quarterly Report for Period
July 1 through September 30, 1995

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for
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Office of Fossil Energy
Morgantown Energy Technology Center
Morgantown, West Virginia

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October 1995

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ABSTRACT

Chlorinated organic compounds, such as carbon tetrachloride, trichloroethylene, 2,4,5-trichlorophenoxyacetic acid (2,4,5-T), and polychlorinated biphenyls (PCBs), have been widely used as organic solvents, pesticides and herbicides, dielectric fluids for transformers and capacitors, and for a variety of other purposes. The environmental problems and health risks associated with these chlorinated organic compounds have been well recognized. The chemical structures of some representative compounds are shown below.

It is the objective of this research program to develop chemical treatment procedures to transform chlorinated organic compounds to less or nontoxic materials. We discovered that sterically hindered triarylboranes are excellent electron carriers for sodium metal and can be used to effectively dechlorinate PCBs from greater than 500 PPM to less than 8 PPM, far less than the 50 ppm standard set by EPA. Because PCBs are among the most inert chlorinated organic compounds, it is likely that this treatment procedure developed for PCBs could also be easily adopted for other chlorinated molecules, including particularly 2,3,7,8-TCDD because of similarity of chemical structures. We will develop a practical procedure to extend this treatment procedure further by synthesizing and fabricating new materials of triarylborane for use in dechlorination of a variety of chlorinated organic compounds. Other chemical treatment procedures for dechlorination of PCBs by using the very reactive hydroxyl radical and by nitration of PCBs to activate the aromatic ring for subsequent dechlorination will also be investigated.

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EXECUTIVE SUMMARY

We have prepared simplified versions of two trimers and a polymer as models for synthesizing a polymer for dechlorination of PCBs. The reaction procedure appears to be efficient and general. Three commercial processes involving dechlorination of PCBs were also evaluated. These process are not particularly applicable to dechlorination of the PCBs-contaminated soil.

1.0 INTRODUCTION

Polychlorinated biphenyls, commonly referred to as PCBs, are one of the major organic pollutants in the environment. The chemical structures of three representative polychlorinated biphenyls are shown in Figure 1. The large scale use of PCBs for a variety of purposes, especially as a dielectric material in capacitors and transformers as well as plasticizers and solvents in plastics and printing inks, coupled with the chemical stability of PCBs against degradation have resulted in their worldwide accumulation in the environment.

Figure 1. Chemical Structures of Three Representative Polychlorinated Biphenyls

The total worldwide production of PCBs through 1980 is estimated to be approximately 2.4 billion pounds. Of the 1.25 billion pounds of PCBs estimated to have been produced in the United States, mainly by Monsanto under the registered trademark of Aroclor, about 24 million pounds are believed to have been released to the environment.

The toxic effects of PCBs have been well documented. One of the most famous cases occurred in Japan in 1968 when PCBs from a defective heat exchanger were leaked into rice oil which was then consumed by more than 1000 people.¹ For those who consumed more than 0.5 grams (average consumption was 2 grams), severe acne, darkened skin, and eye damage developed. Recovery was slow and these symptoms were still present even after three years. Numerous studies have also reported the toxic effect of PCBs to a wide range of wildlife, including mink, some species of shellfish, shrimp, and fish, and especially those birds that are at the top of the food chain, such as eagles, hawks, falcons, and pelicans.² The chronic (long-term) toxicity to humans and other species is yet to be fully realized.

Because of the thermodynamic stability of PCBs, destruction by incineration and other chemical degradation processes are difficult. Disposal of untreated PCBs by landfill is virtually banned by the Resource Conservation and Recovery Act (RCRA). Currently, incineration is still the most widely used method for treating many hazardous wastes, including PCBs. Incinerators are strictly regulated to assure effective destruction of PCBs. For example, the regulation requires 99.9999% (six-9's) efficiency for the degradation of nonliquid PCBs by incineration.

However, despite such strict regulations it is possible that trace amounts of PCBs as well as other combustion byproducts, including the much more toxic polychlorinated benzofurans and dioxins, could still be released to the environment through stack emission. Concerns about the health impact of PCBs, dioxins, and other organic compounds formed and emitted into the environment have on surrounding communities have created many controversies and strong opposition from various environmental groups. It is now typical to take more than ten years and prolonged legal battle before an incinerator for industrial hazardous wastes could be constructed and operated. One recent example involves the Waste Technologies Industries (WTI) facility in East Liverpool, Ohio which recently began its test burn only after 13 years of planning and construction, more than 20 court cases, and even the intervention of the Vice President of the United States. In an article of the *Chemical and Engineering News*, many issues concerning hazardous waste incineration were raised and discussed.³ It is clear that there is a need to continue research and development of alternative chemical processes for treating hazardous wastes in general and PCBs and other chlorinated aromatic compounds in particular.

2.0 Purpose

It is the purpose of this research project to first evaluate the existing technologies for in situ dechlorination of PCBs-contaminated soil. Development of a new chemical treatment procedure for dechlorination of PCBs will also be a major goal.

3.0 Background

Development of chemical process for the destruction of PCBs and other chlorinated aromatic compounds continues to be a research area of intense interest. Limited success has been achieved in some specific cases. We recently discovered that sterically hindered triarylboranes are excellent electron carriers for sodium metal and can be used to effectively dechlorinate PCBs from greater than 500 PPM to less than 8 PPM, far less than the 50 ppm standard set by EPA. Because PCBs are among the most inert chlorinated organic compounds, it is likely that this treatment procedure developed for PCBs could also be easily adopted for other chlorinated molecules, including particularly 2,3,7,8-TCDD because of similarity of chemical structures. The use of the very reactive hydroxyl radical for dechlorination of PCBs was also found to be a promising process.

4.0 Methodology

We will develop a practical synthetic procedure to prepare and fabricate new materials containing triarylboranes as electron carriers for dechlorination of PCBs. Synthetic methods involving organic reactions will be employed to produce these new materials. The use of the very reactive hydroxyl radical, to be generated by the Fenton reaction ($\text{FeSO}_4/\text{H}_2\text{O}_2$) and other methods, for dechlorination of PCBs will also be investigated. Furthermore, an alternative strategy involving an initial activation of the benzene rings of PCBs by nitration ($\text{HNO}_3/\text{H}_2\text{SO}_4$) followed by attacking of the activated benzene rings with NaOH could also provide a solution for degradation of PCBs.

5.0 Work Performed This Period

We have continued our investigations in trying to develop a procedure for the synthesis of a polymer containing sterically hindered triarylboryl functionalities as an electron carrier for dechlorination. In order to simplify the key step and to allow characterization of the reaction product by spectroscopic methods, we have focused our efforts in synthesizing simpler model compounds. Two trimers were synthesized and their chemical structures were fully characterized by ^1H and ^{13}C NMR spectra as well as mass spectra. A polyphenyl polymer was also synthesized by using a procedure that was designed for preparation of a polymer having the electron-carrying triarylboryl functionalities. This procedure appears to produce the desired polymer in the model studies.

6.0 Results and Discussion

The synthetic route summarized in Figure 2 provides an easy access to trimers **4** and **5** in a single step by using a palladium-catalyzed cross-coupling reaction between dibromides **1** or **2** with boronic acid **3**. Because these trimers have relative low molecular weights, it was possible to fully characterize them by ^1H and ^{13}C NMR spectra as well as mass spectra.

Figure 2. Synthesis of Trimers **4** and **5**

Dibromides **1** and **2** are readily available from commercial sources. Boronic acid **3** were synthesized in two straightforward steps (Figure 3). The first step involves lithiation of 1,3-dibromobenzene with *n*-butyllithium followed by treatment with chlorotrimethylsilane to afford **6** in 94 % yield. A second lithiation followed by treatment with trimethyl borate produced, after hydrolytic workup, **3** in 88 % yield.

Figure 3. Synthesis of Boronic Acid **3**

An attempt to convert the two trimethylsilyl groups in **4** to the corresponding diiodide **7** for subsequent transformation to a polymer was also carried out by treating **4** with ICl. While the initial result appeared to indicate a successful conversion of **4** to the corresponding diiodide (Figure 4), an undesirable side reaction also occurred. We believed that this undesirable side reaction is due to the presence of HI in ICl, which produced protonolysis adducts. This undesirable side reaction could be avoided by introducing an acid scavenger in the reaction mixture.

Figure 4. Synthesis of Diiodide **7**

We also synthesized two polymers **8** and **9** as shown in Figure 5. These two polymers have not been fully characterized. However, polymer **9** is more soluble in diethyl ether as can be expected for a material containing bulky organic substituents.

Figure 5. Synthesis of Polymers 8 and 9

Three commercial processes involving dechlorination of PCBs by (1) Trinity Environmental Technologies, Inc., (2) Chemical Waste Management, Inc., and (3) Roy F. Weston, Inc. were also evaluated. The Trinity Environmental Technologies, Inc. uses a modified version of the Goodyear process for dechlorination of PCBs oils. It is claimed that this process is cost competitive compared to incineration. However, this process will not be able to treat the PCBs-contaminated soil.

The Chemical Waste Management, Inc. uses the KGME process, a modified KPEG process, for dechlorination of PCBs. A demonstration of the KGME process was conducted at the ReSolve Superfund sit at North Dartmouth, Massachusetts in the summer of 1992 under the sanction of EPA. A private communication with Dr. Richard J. Ayen, Vice President and General Manager of the Chemical Waste Management, Inc., indicates that the KGME process is more expensive to operate than thermal desorption of PCB contaminated soil followed by off-site incineration of the resulting oil. The Chemical Waste Management, Inc. has a thermal desorption process to treat the PCBs-contaminated soil.

The procedure employed by Roy F. Weston, Inc. involves the use of zinc and a mild organic acid to generate nascent (atomic) hydrogen, which replaces aromatic halogen atoms in toxic organics in the presence of gentle heat and an unspecified catalyst. This process has been tested only in the laboratory in gram quantity of PCBs oil and has not been scaled up to pilot plant level.

7.0 Conclusions

We have successfully produced two additional trimers as models for the synthesis of higher molecular weight polymers. The synthesis of a simplified polymer 8 also provides a guide to prepare the desired polymer 9. Three commercial processes involving dechlorination of PCBs were also evaluated. These process are not particularly applicable to dechlorination of the PCBs-contaminated soil.

8.0 Work Planned for Next Period

We plan to produce larger amount of polymer 9 by the procedure developed so far. A more definitive characterization of this new material for dechlorination of PCBs will also be performed

References

- (1) Bailey, R.A.; Clarke, H.M.; Ferris, J.P.; Krause, S.; Strong, R.L., *Chemistry and the Environment*, Academic Press: New York, 1978; p 158.
- (2) See reference 1 pp 172-174.
- (3) Hanson, D.J., *Chemical and Engineering News* **1993**, 71, 7.

**CONTINUED DEVELOPMENT OF AN ATMOSPHERIC
MONITORING MASS SPECTROMETRY SYSTEM**

METC TASK # 2.2

**Quarterly Technical Progress Report
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ABSTRACT

The objective of this project is the development of a mass spectrometric methodology applicable to the field determination of Volatile Organic Compounds (VOC's), such as BTEX components (Benzene, Toluene, Ethylbenzene, and Xylenes). A combination of chemical ionization, selective ion storage, and tandem mass spectrometry will be employed with an ion trap mass spectrometry system. The Gas Chromatography Mass Spectrometry (GC-MS) interface on the ion trap system will be modified to permit direct atmospheric monitoring. Through the use of tandem mass spectrometry methods the need for chromatographic separation will be eliminated reducing the overall size and complexity of the system. Existing literature methods and newly developed methods will be compared for sensitivity, accuracy, and precision.

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EXECUTIVE SUMMARY

During this quarter the molecular beam sampling interface was constructed and installed during the month of July. This began a series of technical problems that have stalled progress as described in the work performed section of this report.

During this quarter personnel working on the project included two part-time technicians, a summer intern student from Case Western, and a full time technician. One of the part-time technicians left in the middle of the quarter to pursue Medical School. The second part-time technician received additional support from the NRCCE through ACF's funding of the Winnfield project. The summer intern student left in the middle of August to return to CWU. The full-time technician on the project was moved to half-time because of difficulties with the instrument.

Collaboration with Varian continues, however, the ion isolation software was tested and found to lack needed flexibility. Varian has been apprised of the needs for future software. Difficulties with instrument control in the software have prevented the further development of methods. The NRCCE has provided additional support of this project in personnel and supply.

1.0 Introduction

In the general area of Characterization, Sensors, and Monitoring, analytical systems are needed that can provide near real-time measurements of hazardous materials and their degradation products at sites where contamination is suspected. Of particular interest are the volatile organic compounds (VOC'S) associated with petrochemicals. Presently, we are investigating the utility of atmospheric sampling mass spectrometry for the determination of benzene, toluene, ethylbenzene, and xylenes in ambient air. Preliminary methods relying on chemical ionization (CI) and/or tandem mass spectrometry (MS/MS) have been identified in a survey of the literature. It is proposed to continue this work by developing methods that employ a combination of CI and MS/MS techniques with the ion trap mass spectrometer for the identification of components in mixtures. This expands upon the previous work by examining the influence of potential interferences on the accuracy of the methods and by developing appropriate protocols to eliminate these interferences or correct for them.

2.0 Purpose

The overall objective of this project is the development of an atmospheric monitoring ion trap mass spectrometry system and associated methods for determination of volatile organic compounds. One of our ultimate goals is to develop methods that can be employed by technician level operators. We believe that this is an essential first step toward the development of truly field portable mass spectrometry systems. Toward the end of the project we anticipate using the system at field sites to demonstrate the methods' capabilities.

3.0 Background

During 1994, the NRCCE acquired an ion trap mass spectrometry system for use in atmospheric monitoring. Through funding of a project entitled "Evaluation of IR and Mass Spectrometric Techniques for On-Site Monitoring of Volatile Organic Compounds" mass spectrometric methods for separation and determination of the principal components in BTEX, (Benzene, Toluene, Ethylbenzene, and Xylenes) were identified in the literature. The literature

methods indicate some interference problems that must be considered to obtain accurate data, ie. the separation of xylenes and ethylbenzene. In the 1995 project year it is proposed to develop complete methods for the speciation of 10 components in an environmental petroleum standard and the speciation of 9 components in an environmental halogenated hydrocarbon standard. Our interest in the petroleum standard is to test the ability of the system to identify components in the atmosphere near a leaking petroleum tank; whereas, the interest in the halocarbons stems from a desire to develop monitoring for off gas from hazardous waste incinerators. During the course of the work potential interferences arising from both the sample and the monitoring environment will be identified. The original methods will then be modified by employing selective reagent chemical ionization and/or tandem mass spectrometry to selectively identify the species of interest and to eliminate the influence of the inteferent species.

4.0 Methodology

It was attempted to employ selective ion storage software to enable the monitoring of the BTEX components. This was done so that parent ions corresponding to the individual sample components could be monitored and quantitation afforded. This was attempted with the GC inlet so as to avoid problems that might arise from the atmospheric interface. 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. After the software was installed by the Varian technician, we could no longer investigate MS/MS. Work with MS/MS will resume in the final quarter.

A molecular beam interface was employed to permit direct sampling of atmospheric species. The interface did not adequately reduce the pressure admitted to the ion trap. The result was spectra with peaks too broad to be interpreted. We are now redesigning the interface.

5.0 Work Performed This Quarter

MS Toolkit Software was installed on the ion trap in July by a Varian service engineer. This software allowed the system to monitor selected ions,

up to five at a time, but precluded the use of tandem mass spectrometry. In initial tests with this software, the detector of the ion trap mass spectrometer was repeatedly damaged by high ion currents. Discussions with Varian revealed that the source of this damage was the abundance of water in the trap employed for Water CI. When we first designed the experiments, we believed that the detector was not powered until a mass scan was initiated. A shortcoming of this software is that the detector is not monitored until the mass scan but is powered at all times. A result of this is that during the ionization period, the detector "sees" all ions generated, a very strong signal, and is effectively "blinded" (burnt out by excessive signal). The nature of this problem was discovered in late August. Using funds from the project and from the NRCCE, two detectors were replaced over the course of the quarter. Varian's support staff suggested that we might avoid this problem by employing a different approach to sample ionization. We are investigating this alternative at the present time.

A molecular beam sampling interface, Figure 1, was installed on the system and tested for performance. From the beginning problems were encountered with the gas load generated on the ion trap by the new interface. Initially, pumping of the interface was achieved with the backing pump of the turbo molecular pump on the ion trap. This approach failed to reduce pressure sufficiently to operate the ion trap. The original backing pump was replaced by a larger backing pump in an effort to alleviate the problem. At this point the trap was operational but yielded poor quality spectra. The spectra exhibited line broadening that we attributed to high working pressure within the ion trap. The system has no pressure monitoring device so exact internal pressures are not known. The next effort was to use two pumping systems, one for the interface and one for the ion trap. After acquiring the second pump, this was attempted. Again the spectra were too poor to provide useful information. At this point, in late August, we decided to reinstall the GC interface and redesign the atmospheric interface. This process is going on at the present time. We also suggested to Varian that future traps allow for a larger turbo molecular pump to be added to the system for atmospheric sampling work.

We spent most of September returning the system to its original configuration and calibrating its performance. During the final quarter we will investigate the use of MS/MS to differentiate xylenes from ethylbenzene.

6.0 Conclusions

The efforts of this quarter were frustrated by a variety of technical problems as described above. Our approach now is to focus on MS/MS experiments with the GC interface to permit the differentiation of ethylbenzene and xylenes. We are investigating approaches to utilizing water chemical ionization without destroying the detector of the ion trap,

Capture of Hazardous Waste Materials Utilizing Fluidization Coating Technology

METC TASK 2.3

Quarterly Technical Progress Report
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For:
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Office of Fossil Energy
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Abstract

The purpose of this research is 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 will be addressed. These solutions will be sprayed into a high temperature fluidized bed containing different types of solids. Due to evaporation of the solution, the non-volatile inorganic materials will either concentrate on the fluidized particles or will form an aerosol of fine particles (<1 micron) due to spray drying. The capture efficiency of the fluidized bed will be determined by evaluating the fraction of the heavy metals which is captured by the fluidized solids. The chemical form of the metals on the solids will also be determined and the leachability of the metals from the solids will be found. Techniques to further stabilize the metals on the fluidized particles will be addressed and may include a secondary spraying of stabilizing chemicals with an additional thermal treatment and over-spraying the fluidized particles with a low melting point glass.

During the 3rd quarter of 1995 the focus of this project was changed (letter to E.E.Cook dated 9//95) from the original plan outlined above. The new focus reflects a closer working relationship with ThermoChem Inc., Columbia, MD. The remainder of the first year of this project will be used to modify and test the experimental equipment to simulate the destruction of organic waste materials in a high temperature steam reforming atmosphere. This work will complement on-going research at ThermoChem, Inc. concerning the evaluation of destruction efficiencies of RCRA organics in their two-stage fluidized bed process for treating mixed wastes.

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Executive Summary (Current Work)

Due to a change in focus of the current research, several changes in the tasks to be performed in year 1 were made. The current emphasis for the project is to investigate the destruction efficiencies of RCRA organics and surrogates in a steam reforming atmosphere. This work ties in more closely with on-going research, being performed by ThermoChem Inc. of Columbia MD, on a two stage fluidized bed system for the destruction of mixed wastes. The purpose of the work covered under this proposal is to simulate the second stage of the ThermoChem process, in which organic materials are to be destroyed in a high temperature steam reforming atmosphere. During the third period of this project, the design of the fluidized bed equipment was modified. This redesign of the system included a provision for a dual gas feed system to accommodate the use of a hydrogen/carbon dioxide mixture with steam. In addition, the gas quench system has been redesigned to accommodate an increased flow of condensed water due to the use of steam as a feed gas. Several additional safety features have also been added to the design due to the use of hydrogen. These features include the use of combustible gas (hydrogen) detectors for the laboratory, the use of a nitrogen dilution stream for the reactor effluent gas and a nitrogen purge of the tube furnace.

1.0 Introduction

The capture and disposal of hazardous inorganic chemicals from liquid solutions and liquid-solid slurries currently is of great concern. Such hazardous chemicals typically contain heavy metal compounds, for example mercury, lead, cadmium, and sometimes radioactive species. The sources of these chemicals are diverse, and include: aqueous streams produced from washing contaminated soils; organic streams such as lead bearing paint; and dilute aqueous solutions of radioactive elements used in hospitals. The source and characteristics of the waste stream will often dictate the method of treatment. Methods such as adsorption on to activated carbon, incineration and gasification are all currently used to dispose of hazardous wastes containing heavy metals and radioactive species. The fate of the heavy metals and the their final chemical form is unclear, Barton et al. (1), for many treatment processes and this forms the *raison d'être* for this research.

The focus of the research was changed during the third reporting period of 1995 (Letter to E.Cook dated 11 September 1995). The current aim of the work is to evaluate destruction efficiencies of RCRA organics and surrogates in a steam reforming atmosphere. This work ties in closely with the development of a new two stage process by ThermoChem Inc. for the destruction of mixed wastes.

2.0 Purpose

The purpose of this research is to investigate the use of fluidized bed coating technology in the collection, concentration and stabilization of hazardous inorganic chemical compounds. Fluidization technology has been utilized in the destruction of waste streams in such applications as Municipal Solid Waste (MSW), Medical Waste and Hazardous Waste Incinerators. However, the emphasis has been on maximizing the destruction efficiency for organic compounds. Recently, with the increasing concern regarding the formation of dioxins and dibenzofurans in such devices, it has been suggested that gasification, rather than combustion, should be considered for the destruction of waste streams, Gallaway and Sprung (2). However, regardless of the method of destruction, if a waste liquid stream containing heavy/radioactive metals is to be fed to an incinerator/gasifier then the mechanism by which the inorganic material leaves the system needs to be investigated. Therefore, it is the purpose of this work to address what happens to such metal species when solutions of them are fed to fluidized bed waste incinerators/gasifiers.

Due to the change in focus of the research, as outlined in Section 1.0 above, the purpose of the work was changed during the third reporting period of 1995. Currently, the purpose of this work is

to assess the destruction efficiencies of RCRA organic compounds and surrogates in a high temperature, steam reforming atmosphere.

3.0 Background

When considering the fate of liquid solutions of heavy metals fed to equipment containing fluidized solids, several removal mechanisms must be considered. It is assumed that the liquid stream will be sprayed into the bed via an atomizing or hydraulic spray nozzle. Clearly, it is important to disperse the liquid into the bed as a fine spray, in order to prevent excessive agglomeration and "wet quenching" of the bed. For waste incineration/gasification equipment typical bed temperatures will be high compared to the boiling point of the liquid and undesirable spray drying of the liquid waste may occur. The object when spraying the liquid feed into the fluid bed is to coat the fluidized particles with feed solution and to avoid spray drying. The efficiency of capture of the liquid is very important since liquid not deposited on particles will evaporate quickly in the vapor phase and effectively spray dry. When spray drying occurs the inorganic material, including any heavy metals, will tend to form a fine solid/aerosol mist that will be very difficult to clean from the gas stream. In fact, the formation of aerosols may so severely affect the efficiency of capture in such devices as scrubbers, bag houses and electrostatic precipitators that the majority of the metals end up in the stack gas. Therefore, the efficiency of spray capture by the fluidized particles is a very important factor in fluidized bed coating operations. For typical coating operations, the capture efficiency ranges from 95 - 99%. However, typical coating operations do not use the level of superheat expected in combustion and gasification equipment.

The second consideration is the fate of the metals once they have been deposited on the solids surface and the liquid evaporated. Obviously, this will depend on the temperature and pressure (usually 1 atm) in the bed, the chemical composition of the bed material and the gas phase composition. The gas phase composition will be mainly, nitrogen, water, carbon dioxide and oxygen with smaller amounts of hydrogen chloride, hydrogen sulfide (gasification) and sulfur dioxide (combustion). Evidence suggests that binding of the metals with the bed material is a strong function of the bed material, Ho et al. (3,4) and that the leachability of metals from bed material is generally low.

Thus two key elements to be investigated are capture efficiency and stabilization of metals once they are on the bed material.

As mentioned above, the focus of the research has changed and currently the destruction of organic materials at elevated temperatures and in a steam reforming atmosphere is of concern. The use of a steam reforming atmosphere for the reaction and elimination of RCRA organics has been shown to significantly reduce

the production of dioxin and furans during the destruction process when compared to oxidation/incineration processes. However, the efficiency of the destruction and the effect of temperature, gas residence time and composition has not yet been fully quantified. Therefore, the goal of the on-going research is to quantify the effect of these parameters on the destruction efficiency of RCRA organics and surrogates.

4.0 Methodology

The overall objectives of this work are to assess the potential of fluidized bed coating techniques to capture, concentrate and stabilize hazardous inorganic chemicals present in solution. The specific objectives are:

Identify model compounds to represent hazardous waste chemicals containing heavy metals.

Demonstrate that aqueous solutions of these model compounds may be sprayed onto a bed of fluidized particles resulting in the capture and concentration of these compounds on the particles.

Evaluate the capture efficiency of the fluidized bed coating process.

Investigate different routes to stabilize the model compounds so that the resulting bed particles have very low levels of leachable heavy metals and are hence non-hazardous.

Due to a change in focus of this project, tasks 4 and 5 for the first year have been changed. These changes are geared towards the modification of the reaction system to enable it to handle a mixture of feed gases and a feed stream of organic material.

Year 1

1. Design of a fluidized bed capable of operating at high temperatures (up to 900°C) to be used in the coating experiments.
2. Construction of fluidized bed system.
3. Choice of a model chemical system for the hazardous waste and the size and materials to be used for the fluidized particles.
4. Redesign the fluidized bed system to accommodate:
 - (i) a new feed gas system to include the use of hydrogen and hydrogen/carbon dioxide mixtures as well as steam.
 - (ii) new distributor plate to allow even distribution of feed gases into the bed.

- (iii) redesign the gas sampling equipment and traps to accommodate the new feed materials and operating conditions.

5. Complete a safety review for the new process conditions with emphasis on the safe use of hydrogen in the experimental program.

5.0 Worked Performed in this Period

The start of the experimental portion of this project was delayed until March 8, 1995 due to funds not being available until this time. During the period 7/1/95-9/30/95, for which this report is written, the following work was accomplished:

Item 1: The three-zone tube furnace has been set-up in the lab and power has been hooked-up. Calibration and testing of the heater is scheduled to start soon.

Item 2: The design of a dual gas feed system has been started. The need for additional feed gases to be used is a consequence of the new shift in project focus. Combinations of hydrogen, carbon monoxide and steam will be used to simulate the reaction atmosphere in the second stage of the ThermoChem Process. To promote easy control and simplicity, hydrogen and carbon dioxide will be fed from separate gas cylinders and the flowrate of each gas will be controlled through a rotameter and a valve, which will act as a critical flow orifice. Steam will be controlled separately through a rotameter or mass flow controller. The new experimental set-up is shown in Figure 1.

Item 3: Due to the use of hydrogen in the laboratory, special safety considerations must be taken. To avoid the possibility of a build-up of unreacted hydrogen in the exhaust system, it is proposed to dilute the gas leaving the unit with nitrogen prior to venting into the fume hood exhaust. The flow of nitrogen will be regulated such that, under the worst case conditions (no reaction of hydrogen), the concentration of hydrogen can never exceed the LEL (lower explosion limit). In addition, two combustible gas detectors will be purchased (Matheson Gas Detector 8059). These instruments are capable of detecting the presence of hydrogen and give audible warnings when the concentration level reaches 10% and 30% of the LEL. Finally, a small nitrogen purge will be used to avoid any hydrogen build up in the vicinity of the heater.

Item 4: The redesign of the gas sampling ports and traps has been started. Due to the use of steam as a primary feed gas, it was necessary to redesign the cold trap on the exit stream from the reactor to accommodate the additional flow of condensed water. The

Figure 1: Sketch of Modified Experimental Apparatus

new design also incorporates a drain valve to allow for the removal of the condensate. The gas sampling port will consist of a swagelok fitting with a rubber septum to allow the removal of gas samples with a gas syringe. The gas sampling port will be located after the cold trap. Finally an activated carbon filter will be added to trap any unreacted organics still in the reactor effluent stream prior to venting to the fume hood exhaust.

6.0 Results and Discussion (Current Period)

Due to a change in project focus and a delay in the installation of the furnace the experimental work for this project has lagged behind schedule. At present, the furnace has been installed and it will be tested in the near future. The main work accomplished in the third period has been to redesign the system as outlined in Section 5 above. Several of the sub-systems, including the gas feeds, cold quench and sampling ports have been designed and are under construction.

7.0 Conclusions (Current Period)

Despite the delay in starting the experimental program it is expected that the modified work schedule for the first year of this project, as outlined in Section 4, will be completed on time.

8.0 Work Planned for Next Period

The feed and exhaust system for the fluidizing gas will be completed. Hydrogen monitors will be bought and installed in the lab. The calibration of the furnace will be completed and thermocouples will be installed inside the reactor to verify the reactor temperature profiles. The redesigned cold trap will be constructed and installed. The gas sampling port, particulate filter and activated carbon bed will be installed in the exit gas line. One hot test run will be performed to verify that all components in the system are functioning properly.

References

1. R.G.Barton, W.D. Clark and W.R.Seeker, "Fate of metals in waste combustion systems", *Comb. Sci. Tech.*, 74:327 (1990)
2. T.R.Gallaway and J.L.Sprung, "Destruction of UST Organics and Nitrates, Polymeric Organic Wastes, and Chlorocarbon Solvents by Steam Reforming", *Proc. Waste Retrieval, Treatment and Processing Meeting*, Houston, TX, 215-221, March (1993)

3. T.C. Ho, H.W.Chu and J.R.Hopper, "Metal volatilization and separation during incineration", *Waste Mgmt.*, 13,455-466 (1993)
4. T.C.Ho, C.Chen, J.R.Hopper and D.A.Oberacker, "Metal capture during fluidized bed incineration of Wastes contaminated with lead chloride", *Combustion Sci. Technol.*, 85, 101-116 (1992)

Acronyms and Abbreviations

LEL - Lower Explosion Limit
MSDS - Material and Safety Data Sheets
MSW - Municipal Solid Waste
RCRA - Resource Conservation and Recovery Act (1976)

ADVANCED PRODUCT APPLICATIONS TESTING
REMEDICATION OF HAZARDOUS SITES WITH STEAM REFORMING

TASK 2.4

Quarterly Report for Period
July 1 through September 30, 1995

Work Performed Under Contract
No.:DE-FC21-92MC29467

For
U.S. Department of Energy
Office of Fossil Energy
Morgantown Energy Technology Center
Morgantown, West Virginia

By:

Manufacturing and Technology Conversion International, Inc.
Columbia, MD 21044

September 1995

ABSTRACT

All components of the system were shipped to and received at MTCI's East Coast Development and Manufacturing Facility.

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1. TECHNICAL BACKGROUND

A complete discussion of the technical background was presented in the quarterly report for the period July 1, 1993 through September 30, 1993. For continuity of the discussion in this part, the following summary paragraph has been included herein.

The MTCI thermochemical reactor system has easily demonstrated at commercial levels its superior performance in the steam reforming of a wide variety of biomass, industrial and municipal waste feedstocks containing chlororganics as well as coal, coal liquefaction bottoms, and mild gasification char at ambient (atmospheric) conditions. The system processed a wide spectrum of feedstocks producing a hydrogen-rich product gas that is free of the diluents (primarily N₂) found in air-blown steam reforming systems and is more cost-effective than oxygen-blown systems. In addition, liquid and solid waste streams from the MTCI system show extremely low levels of toxics and leachability, permitting easier landfill or industrial toxic by-product recovery. The feasibility of developing a pressurized system based on the MTCI technology would permit even greater gains in processing yields, system modularity, and capital and operating costs for processing hazardous and other waste. This would especially be applicable to the cleanup and treatment of large volumes of soils contaminated with toxic organics, i.e., PCBs, pesticides, cyanides, RCRA metals, and dioxin/furans. Reformation of toxic organics in the oxidizing environment of incinerators are completely eliminated because of the reducing environment present in the MTCI thermochemical reactor (steam reformer).

2. EXPERIMENTAL METHODOLOGY

The test plan and methodology remain the same as previously reported.

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3. EXPERIMENTAL RESULTS AND DISCUSSIONS

During this reporting period, a corporate decision was made to consolidate all experimental, testing and fabrication activities at MTCI's East Coast Development and Manufacturing Facility. As a result of this decision, all parts and equipment have been packaged and shipped to Baltimore.

4. CONCLUSIONS

No direct labor was expended against the contract in July and August. It is anticipated that start-up of the work at Baltimore will begin in the next quarter.

PLANS FOR NEXT REPORTING PERIOD

- Unpack and layout equipment and parts.
- Initiate assembly of the system.

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"ENVIRONMENTAL POLLUTION CONTROL DEVICES BASED ON NOVEL FORMS OF CARBON"

Final Draft for Approval

Work Performed Under METC Task 2.5
as Part of the WVU-DOE Cooperative Agreement,
DE-FC21-92MC29467

For
U. S. Department of Energy
Morgantown Energy Technology Center
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ABSTRACT

The use of electrochemistry is an effective means to remove heavy metal contaminants from aqueous effluent streams. Electrochemical processes also exist for the removal of salts as well as bacteria and organic compounds from water. This project deals with the development and testing of carbon nanofibers for the electrolytic removal of heavy metals from the effluent stream. Both electroplating and electrosorption are employed for this task.

This work was to develop and test a carbonaceous material with an extremely large ratio of surface area to electrolyte volume. This was accomplished by using a packed-bed of carbon nanofibers or by growing carbon nanofibers on a conductive support. The surface area can be increased by 2-3 orders of magnitude. The increased surface area can help minimize the length of electrode through which the solution must pass. The decreased distance leads to reduced resistance to solution flow.

A novel type of carbon nanofibers has been tested for its ability to remove heavy metal ions from aqueous samples via electroplating and electrosorption. Removal efficiencies above 90% have been obtained for the reductive removal of cadmium and lead. These enhanced removal efficiencies are capable due to the large surface area of these carbon nanofibers ($200^+ \text{ m}^2/\text{gram}$). Long-term removal of lead over a period of 72 hours using electroplating decreased the concentration of a 100 ppm lead feed to less than 10 ppm. Even after 72 hours, the carbon fibers showed no sign of saturation. For the 72 hour period, a capacity of $0.90 \text{ g}_{\text{Pb}}/\text{g}_{\text{nanofibers}}$ is realized.

Removal via electrosorption produced similar results, but with a early drop-off of efficiency and a much smaller capacity ($7.1 \times 10^{-4} \text{ g}_{\text{Pb}}/\text{g}_{\text{nanofibers}}$ for a 57 hour period). This is due to the neutralization of the charge on the carbon nanofiber surface caused by the electrosorption of the positively-charged metal ions. It is envisioned that for aqueous streams, electrosorption will be applied to remove radionuclides and other metals that have reduction potentials greater than water. The removal of radionuclides would decrease the volume of radioactive waste produced from the clean-up of decommissioned nuclear sites.

The recovery of metals using electrosorption was demonstrated using lead ions. the recovered effluent was concentrated 331% in lead after reversal of the potential applied to the remediation cell. This resulted in a decrease in the volume of high level lead waste effluent by 1:10.

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EXECUTIVE SUMMARY

A novel type of carbon nanofibers has been tested for its ability to remove heavy metal ions from aqueous samples via electroplating and electrosorption. Removal efficiencies above 90% have been obtained for the reductive removal of cadmium and lead. These enhanced removal efficiencies are capable due to the large surface area of these carbon nanofibers ($200^+ \text{ m}^2/\text{gram}$). Long-term removal of lead over a period of 72 hours using electroplating decreased the concentration of a 100 ppm lead feed to less than 10 ppm. Even after 72 hours, the carbon fibers showed no sign of saturation. For the 72 hour period, a capacity of $0.90 \text{ g}_{\text{Pb}}/\text{g}_{\text{nanofibers}}$ is realized.

Removal via electrosorption produced similar results, but with an early drop-off of efficiency and a much smaller capacity ($7.1 \times 10^{-4} \text{ g}_{\text{Pb}}/\text{g}_{\text{nanofibers}}$ for a 57 hour period). This is due to the neutralization of the charge on the carbon nanofiber surface caused by the electrosorption of the positively-charged metal ions. It is envisioned that for aqueous streams, electrosorption will be applied to remove radionuclides and other metals that have reduction potentials greater than water. The removal of radionuclides would decrease the volume of radioactive waste produced from the clean-up of decommissioned nuclear sites.

The recovery of metals using electrosorption was demonstrated using lead ions. The recovered effluent was concentrated 331% in lead after reversal of the potential applied to the remediation cell. This resulted in a decrease in the volume of high level lead waste effluent by 1:10.

ELECTROCHEMICAL STUDY OF CARBON NANOFIBERS

INTRODUCTION

PURPOSE

The purpose of this research was to assess the feasibility of using carbon nanofiber devices to remove heavy metal contaminants from aqueous streams. This work will address the fabrication, behavior and analytical utility of these novel carbonaceous materials. Standard electrochemical techniques will be employed to meet this objective.

BACKGROUND

Electrochemical techniques pertain to measurements involving the flow of electrons during a reduction-oxidation (redox) reaction. These measurements involve current, potential, charge and/or time as the primary variables. Electrochemical studies typically incorporate the use of a three electrode system. This systems includes a working, reference and auxiliary electrode. The redox reaction occurs at the surface of the working electrode as a result of the applied potential. Therefore, it is critical to choose a suitable material for the working electrode. To be effective, the material must meet certain requirements. The electrode material should exhibit high electrical conductivity, be chemically inert over the potential region of interest, show favorable electrochemical behavior with the analyte(s), have a low background current and have an easily reproducible surface (1). Carbon materials are well suited for use as working electrodes. Graphite (2,3), carbon paste (4), glassy carbon (5) and reticulated vitreous carbon (RVC) (6) are a few examples of carbonaceous materials that have been used as working electrodes. A detailed discussion of carbon electrodes has been compiled by Dryhurst and McAllister (7).

Carbonaceous materials have been used to produce flow-through porous electrodes. Electrode materials have included graphite chips (8) or granules (9), glassy carbon grains (10), crushed graphite (11), screens of graphite (12) or carbon (13) and RVC (14). These porous flow-through electrodes have been used to remove metal ions from aqueous solutions. This is of major importance to industrial processes and environmental applications. The large surface area of porous flow-through electrodes makes them excellent candidates for the removal of metal ions from solution. Removal efficiencies approaching 100% can be achieved (14).

The present work will address the use of various carbon materials, including carbon nanofibers, to produce porous flow-through electrodes for the removal of metal ions from aqueous media. The resulting effluent will be monitored downstream using electrochemistry and/or Atomic Absorption (AA) to assess the decrease in analyte concentration and hence the electrode efficiency. Whenever possible, Anodic Stripping Voltammetry (ASV) will be used to measure the metal ion concentration in solution because of its inherent sensitivity and low detection limits (sub parts-per-billion). Moreover, using ASV it is possible to determine the concentration of multiple metal ions in solution simultaneously. Atomic Absorption will be used to confirm results obtained using electrochemistry and whenever electrochemical techniques can not be used.

EXPERIMENTAL METHODOLOGY

A schematic diagram of the apparatus used to carry out these experiments is shown in Figure 1. It was designed in the WVU lab and was produced by the WVU machinist. It is a two-cell system. The upstream, working cell removes metal ions from the flowing stream. The downstream, analytical cell is used to measure the metal ion concentrations in the resulting effluent. The analysis of the analyte concentration leaving the working cell is measured by anodic stripping voltammetry (ASV). This is necessary since the ion concentration of the metals leaving the working cell is expected to be in the parts-per-billion (ppb) range and such an analytical cell is essential to obtain sensitive and accurate measurements at these low concentration levels. A typical 3-cell electrode system, using a silver/silver chloride (Ag/AgCl) reference electrode will be used for all studies.

METAL REMOVAL CELL

The upper cell (Figure 2) is used to test the various carbonaceous electrode materials for their ability to remove certain heavy metal ions from an aqueous stream. The cylindrical body of the upper (working) flow-through cell is made of Lexan. A solution flow channel is drilled through the Lexan body. The carbonaceous working electrode material is placed into the flow channel. Contact to the working electrode is accomplished using a platinum wire and mesh inserted through an access port in the Lexan wall. The Ag/AgCl reference electrode and platinum wire auxiliary electrode are introduced into the flow channel by similar access ports in the wall. Teflon tubing is used to connect the sample reservoirs, the pump and the upper and lower cells.

The sample is pumped into the upper working cell and through the carbonaceous working electrode material. A peristaltic pump is used to control the flow rate for all experiments. For the cathodic removal of metal ions, a potential more negative than the standard reduction potential of the metal ions of interest is applied to the working electrode (see Table I). This applied potential forces the plating of the metals onto the electrode

surface thus removing the contaminant metals from solution. Experimental parameters require optimization to maximize the removal of these metals. These parameters include pH, buffer concentration, solution flow rate, applied potential and carbon bed thickness. Conversion efficiency, long-term stability and loading capacity need assessed as well. Finally, the pressure drop and flow rate characteristics of the solution flowing through the upper cell also need to be evaluated.

Many metals can not be reduced at the electrode surface due to their large negative standard reduction potentials. The problem with these species is that their large negative reduction potentials are greater than that needed to electrolyze water to $H_2(g)$ and $O_2(g)$. Hence for aqueous solutions, water will be electrolyzed before these metals are electroplated onto the carbon surface. In these cases, electrosorption is applied. Electrosorption utilizes a potential more positive than the potential necessary to reduce the metal ion (i.e. reduction potential). The positive charge of the metal ion is attracted to the negative charge on the electrode surface. The metal ions are loosely bound to the electrode surface due to electrostatic forces and removed from the aqueous stream. Due to the neutralization of charge on the electrode surface, lower removal efficiencies should be observed. It is anticipated that most radionuclides will be removed by electrosorption since they generally have large standard reduction potentials.

DETECTOR CELL

The lower flow-through detector (analytical cell) is used to determine the metal ion concentration in the effluent stream. The detector working electrode is a glassy carbon disk. The reference electrode is Ag/AgCl and the stainless steel body of the cell acts as the auxiliary electrode (Figure 3). A thin mercury film is deposited onto the working electrode surface by applying a negative potential (usually -1.00 V) while a solution containing mercuric ions (Hg^{2+}) flows past the glassy carbon electrode. Mercuric ions are reduced to mercury metal forming a thin film of mercury on the glassy carbon surface.

The mercury film is used to preconcentrate the metal ions of interest (i.e. Cd, Pb, Cu and Zn) at the electrode surface prior to measurement. The metal ion concentration in the mercury film can be 10-100 times greater than the metal ion concentration in the effluent stream. In order to accumulate the metal ions, the mercury solution flow is stopped and the analyte solution is passed over the mercury-coated disk. A potential more negative than the standard reduction potential of the metals being removed is applied to the glassy carbon working electrode as the effluent stream flows past. Any metal ions not removed by the upper flow-through cell will be preconcentrated into the mercury film of the detector. The metal ions are subsequently stripped (removed) from the mercury film by scanning the potential in the positive direction. This forces the oxidation of the metal ions near their standard redox potential. The electron transfer involved in this oxidation is measured as a current flow at the working electrode surface. The current response obtained from this

anodic stripping of the metals from the mercury film is used to determine the metal ion concentration in the effluent stream. Once the concentration is known, the efficiency of the upper flow-through cell and hence the carbon material under test can be evaluated. In order to determine the metal ion concentration, the flow rate through the upstream working cell and the downstream analytical cell must be measured accurately. This is accomplished by collecting a known amount of the solution at the cell outlet in a precisely calibrated graduated burette while measuring the time using a stopwatch. Accurate and reproducible flow rates are calibrated to one-hundredths of a milliliter/minute. Measurement of metal ion concentration levels down to and below 0.2 ppb are possible with this detection method dependent of the metal under investigation.

SAMPLES

Several carbonaceous electrode materials have been obtained from a variety of sources for comparison. To date, the following samples have been obtained:

Carbon Nanofibers (#1094-A) from PSU (University Park, PA).

Carbon Nanofibers (#1094-B) from PSU (University Park, PA).

Carbon Nanofibers (NF46, unsupported) from PSU (University Park, PA).

Graphite Fiber Mats from PSU (University Park, PA).

Carbon Nanofibers Grown on Graphite Fiber Mats (# 0295-A) from PSU (University Park, PA).

Graphite Felt (0695-A) from PSU (University Park, PA).

Carbon Nanofibers Grown on Graphite Felt (NF46, F100, CN37 and CF37) from PSU (University Park, PA).

Reticulated Vitreous Carbon (RVC) foam (Duocel[®], 3% density) from Energy Research and Generation, Inc. (ERG, Oakland, CA). (10, 20, 30, 45, 80 and 100 ppi).

Vapor Grown Carbon Fibers (VGCF) (PYROGRAF III, Lot ADNH-104-107) from Applied Sciences, Inc. (ASI, Cedarville, OH).

CARBON NANOFIBERS

The carbon nanofibers were produced by our collaborators at Pennsylvania State University (PSU) under the supervision of Dr. R. Terry K. Baker. This new type of fibrous material is generated using the catalytic carbon vapor deposition technique. The nanofiber material is a microscopic version of a carbon fiber. It is produced by the metal catalyzed decomposition of certain hydrocarbons (15,16). Various degrees of graphitization are possible. A more detailed description is included in the original project proposal.

VAPOR GROWN CARBON FIBER (17)

The VGCF manufactured by Applied Sciences, Inc. (ASI) is produced by a combination of catalytic and chemical vapor deposition processes which allow for control of the fiber dimensions, such as filament length and diameter. Lengths are available from 1 mm to tens of centimeters and diameters can vary from under 0.1 to over 100 μm . The resulting fiber has a lamellar morphology and is highly graphitic. VGCF can be heat treated to further improve the graphitization. Cross section and overall views of these samples were provided in the first quarterly report.

RETICULATED VITREOUS CARBON (18)

Reticulated Vitreous Carbon (RVC) is an open-pore material with a honeycomb (foam) structure (14). RVC is a form of carbon that combines some of the properties of glass with normal industrial carbon. RVC has a large void volume (97%) and a small surface area (0.09 m^2/gram). It has a self-supporting rigid structure, a low resistance to flow and is resistant to temperatures up to 600 $^{\circ}\text{F}$ in air (6330 $^{\circ}\text{F}$ in a non-oxidizing environment) (19). A more thorough discussion of vitreous carbon is available in the literature (20-24). The samples obtained had various pores sizes. Sizes included 10, 20, 30, 45, 80 and 100 ppi (pores per inch). The 100 ppi RVC foam will be tested in our study.

GRAPHITE FIBER MATS

Obtained commercially by Dr. Baker at The Pennsylvania State University.

GRAPHITE FELTS

Obtained commercially by Dr. Baker at The Pennsylvania State University.

All materials were used as received without any further pretreatment. If necessary to help activate or clean the surface, mild electrochemical or chemical methods were employed.

WORK PERFORMED

EXPERIMENTAL

Surface Area

The surface area of the samples has been determined and the data are shown in Table II. The surface areas were obtained by WVU using a Gemini III 2375 Surface Area Analyzer (Micrometrics Instrument Corporation, Norcross, GA). Standard operating procedures have been followed as outlined in the operator's manual.

A pre-weighed sample of the carbonaceous material was placed into a clean, dry sample tube. The sample was thoroughly degassed using nitrogen. The dewar was filled with liquid nitrogen and the system prepared for analysis.

The sample tube was connected to the analysis port and the balance tube was connected to the balance port. Care was taken to minimize exposure of the sample to air. The doors to the sample station were closed and the analysis initiated. Saturation pressure was set to 740.53 mm Hg and the evacuation rate to 599 mm Hg/min. The Gemini III 2375 Surface Area Analyzer performs automated analysis. It is capable of simultaneously performing BET multipoint and single point surface area, Langmuir surface area, t-method micropore, and BJH adsorption/desorption distribution. The resulting data were recorded on an Epson plotter (Model P84FA).

Electrochemical Apparatus

A two-cell system is used for this study. The upper, or working cell removes metal ions from the flowing stream. The downstream or analytical cell is used to assess the performance of the working cell by measuring the metal ion concentration in the effluent. The upper flow-through cell design is shown in Figure 2. The cylindrical body of the upper cell is made of Lexan (5.0 cm diam., 6.0 cm length). The flow channel (1.6 cm i.d.) was drilled through the Lexan body. The Ag/AgCl reference electrode (3M NaCl, Model RE-4, BioAnalytical Systems, Inc. (BAS) West Lafayette, IN) is introduced into the flow channel

through a Lexan sleeve positioned 90 degrees to the flow channel. Leakage is prevented using an o-ring and compression-type fitting. A piece of coiled platinum wire inserted at the outlet of the cell is used as the auxiliary electrode. Contact to the working electrode is established via platinum mesh positioned through the cell wall and sealed with an o-ring.

The thin-layer flow cell, as shown in Figure 3. was purchased from BioAnalytical Systems (Model LC-44-01000). The working electrode is a glassy carbon disk (0.3 cm diameter) over which the solution flows. Two 50 μm spacers are used to produce the flow channel and direct the effluent flow across the carbon disk. Prior to use, the glassy carbon disk is polished using successive slurries of 1.0, 0.3 and 0.05 μm alumina until a mirror-like surface is obtained. The glassy carbon electrode is then washed thoroughly with deionized water. All potentials are measured relative to the Ag/AgCl reference electrode (BAS).

Solution reservoirs for the mercury (II) plating solution and samples are 1000 ml Nalgene jars fitted with covers. The solution reservoirs are connected to the working cell using Tygon tubing. Solution flow is controlled with a peristaltic pump (Cole-Parmer Instrument Co., Niles, IL) located upstream from the two cells. All solutions were deaerated using nitrogen gas prior to use. A nitrogen head space is maintained above the solutions to prevent the re-dissolution of oxygen.

The potential of the upper flow-through cell is controlled using an BAS Model PWR-3 Power Module. Stripping voltammograms at the thin-layer flow cell are obtained using the BAS Model CV-27 Voltammograph in conjunction with a HP Model 7044b X-Y recorder.

Reagents

Stock solutions of Cd, Pb and Cu ions are prepared using standard solutions (1000 ppm, Fisher Scientific, Fair Lawn, NJ) and deionized water. The deionized water used was further purified using a NANOpure™ ultrapure water purification system (Barnstead/Thermolyne, Dubuque, IA). These solutions are stored in polyethylene containers to avoid contamination. Portions of these solutions are diluted as needed for experimentation. The $1 \times 10^{-4}\text{M}$ Hg(II) solution used for mercury plating is prepared from $\text{Hg}(\text{NO}_3)_2$ as needed. The mercury ion and sample solutions are prepared in 0.1M KNO_3 supporting electrolyte. The pH is adjusted to 3.5 using HNO_3 . (All chemicals were certified ACS grade purchased from Fisher Scientific unless otherwise noted).

PROCEDURE

Metal Removal Cell

The carbon material to be studied was pretreated to oxidize and assist in the wetting of the carbonaceous surface. This was accomplished by placing the carbon material in a

dilute solution (10%) of nitric acid overnight in a covered beaker. The material was then thoroughly washed using deionized water. The carbonaceous material was then positioned into the lower end of the flow channel in the upper working cell (Figure 2) using a clean glass rod.

A threaded plug is used to press the material between a platinum mesh and a piece of filter paper. The carbon material is placed into the working cell and the threaded plug is screwed into place snugly against it. The pressure on the carbon nanofibers can be easily adjusted by turning the threaded plug. Rigid samples, such as Reticulated Vitreous Carbon were positioned using a snug fit. Electrical contact to the working electrode material was established using the platinum mesh. The reference electrode was inserted into the sleeve and the cell was connected to the pump using Tygon tubing. A 0.1M KNO_3 electrolyte solution was pumped through the flow cell. In order to help remove air bubbles and wet the electrode surface, a mild electrochemical pretreatment was used. The cell potential was held at +1.00 V for 10 minutes followed by -1.00 V for 10 minutes.

The performance of the carbonaceous material under study was tested by placing a solution containing a known concentration of metal ions (Cd, Pb and/or Cu) into the sample reservoir. The solution was then allowed to pass through the metal removal (working) cell at a known flow rate and applied potential. The performance was assessed by measuring the metal ion concentration in the effluent and comparing it to the initial ion concentration. The percentage efficiency of the cell is equal to the percentage of metal ions removed from the solution by the electrolytic cell.

For these studies, the effluent was collected in a Nalgene bottle for subsequent analysis using ASV and/or AA.

Analytical Cell

A pre-plated mercury film is used for downstream anodic stripping voltammetric (ASV) detection of the metal ions in the effluent stream. A 1×10^{-4} M Hg(II) solution in 0.1M KNO_3 is purged with nitrogen for 20 minutes. The mercury film is produced by applying a potential of -1.00 V at the glassy carbon electrode while passing the Hg(II) solution through the cell at 0.87 ml/min for 5 minutes. After this period, the potential is held at +0.05 V for 90 seconds. Following this conditioning, the stopcock is turned to stop the flow of mercuric ions and allow the flow of the deaerated sample through the cell. This flow is continued for 3 minutes to flush any mercuric ions from the system and replace all of the solution in the system with the sample to be studied.

While the solution is flowing at a known flow rate (0.87 ml/min), the ASV deposition potential is applied to the thin-layer flow cell (usually for 1 minute) and the metal ions are accumulated. At this point, the solution flow is stopped to the analytical cell and after a 30

second equilibrium period, a ramp is initiated (-1.00 V to + 0.20 V) and the stripping voltammogram recorded. The scan is terminated at + 0.20 V. Sample solution flow is renewed and the electrode cleaned at + 0.05 V for 90 seconds to prepare the system for the next determination.

The mercury film and plated metals are removed at the end of a series of experiments using a moist Kimwipe. The electrode is subsequently polished for the next series of studies.

RESULTS and DISCUSSION

After preliminary testing of the initial remediation cell design (as shown in Figure 1), it was found that some modifications were required.

First: If varying thicknesses of carbonaceous electrode material are to be tested, the distance between the working and the reference electrodes would not be constant. This would lead to differences in the solution resistance and therefore, differences in uncompensated potential (iR) losses.

Second: There was great difficulty in establishing good electrical contact between the working electrode material (the carbon nanofibers) and the platinum wire lead. This problem induced a large cell resistance, and high voltage drops across the carbon electrode.

In order to maintain a constant distance between the working electrode and the reference electrode and minimize cell resistance, a new cell design was created. This new design is shown in Figure 2.

A major complication involved the loose carbon nanofibers in the earlier cell. Loosely packed carbon-fibers allowed solution flow, but electrical contact was sacrificed. If the particles were packed more tightly, improved (although not great) contact was established, but a high resistance to solution flow resulted. Steps taken in the new cell design are the addition of the threaded plug so that the amount of compression of the nanofibers can be carefully adjusted and controlled and the use of a platinum mesh to maximize electrical contact with the carbon nanofibers.

A threaded plug is used to press the carbonaceous working electrode material firmly against the platinum mesh. This platinum mesh is used as the working electrode contact. The surface area of the platinum mesh is negligible relative to the surface area of the carbon material, but should still afford much better contact with the carbonaceous material than the single platinum wire used in the previous design. Minimal electrolytic contribution is gained from the platinum mesh while maximizing the electrical contact. The reference

electrode was positioned as close as possible to the working electrode through a Lexan sleeve. Special care was taken to allow varying amounts of carbon material to be used, while maintaining constant electrode distances. Through the use of flanges and an o-ring, the design also allows easy removal and replacement of the carbon material.

ANALYTICAL CELL

The inherent sensitivity of Anodic Stripping Voltammetry (ASV) makes it an excellent choice for the detection of heavy metal ions in solution. The detectable limits are often below those attainable using Flame and/or Flameless Atomic Absorption / Emission Spectroscopy. Figure 4 demonstrates the ability to detect these low limits using a thin mercury film coated on a glassy carbon electrode. The mercury film yields well-defined and sharp peaks, good resolution between neighboring signals and a low background current. The response shown is for a sample solution containing 10 parts per billion (ppb) cadmium, lead and copper in 0.1 M KNO_3 at various deposition times (0, 30, 60, 90 and 180 seconds). The increased accumulation of the metals in the mercury film with time is quite evident. The dependence of the peak current on the deposition time is shown in Figure 5. The effect of the deposition time on the peak current was studied using a solution containing 100 ppb copper and lead. As expected, a linear relationship was obtained with a slope of $2.293 \mu\text{A}/\text{min}$ (Cu) and $1.180 \mu\text{A}/\text{min}$ (Pb) with correlation coefficients of 0.9937 (Cu) and 0.9926 (Pb). The peak current is used to calculate the concentration of metal ions in the effluent stream.

Figure 6 examines the effect of the ASV scan rate on the stripping response of 100 ppb copper and lead. The peak current increases with the increased scan rate. However, at scan rates above 10 mV/sec, the peaks begin to broaden, leading to an overlapping of neighboring peaks.

Calibration data acquired with lead (1-5 ppm) yielded well-defined and sharp peaks. The resulting calibration plot (Figure 7), was highly linear ($R=0.9932$), with a slope of $1.066 \mu\text{A}/\mu\text{g}$.

The response for 6 repetitive measurements of cadmium, lead and copper was examined. Figure 8 shows the exceptional precision of the response for 30 second deposition of 2 ppm copper and lead. An average peak current and relative standard deviation of $14.413 \mu\text{A}$ and 2.05% for copper and $7.272 \mu\text{A}$ and 3.42% for lead demonstrate the degree of reproducibility. The precision of 1 ppm cadmium (not shown) did not produce such outstanding results. The relative standard deviation of 7.80% illustrates this point. Fine tuning of the experimental procedure is necessary to obtain improved precision.

METAL REMOVAL

The effectiveness of a cylindrical piece of Reticulated Vitreous Carbon (RVC) (6 mm diam., 6 mm length) was examined for its performance as the cathode material of the upstream electrolytic remediation cell. Cathodic removal of the metal ions via reductive plating on the RVC was investigated. Figure 9 shows the performance of the RVC. A sample solution containing 50 ppb cadmium, lead and copper was analyzed using a flow rate through the remediation cell of 1.22 ml/min. Curve 'A' shows the response of the solution prior to passing it through the electrolytic cell. Further, Curve 'B' shows the negligible removal of the metals ions in the cell due to adsorption alone on the carbonaceous surface ($E_{\text{applied}} = 0.00\text{V}$). Only the response for cadmium was affected (16% decrease). Upon applying a potential well negative of the reduction potentials of all three metals (-1.00 V), a significant decrease in peak current is observed due to the removal of the metals (Curve 'C'). A 64.7% and 50.0% efficiency was observed for copper and cadmium, respectively. A small 10% efficiency was seen for lead. At -1.00 V and using a slower flow rate of 0.87 ml/min (not shown), preliminary removal efficiencies of 90% or greater were obtained for the three metals.

In order to improve these efficiencies, several parameters must be addressed. By increasing the ratio of cathode surface area to electrolyte solution volume, increasing the time that the solution remains in the electrode material and/or by optimizing the potential applied to the cell, greater efficiencies can be obtained. One option would be to lower the flow rate of the solution through the cell. This would allow more time for the metal ions to be removed, but would increase the process time. A simpler solution would be to increase the electrode surface area. This can be accomplished in any number of ways. A longer flow path through the cathode would increase the surface area and the residence time. Another method is to increase the surface area of the solid 3-dimensional support by growing carbon nanofibers onto the surface. This should produce a cathode material with a 2-3 orders of magnitude increase in surface area. Carbon nanofibers have been grown on a graphite mat and a graphite felt at The Pennsylvania State University. Surface area measurements of this material have been performed (see Table II). The increase in surface area from the addition of the carbon nanofibers on the surface is quite evident. Attempts by co-workers at The Pennsylvania State University to grown carbon nanofibers on the RVC surface were unsuccessful.

Two samples of loose carbon nanofibers were received from The Pennsylvania State University. The more conductive and graphitic sample (#1094-A) was used for analysis. The surface area of these loose nanofibers has been measured ($115\text{ m}^2/\text{g}$). This is 1000 times greater than the surface area of the reticulated vitreous carbon material tested previously. This large surface area should enhance the removal efficiencies of the working cell. The carbon nanofibers were treated overnight in 10% HNO_3 . This treatment improved the wetting ability of the nanofibers. This acid treatment also increased the

surface area of the carbon nanofibers to 228 m²/g. The effect of the acid treatment on the surface area of the other samples was also examined.

Using the new cell design, good electrical contact was easily established between the loose carbon nanofibers and the platinum mesh lead. The ability of these nanofibers to remove cadmium and lead from water was addressed. No effect was observed for the removal of the metal ions due to adsorption alone (i.e. Passing the feed solution through the cell with no applied potential on the carbon electrode). Application of a negative potential, greatly improved this material's ability to remove the metal ions. Figure 10 shows the effectiveness of these loose carbon nanofibers to remove cadmium and lead. Removal efficiencies of 91% for cadmium and 95% for lead were obtained at these conditions. These enhanced removal efficiencies, relative to those shown using RVC, show great promise for the use of these novel carbon nanofibers for the reductive removal of metal ions from aqueous streams.

Samples of graphite fiber mats with and without carbon nanofibers were obtained from Dr. Terry Baker. The surface area of each sample was determined. The surface area of the graphite fiber mat was 0.60 m²/g. This area was greatly increased by growing carbon nanofibers onto the mat. The surface area of the graphite fiber mat with carbon nanofibers was 99.9 m²/g. This surface area is 167 times greater than that of the graphite fiber mats alone.

The performance of the graphite fiber mats with carbon nanofibers was assessed. Good electrical contact and conductivity were obtained between the cathode material and the platinum mesh lead. The effectiveness of the carbon nanofibers grown on graphite fiber mats to remove metal ions from an aqueous stream was then studied. The removal of the metal ions by adsorption only (no applied potential) onto the cathode resulted in minimal removal of the metal ions. Upon applying a sufficiently negative potential to the cathode, improved ion removal was attained. Figure 11 illustrates the performance of the cathode material. The lower curve shows the response of the sample solution prior to passing it through the electrolytic cell. The middle curve shows the decrease in peak current due to the removal of the metal ions using a potential of -0.00V. The response for the effluent when applying potential of -1.00V to the cell is shown in the upper curve. Removal efficiencies of 99%, 91% and 88% were obtained for Cu, Pb and Cd, respectively. At an applied of -1.20V (not shown), no response was seen for any of the metals. (i.e. removal of metal ions to concentrations below detectable limits).

A conductive graphite felt was analyzed in the next study. Both unmodified graphite felt and graphite felt with carbon nanofibers grown on it were utilized. Surface area measurements demonstrate the ability to increase the surface area of the sample using the carbon nanofibers. Prior to growing carbon nanofibers, the surface area of the graphite felt was 0.17 m²/g. Upon growing carbon nanofibers onto the surface, the surface area of the sample was increased to 55.41 m²/g, over a 300-fold increase.

The performance of the bare graphite felt was first assessed. Minimal removal was seen due to adsorption alone. Upon applying a potential of -1.00 V to the cathode, most of the lead (97%), but only 22% of the cadmium was removed. The resulting voltammograms are shown in Figure 12. No reason could be found for the low removal of the cadmium although we suspect the properties of the graphite felt may be causing a severe overpotential. Application of a more negative potential (-1.20 or greater) should remove the cadmium as well.

The response for solutions collected under the same conditions using the graphite felt with nanofibers is shown in Figure 13. Once again a minimal amount of the metal is removed by the carbonaceous material in the absence of an applied potential. When a reductive potential is applied, almost complete removal of lead, as well as a improved removal of cadmium is acquired (46%).

To confirm minimal contribution from the platinum mesh to the working electrode, the system was tested in the absence of any carbonaceous cathode material. The response of the original feed solution was compared to the response of the effluent collected at -1.00 V . It was shown that the platinum mesh does not contribute significantly ($<2\%$) to the removal of the metal ions from solution (see Figure 14). Therefore, the removal of metal ions seen so far is due to their reductive removal onto the carbonaceous cathode materials and is not significantly influenced by the platinum mesh. A comparison of the metal removal efficiencies is summarized in Table III.

In order to assess electrosorption, the loose carbon nanofibers were tested for their ability to remove cadmium and lead at potentials more positive than that required to reduce the metal ions. The removal of cadmium was examined at various potentials above and below its theoretical reduction potential. Figure 15 shows the ASV response for a cadmium solution passed through the remediation cell at these potentials. Based on the initial cadmium feed concentration (100 ppb), the potential at which the cadmium ions should be reduced is -0.58 V . Electrosorption removed 46% of the cadmium from solution at -0.20 V and 78% at -0.40 V . At potentials more negative electroplating removes 89% (-0.60 V), 91% (-0.80 V) and almost all (99% at -1.0 V) of the cadmium. The percent of cadmium removed versus the applied potential is also shown (inset).

Figure 16 shows the response for the removal of lead under the same conditions. The theoretical reduction potential for lead is -0.54 V . Removal of lead via electrosorption is also shown to occur at potentials more positive than the reduction potential. The removal efficiencies were 88% at -0.20 V and 92% at -0.40 V .

Continuous removal of lead from an aqueous stream using electroplating and electrosorption was used to demonstrate the long-term effectiveness of the carbon nanofibers. The lead solution was passed through the remediation cell and the ions were

removed by applying the desired potential to the carbon nanofibers. A potential of -1.00 V was applied to the remediation cell to remove the lead ions via electroplating. Over a continuous period of 72 hours, removal efficiencies of 89% or greater were achieved for an inlet lead ion concentration of 100 ppm. Calculation of the lead removal over this period demonstrates a capacity above $0.90 \text{ g}_{\text{Pb}}/\text{g}_{\text{nanofibers}}$, but it should be stressed that even at 72 hours, the carbon showed no signs of saturation (see Figure 17).

Removal of lead via electrosorption was carried out using a potential of -0.40 V. For an inlet lead ion concentration of 100 ppb, good removal efficiencies (90%) are obtained for the first 12 hours (see Figure 18). After that time a noticeable decrease in efficiency is evident. The removal efficiency drops to less than 50% after 57 hours. This decrease in removal efficiency is expected due to neutralization of the charge on the electrode surface. Regeneration or replacement of the nanofibers would be required to maintain high removal efficiencies. For the first 12 hours of removal a capacity of $1.9 \times 10^{-4} \text{ g}_{\text{Pb}}/\text{g}_{\text{nanofibers}}$ is obtained. At 57 hours this capacity increases to $7.1 \times 10^{-4} \text{ g}_{\text{Pb}}/\text{g}_{\text{nanofibers}}$. Electrosorption of lead using 100 ppm lead was attempted. Due to the smaller capacity of the nanofibers when using electrosorption, the efficiency should drop off quickly. As expected, within the first two hours removal efficiencies drop to less than 20%.

The final desire is to recover the metals once they have been removed from the aqueous stream. It is possible to remove the metal ions are removed resulting in a purified effluent stream, the metal ions can be recovered metal ions plated on the electrode surface simply by reversing the potential. Once the in solution more concentration than the feed. Electrodeposition and the subsequent recovery from the nanofiber surface was demonstrated with a 100 ppm lead solution. The lead was removed from the aqueous stream at a potential of -1.00 V. Subsequent recovery of the lead at a potential of 1.00 V, produced an effluent stream more concentrated in lead. The lead concentration of the effluent was 331 ppm lead, demonstrating a 3:1 concentration of the waste stream. Individual metals can be selectively removed and recovered by these means.

A summary of the removal efficiencies for all of the materials involving carbon nanofibers is given in Table III. These results are for electroplating only. As can be seen, the carbon nanofibers are extremely effective devices for the removal of heavy metal ions from solution.

CONCLUSION

All proposed objectives have been met (see Table IV). An extensive search of the literature has been conducted in the areas of heavy metal removal, waste water treatment and water remediation. More than 150 papers have been amassed in these areas with special interest in the areas of electrochemistry and electrowinning using carbonaceous materials.

The thin-layer flow-cell to be used as the on-line detector has been assembled and has been thoroughly tested. This testing included characterization, calibration and verification. The flow-cell will be connected on-line and used to monitor the effluent stream of the upstream metal removal cell.

The preliminary cell design for metal removal from aqueous streams has been tested. Modifications have been made to the cell design and the new cell has been produced. The modifications and problems they solve have been discussed earlier.

The performance of the RVC cell was satisfactory. Due to the problems with growing carbon nanofibers, the RVC could not be used as a support. The RVC was destroyed in all attempts to grow carbon nanofibers on it. Therefore, no conclusions can be drawn on the enhanced performance due to the increase in surface area due to carbon nanofibers grown on the surface of the RVC.

Loose carbon nanofibers with relatively large surface areas of $100^+ \text{ m}^2/\text{g}$ effectively removed over 90% of cadmium and lead from an aqueous sample. Electrical contact was easily established using the new cell design. Further chemical and physical activation of the nanofibers should increase the surface areas even more and improve electrical conductivity. These two factors can be used to improve the already superb results seen so far using these materials.

One material on which carbon nanofibers were successfully grown, was a woven mat of graphite fibers. Surface area analysis showed that this material had a very large surface area (approximately $200 \text{ m}^2/\text{g}$). Analysis of this sample to remove metal ions from the aqueous sample were favorable. The carbon nanofibers grown on graphite fiber mats performed well for removing the metal ions. Removal efficiencies of 90% and above (99^+ for Cu) were easily obtained. Through the use of several mats, these metal removal efficiencies should be maintained at even higher solution flow rates due to the large increase in cathode surface area.

Another material on which carbon nanofibers were grown was graphite felt. Samples of the graphite felt with and without carbon nanofibers were studied. A removal efficiency above 95% was obtained for both samples for the removal of lead. Small removal efficiencies were seen for cadmium. Application of a more negative potential than -1.00 V should increase the amount of cadmium removed. Further analysis will be conducted to optimize the removal of cadmium.

A study to determine the contribution of the platinum wire mesh to the removal of metal ions demonstrated that the contribution was negligible. The metal ion removal is accomplished predominantly by the carbonaceous cathode material.

Tests conducted to determine if the carbon nanofibers could be used to electrosorb metal ions were successful. Cadmium and lead were both removed from an aqueous solution at a potential more positive than their reduction potentials. Short-term removal efficiencies of 78% for cadmium and 92% for lead were obtained at a remediation cell potential of -0.40 V. A future application of electrosorption would be to remove radionuclides that have reduction potentials greater than that required to reduce water.

Long-term removal of lead over a continuous period of 72 hours using electroplating 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. The continuous removal of lead using electrosorption decreased the concentration of a 100 ppb lead feed to 10 ppb for the first 12 hours. Removal efficiencies for electrosorption dropped to less than 50% after 57 hours. At 102 hours removal efficiencies were approaching 20%. Removal via electrosorption will require a much larger quantity of carbon nanofibers to be used over that used for electroplating.

Finally, the recovery of lead using electroplating resulted in the increased concentration of the recovered effluent stream by 331%. Optimization of the recovery procedure should lead to greater concentration of the recovered metal of interest.

FIGURE 1: Electrochemical Remediation Cell and Detector.

FIGURE 2: Remediation Cell.

FIGURE 3: Thin-layer Flow Cell for Metal Detection.

Figure 4: ASV Response for 10 ppb Cadmium, Lead and Copper at a Mercury Film Electrode.

(Mercury Film Plating: 5 min @ -1.00V, 1×10^{-4} M Hg(II), 90 sec @ +0.05 V, flow = 0.87 ml/min. ASV: Deposition: 30 (a), 60 (b), 90 (c) and 120 (d) seconds @ -1.00V, 10 ppb Cd, Pb and Cu in 0.10 M KNO_3 , pH=3.5, flow = 0.87 ml/min; EQ time = 15 sec; Stripping: -1.00 to -0.300 V, 10 mV/sec, stopped flow)

Figure 5: Time Study.

(Conditions: same as Figure 4. 100 ppb Pb and Cu)

Figure 6: Scan Rate.

(Conditions: same as Figure 4. 30 second deposition, 100 ppb Pb and Cu)

Figure 7: Calibration of Lead.
(Conditions: same as Figure 4. 2 minute deposition)

Figure 8: Precision.
(Conditions: Same as Figure 4. 5 minute deposition)

Figure 9: Metal Ion Removal Using RVC Electrode.

(Conditions: Same as Figure 4. 50 ppb Cd, Pb and Cu, 60 second deposition)

(A) Metal ion solution response prior to passing through working cell.

Solution response after passing through working cell with applied potential 0.00 V (B) and -1.00 V (C). (dotted line corresponds to blank solution)

Figure 10: Metal Removal Using Loose Carbon Nanofibers.

(Conditions: Same as Figure 4. 100 ppb Cd, Pb and Cu, 60 Second deposition)
Metal solution response prior to passing through the remediation cell (lower), solution response after passing through the cell with no applied potential (middle: 0.00 V) and after passing through the remediation cell at -1.00 V (upper).

Figure 11: Metal Ion Removal Using Carbon Nanofibers on a Graphite Fiber Mat.

(Conditions: Same as Figure 10.)

Figure 12: Metal Ion Removal Using Graphite Felt without Carbon Nanofibers.

(Conditions: Same as Figure 10)

Figure 13: Metal Ion Removal Using Carbon Nanofibers Grown on a Graphite Felt.
(Conditions: Same as Figure 10)

Figure 14: Metal Removal Using Bare Platinum Wire Mesh.
(Conditions: Same as Figure 10)

Figure 15: Effect of Remediation Cell Potential on Cadmium Removal.
(Conditions: Same as Figure 10)

Figure 16: Effect of Remediation Cell Potential on Lead Removal.
(Conditions: Same as Figure 10)

REMOVAL of Pb USING CARBON NANOFIBERS

Figure 17: Long-Term (72 hr) Removal of Lead via Electroplating.
(Conditions: $E_{\text{CELL}} = -1.00$ V; Flow = 0.87 ml/min)

REMOVAL of Pb USING CARBON NANOFIBERS

Figure 18: Long-Term (102 hr) Removal of Lead via Electrosorption.
(Conditions: $E_{\text{CELL}} = -0.40 \text{ V}$; Flow = 0.87 ml/min)

Table I

STANDARD REDUCTION POTENTIALS OF THE METAL
IONS OF INTEREST

<u>Metal Ion Reaction</u>	<u>E°, (vs.Ag/AgCl)</u>
$\text{Zn}^{+2} + 2\text{e}^- \rightleftharpoons \text{Zn (s)}$	-0.986 V
$\text{Cd}^{+2} + 2\text{e}^- \rightleftharpoons \text{Cd (s)}$	-0.624 V
$\text{Cd}^{+2} + 2\text{e}^- \rightleftharpoons \text{Cd (in Hg)}$	-0.602 V
$\text{Pb}^{+2} + 2\text{e}^- \rightleftharpoons \text{Pb (s)}$	-0.348 V
$\text{Pb}^{+2} + 2\text{e}^- \rightleftharpoons \text{Pb (in Hg)}$	-0.343 V
$\text{Cu}^{+2} + 2\text{e}^- \rightleftharpoons \text{Cu (s)}$	+0.115 V
$\text{Cu}^{+2} + 2\text{e}^- \rightleftharpoons \text{Cu (in Hg)}$	+0.123 V

Table II

PROPERTIES of CARBON MATERIALS

SURFACE AREA

Material	Surface Area (m ² /gram)	
	BET	Langmuir
Carbon Nanofibers		
1094-A	115.13 (227.8)*	186.78
1094-B	182.77 (192.3)*	286.03
NF46 (unsupported)	43.28	
Graphite Fiber Mats	0.59	
Carbon Nanofibers on Graphite Mats	99.92 (112.8)*	-
Graphite Felt	0.17	-
Carbon Nanofibers on Graphite Felt		
NF46	55.41	-
F100	54.54	-
CF37	13.96	-
CN37	35.31	-
VGCF	76.78 (73.6)*	122.66
RVC		
100 ppi	0.092	-
80 ppi	44.80	-
Activated Carbon	784.32	-

* Value in parenthesis is the surface area measured after acid treatment

Table III

TABLE OF REMOVAL EFFICIENCIES

<u>Cathode Material</u>	<u>Metal Removed</u>		
	<u>Cathode Potential, V</u>	<u>Cd</u>	<u>Pb</u>
RVC	0.00	16%	0%
	-1.00	50%	8%
Loose Carbon Nanofibers (#1094-A)	0.00	0%	0%
	-1.00	91%	95%
Carbon Nanofibers on Graphite Mats	0.00	0%	0%
	-1.00	90%	92%
Graphite Felt	0.00	13%	7%
	-1.00	22%	97%
Carbon Nanofibers on Graphite Felt	0.00	0%	0%
	-1.00	46%	99%
Platinum Mesh	0.00	0%	0%
	-1.00	0%	9%

Table IV

"ENVIRONMENTAL POLLUTION CONTROL DEVICES BASED ON NOVEL FORMS OF CARBON"

PROJECT COMPLETION

<u>TASK #</u>	<u>WBS CODE</u>	<u>TASK NAME</u>	<u>DUR</u>	
1	1.0	PRELIMINARY RESEARCH		
2	1.1	Electrochemical Remediation (ECR)	OCT-DEC	
3	1.2	Technical Evaluation	NOV-DEC	
4	2.0	ANALYTICAL TECHNIQUES	OCT-JUN	
5	3.0	PREPARATION FOR TRIALS		
6	3.1	Hire Post-Doctoral	SEP-OCT	
7	3.2	Purchase Electrochemical System	SEP-NOV	
8	3.3	Obtain Chemicals and Reagents	OCT-NOV	
9	3.4	Obtain Carbon Samples (A-?)	OCT-DEC	
10	3.5	Characterize Carbon Samples	OCT-FEB	
11	4.0	TESTING		
12	4.1	ECR - Sample A: Nanofibers (1094-A)	NOV-JUN	
13	4.2	ECR - Sample B: Nanofibers (1094-B)	NOV-JUN	
14	4.3	ECR - Sample C: RVC (100 ppi)	NOV-JUN	
15	4.4	ECR - Sample D: RVC (80 ppi)	NOV-JUN	
16	4.5	ECR - Sample E: PYROGRAF III (LOT ADN H)	NOV-JUN	
17	4.6	ECR - Sample F - Nanofibers on C Mat (0295-A)	NOV-JUN	
18	4.7	ECR - Sample G - Graphite Felt	NOV-JUN	
19	4.8	ECR - Sample H - Nanofibers on Graphite Felt	NOV-JUN	
20	4.9	Trial Repeats (Concurrent)	MAR-JUN	
21	5.0	ANALYSIS and REPORTING		
22	5.1	Analysis and Data Reduction	JUN-JUL	
23	5.2	Reports and Manuscripts	OCT-JUL	
24	6.0	CLOSURE	JUL	
25	7.0	OVERALL WORK COMPLETE	AUG	Complete

REFERENCES

1. Wang, J. "Stripping Analysis: Principles, Instrumentation, and Application"; VCH Publishers: Deerfield Beach, FL, 1985.
2. Gaylor, V. F.; Elving, P.J.; Conrad, A. L. *Anal. Chem.*, **1953**, *25*, 1078.
3. Morris, J. B.; Schempf, J. M. *Anal. Chem.*, **1959**, *31*, 286.
4. Adams, R. N. *Anal. Chem.*, **1958**, *30*, 1576.
5. Yamado, S.; Sato, H. *Nature*, **1962**, *193*, 261.
6. Blaedel, W. J.; Wang, J. *Anal. Chem.*, **1980**, *52*, 1697.
7. Dryhurst, G.; McAllister, D. L. in "Laboratory Techniques in Electroanalytical Chemistry", Kissinger, P. T. and Heinenman, W. R., Eds.; Marcel Dekker, Inc.: New York, NY, 1984; Chapter 10.
8. Bennion, D. N.; Newman, J. *J. Appl. Electrochem.*, **1972**, *2*, 113.
9. Chu, A. K. P.; Fleischmann, M.; Hills, G. J. *J. Appl. Electrochem.*, **1974**, *4*, 323.
10. Fujinaga, T.; Kihara, S. *Crit. Rev. Anal. Chem.*, **1977**, *6*, 223.
11. Blaedel, W. J.; Strohl, J. H. *Anal. Chem.*, **1964**, *36*, 1245.
12. Yaniv, D.; Ariel, M. *J. Electroanal. Chem. Interfacial Electrochem.*, **1977**, *79*, 159.
13. Suzkover, E. Ph.D. Dissertation, Technion-I.I.T., Haifa, 1977.
14. Wang, J.; Dewald, H. D. *J. Electrochem. Soc.*, **1983**, *130*(9), 1814.
15. Baker, R. T. K., Rodriguez, N.M. U.S. Patent 5,149,584.
16. Rodriguez, N.M., Baker, R.T.K. Patent Application filed October 1992.
17. Applied Sciences, Inc. Technical data sheet on Advanced Material Development.
18. Wang, J. *Electrochim. Acta.*, **1981**, *26*, 1721.
19. Reticulated Vitreous Carbon (An Exciting New Material), Energy Research and Generation, Inc., Oakland, CA
20. Cowlard, F.C., Lewis, J. C. *J. of Materials Sciences*, **1967**, *2*, 507.
21. Noda, T., Inagaki, M., Yamada, S. *J. of Non-Crystalline Solids*, **1969**, *1*, 285.
22. Lewis, J. C., Murdoch, R., Moul, A. N. *Nature*, **1969**, *vol 221*, 1137.
23. Kawamura, K., Ryan, T., Jenkins, G. "The Incorporation of Glassy Carbons in Metals," Paper presented at 9th Carbon Conference.
24. Tamaguchi, T. *Carbon*, **1963**, *1*, 47.

"ENVIRONMENTAL POLLUTION CONTROL DEVICES BASED ON NOVEL FORMS OF CARBON"

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ABSTRACT

The use of electrochemistry is an effective means to remove heavy metal contaminants from aqueous effluent streams. Electrochemical processes also exist for the removal of salts as well as bacteria and organic compounds from water. This project deals with the development and testing of carbon nanofibers for the electrolytic removal of heavy metals from the effluent stream. Both electroplating and electrosorption are employed for this task.

This work was to develop and test a carbonaceous material with an extremely large ratio of surface area to electrolyte volume. This was accomplished by using a packed-bed of carbon nanofibers or by growing carbon nanofibers on a conductive support. The surface area can be increased by 2-3 orders of magnitude. The increased surface area can help minimize the length of electrode through which the solution must pass. The decreased distance leads to reduced resistance to solution flow.

A novel type of carbon nanofibers has been tested for its ability to remove heavy metal ions from aqueous samples via electroplating and electrosorption. Removal efficiencies above 90% have been obtained for the reductive removal of cadmium and lead. These enhanced removal efficiencies are capable due to the large surface area of these carbon nanofibers ($200^+ \text{ m}^2/\text{gram}$). Long-term removal of lead over a period of 72 hours using electroplating decreased the concentration of a 100 ppm lead feed to less than 10 ppm. Even after 72 hours, the carbon fibers showed no sign of saturation. For the 72 hour period, a capacity of $0.90 \text{ g}_{\text{Pb}}/\text{g}_{\text{nanofibers}}$ is realized.

Removal via electrosorption produced similar results, but with a early drop-off of efficiency and a much smaller capacity ($7.1 \times 10^{-4} \text{ g}_{\text{Pb}}/\text{g}_{\text{nanofibers}}$ for a 57 hour period). This is due to the neutralization of the charge on the carbon nanofiber surface caused by the electrosorption of the positively-charged metal ions. It is envisioned that for aqueous streams, electrosorption will be applied to remove radionuclides and other metals that have reduction potentials greater than water. The removal of radionuclides would decrease the volume of radioactive waste produced from the clean-up of decommissioned nuclear sites.

The recovery of metals using electrosorption was demonstrated using lead ions. the recovered effluent was concentrated 331% in lead after reversal of the potential applied to the remediation cell. This resulted in a decrease in the volume of high level lead waste effluent by 1:10.

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EXECUTIVE SUMMARY

A novel type of carbon nanofibers has been tested for its ability to remove heavy metal ions from aqueous samples via electroplating and electrosorption. Removal efficiencies above 90% have been obtained for the reductive removal of cadmium and lead. These enhanced removal efficiencies are capable due to the large surface area of these carbon nanofibers ($200^+ \text{ m}^2/\text{gram}$). Long-term removal of lead over a period of 72 hours using electroplating decreased the concentration of a 100 ppm lead feed to less than 10 ppm. Even after 72 hours, the carbon fibers showed no sign of saturation. For the 72 hour period, a capacity of $0.90 \text{ g}_{\text{Pb}}/\text{g}_{\text{nanofibers}}$ is realized.

Removal via electrosorption produced similar results, but with an early drop-off of efficiency and a much smaller capacity ($7.1 \times 10^{-4} \text{ g}_{\text{Pb}}/\text{g}_{\text{nanofibers}}$ for a 57 hour period). This is due to the neutralization of the charge on the carbon nanofiber surface caused by the electrosorption of the positively-charged metal ions. It is envisioned that for aqueous streams, electrosorption will be applied to remove radionuclides and other metals that have reduction potentials greater than water. The removal of radionuclides would decrease the volume of radioactive waste produced from the clean-up of decommissioned nuclear sites.

The recovery of metals using electrosorption was demonstrated using lead ions. The recovered effluent was concentrated 331% in lead after reversal of the potential applied to the remediation cell. This resulted in a decrease in the volume of high level lead waste effluent by 1:10.

ELECTROCHEMICAL STUDY OF CARBON NANOFIBERS

INTRODUCTION

PURPOSE

The purpose of this research was to assess the feasibility of using carbon nanofiber devices to remove heavy metal contaminants from aqueous streams. This work will address the fabrication, behavior and analytical utility of these novel carbonaceous materials. Standard electrochemical techniques will be employed to meet this objective.

BACKGROUND

Electrochemical techniques pertain to measurements involving the flow of electrons during a reduction-oxidation (redox) reaction. These measurements involve current, potential, charge and/or time as the primary variables. Electrochemical studies typically incorporate the use of a three electrode system. This systems includes a working, reference and auxiliary electrode. The redox reaction occurs at the surface of the working electrode as a result of the applied potential. Therefore, it is critical to choose a suitable material for the working electrode. To be effective, the material must meet certain requirements. The electrode material should exhibit high electrical conductivity, be chemically inert over the potential region of interest, show favorable electrochemical behavior with the analyte(s), have a low background current and have an easily reproducible surface (1). Carbon materials are well suited for use as working electrodes. Graphite (2,3), carbon paste (4), glassy carbon (5) and reticulated vitreous carbon (RVC) (6) are a few examples of carbonaceous materials that have been used as working electrodes. A detailed discussion of carbon electrodes has been compiled by Dryhurst and McAllister (7).

Carbonaceous materials have been used to produce flow-through porous electrodes. Electrode materials have included graphite chips (8) or granules (9), glassy carbon grains (10), crushed graphite (11), screens of graphite (12) or carbon (13) and RVC (14). These porous flow-through electrodes have been used to remove metal ions from aqueous solutions. This is of major importance to industrial processes and environmental applications. The large surface area of porous flow-through electrodes makes them excellent candidates for the removal of metal ions from solution. Removal efficiencies approaching 100% can be achieved (14).

The present work will address the use of various carbon materials, including carbon nanofibers, to produce porous flow-through electrodes for the removal of metal ions from aqueous media. The resulting effluent will be monitored downstream using electrochemistry and/or Atomic Absorption (AA) to assess the decrease in analyte concentration and hence the electrode efficiency. Whenever possible, Anodic Stripping Voltammetry (ASV) will be used to measure the metal ion concentration in solution because of its inherent sensitivity and low detection limits (sub parts-per-billion). Moreover, using ASV it is possible to determine the concentration of multiple metal ions in solution simultaneously. Atomic Absorption will be used to confirm results obtained using electrochemistry and whenever electrochemical techniques can not be used.

EXPERIMENTAL METHODOLOGY

A schematic diagram of the apparatus used to carry out these experiments is shown in Figure 1. It was designed in the WVU lab and was produced by the WVU machinist. It is a two-cell system. The upstream, working cell removes metal ions from the flowing stream. The downstream, analytical cell is used to measure the metal ion concentrations in the resulting effluent. The analysis of the analyte concentration leaving the working cell is measured by anodic stripping voltammetry (ASV). This is necessary since the ion concentration of the metals leaving the working cell is expected to be in the parts-per-billion (ppb) range and such an analytical cell is essential to obtain sensitive and accurate measurements at these low concentration levels. A typical 3-cell electrode system, using a silver/silver chloride (Ag/AgCl) reference electrode will be used for all studies.

METAL REMOVAL CELL

The upper cell (Figure 2) is used to test the various carbonaceous electrode materials for their ability to remove certain heavy metal ions from an aqueous stream. The cylindrical body of the upper (working) flow-through cell is made of Lexan. A solution flow channel is drilled through the Lexan body. The carbonaceous working electrode material is placed into the flow channel. Contact to the working electrode is accomplished using a platinum wire and mesh inserted through an access port in the Lexan wall. The Ag/AgCl reference electrode and platinum wire auxiliary electrode are introduced into the flow channel by similar access ports in the wall. Teflon tubing is used to connect the sample reservoirs, the pump and the upper and lower cells.

The sample is pumped into the upper working cell and through the carbonaceous working electrode material. A peristaltic pump is used to control the flow rate for all experiments. For the cathodic removal of metal ions, a potential more negative than the standard reduction potential of the metal ions of interest is applied to the working electrode (see Table I). This applied potential forces the plating of the metals onto the electrode

surface thus removing the contaminant metals from solution. Experimental parameters require optimization to maximize the removal of these metals. These parameters include pH, buffer concentration, solution flow rate, applied potential and carbon bed thickness. Conversion efficiency, long-term stability and loading capacity need assessed as well. Finally, the pressure drop and flow rate characteristics of the solution flowing through the upper cell also need to be evaluated.

Many metals can not be reduced at the electrode surface due to their large negative standard reduction potentials. The problem with these species is that their large negative reduction potentials are greater than that needed to electrolyze water to $H_2(g)$ and $O_2(g)$. Hence for aqueous solutions, water will be electrolyzed before these metals are electroplated onto the carbon surface. In these cases, electrosorption is applied. Electrosorption utilizes a potential more positive than the potential necessary to reduce the metal ion (i.e. reduction potential). The positive charge of the metal ion is attracted to the negative charge on the electrode surface. The metal ions are loosely bound to the electrode surface due to electrostatic forces and removed from the aqueous stream. Due to the neutralization of charge on the electrode surface, lower removal efficiencies should be observed. It is anticipated that most radionuclides will be removed by electrosorption since they generally have large standard reduction potentials.

DETECTOR CELL

The lower flow-through detector (analytical cell) is used to determine the metal ion concentration in the effluent stream. The detector working electrode is a glassy carbon disk. The reference electrode is Ag/AgCl and the stainless steel body of the cell acts as the auxiliary electrode (Figure 3). A thin mercury film is deposited onto the working electrode surface by applying a negative potential (usually -1.00 V) while a solution containing mercuric ions (Hg^{2+}) flows past the glassy carbon electrode. Mercuric ions are reduced to mercury metal forming a thin film of mercury on the glassy carbon surface.

The mercury film is used to preconcentrate the metal ions of interest (i.e. Cd, Pb, Cu and Zn) at the electrode surface prior to measurement. The metal ion concentration in the mercury film can be 10-100 times greater than the metal ion concentration in the effluent stream. In order to accumulate the metal ions, the mercury solution flow is stopped and the analyte solution is passed over the mercury-coated disk. A potential more negative than the standard reduction potential of the metals being removed is applied to the glassy carbon working electrode as the effluent stream flows past. Any metal ions not removed by the upper flow-through cell will be preconcentrated into the mercury film of the detector. The metal ions are subsequently stripped (removed) from the mercury film by scanning the potential in the positive direction. This forces the oxidation of the metal ions near their standard redox potential. The electron transfer involved in this oxidation is measured as a current flow at the working electrode surface. The current response obtained from this

anodic stripping of the metals from the mercury film is used to determine the metal ion concentration in the effluent stream. Once the concentration is known, the efficiency of the upper flow-through cell and hence the carbon material under test can be evaluated. In order to determine the metal ion concentration, the flow rate through the upstream working cell and the downstream analytical cell must be measured accurately. This is accomplished by collecting a known amount of the solution at the cell outlet in a precisely calibrated graduated burette while measuring the time using a stopwatch. Accurate and reproducible flow rates are calibrated to one-hundredths of a milliliter/minute. Measurement of metal ion concentration levels down to and below 0.2 ppb are possible with this detection method dependent of the metal under investigation.

SAMPLES

Several carbonaceous electrode materials have been obtained from a variety of sources for comparison. To date, the following samples have been obtained:

Carbon Nanofibers (#1094-A) from PSU (University Park, PA).

Carbon Nanofibers (#1094-B) from PSU (University Park, PA).

Carbon Nanofibers (NF46, unsupported) from PSU (University Park, PA).

Graphite Fiber Mats from PSU (University Park, PA).

Carbon Nanofibers Grown on Graphite Fiber Mats (# 0295-A) from PSU (University Park, PA).

Graphite Felt (0695-A) from PSU (University Park, PA).

Carbon Nanofibers Grown on Graphite Felt (NF46, F100, CN37 and CF37) from PSU (University Park, PA).

Reticulated Vitreous Carbon (RVC) foam (Duocel[®], 3% density) from Energy Research and Generation, Inc. (ERG, Oakland, CA). (10, 20, 30, 45, 80 and 100 ppi).

Vapor Grown Carbon Fibers (VGCF) (PYROGRAF III, Lot ADNH-104-107) from Applied Sciences, Inc. (ASI, Cedarville, OH).

CARBON NANOFIBERS

The carbon nanofibers were produced by our collaborators at Pennsylvania State University (PSU) under the supervision of Dr. R. Terry K. Baker. This new type of fibrous material is generated using the catalytic carbon vapor deposition technique. The nanofiber material is a microscopic version of a carbon fiber. It is produced by the metal catalyzed decomposition of certain hydrocarbons (15,16). Various degrees of graphitization are possible. A more detailed description is included in the original project proposal.

VAPOR GROWN CARBON FIBER (17)

The VGCF manufactured by Applied Sciences, Inc. (ASI) is produced by a combination of catalytic and chemical vapor deposition processes which allow for control of the fiber dimensions, such as filament length and diameter. Lengths are available from 1 mm to tens of centimeters and diameters can vary from under 0.1 to over 100 μ m. The resulting fiber has a lamellar morphology and is highly graphitic. VGCF can be heat treated to further improve the graphitization. Cross section and overall views of these samples were provided in the first quarterly report.

RETICULATED VITREOUS CARBON (18)

Reticulated Vitreous Carbon (RVC) is an open-pore material with a honeycomb (foam) structure (14). RVC is a form of carbon that combines some of the properties of glass with normal industrial carbon. RVC has a large void volume (97%) and a small surface area (0.09 m²/gram). It has a self-supporting rigid structure, a low resistance to flow and is resistant to temperatures up to 600 °F in air (6330 °F in a non-oxidizing environment) (19). A more thorough discussion of vitreous carbon is available in the literature (20-24). The samples obtained had various pore sizes. Sizes included 10, 20, 30, 45, 80 and 100 ppi (pores per inch). The 100 ppi RVC foam will be tested in our study.

GRAPHITE FIBER MATS

Obtained commercially by Dr. Baker at The Pennsylvania State University.

GRAPHITE FELTS

Obtained commercially by Dr. Baker at The Pennsylvania State University.

All materials were used as received without any further pretreatment. If necessary to help activate or clean the surface, mild electrochemical or chemical methods were employed.

WORK PERFORMED

EXPERIMENTAL

Surface Area

The surface area of the samples has been determined and the data are shown in Table II. The surface areas were obtained by WVU using a Gemini III 2375 Surface Area Analyzer (Micrometrics Instrument Corporation, Norcross, GA). Standard operating procedures have been followed as outlined in the operator's manual.

A pre-weighed sample of the carbonaceous material was placed into a clean, dry sample tube. The sample was thoroughly degassed using nitrogen. The dewar was filled with liquid nitrogen and the system prepared for analysis.

The sample tube was connected to the analysis port and the balance tube was connected to the balance port. Care was taken to minimize exposure of the sample to air. The doors to the sample station were closed and the analysis initiated. Saturation pressure was set to 740.53 mm Hg and the evacuation rate to 599 mm Hg/min. The Gemini III 2375 Surface Area Analyzer performs automated analysis. It is capable of simultaneously performing BET multipoint and single point surface area, Langmuir surface area, t-method micropore, and BJH adsorption/desorption distribution. The resulting data were recorded on an Epson plotter (Model P84FA).

Electrochemical Apparatus

A two-cell system is used for this study. The upper, or working cell removes metal ions from the flowing stream. The downstream or analytical cell is used to assess the performance of the working cell by measuring the metal ion concentration in the effluent. The upper flow-through cell design is shown in Figure 2. The cylindrical body of the upper cell is made of Lexan (5.0 cm diam., 6.0 cm length). The flow channel (1.6 cm i.d.) was drilled through the Lexan body. The Ag/AgCl reference electrode (3M NaCl, Model RE-4, BioAnalytical Systems, Inc. (BAS) West Lafayette, IN) is introduced into the flow channel

through a Lexan sleeve positioned 90 degrees to the flow channel. Leakage is prevented using an o-ring and compression-type fitting. A piece of coiled platinum wire inserted at the outlet of the cell is used as the auxiliary electrode. Contact to the working electrode is established via platinum mesh positioned through the cell wall and sealed with an o-ring.

The thin-layer flow cell, as shown in Figure 3, was purchased from BioAnalytical Systems (Model LC-44-01000). The working electrode is a glassy carbon disk (0.3 cm diameter) over which the solution flows. Two 50 μm spacers are used to produce the flow channel and direct the effluent flow across the carbon disk. Prior to use, the glassy carbon disk is polished using successive slurries of 1.0, 0.3 and 0.05 μm alumina until a mirror-like surface is obtained. The glassy carbon electrode is then washed thoroughly with deionized water. All potentials are measured relative to the Ag/AgCl reference electrode (BAS).

Solution reservoirs for the mercury (II) plating solution and samples are 1000 ml Nalgene jars fitted with covers. The solution reservoirs are connected to the working cell using Tygon tubing. Solution flow is controlled with a peristaltic pump (Cole-Parmer Instrument Co., Niles, IL) located upstream from the two cells. All solutions were deaerated using nitrogen gas prior to use. A nitrogen head space is maintained above the solutions to prevent the re-dissolution of oxygen.

The potential of the upper flow-through cell is controlled using an BAS Model PWR-3 Power Module. Stripping voltammograms at the thin-layer flow cell are obtained using the BAS Model CV-27 Voltammograph in conjunction with a HP Model 7044b X-Y recorder.

Reagents

Stock solutions of Cd, Pb and Cu ions are prepared using standard solutions (1000 ppm, Fisher Scientific, Fair Lawn, NJ) and deionized water. The deionized water used was further purified using a NANOpure™ ultrapure water purification system (Barnstead/Thermolyne, Dubuque, IA). These solutions are stored in polyethylene containers to avoid contamination. Portions of these solutions are diluted as needed for experimentation. The $1 \times 10^{-4} \text{M}$ Hg(II) solution used for mercury plating is prepared from $\text{Hg}(\text{NO}_3)_2$ as needed. The mercury ion and sample solutions are prepared in 0.1M KNO_3 supporting electrolyte. The pH is adjusted to 3.5 using HNO_3 . (All chemicals were certified ACS grade purchased from Fisher Scientific unless otherwise noted).

PROCEDURE

Metal Removal Cell

The carbon material to be studied was pretreated to oxidize and assist in the wetting of the carbonaceous surface. This was accomplished by placing the carbon material in a

dilute solution (10%) of nitric acid overnight in a covered beaker. The material was then thoroughly washed using deionized water. The carbonaceous material was then positioned into the lower end of the flow channel in the upper working cell (Figure 2) using a clean glass rod.

A threaded plug is used to press the material between a platinum mesh and a piece of filter paper. The carbon material is placed into the working cell and the threaded plug is screwed into place snugly against it. The pressure on the carbon nanofibers can be easily adjusted by turning the threaded plug. Rigid samples, such as Reticulated Vitreous Carbon were positioned using a snug fit. Electrical contact to the working electrode material was established using the platinum mesh. The reference electrode was inserted into the sleeve and the cell was connected to the pump using Tygon tubing. A 0.1M KNO_3 electrolyte solution was pumped through the flow cell. In order to help remove air bubbles and wet the electrode surface, a mild electrochemical pretreatment was used. The cell potential was held at +1.00 V for 10 minutes followed by -1.00 V for 10 minutes.

The performance of the carbonaceous material under study was tested by placing a solution containing a known concentration of metal ions (Cd, Pb and/or Cu) into the sample reservoir. The solution was then allowed to pass through the metal removal (working) cell at a known flow rate and applied potential. The performance was assessed by measuring the metal ion concentration in the effluent and comparing it to the initial ion concentration. The percentage efficiency of the cell is equal to the percentage of metal ions removed from the solution by the electrolytic cell.

For these studies, the effluent was collected in a Nalgene bottle for subsequent analysis using ASV and/or AA.

Analytical Cell

A pre-plated mercury film is used for downstream anodic stripping voltammetric (ASV) detection of the metal ions in the effluent stream. A 1×10^{-4} M Hg(II) solution in 0.1M KNO_3 is purged with nitrogen for 20 minutes. The mercury film is produced by applying a potential of -1.00 V at the glassy carbon electrode while passing the Hg(II) solution through the cell at 0.87 ml/min for 5 minutes. After this period, the potential is held at +0.05 V for 90 seconds. Following this conditioning, the stopcock is turned to stop the flow of mercuric ions and allow the flow of the deaerated sample through the cell. This flow is continued for 3 minutes to flush any mercuric ions from the system and replace all of the solution in the system with the sample to be studied.

While the solution is flowing at a known flow rate (0.87 ml/min), the ASV deposition potential is applied to the thin-layer flow cell (usually for 1 minute) and the metal ions are accumulated. At this point, the solution flow is stopped to the analytical cell and after a 30

second equilibrium period, a ramp is initiated (-1.00 V to + 0.20 V) and the stripping voltammogram recorded. The scan is terminated at + 0.20 V. Sample solution flow is renewed and the electrode cleaned at + 0.05 V for 90 seconds to prepare the system for the next determination.

The mercury film and plated metals are removed at the end of a series of experiments using a moist Kimwipe. The electrode is subsequently polished for the next series of studies.

RESULTS and DISCUSSION

After preliminary testing of the initial remediation cell design (as shown in Figure 1), it was found that some modifications were required.

First: If varying thicknesses of carbonaceous electrode material are to be tested, the distance between the working and the reference electrodes would not be constant. This would lead to differences in the solution resistance and therefore, differences in uncompensated potential (iR) losses.

Second: There was great difficulty in establishing good electrical contact between the working electrode material (the carbon nanofibers) and the platinum wire lead. This problem induced a large cell resistance and high voltage drops across the carbon electrode.

In order to maintain a constant distance between the working electrode and the reference electrode and minimize cell resistance, a new cell design was created. This new design is shown in Figure 2.

A major complication involved the loose carbon nanofibers in the earlier cell. Loosely packed carbon-fibers allowed solution flow, but electrical contact was sacrificed. If the particles were packed more tightly, improved (although not great) contact was established, but a high resistance to solution flow resulted. Steps taken in the new cell design are the addition of the threaded plug so that the amount of compression of the nanofibers can be carefully adjusted and controlled and the use of a platinum mesh to maximize electrical contact with the carbon nanofibers.

A threaded plug is used to press the carbonaceous working electrode material firmly against the platinum mesh. This platinum mesh is used as the working electrode contact. The surface area of the platinum mesh is negligible relative to the surface area of the carbon material, but should still afford much better contact with the carbonaceous material than the single platinum wire used in the previous design. Minimal electrolytic contribution is gained from the platinum mesh while maximizing the electrical contact. The reference

electrode was positioned as close as possible to the working electrode through a Lexan sleeve. Special care was taken to allow varying amounts of carbon material to be used, while maintaining constant electrode distances. Through the use of flanges and an o-ring, the design also allows easy removal and replacement of the carbon material.

ANALYTICAL CELL

The inherent sensitivity of Anodic Stripping Voltammetry (ASV) makes it an excellent choice for the detection of heavy metal ions in solution. The detectable limits are often below those attainable using Flame and/or Flameless Atomic Absorption / Emission Spectroscopy. Figure 4 demonstrates the ability to detect these low limits using a thin mercury film coated on a glassy carbon electrode. The mercury film yields well-defined and sharp peaks, good resolution between neighboring signals and a low background current. The response shown is for a sample solution containing 10 parts per billion (ppb) cadmium, lead and copper in 0.1 M KNO_3 at various deposition times (0, 30, 60, 90 and 180 seconds). The increased accumulation of the metals in the mercury film with time is quite evident. The dependence of the peak current on the deposition time is shown in Figure 5. The effect of the deposition time on the peak current was studied using a solution containing 100 ppb copper and lead. As expected, a linear relationship was obtained with a slope of $2.293 \mu\text{A}/\text{min}$ (Cu) and $1.180 \mu\text{A}/\text{min}$ (Pb) with correlation coefficients of 0.9937 (Cu) and 0.9926 (Pb). The peak current is used to calculate the concentration of metal ions in the effluent stream.

Figure 6 examines the effect of the ASV scan rate on the stripping response of 100 ppb copper and lead. The peak current increases with the increased scan rate. However, at scan rates above 10 mV/sec, the peaks begin to broaden, leading to an overlapping of neighboring peaks.

Calibration data acquired with lead (1-5 ppm) yielded well-defined and sharp peaks. The resulting calibration plot (Figure 7), was highly linear ($R=0.9932$), with a slope of $1.066 \mu\text{A}/\mu\text{g}$.

The response for 6 repetitive measurements of cadmium, lead and copper was examined. Figure 8 shows the exceptional precision of the response for 30 second deposition of 2 ppm copper and lead. An average peak current and relative standard deviation of $14.413 \mu\text{A}$ and 2.05% for copper and $7.272 \mu\text{A}$ and 3.42% for lead demonstrate the degree of reproducibility. The precision of 1 ppm cadmium (not shown) did not produce such outstanding results. The relative standard deviation of 7.80% illustrates this point. Fine tuning of the experimental procedure is necessary to obtain improved precision.

METAL REMOVAL

The effectiveness of a cylindrical piece of Reticulated Vitreous Carbon (RVC) (6 mm diam., 6 mm length) was examined for its performance as the cathode material of the upstream electrolytic remediation cell. Cathodic removal of the metal ions via reductive plating on the RVC was investigated. Figure 9 shows the performance of the RVC. A sample solution containing 50 ppb cadmium, lead and copper was analyzed using a flow rate through the remediation cell of 1.22 ml/min. Curve 'A' shows the response of the solution prior to passing it through the electrolytic cell. Further, Curve 'B' shows the negligible removal of the metals ions in the cell due to adsorption alone on the carbonaceous surface ($E_{\text{applied}} = 0.00\text{V}$). Only the response for cadmium was affected (16% decrease). Upon applying a potential well negative of the reduction potentials of all three metals (-1.00 V), a significant decrease in peak current is observed due to the removal of the metals (Curve 'C'). A 64.7% and 50.0% efficiency was observed for copper and cadmium, respectively. A small 10% efficiency was seen for lead. At -1.00 V and using a slower flow rate of 0.87 ml/min (not shown), preliminary removal efficiencies of 90% or greater were obtained for the three metals.

In order to improve these efficiencies, several parameters must be addressed. By increasing the ratio of cathode surface area to electrolyte solution volume, increasing the time that the solution remains in the electrode material and/or by optimizing the potential applied to the cell, greater efficiencies can be obtained. One option would be to lower the flow rate of the solution through the cell. This would allow more time for the metal ions to be removed, but would increase the process time. A simpler solution would be to increase the electrode surface area. This can be accomplished in any number of ways. A longer flow path through the cathode would increase the surface area and the residence time. Another method is to increase the surface area of the solid 3-dimensional support by growing carbon nanofibers onto the surface. This should produce a cathode material with a 2-3 orders of magnitude increase in surface area. Carbon nanofibers have been grown on a graphite mat and a graphite felt at The Pennsylvania State University. Surface area measurements of this material have been performed (see Table II). The increase in surface area from the addition of the carbon nanofibers on the surface is quite evident. Attempts by co-workers at The Pennsylvania State University to grow carbon nanofibers on the RVC surface were unsuccessful.

Two samples of loose carbon nanofibers were received from The Pennsylvania State University. The more conductive and graphitic sample (#1094-A) was used for analysis. The surface area of these loose nanofibers has been measured ($115\text{ m}^2/\text{g}$). This is 1000 times greater than the surface area of the reticulated vitreous carbon material tested previously. This large surface area should enhance the removal efficiencies of the working cell. The carbon nanofibers were treated overnight in 10% HNO_3 . This treatment improved the wetting ability of the nanofibers. This acid treatment also increased the

surface area of the carbon nanofibers to 228 m²/g. The effect of the acid treatment on the surface area of the other samples was also examined.

Using the new cell design, good electrical contact was easily established between the loose carbon nanofibers and the platinum mesh lead. The ability of these nanofibers to remove cadmium and lead from water was addressed. No effect was observed for the removal of the metal ions due to adsorption alone (i.e. Passing the feed solution through the cell with no applied potential on the carbon electrode). Application of a negative potential, greatly improved this material's ability to remove the metal ions. Figure 10 shows the effectiveness of these loose carbon nanofibers to remove cadmium and lead. Removal efficiencies of 91% for cadmium and 95% for lead were obtained at these conditions. These enhanced removal efficiencies, relative to those shown using RVC, show great promise for the use of these novel carbon nanofibers for the reductive removal of metal ions from aqueous streams.

Samples of graphite fiber mats with and without carbon nanofibers were obtained from Dr. Terry Baker. The surface area of each sample was determined. The surface area of the graphite fiber mat was 0.60 m²/g. This area was greatly increased by growing carbon nanofibers onto the mat. The surface area of the graphite fiber mat with carbon nanofibers was 99.9 m²/g. This surface area is 167 times greater than that of the graphite fiber mats alone.

The performance of the graphite fiber mats with carbon nanofibers was assessed. Good electrical contact and conductivity were obtained between the cathode material and the platinum mesh lead. The effectiveness of the carbon nanofibers grown on graphite fiber mats to remove metal ions from an aqueous stream was then studied. The removal of the metal ions by adsorption only (no applied potential) onto the cathode resulted in minimal removal of the metal ions. Upon applying a sufficiently negative potential to the cathode, improved ion removal was attained. Figure 11 illustrates the performance of the cathode material. The lower curve shows the response of the sample solution prior to passing it through the electrolytic cell. The middle curve shows the decrease in peak current due to the removal of the metal ions using a potential of -0.00V. The response for the effluent when applying potential of -1.00V to the cell is shown in the upper curve. Removal efficiencies of 99%, 91% and 88% were obtained for Cu, Pb and Cd, respectively. At an applied of -1.20V (not shown), no response was seen for any of the metals. (i.e. removal of metal ions to concentrations below detectable limits).

A conductive graphite felt was analyzed in the next study. Both unmodified graphite felt and graphite felt with carbon nanofibers grown on it were utilized. Surface area measurements demonstrate the ability to increase the surface area of the sample using the carbon nanofibers. Prior to growing carbon nanofibers, the surface area of the graphite felt was 0.17 m²/g. Upon growing carbon nanofibers onto the surface, the surface area of the sample was increased to 55.41 m²/g, over a 300-fold increase.

The performance of the bare graphite felt was first assessed. Minimal removal was seen due to adsorption alone. Upon applying a potential of -1.00 V to the cathode, most of the lead (97%), but only 22% of the cadmium was removed. The resulting voltammograms are shown in Figure 12. No reason could be found for the low removal of the cadmium although we suspect the properties of the graphite felt may be causing a severe overpotential. Application of a more negative potential (-1.20 or greater) should remove the cadmium as well.

The response for solutions collected under the same conditions using the graphite felt with nanofibers is shown in Figure 13. Once again a minimal amount of the metal is removed by the carbonaceous material in the absence of an applied potential. When a reductive potential is applied, almost complete removal of lead, as well as a improved removal of cadmium is acquired (46%).

To confirm minimal contribution from the platinum mesh to the working electrode, the system was tested in the absence of any carbonaceous cathode material. The response of the original feed solution was compared to the response of the effluent collected at -1.00 V. It was shown that the platinum mesh does not contribute significantly ($<2\%$) to the removal of the metal ions from solution (see Figure 14). Therefore, the removal of metal ions seen so far is due to their reductive removal onto the carbonaceous cathode materials and is not significantly influenced by the platinum mesh. A comparison of the metal removal efficiencies is summarized in Table III.

In order to assess electrosorption, the loose carbon nanofibers were tested for their ability to remove cadmium and lead at potentials more positive than that required to reduce the metal ions. The removal of cadmium was examined at various potentials above and below its theoretical reduction potential. Figure 15 shows the ASV response for a cadmium solution passed through the remediation cell at these potentials. Based on the initial cadmium feed concentration (100 ppb), the potential at which the cadmium ions should be reduced is -0.58 V. Electrosorption removed 46% of the cadmium from solution at -0.20 V and 78% at -0.40 V. At potentials more negative electroplating removes 89% (-0.60 V), 91% (-0.80 V) and almost all (99% at -1.00 V) of the cadmium. The percent of cadmium removed versus the applied potential is also shown (inset).

Figure 16 shows the response for the removal of lead under the same conditions. The theoretical reduction potential for lead is -0.54 V. Removal of lead via electrosorption is also shown to occur at potentials more positive than the reduction potential. The removal efficiencies were 88% at -0.20 V and 92% at -0.40 V.

Continuous removal of lead from an aqueous stream using electroplating and electrosorption was used to demonstrate the long-term effectiveness of the carbon nanofibers. The lead solution was passed through the remediation cell and the ions were

removed by applying the desired potential to the carbon nanofibers. A potential of -1.00 V was applied to the remediation cell to remove the lead ions via electroplating. Over a continuous period of 72 hours, removal efficiencies of 89% or greater were achieved for an inlet lead ion concentration of 100 ppm. Calculation of the lead removal over this period demonstrates a capacity above $0.90 \text{ g}_{\text{Pb}}/\text{g}_{\text{nanofibers}}$, but it should be stressed that even at 72 hours, the carbon showed no signs of saturation (see Figure 17).

Removal of lead via electrosorption was carried out using a potential of -0.40 V. For an inlet lead ion concentration of 100 ppb, good removal efficiencies (90%) are obtained for the first 12 hours (see Figure 18). After that time a noticeable decrease in efficiency is evident. The removal efficiency drops to less than 50% after 57 hours. This decrease in removal efficiency is expected due to neutralization of the charge on the electrode surface. Regeneration or replacement of the nanofibers would be required to maintain high removal efficiencies. For the first 12 hours of removal a capacity of $1.9 \times 10^{-4} \text{ g}_{\text{Pb}}/\text{g}_{\text{nanofibers}}$ is obtained. At 57 hours this capacity increases to $7.1 \times 10^{-4} \text{ g}_{\text{Pb}}/\text{g}_{\text{nanofibers}}$. Electrosorption of lead using 100 ppm lead was attempted. Due to the smaller capacity of the nanofibers when using electrosorption, the efficiency should drop off quickly. As expected, within the first two hours removal efficiencies drop to less than 20%.

The final desire is to recover the metals once they have been removed from the aqueous stream. It is possible to remove the metal ions are removed resulting in a purified effluent stream, the metal ions can be recovered metal ions plated on the electrode surface simply by reversing the potential. Once the in solution more concentration than the feed. Electrodeposition and the subsequent recovery from the nanofiber surface was demonstrated with a 100 ppm lead solution. The lead was removed from the aqueous stream at a potential of -1.00 V. Subsequent recovery of the lead at a potential of 1.00 V, produced an effluent stream more concentrated in lead. The lead concentration of the effluent was 331 ppm lead, demonstrating a 3:1 concentration of the waste stream. Individual metals can be selectively removed and recovered by these means.

A summary of the removal efficiencies for all of the materials involving carbon nanofibers is given in Table III. These results are for electroplating only. As can be seen, the carbon nanofibers are extremely effective devices for the removal of heavy metal ions from solution.

CONCLUSION

All proposed objectives have been met (see Table IV). An extensive search of the literature has been conducted in the areas of heavy metal removal, waste water treatment and water remediation. More than 150 papers have been amassed in these areas with special interest in the areas of electrochemistry and electrowinning using carbonaceous materials.

The thin-layer flow-cell to be used as the on-line detector has been assembled and has been thoroughly tested. This testing included characterization, calibration and verification. The flow-cell will be connected on-line and used to monitor the effluent stream of the upstream metal removal cell.

The preliminary cell design for metal removal from aqueous streams has been tested. Modifications have been made to the cell design and the new cell has been produced. The modifications and problems they solve have been discussed earlier.

The performance of the RVC cell was satisfactory. Due to the problems with growing carbon nanofibers, the RVC could not be used as a support. The RVC was destroyed in all attempts to grow carbon nanofibers on it. Therefore, no conclusions can be drawn on the enhanced performance due to the increase in surface area due to carbon nanofibers grown on the surface of the RVC.

Loose carbon nanofibers with relatively large surface areas of $100^+ \text{ m}^2/\text{g}$ effectively removed over 90% of cadmium and lead from an aqueous sample. Electrical contact was easily established using the new cell design. Further chemical and physical activation of the nanofibers should increase the surface areas even more and improve electrical conductivity. These two factors can be used to improve the already superb results seen so far using these materials.

One material on which carbon nanofibers were successfully grown, was a woven mat of graphite fibers. Surface area analysis showed that this material had a very large surface area (approximately $200 \text{ m}^2/\text{g}$). Analysis of this sample to remove metal ions from the aqueous sample were favorable. The carbon nanofibers grown on graphite fiber mats performed well for removing the metal ions. Removal efficiencies of 90% and above (99%+ for Cu) were easily obtained. Through the use of several mats, these metal removal efficiencies should be maintained at even higher solution flow rates due to the large increase in cathode surface area.

Another material on which carbon nanofibers were grown was graphite felt. Samples of the graphite felt with and without carbon nanofibers were studied. A removal efficiency above 95% was obtained for both samples for the removal of lead. Small removal efficiencies were seen for cadmium. Application of a more negative potential than -1.00 V should increase the amount of cadmium removed. Further analysis will be conducted to optimize the removal of cadmium.

A study to determine the contribution of the platinum wire mesh to the removal of metal ions demonstrated that the contribution was negligible. The metal ion removal is accomplished predominantly by the carbonaceous cathode material.

Tests conducted to determine if the carbon nanofibers could be used to electrosorb metal ions were successful. Cadmium and lead were both removed from an aqueous solution at a potential more positive than their reduction potentials. Short-term removal efficiencies of 78% for cadmium and 92% for lead were obtained at a remediation cell potential of -0.40 V. A future application of electrosorption would be to remove radionuclides that have reduction potentials greater than that required to reduce water.

Long-term removal of lead over a continuous period of 72 hours using electroplating 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. The continuous removal of lead using electrosorption decreased the concentration of a 100 ppb lead feed to 10 ppb for the first 12 hours. Removal efficiencies for electrosorption dropped to less than 50% after 57 hours. At 102 hours removal efficiencies were approaching 20%. Removal via electrosorption will require a much larger quantity of carbon nanofibers to be used over that used for electroplating.

Finally, the recovery of lead using electroplating resulted in the increased concentration of the recovered effluent stream by 331%. Optimization of the recovery procedure should lead to greater concentration of the recovered metal of interest.

FIGURE 1: Electrochemical Remediation Cell and Detector.

FIGURE 2: Remediation Cell.

FIGURE 3: Thin-layer Flow Cell for Metal Detection.

Figure 4: ASV Response for 10 ppb Cadmium, Lead and Copper at a Mercury Film Electrode.

(Mercury Film Plating: 5 min @ -1.00V, 1×10^{-4} M Hg(II), 90 sec @ +0.05 V, flow = 0.87 ml/min. ASV: Deposition: 30 (a), 60 (b), 90 (c) and 120 (d) seconds @ -1.00V, 10 ppb Cd, Pb and Cu in 0.10 M KNO_3 , pH=3.5, flow = 0.87 ml/min; EQ time = 15 sec; Stripping: -1.00 to -0.300 V, 10 mV/sec, stopped flow)

Figure 5: Time Study.

(Conditions: same as Figure 4. 100 ppb Pb and Cu)

Figure 6: Scan Rate.

(Conditions: same as Figure 4. 30 second deposition, 100 ppb Pb and Cu)

Figure 7: Calibration of Lead.
(Conditions: same as Figure 4. 2 minute deposition)

Figure 8: Precision.
(Conditions: Same as Figure 4. 5 minute deposition)

Figure 9: Metal Ion Removal Using RVC Electrode.

(Conditions: Same as Figure 4. 50 ppb Cd, Pb and Cu, 60 second deposition)

(A) Metal ion solution response prior to passing through working cell.

Solution response after passing through working cell with applied potential 0.00 V (B) and -1.00 V (C). (dotted line corresponds to blank solution)

Figure 10: Metal Removal Using Loose Carbon Nanofibers.

(Conditions: Same as Figure 4. 100 ppb Cd, Pb and Cu, 60 Second deposition)
Metal solution response prior to passing through the remediation cell (lower), solution response after passing through the cell with no applied potential (middle: 0.00 V) and after passing through the remediation cell at -1.00 V (upper).

Figure 11: Metal Ion Removal Using Carbon Nanofibers on a Graphite Fiber Mat.

(Conditions: Same as Figure 10.)

Figure 12: Metal Ion Removal Using Graphite Felt without Carbon Nanofibers.

(Conditions: Same as Figure 10)

Figure 13: Metal Ion Removal Using Carbon Nanofibers Grown on a Graphite Felt.
(Conditions: Same as Figure 10)

Figure 14: Metal Removal Using Bare Platinum Wire Mesh.
(Conditions: Same as Figure 10)

Figure 15: Effect of Remediation Cell Potential on Cadmium Removal.
(Conditions: Same as Figure 10)

Figure 16: Effect of Remediation Cell Potential on Lead Removal.
(Conditions: Same as Figure 10)

REMOVAL of Pb USING CARBON NANOFIBERS

Figure 17: Long-Term (72 hr) Removal of Lead via Electroplating.
(Conditions: $E_{\text{CELL}} = -1.00 \text{ V}$; Flow = 0.87 ml/min)

REMOVAL of Pb USING CARBON NANOFIBERS

Figure 18: Long-Term (102 hr) Removal of Lead via Electrosorption.
(Conditions: $E_{\text{CELL}} = -0.40 \text{ V}$; Flow = 0.87 ml/min)

Table I

STANDARD REDUCTION POTENTIALS OF THE METAL
IONS OF INTEREST

<u>Metal Ion Reaction</u>	<u>E°, (vs. Ag/AgCl)</u>
$\text{Zn}^{+2} + 2\text{e}^- \rightleftharpoons \text{Zn (s)}$	-0.986 V
$\text{Cd}^{+2} + 2\text{e}^- \rightleftharpoons \text{Cd (s)}$	-0.624 V
$\text{Cd}^{+2} + 2\text{e}^- \rightleftharpoons \text{Cd (in Hg)}$	-0.602 V
$\text{Pb}^{+2} + 2\text{e}^- \rightleftharpoons \text{Pb (s)}$	-0.348 V
$\text{Pb}^{+2} + 2\text{e}^- \rightleftharpoons \text{Pb (in Hg)}$	-0.343 V
$\text{Cu}^{+2} + 2\text{e}^- \rightleftharpoons \text{Cu (s)}$	+0.115 V
$\text{Cu}^{+2} + 2\text{e}^- \rightleftharpoons \text{Cu (in Hg)}$	+0.123 V

Table II

PROPERTIES of CARBON MATERIALS

SURFACE AREA

Material	Surface Area (m ² /gram)	
	BET	Langmuir
Carbon Nanofibers		
1094-A	115.13 (227.8)*	186.78
1094-B	182.77 (192.3)*	286.03
NF46 (unsupported)	43.28	
Graphite Fiber Mats	0.59	
Carbon Nanofibers on Graphite Mats	99.92 (112.8)*	-
Graphite Felt	0.17	-
Carbon Nanofibers on Graphite Felt		
NF46	55.41	-
F100	54.54	-
CF37	13.96	-
CN37	35.31	-
VGCF	76.78 (73.6)*	122.66
RVC		
100 ppi	0.092	-
80 ppi	44.80	-
Activated Carbon	784.32	-

* Value in parenthesis is the surface area measured after acid treatment

Table III

TABLE OF REMOVAL EFFICIENCIES

<u>Cathode Material</u>	<u>Metal Removed</u>		
	<u>Cathode Potential, V</u>	<u>Cd</u>	<u>Pb</u>
RVC	0.00	16%	0%
	-1.00	50%	8%
Loose Carbon Nanofibers (#1094-A)	0.00	0%	0%
	-1.00	91%	95%
Carbon Nanofibers on Graphite Mats	0.00	0%	0%
	-1.00	90%	92%
Graphite Felt	0.00	13%	7%
	-1.00	22%	97%
Carbon Nanofibers on Graphite Felt	0.00	0%	0%
	-1.00	46%	99%
Platinum Mesh	0.00	0%	0%
	-1.00	0%	9%

Table IV

"ENVIRONMENTAL POLLUTION CONTROL DEVICES BASED ON NOVEL FORMS OF CARBON"

PROJECT COMPLETION

<u>TASK #</u>	<u>WBS CODE</u>	<u>TASK NAME</u>	<u>DUR</u>	
1	1.0	PRELIMINARY RESEARCH		
2	1.1	Electrochemical Remediation (ECR)	OCT-DEC	
3	1.2	Technical Evaluation	NOV-DEC	
4	2.0	ANALYTICAL TECHNIQUES	OCT-JUN	
5	3.0	PREPARATION FOR TRIALS		
6	3.1	Hire Post-Doctoral	SEP-OCT	
7	3.2	Purchase Electrochemical System	SEP-NOV	
8	3.3	Obtain Chemicals and Reagents	OCT-NOV	
9	3.4	Obtain Carbon Samples (A-?)	OCT-DEC	
10	3.5	Characterize Carbon Samples	OCT-FEB	
11	4.0	TESTING		
12	4.1	ECR - Sample A: Nanofibers (1094-A)	NOV-JUN	
13	4.2	ECR - Sample B: Nanofibers (1094-B)	NOV-JUN	
14	4.3	ECR - Sample C: RVC (100 ppi)	NOV-JUN	
15	4.4	ECR - Sample D: RVC (80 ppi)	NOV-JUN	
16	4.5	ECR - Sample E: PYROGRAF III (LOT ADNH)	NOV-JUN	
17	4.6	ECR - Sample F - Nanofibers on C Mat (0295-A)	NOV-JUN	
18	4.7	ECR - Sample G - Graphite Felt	NOV-JUN	
19	4.8	ECR - Sample H - Nanofibers on Graphite Felt	NOV-JUN	
20	4.9	Trial Repeats (Concurrent)	MAR-JUN	
21	5.0	ANALYSIS and REPORTING		
22	5.1	Analysis and Data Reduction	JUN-JUL	
23	5.2	Reports and Manuscripts	OCT-JUL	
24	6.0	CLOSURE	JUL	
25	7.0	OVERALL WORK COMPLETE	AUG	Complete

REFERENCES

1. Wang, J. "Stripping Analysis: Principles, Instrumentation, and Application"; VCH Publishers: Deerfield Beach, FL, 1985.
2. Gaylor, V. F.; Elving, P.J.; Conrad, A. L. *Anal. Chem.*, **1953**, *25*, 1078.
3. Morris, J. B.; Schempf, J. M. *Anal. Chem.*, **1959**, *31*, 286.
4. Adams, R. N. *Anal. Chem.*, **1958**, *30*, 1576.
5. Yamado, S.; Sato, H. *Nature*, **1962**, *193*, 261.
6. Blaedel, W. J.; Wang, J. *Anal. Chem.*, **1980**, *52*, 1697.
7. Dryhurst, G.; McAllister, D. L. in "Laboratory Techniques in Electroanalytical Chemistry", Kissinger, P. T. and Heinenman, W. R., Eds.; Marcel Dekker, Inc.: New York, NY, 1984; Chapter 10.
8. Bennion, D. N.; Newman, J. J. *Appl. Electrochem.*, **1972**, *2*, 113.
9. Chu, A. K. P.; Fleischmann, M.; Hills, G. J. *J. Appl. Electrochem.*, **1974**, *4*, 323.
10. Fujinaga, T.; Kihara, S. *Crit. Rev. Anal. Chem.*, **1977**, *6*, 223.
11. Blaedel, W. J.; Strohl, J. H. *Anal. Chem.*, **1964**, *36*, 1245.
12. Yaniv, D.; Ariel, M. *J. Electroanal. Chem. Interfacial Electrochem.*, **1977**, *79*, 159.
13. Suzkover, E. Ph.D. Dissertation, Technion-I.I.T., Haifa, 1977.
14. Wang, J.; Dewald, H. D. *J. Electrochem. Soc.*, **1983**, *130*(9), 1814.
15. Baker, R. T. K., Rodriguez, N.M. U.S. Patent 5,149,584.
16. Rodriguez, N.M., Baker, R.T.K. Patent Application filed October 1992.
17. Applied Sciences, Inc. Technical data sheet on Advanced Material Development.
18. Wang, J. *Electrochim. Acta.*, **1981**, *26*, 1721.
19. Reticulated Vitreous Carbon (An Exciting New Material), Energy Research and Generation, Inc., Oakland, CA
20. Cowlard, F.C., Lewis, J. C. *J. of Materials Sciences*, **1967**, *2*, 507.
21. Noda, T., Inagaki, M., Yamada, S. *J. of Non-Crystalline Solids*, **1969**, *1*, 285.
22. Lewis, J. C., Murdoch, R., Moul, A. N. *Nature*, **1969**, *vol 221*, 1137.
23. Kawamura, K., Ryan, T., Jenkins, G. "The Incorporation of Glassy Carbons in Metals," Paper presented at 9th Carbon Conference.
24. Tamaguchi, T. *Carbon*, **1963**, *1*, 47.

TASK 3.0
INFORMATION SYSTEMS,
PUBLIC POLICY,
COMMUNITY OUTREACH,
AND ECONOMICS

**INFORMATION SYSTEMS, PUBLIC POLICY,
COMMUNITY OUTREACH AND ECONOMICS**

WINFIELD LOCK AND DAM ASSISTANCE PROGRAM

TASK 3.1

Quarterly Report for Period
July 1 through September 30, 1995

Work Performed Under Contract
No.:DE-FC21-92MC29467

For
U.S. Department of Energy
Office of Fossil Energy
Morgantown Energy Technology Center
Morgantown, West Virginia

By:

Raymond J. Lovett
National Research Center for Coal and Energy
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October 1995

Abstract

The United States Army Corps of Engineers (ACE) must remediate a contaminated industrial site, formerly owned by ACF Industries, Inc., in order to build a new lock on the Kanawha River at Winfield, WV. The original remediation plan, to incinerate the contaminated soil, generated much controversy in the surrounding communities, notably Eleanor, WV.

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 has been two-pronged. WVU has 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 is to inform the citizens of possible health and safety problems with proposed operations. Additionally, WVU has interacted with the U.S. Army Corps of Engineers to implement appropriate technology at the site.

These investigations are being conducted by the National Research Center for Coal and Energy (NRCCE) Environmental Technology Division (ETD) staff and WVU faculty.

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EXECUTIVE SUMMARY

The contaminated material from the Winfield Lock and Dam is being excavated and shipped to Utah. As of 30 September, the excavation is scheduled to continue until roughly the end of the year. The digging began about August 15, 1995. WVU is conducting a dust monitoring program during the excavation. One monitor is currently operating. Another will be added and, if ready, a volatile organic monitor will be deployed.

1.0 INTRODUCTION

The site of the former ACF Industries, Inc. railroad tank car maintenance shop is 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 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 is, thus, funded by this Cooperative Agreement and consists 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).

2.0 WORK PERFORMED THIS PERIOD

NO UMBRELLA COMMITTEE MEETINGS HAVE BEEN HELD SINCE JUNE.

The particulate real time air monitoring system designated by Dr. M. Gautum is the MIE Dataram. This unit can sample continuously and record up to 10,000 points

designating the actual ug/m³ of respirable dust in the air. The units are difficult to calibrate, so they are being used as relative monitors.

The Dataram units were evaluated at the NRCCE (battery time, download method, etc.) Humid conditions provide a positive error, so a heater unit bought with the Dataram is being used. The first unit was deployed on August 30, 1995. The unit sits on the west end of the site, in the direction of Eleanor, WV. The unit was set to measure the PM₁₀ value every minute for a week. The first few weeks, the unit (which was typically set on a Wednesday) failed by Friday. The failure was found to be due to a dead electrical socket at the air monitoring station, essentially minute by minute readings have been recorded since September 15. The week of the 15th, the heater was not on, so the results may be high. A sample output is appended to this report.

3.0 WORK PLANNED FOR NEXT PERIOD

The air monitoring will continue. The second unit will be installed the week of October 7. The volatile organic monitor will be installed as soon as possible.

4.0 TECHNICAL/ADMINISTRATIVE DIFFICULTIES

The development of the MS/MS system was slowed due to numerous problems.

**INFORMATION SYSTEMS, PUBLIC POLICY,
COMMUNITY OUTREACH AND ECONOMICS**

**A GIS - BASED INFRASTRUCTURE
FOR SITE CHARACTERIZATION AND REMEDIATION**

TASK 3.2

Quarterly Report for Period
July 1 through September 30, 1995

Work Performed Under Contract
No.:DE-FC21-92MC29467

For
U.S. Department of Energy
Office of Fossil Energy
Morgantown Energy Technology Center
Morgantown, West Virginia

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ABSTRACT

The primary goal of this work is to determine an effective GIS-based infrastructure for describing, characterizing, and remediating contaminated sites. The work is being carried out using the remediation needs of the U.S. Army Corps of Engineers Huntington, WV district office as a basis--giving the benefit of real needs of on-going remediation projects. The work includes devising and specifying an integrated system with features targeted to site remediation/restoration needs, establishing operational procedures for effective use of the integrated system, and establishing methods for effective technology transfer. The effort will also result in the establishment of a professional team at Marshall University with capability and availability to provide supporting services in the application of GIS-based tools and methods in site restoration efforts.

EXECUTIVE SUMMARY

This document constitutes the required Quarterly Report for the third quarter of 1995, for Task No. MC28-95MU under the DOE/METC/WVU Cooperative Agreement, contract no. DE-FC21-92MC29467. It documents technical accomplishments and projections, and also provides cost status and projections as of September 30, 1995.

Of five tasks, we completed tasks 1 and 2 by the end of the second quarter, and are on schedule for task 3 which is approximately 80 percent complete. In the third quarter, all effort was spent on task 3. We received almost all the necessary hardware and software components for the GIS system. We configured and installed the hardware components, which includes a server, workstation, color plotter, and color printer, and connected them using an Ethernet network. We installed the various software components of the Intergraph MGE software and were able to work with the training data acquired in the second quarter. We have also installed PC ARC/INFO, which is the other GIS product we had proposed in the second quarter.

We continue to have a very productive working relationship with personnel of the Corps Huntington district office. We made a trip to Nashville Corps office to view the data for a real HTRW remediation project currently being undertaken by the Huntington Corps office. Legal issues within the Corps with regards to providing us with the data have now been resolved and we will acquire the data early in the fourth quarter.

In summary, we are in an excellent position to successfully complete all tasks during this calendar year, and thus to achieve the overall goal of determining an effective GIS-based infrastructure for describing, characterizing, and remediating contaminated sites.

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1.0 INTRODUCTION

This effort focuses on determining GIS-based capabilities for site characterization and remediation. This is a pressing need, largely unsatisfied at the current time. Although there are numerous available GIS systems, and many different software components that could be useful in site characterization and remediation, there is no available system that brings together the numerous needed capabilities. The approach is to base a needs assessment for such a GIS-based system on the on-going work of the Huntington Corps district office. This will provide a realistic needs determination: the Huntington Corps office is faced with an immediate need for effective GIS-based software tools to more effectively manage site remediation in the district. Further, a working relationship has already been established between the Marshall University team and personnel within the Corps office. The U.S. Department of Energy (DOE) Morgantown Energy Technology Center (METC), and other agencies, stand to benefit from the results of this work, since it will be grounded in real needs of real, on-going remediation projects.

2.0 PURPOSE

The primary goal of this work is to determine an effective GIS-based infrastructure for describing, characterizing, and remediating contaminated sites. Objectives involved in achieving this goal include:

- (a) devising and specifying an integrated system whose features are targeted to specific needs for site remediation/restoration--including a set of GIS-based software tools and supporting computer hardware,
- (b) establishing operational procedures for effective application of the system,
- (c) establishing methods for effective transfer of technology (system, procedures) to a user organization (USACE Huntington District office, in the first instance), and
- (d) simultaneously establishing a professional team at Marshall University with the capability and availability to provide supporting services and consultation in the application of GIS-related tools in site restoration efforts.

3.0 BACKGROUND

Geographic Information Systems (GISs) are increasing rapidly in numbers and areas of application. No doubt the expansion is influenced strongly by the growing national interest in environmental protection and restoration. Numerous GIS systems are available--including commercial (e.g., ARC/INFO, Intergraph MGE, MapInfo), government-sponsored (GRASS), and university research based (IDRISI, ICASE/GRACE). The desired applicability of GISs is extremely broad (e.g., air quality monitoring, groundwater contamination, areas in a city accessible by public transport). Thus the GIS systems must be very generic in their capabilities. This genericness is attractive in providing versatility of application breadth, but of necessity limits the depth of features for a given application area.

The nation faces a massive problem relative to contaminated sites. The U.S. Department of Energy, the U.S. Army Corps of Engineers, and many other government agencies are faced with requirements to remediate contaminated sites under their purview. The Huntington District of the U.S. Army Corps of Engineers (USACE) has undertaken to assemble computer-based tools to help them in describing, characterizing, and remediating contaminated sites. They have obtained the Integrated Computer Assisted Site Evaluator / Graphical Remedial Assessment and Cost Evaluation (ICASE/GRACE) system, developed at the University of Cincinnati, for evaluation. They have also obtained and installed Intergraph's MGE system, and anticipate obtaining Intergraph's ERMA (for Environmental Resource Management Application) system, intended to support site assessment, modeling and remediation. Under a previous METC task, Marshall

University evaluated ICASE/GRACE for use by the Huntington USACE District.

4.0 METHODOLOGY

Following are descriptions of the tasks to be conducted, and associated schedules.

Task 1: Information Required for the National Environmental Policy Act

To be supplied within 60 days after contract award.

Task 2: Determine System Requirements

Interview USACE Huntington District office personnel involved with remediation projects, assess needs as they perceive them for describing, characterizing, and remediating contaminated sites. Consider approaches of other organizations with remediation requirements, including other USACE offices, and other Department of Energy-funded work. From this input, determine and specify system requirements necessary to fulfill the identified needs.

Schedule: January 1 through March 31, 1995.

Task 3: Devise and Specify an Integrated System

Undertake to determine and specify a system that satisfies the requirements identified in Task 2. Note that the outcome of this task will be a specification of a recommended system, and not an implementation as such.

Determine a GIS system to serve as the basis for the overall system--evaluating candidate GIS systems based on their inherent suitability for the role, as well as their current importance to organizations with whom data interchange may be necessary. We will emphasize commercially-available systems and government-sponsored systems to the maximum extent feasible. One GIS system we will evaluate is Intergraph's MGE system, Windows NT version, due to the fact that the USACE Nashville District office uses this MGE version, and the Huntington office must be able to interchange data with the Nashville office.

Determine a means to integrate other needed software and data sources--currently existing and anticipated--into an overall system based on an identified GIS system, with the overall system having a uniform "look and feel". Examples of other needs are a cost modeling tool in current USACE use, Modflow software, and various features of ICASE/GRACE. Means to integrate other components into a GIS system could include data translation software utilities and windows-based dialog boxes, for example. The means will be provided to augment the software complement with additional capabilities in the future.

The most desirable outcome would be that carefully-selected software can be integrated, without modification or additional software development, into a system that fully satisfies all identified requirements. In the event that is not a feasible outcome, we will determine and recommend approaches for meeting the unsatisfied requirements.

A necessary, and interwoven, aspect of this task is to ensure that the software system being devised can be accommodated by an acceptable range of computing hardware; i.e., by both lap-top PCS and high-end Pentium PCS, and even by Unix-based workstations if that is found to be a requirement.

It may be that multiple feasible approaches will be identified to accomplish some aspects of the required system. If so, we will document the options, and give trade-off considerations for making choices.

Schedule: January 1 through November 30, 1995.

Task 4: Determine Operating Procedures

Determine and describe effective procedures for using the system. This will include guidance concerning combinations--and sequences--of software tools to use for certain classes of applications, set-up assumptions for each tool, and inter-tool control and data management. Representative scenarios will be devised and documented.

If it is found to be necessary to modify some software or to develop some additional software to achieve all requirements, we will nonetheless summarize procedures involving the system features expected to be available after modification and/or development, so that a comprehensive understanding of the full resulting system can be gained, and also to offer perspective and guidance in developing and providing any additional features.

Schedule: October 1 through November 30, 1995.

Task 5: Develop Materials for Technology Transfer

Establish means for effective transfer of technology--the integrated system and operating procedures --to a user organization. The USACE Huntington District office will be the initial user organization, in concept, since we will be basing much of our requirements determination efforts on their needs. However, our efforts in technology transfer will be guided by the need for various user organizations to be accommodated.

Emphasis will be placed on development of tutorial materials, including on-line materials, and on development of seminar presentation materials to provide an overview of the tools and procedures. Full documentation of system requirements, system specification, and operating procedures will, of course, be provided as well.

Schedule: November 1 through December 31, 1995.

Deliverables:

Deliverables from this work will be:

- A written statement of requirements for software and hardware necessary to conduct site description and characterization, and assess remediation strategies--based on detailed analysis of needs of the Huntington Corps office, with participation and cooperation of their personnel
- Written descriptions of in-depth evaluations of various candidate software and hardware approaches for meeting the statement of requirements, with the relative merits of specific approaches, and rationale for each approach recommended
- A detailed description of a recommended system: hardware and software components--including use of available commercial or government software, strategies for integrating the components, and if necessary, details of a limited amount of software requiring development in order to achieve a satisfactory system
- Operating procedures for effective application of the system
- Educational/training tutorial materials to enable technology transfer for system capabilities and operating procedures
- Recommendations concerning strategies for undertaking system implementation based on the system description

5.0 WORK PERFORMED THIS PERIOD

5.1 Activities

All of the effort during this period was expended on Task 3 (Devise and Specify an Integrated System).

Task 1: Information Required for the National Environmental Policy Act

This material was prepared and delivered during the first half of April.

Task 2: Determine System Requirements

Task 2 was completed successfully by the end of the second quarter.

Task 3: Devise and Specify an Integrated System

Based on the systems requirements of Task 2, we have devised a system which will allow us to successfully integrate the data processing and visualization software (GISs), along with external commercial project management and modeling software. We received most of the software and hardware components in this quarter. Most of the hardware has been set up in a network configuration as per requirement and we have successfully installed the majority of the software components. Below we describe the work performed on the software and hardware components of the system. We have also included a description of the effort expended on processing various types of data.

1. Software:

a. Geographic Information Systems (GISs):

The two GISs we have acquired are MGE from Intergraph and PC ARC/INFO from ESRI. MGE runs under the Windows NT platform. PC ARC/INFO runs under MS DOS. For the Intergraph MGE product, we have acquired the following components:

1. MGE Basic Nucleus
2. MGE Basic Administrator
3. MGE Base Mapper
4. MGE Analyst
5. MGE Modeler
6. MGE Projection Manager
7. MGE VistaMap
8. MGE ASCII Loader
9. MGE Base Imager
10. MGE Map Finisher
11. RIS for Windows NT
12. Microstation.
13. ERMA Groundwater
14. ERMA Site Geologist
15. ERMA Data Manager
16. Interplot Server
17. Interplot Client

Microstation is the underlying design package which is necessary for all the other MGE software. RIS (Relational Interface System) is the component which does a two way translation of data from various relational databases (such as MS SQL, Oracle, etc) to MGE. This component is necessary to make MGE independent of the underlying database. RIS supports automatic conversion, and querying of data from various relational databases such as MS SQL and Oracle. The three base components necessary for running MGE are the Basic Nucleus, Basic Administrator, and the Base Mapper. The other components are necessary to analyze and view data in different forms. The Interplot software components are necessary for controlling the plotting of maps.

The basic MGE system was installed on the TD3 workstation as a stand-alone system. We brought up the project that was covered in the MGE training class and went over the entire training session in-house. This exercise helped us get a better understanding of the software, and also provided an opportunity for other personnel to learn the MGE product. We are now in the process of installing the other components of the suite. The ERMA suite is for remediation analysis. We will install the ERMA suite in the fourth quarter, and conduct a preliminary analysis of the remediation strategies provided.

For the PC ARC/INFO suite, we have acquired the basic lab kit and a copy of ArcView. ArcView allows the user to view ARC/INFO data independent of ARC/INFO. The lab kit consists of limited training materials and training videos. We have installed the PC ARC/INFO software and are in the process of reviewing the project conducted at the training session. We are also investigating the possibility of running PC ARC/INFO directly under Windows NT as a DOS product.

b. Database system:

The database system we have acquired is MS SQL Server and Client. In order to run the database in a server-client mode, it is necessary that the database system be installed on the operating system server (Windows NT server) in a network configuration. While the SQL Server and the Windows NT Server were on order, we installed the SQL database in a workstation (client) environment to test the MGE suite. In the last week of September, we received the Windows NT Server 3.51 software which enabled us to install the MS SQL Server. We are currently in the process of setting up the operational details of running MS SQL in a server/client configuration.

c. Operating System:

The operating system we have acquired is Windows NT Server 3.51. We decided to acquire the newer version as compared to version 3.5 because of bug fixes and additional drivers. Version 3.51 was released by Microsoft in the second quarter, and university contract pricing was not available until mid-August. We have successfully installed Windows 3.51 in a server/client with the TD4 machine being the server and the TD3 serving as a client.

d. Network Software:

We are using the networking capabilities of Windows NT Server 3.51 as the basic software for network support.

e. Integrating External Software:

The project management software we have acquired is MS Project. We have also acquired the MS Office suite of software for document preparation. The MS Office suite consists of MS Word (word processor), MS Excel (spreadsheet), MS Access (database), and MS Powerpoint (presentation software). Our choice of these products was based on their capabilities, integration effectiveness, popularity, and availability under university pricing. We have installed these products and are currently investigating the process of transferring MGE project related information from MGE into the Office suite for report generation.

2. Hardware:

The computing hardware we have acquired consists of: one server workstation, one development workstation, one color printer, one color plotter and other peripheral equipment. We will acquire one laptop system which can be used as a "field computer" in the fourth quarter. Below we describe the status of each piece of the equipment.

a. The server workstation:

The server workstation we have acquired is the Technical Desktop 4 (TD4) from Intergraph. Brief technical specifications of the machine are: dual Pentium 90 MHZ processors, 32 MB RAM, 1 GB hard drive, Ethernet card, 17 inch color monitor and a G91 accelerated graphics card. We have successfully set up this machine as the server, running the Windows NT 3.51 Server software as the operating system.

b. The client workstation:

The client workstation we have acquired is the Technical Desktop 3 (TD3) from Intergraph. Brief technical specifications of the machine are: Pentium 90 MHZ processor, 32 MB RAM, 1 GB hard drive, Ethernet card, 20 inch monitor and a G91 accelerated graphics card. We have successfully set up this machine to operate under the Windows 3.51 operating system as a client, with the TD4 being the server.

Both the client and the workstation hardware were received in the second quarter, but were successfully installed and configured in the current quarter.

c. The plotter and printer:

In the initial proposal, we had budgeted to acquire a color laser printer. Two factors caused us to arrive at a different decision : (i) we did not have a mechanism for printing large maps, and it would not have been possible to print large maps using a laser printer and (ii) color inkjet printers, in the meantime, became extremely competitive in terms of increased quality for a better price. Hence, in the interest of maximizing the cost/benefit ratio of available funds, and establishing a capability of printing large maps, we decided to buy a color plotter (for large maps) and a color inkjet printer, instead of the laser printer. The color plotter we acquired is the HP DesignJet 650C/PS. Brief technical specifications of the plotter are: 36-inch (E size) continuous feed roll of paper, 300 dpi, Postscript capability, 4 MB of RAM. The 4 MB of RAM is not sufficient for printing large maps, and we have currently supplemented it by another 8 MB (to make a total of 12 MB) on a temporary basis from another computer. The color printer we have acquired is HP DeskJet 1200C. Brief technical specifications of the printer are: 600x300 dpi on special paper, 2 MB of RAM. We purchased 2 MB of additional memory to enable printing of large documents. For the plotter and the printer, we have purchased the JetDirect Ethernet card which allows the device to be connected to a network.

We have successfully installed the plotter and printer, and configured them to work on the local Windows NT 3.51 network. We have thoroughly tested the printing of various types of files, across the network, to each of these printing devices.

d. The network:

We are using a local twisted pair Ethernet network configuration as the backbone architecture to connect all the hardware devices. The network (and its peripherals such as the routing box, etc.,) was installed by the MU Computer Center staff, to keep it in-line with the overall university network configuration. Our network runs as a mini-network attached to the main campus network. The mini-network allows us to exercise various levels of access to the individual devices, whereas the connection to the main network allows us to piggy-back on the services available from the main network such as Internet access, ftp, etc. We have individual IP (Internet

protocol) addresses for each hardware device, enabling anyone with Internet access and proper passwords to access the files and printing facilities. We have thoroughly tested our network and are in the process of making incremental enhancements. To test the network for remote access, we used it to retrieve very large files from a remote location, for another project with the Corps. We were very satisfied with the speed and performance of the network.

e. The peripheral devices:

The peripheral devices we acquired are: (i) APC Smart UPS (Un-interruptible Power Supply). Brief technical specifications are: 650VA, RJ45 input/output, compatible with Windows NT. The server is connected to the UPS to prevent it from shutting down due to intermittent power failure. In the case of long-term power failure, the UPS has a capability of letting all clients know about the shutdown by issuing a message. (ii) Panamax surge protector. All hardware devices are connected through the surge protector to prevent damage from occasional power spikes. (iii) 4294 MB Seagate SCSI internal hard drive. This hard drive is mounted inside the server (TD4). This provides the capability of having user accounts on the server, based on various project needs. Generally, GIS related data files are significantly large and augmentation of the hard drive space was necessary.

f: The notebook computer:

We had planned to acquire the notebook computer in the third quarter. However, the notebook market was very volatile at that time, and implementation of many technological changes were anticipated in the next month. Hence we decided to buy the notebook computer in the fourth quarter. We have configured the computer we require, and we will acquire the notebook computer early in the fourth quarter.

3. Data

After the installation of the basic MGE modules in the workstation mode, we ran the software on the training data acquired during the Intergraph MGE training session we attended in the second quarter. Two purposes for doing this were: (i) to check for the proper installation and configuration of the software and (ii) to let other personnel get familiar with the MGE system. We went through the entire training session successfully, and were able to work with the training data.

In order to gain more competence with the MGE system, we created a small project, consisting of Marshall university buildings and associated them with the campus map.

In order to test the network configuration and the installation of the hardware components, we used the equipment for another small project with the Huntington Corps Planning office. This project required the transfer, manipulation, printing and plotting of very large map files. We were very satisfied with the performance of the equipment on this project.

We made a trip to the Nashville Corps office, along with the Huntington District Corps personnel, to understand the status of the data for the WV Ordnance site in Mason County. In conversation with the Nashville Corps personnel, and from what we were able to view of the data, we can conclude the following about the work done by the Nashville Corps personnel. (i) They have designed and created a database which consists primarily of chemical and geological data. They have not yet entered all the data from all the site locations. (ii) They were able to post certain queries based on the data. (iii) They have not yet made linkages between the data in the database to the maps of the region.

We have established a mechanism for acquiring the data, (since resolving the legal issues), in the early part of the fourth quarter. After analyzing the data, and based on the needs of the Huntington Corps personnel, we will establish mechanisms for data handling.

5.2 Schedule and Costs

We are on target for both the schedule and spending rate in the third quarter.

The Task status is as follows:

Task 1: Completed
Task 2: Completed
Task 3: About 80% complete.
Task 4 and 5: Scheduled to begin later in the fourth quarter.

Costs invoiced in the third quarter are summarized below. Note that some amounts were expended in the second quarter, but were invoiced in the third quarter, due to delayed billing by the vendors. (This is an unofficial cost summary; Marshall University Research Corporation is the agent for formal contract and financial transactions.)

Personnel (including fringe benefits)	\$ 35,206.81
Travel and Training	7,672.54
Telephone/Report Preparation	1,088.63
Equipment	
Hardware	\$ 25,048.09
Software	6,152.57
Indirect Cost (less Hardware)	19,045.81
Total	\$ 94,214.45

6.0 RESULTS AND DISCUSSION (CURRENT PERIOD)

We have completed Task 1 and Task 2 successfully.

We had begun Task 3 (Devising and specifying an integrated system) in the first quarter, and continued the effort on it in the second quarter and in this quarter. We are now approximately on schedule, for both effort and expenditure, for this task. We have received almost all the software and hardware and have successfully installed most of them. We are in the process of ironing out the details of running the software in the server/client setup. We will continue our efforts on this task to set up an integrated system.

We are working in close cooperation with the Huntington Corps personnel. We went for a site visit, along with the personnel of the Huntington District Corps personnel, to view and understand about the status of the Hazardous, Toxic & Radioactive Waste (HTRW) data from the Nashville District Corps office. This will enable us to experiment with the features of the GIS software on actual data, giving us a better basis for assessing the capabilities and limitations.

7.0 CONCLUSIONS (CURRENT PERIOD)

We are now approximately on schedule, in terms of both effort and expenditure, at the end of this quarter. This puts us in an excellent position to complete all tasks during this calendar year.

We have delivered the National Environmental Policy Act material, and have completed the systems requirements determination. We have installed most of the hardware and software required for the integrated GIS system.

We are continuing our productive relationship with the Huntington district Corps personnel and expect to work with real HTRW data provided by them very soon.

8.0 WORK PLANNED FOR NEXT PERIOD

8.1 Activities

Following is a summary of the various activities planned during the fourth quarter of 1995.

Task 3: Devise and Specify an Integrated System

We will set up the operational details of running the software in a network client/server environment.

We will acquire the notebook computer and set it up so that it can be integrated into the network.

We will acquire data from the Corps and assess the capabilities of the various GIS components using that data.

We will explore the possibility of integrating external commercial off-the-shelf (COTS) packages with the GIS system.

Task 4: Determine Operating Procedures

We will determine and describe effective procedures for using the system. This will include guidance concerning combinations--and sequences--of software tools to use for certain classes of applications, set-up assumptions for each tool, and inter-tool control and data management. Representative scenarios will be devised and documented. Schedule: October 1 through November 30, 1995.

Task 5: Develop Materials for Technology Transfer

We will establish means for effective transfer of technology--the integrated system and operating procedures --to the USACE Huntington District office. Schedule: November 1 through December 31, 1995.

8.2 Schedule and Costs

The following table summarizes expenditures anticipated for the final calendar quarter of this contract. (Note that this is an unofficial cost summary; Marshall University Research Corporation is the agent for formal contract and financial transactions.)

Travel and Training	2,300.00
Telephone and Report Prep.	327.00
Hardware/Software	6,483.86
Indirect Costs (38% excluding hardware)	10,323.89
Personnel (including fringe benefits)	\$ 24,441.13
Total:	\$ 43,875.88

Following is a chart which summarizes schedule and costs--both actual and projections--as of September 30, 1995. For convenience, a summary of task titles and durations are repeated here.

- Task 1 Information Required for the National Environmental Policy Act: due within 60 days after award
- Task 2 Determine System Requirements: January 1 through March 31, 1995
- Task 3 Devise and Specify an Integrated System: January 1 through November 30, 1995
- Task 4 Determine Operating Procedures: October 1 through November 30, 1995
- Task 5 Develop Materials for Technology Transfer: November 1 through December 31, 1995

Schedule and Costs: Status and Projections as of September 30, 1995

1995	first qtr.			second qtr.			third qtr.			fourth qtr.		
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec

Tasks:

1												
2												
3												
4												
5												

Legend: == original
 *** revised
 ^ completion

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
first qtr.	second qtr.	third qtr.	fourth qtr.								

Costs by quarter:

\$15,920.79	\$46,676.40	\$94,214.45	\$43,875.88
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Cumulative:

\$15,920.79	\$62,597.19	\$156,811.64	\$200,688
Actual			Projected

9.0 TECHNICAL/ADMINISTRATIVE DIFFICULTIES

None.

APPENDICES

A. LIST OF ACRONYMS AND ABBREVIATIONS

CD-ROM	compact disk read only memory
COTS	commercial off-the-shelf
DOS	disk operating system
ERMA	Environmental Resource Management Application (an Intergraph product)
GB	gigabyte; approximately 1,000 MB
GIS	geographic information system
HP	Hewlett Packard
HTRW	hazardous, toxic & radioactive waste
ICASE/GRACE	Integrated Computer Assisted Site Evaluator/Graphical Remedial Assessment and Cost Evaluator
IP	Internet protocol
LCD	liquid crystal display
MB	megabyte; approximately one million bytes
MGE	Modular GIS Environment (an Intergraph product)
MHZ	megahertz
MS	Microsoft
NT	New Technology (as part of Windows NT)
PC	personal computer
RAM	random access memory
RIS	relational interface system
SCSI	small computer systems interface
SQL	system query language
TD 3	Technical Desktop 3
TD 4	Technical Desktop 4
UPS	un-interruptible power supply
USACE	United States Army Corps of Engineers

**INFORMATION SYSTEMS, PUBLIC POLICY,
COMMUNITY OUTREACH AND ECONOMICS**

SMALL BUSINESS SUPPORT PROGRAM

TASK 3.3

**Quarterly Technical Progress Report
July 1 through September 30, 1995**

**Work Performed Under Contract
No.: DE-FC21-92MC29467**

For

**U.S. Department of Energy
Office of Fossil Energy
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September 1995

Executive Summary

From 3.3, one new task was developed with Vortec Inc. On ex situ vitrification and will be funded in the FY96 Cooperative Agreement Program. Development of the FY96 WVU Cooperative Agreement Plan was initiated and great efforts were made to tie existing projects closer to METC's/DOE's needs. This was in fact the main criteria for proposals submitted for possible funding in the FY96 Program. The WVHTC Foundations Environmental Technology Support Program (METC Task 3.7) was also initiated during this period.

1.0 Introduction

Task 3.3, Small Business Support Program, was initiated to address the technical problems or barriers to commercialization of the innovative site remediation technologies developed by the small businesses that are funded by METC. Once a problem or opportunity was defined, researchers from WVU, Marshall or other sources would be solicited to work with the small business in a research project to solve the problem or alleviate the barrier.

Additionally, a new small business incubator program targeted towards site remediation and small businesses in the West Virginia region was initiated.

2.0 Purpose

The Small Business Support Program was initiated to explicitly address the problems and barriers to commercialization of the innovative site remediation technologies developed by the small businesses funded by METC.

3.0 Background

Over the past two years the METC/WVU Cooperative Agreement has funded numerous projects at WVU and Marshall University. This has resulted in defining at least three areas of core competencies at WVU which may be called upon to provide assistance to the small businesses that METC funds in the area of site remediation.

The core competencies are found mainly in the in-situ remediation area including:

- * Remediation Processes such as surfactant flushing of soils and chemical and biological destruction of polyaromatic chlorinated hydrocarbons
- * Confinement Barriers such as the Circulating Air Barrier and Chemical Grouting Barriers
- * Fluid Recirculating Systems such as the Drain Enhanced Surfactant Flushing

4.0 Methodology

By attending the kickoff meetings and other periodic meetings of the small businesses funded by METC an understanding of the project is obtained. During the presentations, value added opportunities for collaboration between the small businesses and university researchers are carefully watched for. Discussions with program managers also provide opportunities for interaction. The Environmental Waste Management Technical Product Team also provides

opportunities to determine needs of the small businesses and resulting research opportunities. For the long range research opportunities, the initiative at DOE HQ level bringing together elements from DOE, DOD, NASA, Commerce and others to coordinate interagency site remediation capabilities and needs will be very helpful.

Also, attendance at various meetings and conferences on site remediation provides insights to research needs.

From all of the previous sources research opportunities are ferreted out and projects are developed with university faculty to carry them out.

5.0 Work Performed This Period

During this period one new task was developed. It actually reflected the culmination of 14 months of interaction with Vortec Inc. It consists of modeling the combustion chamber of Vortec's ex situ vitrification process to maximize the efficiency of the process. This work will be done by Dr. Ismail Celik of the WVU Mechanical Engineering Department. It has been placed in the FY96 WVU Cooperative Agreement for funding beginning January 1, 1996.

Development and planning of the FY 96 WVU Cooperative Agreement was initiated with a pre-proposal call in early July. Some 24 preproposals were submitted and 11 of them were asked to submit full proposals. The bulk of the proposals were for continuation of existing projects but great efforts have been made to see that they serve METC/DOE needs. The great thrust has been to get all of the projects tied in with some existing small business developing site remediation technologies for DOE or with other problems identified by METC/DOE.

Appropriate conferences were attended during this period. Numerous contacts were made at the Decontamination and Decommissioning Workshop, ER95 in Denver Colorado and at the conference on Emerging Technologies in Hazardous Waste Management in Atlanta, Georgia. From these, new grouting chemicals, (Polydimethylsiloxane and colloidal silica materials) were discussed with investigators from Lawrence Livermore Lab for further study in the chemical grouting project.

Also the bioremediation project may be altered to reflect new findings in use of zero valent iron and iron sulfide for the reductive dechlorination of ethylene chloride. Bacterial desulfurization of iron sulfate can be used to generate iron sulfide which has the capability of also accomplishing reductive dechlorination of ethylene chloride. Principal investigators on the bioremediation project have scheduled meetings with investigators in the field (GE Research-

Schenetchy NY) to determine if they may be able to cooperate and share research findings to the benefit of all.

Numerous meetings were attended to initiate the West Virginia High Tech Consortium Foundations Environmental Technology Support Program (Incubator). It is reported elsewhere in this document as Task 3.7 WVHTC Foundations Environmental Technology Support Program.

6.0 Results and Discussion N/A

7.0 Conclusions N/A

Task33.out

**INFORMATION SYSTEMS, PUBLIC POLICY,
COMMUNITY OUTREACH AND ECONOMICS**

**APPROACH FOR ASSESSING POTENTIAL VOLUNTARY
ENVIRONMENTAL PROTECTION,
KANAWHA VALLEY AREA**

TASK 3.4

Quarterly Report for Period
July 1 through September 30, 1995

Work Performed Under Contract
No.:DE-FC21-92MC29467

For
U.S. Department of Energy
Office of Fossil Energy
Morgantown Energy Technology Center
Morgantown, West Virginia

By:
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Environmental Technology Division
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James J. Kohanek
Clean Sites, Inc.
Alexandria, VA

Paul Hill
National Institute for Chemical Studies
Charleston, WV

APPROACH FOR ASSESSING POTENTIAL VOLUNTARY ENVIRONMENTAL PROTECTION, KANAWHA VALLEY AREA

Quarterly Technical Progress Report
for Period July 1 through September 30, 1995

Work Performed Under
Contract No.: DE-FC21-92MC29467

For
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Office of Fossil Energy
Morgantown Energy Technology Center
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October 1995

ABSTRACT

This project concerns investigation of the feasibility of establishing voluntary remediation programs in the Kanawha Valley, WV.

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EXECUTIVE SUMMARY

The United States contains numerous hazardous waste sites. Many sites are on private land near operating units of various companies. An effort is being made to determine the conditions under which such sites can be remediated voluntarily. Such voluntary remediation would result in an accelerated clean-up of U.S. sites and a significant cost savings. Meetings are being held with U.S. companies to evaluate the potential for actually initiating voluntary clean-ups.

1.0 INTRODUCTION

The objective of the project will be 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 will be to implement the activities agreed upon by the interested parties. The project will first involve individual discussions with the industrial, government, and other organized groups in the area. These discussions will help determine the feasibility of organizing voluntary efforts. If the discussions indicate that conditions may be favorable for developing individual or group voluntary cleanup projects, a working group will be convened to establish the environmental goals of the project as well as the technical approach for achieving those goals.

2.0 WORK PERFORMED THIS PERIOD

Discussions between the principals, Raymond Lovett of West Virginia University, Paul Hill of the National Institute of Chemical Studies, and Jim Kohanek, late of Clean Sites now with TLI (and participating here as a consultant to Clean Sites) derived a strategy to have Paul Hill discuss the concept with selected individuals in the Kanawha Valley to determine the initial interest. These initial discussions led to a presentation before the Kanawha Valley Chemical Plant Managers group detailing the project. Subsequent to that meeting, individual meetings with the companies were scheduled, two of which occurred in this quarter.

The two meetings were conducted in the strictest confidentiality. The gist of these first two meetings is a continuing willingness of the companies to develop the issue and a definite interest in using new technologies in clean-ups.

3.0 WORK PLANNED FOR NEXT PERIOD

Meetings with two other companies are scheduled. Meetings with regulatory agencies and citizen's groups will follow.

4.0 TECHNICAL/ADMINISTRATIVE DIFFICULTIES -None

**INFORMATION SYSTEMS, PUBLIC POLICY,
COMMUNITY OUTREACH AND ECONOMICS**

**INTERAGENCY ENVIRONMENTAL TECHNOLOGIES OFFICE (IETO)
GRADUATE INTERN PROGRAM**

TASK 3.6

**Quarterly Technical Progress Report for Period
July 1 through September 30, 1995**

**Work Performed Under Contract
No.: DE-FC21-92MC29467**

For

**U.S. Department of Energy
Office of Fossil Energy
Morgantown Energy Technology Center
P.O. Box 880, 3610 Collins Ferry Road
Morgantown, West Virginia**

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September 1995

EXECUTIVE SUMMARY

From Task 3.6, five interns were provided from WVU to the Interagency Environmental Technologies Office (IETO) to provide assistance to IETO and provide a training opportunity for the students over the three (3) month summer period. The IETO is to foster private/public collaborations that stimulate environmental technology development, reduce regulatory barriers and increase global market share. Three of the interns contracts were extended to December 31, 1995.

1.0 Introduction

Task 3.6, Interagency Environmental Technologies Office (IETO) Graduate Intern Program was initiated to provide help to IETO and provide a training opportunity for students.

2.0 Purpose

The IETO is to foster private/public collaborations that stimulate environmental technology development, reduce regulatory barriers and increase global market share. It is a one stop shopping place for information on federal environmental technical programs. Through an interagency environmental technology office, experts can share information with individuals and organizations within and outside government.

3.0 Background

The hazardous site remediation program has been fragmented throughout the federal government with each federal agency "doing its own thing". There has been much repetition, overlap and outright duplication in technologies utilized by the various agencies to remediate their hazardous waste sites. This, along with difficulties in gaining acceptance of proven site remediation technologies by the various agencies create barriers to commercialization of the technologies.

4.0 Methodology

Interns will assist the executive director of IETO by conducting research, analysis and documentation in the field of environmental technology development and commercialization. It is anticipated that interns will be residents of the Washington metropolitan area, serving on a half-time basis during the academic year and on a full time basis during the summer. Depending on background, experience and interest, opportunities are available in four areas.

1. Development of integrated government technology data bases to establish a "one stop shop" private sector focused business and technology information exchange.
2. Facilitation of improved government technology collaboration to increase market understanding, stimulate technology development cooperation, reduce applied technology costs, and enhance decentralization of decisionmaking.
3. Stimulation of the rapid commercialization of "nearly ready" technologies through focused cooperative management initiatives that accelerate government, business planning and investment decisions.

4. Coordination of agency actions directed toward the elimination of procurement, program, organizational and regulatory barriers to the use of innovative advanced environmental technology.

5.0 Work Performed This Period

Five student interns were provided to IETO to assist the director of IETO by conducting research, analysis and documentation in the field of environmental technology development and commercialization. Their contract ran from May 16, 1995 to August 15, 1995. Three were extended in the fall with contracts extended to December 31, 1995.

The interns are being utilized mainly in the following areas:

- * Organizing various workshops/seminars for the IETO technical seminar series
- * Developing IETO outreach materials for use with both internal and external clients (briefing packets, weekly fax update on domestic/international ET issues, etc.)
- * Working with Federal agencies to develop global contacts and outreach systems in the international sector
- * Gathering information on Associations that would be potential players with IETO
- * Working with the Environmental Enterprise Assistance Fund (EEAF) in identifying technical experts for the EEAF September Symposium and other possible co-sponsored IETO technical seminars
- * Working with the IETO international sector to help develop global contacts and information systems
- * Assist in creating a site catalog for new technology testing. The catalog is intended for use by mostly small to medium sized businesses with new environmental technologies that need testing at full scale
- * Providing quality control checks for a budget database, prepare memos of meetings and updating the filing system
- * Initiate legal research as applicable to IETO

6.0	Results & Discussion	N/A
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7.0	Conclusions	N/A
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**WVHTC Foundation's
Environmental Technology Support Program
METC Task No. 3.7**

Quarterly Technical Progress Report
Reporting Period: July - September 1995

Work Performed Under Contract
No.: DE-FC21-92MC29467

For:

U.S. Department of Energy
Office of Fossil Energy
Morgantown Energy Technology Center
Morgantown, West Virginia

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ETI - Quarterly Report

Executive Summary

The last quarter has been a busy one for the new Environmental Technology Incubator. Initial operations have begun, and the location for the new incubator has been established at the National Research Center for Coal and Energy (NRCCE) with additional office space available at the Grand Central Station Business and Enterprise Center. Additionally, negotiations with five environmental firms are in progress. An Environmental Technology Incubator Dedication and Conference is scheduled at the NRCCE for October 6, 1995, to promote the new initiative and to help the key community leaders understand their roles in making the new Center a success. A total of \$2,770.42 has been spent on the project. However, totals for the month of September 1995 are not included in this figure. Finally, a rigorous project timeline has been established for the next quarter and plans to continue to inventory Department of Energy technology and to establish the regional environmental technology know-how networks are in place.

1.0 Introduction

The West Virginia High Technology Consortium (WVHTC) Foundation's Environmental Technology Support Program was funded in July 1995. The support program involves an advanced concept for the accelerated commercialization of Department of Energy technology. The program also will help establish an Environmental Technology Incubator in Morgantown, West Virginia. We have requested a total of \$187,000 in funds from the Department of Energy to support the management and operation of the new Environmental Technology Incubator which will be established in Morgantown, West Virginia. This funding will support the WVHTC Foundation's Environmental Technology Support Program. Funds for the program are also in place from the U.S. Small Business Administration and the Environmental Protection Agency to further the initiative.

2.0 Purpose

The WVHTC Foundation's mission is to create a high technology business sector in north central West Virginia, and this mission will be supported through the efforts of the new environmental support program. The new program will enhance the development and growth of the environmental industry in our region. Further, the Foundation's Environmental Technology Support Program will facilitate technology transfer and the commercialization of Department of Energy technology.

3.0 Background

The WVHTC Foundation is currently working with government, business and educational entities to coordinate the economic development efforts of these three groups, and the Foundation's Environmental Technology Incubator will foster this endeavor. As a

catalyst organization for economic change, the Foundation will link entrepreneurs with the technology, capital and knowledge they need to develop into sustainable high technology environmental businesses.

4.0 Methodology

The methodology for the establishment of the Environmental Technology Incubator will include a three phase implementation schedule. The three phases are as follows:

Phase 1 - Planning and Start-up (July 1995-December 1995)

Phase 2 - Implementation (January 1996-June 1996)

Phase 3 - Continued ETI Development (July 1996-December 1996)

More specifically, the WVHTC Foundation will initiate the formation of a small business Environmental Technology Incubator to develop expertise and competitiveness in emerging high technology areas of environmental remediation. The WVHTC Foundation has been funded for the first phase of the project. Four specific tasks have been assigned during Phase 1 of the assignment. These tasks include:

- Task 1: Plan the formation of the small business Environmental Technology Incubator, work out the details for operation of the incubator and find an appropriate site for its location,
- Task 2: Begin to inventory Department of Energy technologies for the incubator clients,
- Task 3: Begin to establish regional environmental technology know-how networks, and
- Task 4: Provide quarterly reports to Dr. E. E. Cook, Director of the WVU Cooperative Agreement.

Phase 1 of the project will be accomplished in the fiscal year 1995 and will require a total of \$68,000 of West Virginia University Cooperative Agreement funding.

5.0 Work Performed this Period

The WVHTC Foundation began to implement Phase 1 of the Environmental Technology Incubator plan in July 1995. The Foundation has completed Task 1 of the assignment and has planned the formation of the small business Environmental Technology Incubator. The site for the Environmental Technology Incubator has been determined. The Environmental Technology Incubator's main office is located at the National Research Center for Coal and Energy (NRCCE) in Room 104. Offices for incubator clients include two rooms, 104A and 104B, located at the NRCCE. An additional nine incubator company offices will be located at the Grand Central Station Business and Enterprise Center also located in Morgantown, West Virginia. Initial start-up operations have begun and the WVHTC Foundation has hired an Assistant Incubator Director for the new Center. An outline of the initial plans for the incubator is depicted in the project timeline below (Figure 1):

Project Timeline

Figure 1 - Environmental Technology Incubator Project Timeline

During July 1995, the Foundation began to acquire initial start-up materials for the Environmental Technology Incubator. Initial operations also began in July, and the incubator's main office located at the NRCCE has been established. The policies and procedures for the new Center are being established and will be finished by the end of Phase 1. Public information folders and information sheets have been developed for broad distribution to promote the newly established incubator and to recruit potential incubator clients in Phases 1 and 2 of operation.

Potential Environmental Technology Incubator clients have been identified for recruitment. During the second quarter of operations, we will begin to screen applications and review candidate companies' business plans. Once policies and procedures have been established and subleases have been drawn up, we will begin to negotiate client agreements.

To promote the new Environmental Technology Incubator, the Foundation is coordinating an Environmental Technology Incubator Dedication and Conference on October 6, 1995. This conference will not only serve to promote the new incubator, but will serve as a catalyst helping to make the community aware of each group's role in supporting this new entity. The conference will bring together the leaders in incubating environmental businesses, and it will overview their success and failures and help identify what works best. Lessons learned from the conference will be used to help structure the new Environmental Technology Incubator. This conference will also help lay the foundation for regional environmental technology know-how networks to be developed. Environmental industry leaders will learn about the new incubator and will be able to understand how they might participate in this new project.

Finally, an affiliate of the Environmental Technology Incubator attended the Morgantown Energy Technology Center's (METC) "Environmental Technology Development Through Industry Partnership" conference which outlines the projects that the Department of Energy is focusing on. The proceedings will be examined from this conference to help begin to understand and inventory Department of Energy technology for incubator clients. Additionally, contacts have been made with the Global Environment and

Technology Foundation who is under contract with METC to identify and assess Department of Energy technologies for commercialization.

Budget Narrative

The budget for the Environmental Technology Incubator totals \$68,000. The total moneys spent toward this budget total \$2,770.42. This total is for personnel costs, overhead and indirect charges made to the grant. This sum is only for the July-August 1995 time period because the month of September 1995 has not been closed out. The charges break down as follows:

Personnel	\$1,448.68
Overhead	\$1,171.11
<u>General & Administrative</u>	<u>\$ 150.63</u>
Total	\$2,770.42

A more complete budget breakdown can be provided when the month of September 1995 is closed out, including a table with the planned versus actual expenditures.

8.0 Work Planned for Next Period

During the next quarter, DOE technologies will continue to be inventoried, Environmental Technology Incubator candidates will be screened, negotiations for incubator space will occur, and regional know-how networks will begin to be established to support this new initiative.