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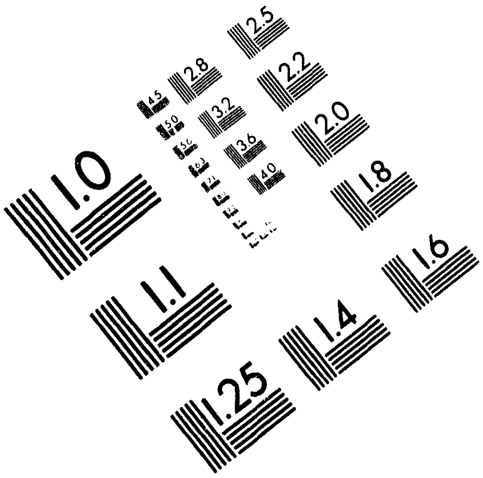

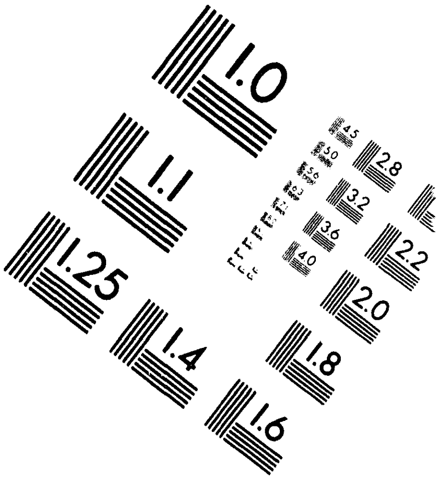

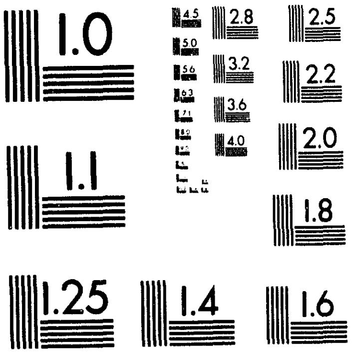

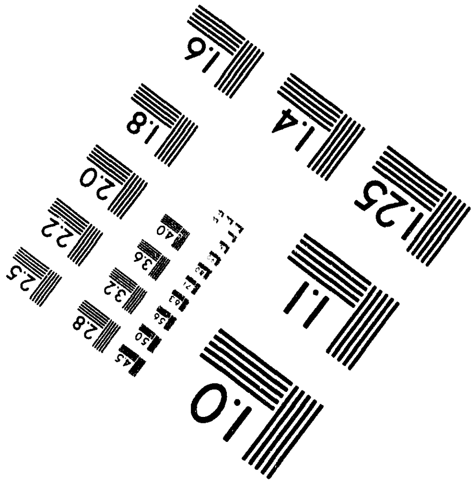

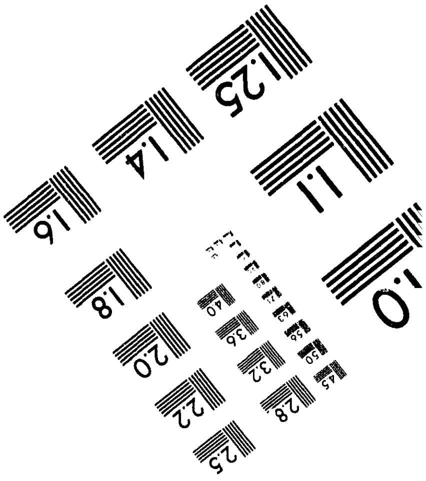

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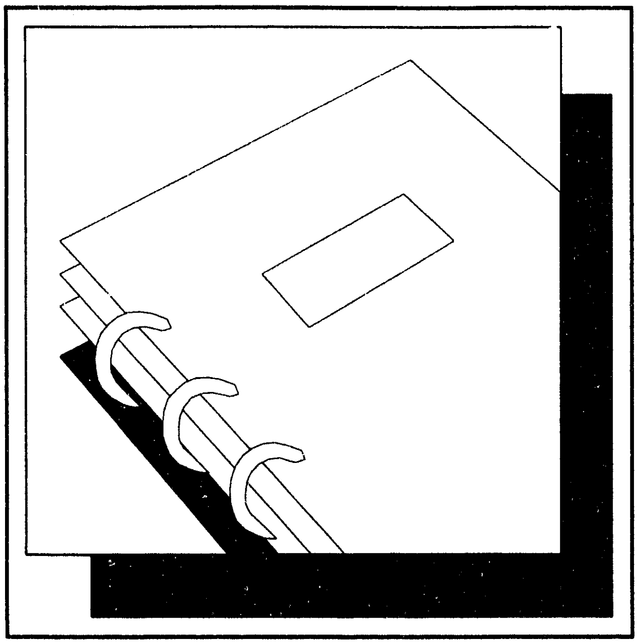

Decontamination Systems Information and Research Program

Quarterly Technical Progress Report
for Period
January 1 through March 31, 1994

Work Performed Under
Contract Number: 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

By
National Research Center for Coal and Energy
West Virginia University
Morgantown, West Virginia 26506

May 1994

MASTER

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

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CHEMICAL DESTRUCTION OF CHLORINATED ORGANIC COMPOUNDS

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ADMINISTRATIVE SUMMARY

West Virginia University (WVU) and the U. S. DOE Morgantown Energy Technology Center (METC) entered into a Cooperative Agreement on August 29, 1992 entitled "Decontamination Systems Information and Research Programs" (DOE Instrument No. : DE-FC21-92MC29467). Stipulated within the Agreement is the requirement that WVU submit to METC a series of Technical Progress Reports on a quarterly basis. This report comprises the first Quarterly Technical Progress Report for Year 2 of the Agreement. This report reflects the progress and/or efforts performed on the sixteen (16) technical projects encompassed by the Year 2 Agreement for the period of January 1 through March 31, 1994.

A. Administrative Action

A Cooperative Agreement was established between WVU and METC in the Fall of 1992. The original Annual Research Plan consisted of six (6) WVU Research projects. NEPA approval for these projects were received by WVU in Mid-March 1993. At the request of METC a presentation, of these six projects, was scheduled for late May 1993, at which time comments and criticisms on these projects were noted. Each of the six WVU Research projects was renewed for 1994 and seven new projects were approved. A presentation on all projects was requested and held at METC on 24 February 1994, at which time comments and criticisms were noted.

A project dealing with the remediation of soil at the Winfield (WV) Lock and Dam was formally approved, for 5 years, in April 1993. This project was also presented at the May 1993 review. A report on its progress is included in this Quarterly report. Another presentation, solely on MC-9, the Winfield Lock and Dam Project, was made to METC in October of 1993. This presentation lasted roughly 3 hours. More details on the Winfield project were presented in the 24 February meeting.

A project, which involves technology evaluations by BDM Federal, Inc.,was approved June 11, 1993. Additionally this project will provide a safety analysis of building B-17 at METC, which WVU has access to through a DOE CRADA. Three of the technical reviews were submitted draft form in the October 1993 Quarterly report; the SARS is to be completed by by May 1994. BDM has requested two extensions to April 15, 1994. No Quarterly report is included in this submission, the final report for BDM will be submitted in May 1994.

Another project, concerning soil remediation by steam reforming was approved in June 22, 1993. This work is being conducted by Manufacturing Technology Conversion, Inc. (MTCI) as a subcontractor. The original project anticipated the conversion of an existing unit to pressurized use, but safety considerations dictated that a new unit be built. MTCI has submitted a request for additional funding.

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B. PROJECT VARIANCES, ACCOMPLISHMENTS AND PROBLEMS

BIOREMEDIATION: The dechlorination study (Sack and Shiemke) focussed on establishing that trichloroethylene could be aerobically and anaerobically degraded. Since this project had experienced analytical problems, little new information has yet been generated. Aqueous cultures do not simulate soil remediation, so their next phase using columns will be more useful.

The biofilter project (Carriere and Mohaghegh) has just begun, but has made substantial progress on their experimental set-up. They should have submitted a more thorough literature review.

The microbial enrichment project (Sexstone and Atkinson) is also new. The project has begun the development of protocols for evaluating innocula and appears to be making good progress.

OTHER REMEDIATION METHODS: The soil drain project (Gabr) is progressing well and should be moved to a larger scale. Studies with surfactants and soil mixtures indicate that increased removal can be achieved.

The chemical destruction project (Wang) has generated some exciting new approaches to dechlorination which use recoverable reagents. These approaches require some additional verification, but could provide improved chemical dechlorination methods. The polymeric borane method is particularly intriguing.

The granular activated carbon project (Reed and Carriere) appears off to a strong start; the ability of these specially prepared columns to remove metals is shown. The project appears to be on schedule.

The packed flotation column project (Cho, Peng and Yang) was somewhat delayed by problems with the physical consistency of the cerium oxide. The project is too new to evaluate fully, but is progressing.

CHARACTERIZATION AND MONITORING: The On-site monitoring project (Seehra, King) has begun. The IR protion is largely evaluative and the initial literature work is completed (but not in the report). The mass spectrometric part will begin when the atmospheric pressure sampling mass spectrometer is delivered. This porion of the project will involve the development of an instrument. The project is on schedule.

The sensor project (Finklea) is not working well. The equipment is set up, but the coatings as yet have not shown a sensitivity for the compounds tested. Many of the coatings attack the aluminum electrodes on the SAW device. Some special devices are on order to alleviate this problem. A delay in testing new coatings may be encountered while waiting for the delivery of the new devices.

The mercuric iodide detector project (Nandi and Lyons) must first grow suitable crystals. A request to DOE for some crystals from EG&G has as yet been unanswered, so they are growing their own, which may delay progress. The crystal growing, however, appears to be successful in methanol.

OTHER PROJECTS: The Database project (Berg) is progressng, since the thrust this year is to determine the current DOE capabilities. The survey of existing DOE (and other) databases has begun.

The dust control project (Peng and Peng) is nearly complete. The next step is to implement the strategies at the Winfield site. Arrangements have been made to do so. This project will be extremely usefula at Winfield.

The economic project (Isserman, Trumbull, Fletcher) has begun evaluating extant cost accounting methods for technologies. They have found that no studies include valuations for non-agency costs. Much of the developmental work on this project will be done this summer. The project is progressing well.

Project Titles with Principal Investigators

BIO-REMEDIATION

MC-2b:
IN SITU BIOREMEDIATION OF CHLORINATED ORGANIC SOLVENTS
W. Sack, P. Carriere and A. Shiemke

MC-18:
MICROBIAL ENRICHMENT FOR ENHANCING IN-SITU BIODEGRADATION OF HAZARDOUS ORGANIC WASTES
A. Sexstone and C. Atkinson

MC-20:
TREATMENT OF VOLATILE ORGANIC COMPOUNDS (VOCs) USING BIOFILTERS
S. Mohaghegh and P. Carriere

MISCELLANEOUS REMEDIATION TECHNOLOGIES

MC-2a:
DRAIN-ENHANCED SOIL FLUSHING (DESF) FOR ORGANIC CONTAMINANTS REMOVAL
M. Gabr and J. Bowders

MC-6:
CHEMICAL DESTRUCTION OF CHLORINATED ORGANIC COMPOUNDS
K. Wang

MC-11:
REMEDIATION OF HAZARDOUS SITES WITH STEAM REFORMING
M. Mansour, R. Chandran, and B. Aghamohammadi

MC-19:
SOIL DECONTAMINATION WITH A PACKED FLOTATION COLUMN
E. Cho, F. Peng, and D. Yang

MC-21:
USE OF GRANULAR ACTIVATED CARBON COLUMNS FOR THE SIMULTANEOUS REMOVAL OF ORGANICS, HEAVY METALS, AND RADIONUCLIDES
B. Reed and P. Carriere

PROJECT TITLES WITH PRINCIPAL INVESTIGATORS (CONT.)

INSTRUMENTATION

MC-7:
MONOLAYER AND MULTILAYER SELF-ASSEMBLED POLYION FILMS FOR GAS-PHASE CHEMICAL SENSORS
H. Finklea

MC-22:
COMPACT MERCURIC IODIDE DETECTOR TECHNOLOGY DEVELOPMENT
D. Lyons and G. Nandi

MC-23:
EVALUATION OF IR AND MASS SPECTROMETRIC TECHNIQUES FOR ON-SITE MONITORING OF VOLATILE ORGANIC COMPOUNDS
M. Seehra and F. King

TECHNOLOGY ASSESSMENTS

MC-1:
A SYSTEMATIC DATABASE OF THE STATE OF HAZARDOUS WASTE CLEAN-UP TECHNOLOGIES
M. Berg

MC-4:
DUST CONTROL METHODS FOR INSITU NUCLEAR AND HAZARDOUS WASTE HANDLING
S. Peng and F. Peng

MC-9:
WINFIELD LOCK AND DAM REMEDIATION
R. Lovett

MC-24:
SOCIO-ECONOMIC ASSESSMENT OF ALTERNATIVE ENVIRONMENTAL RESTORATION TECHNOLOGIES
A. Isserman, W. Trumbull, and J. Fletcher

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PROJECT TRACKING DATA

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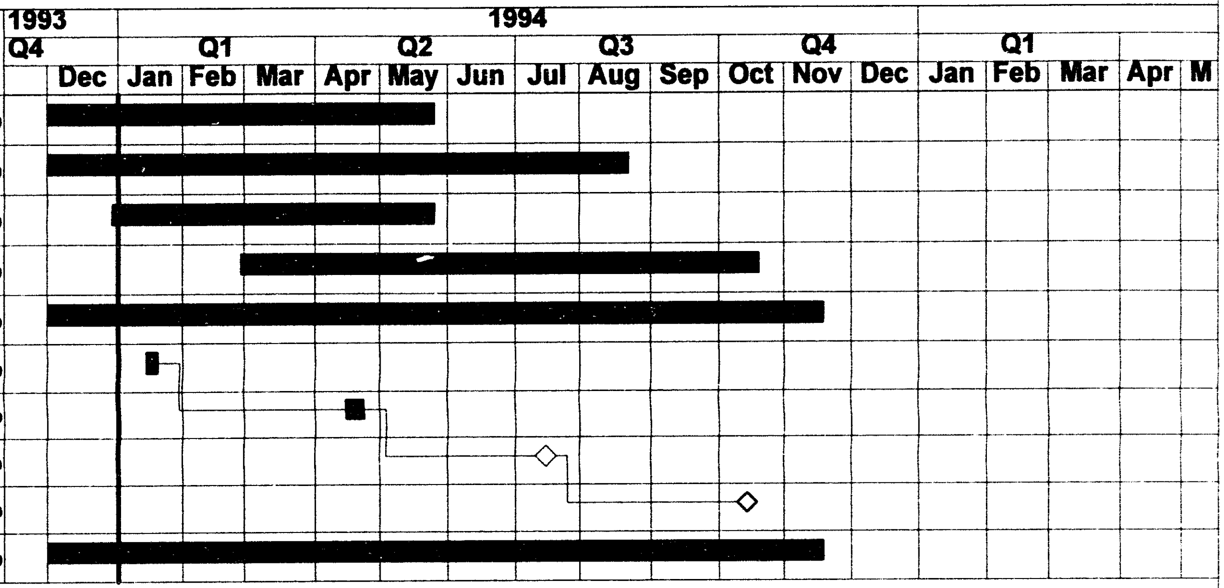
BIO-REMEDIATION

MC-2b In-Situ Bioremediation

#	WBS	Task Name	Dura	%Compl
1	1.0	Construct and Operate Ae	6M	75.00%
2	2.0	Construct and Operate Ae	9M	20.00%
3	3.0	Comparison of Biotransfo	5M	0.00%
4	4.0	Utlization of the Symbioti	8M	0.00%
5	5.0	Reporting	12M	50.00%
6	5.1	Quarterly Report 1	4d	100.00%
7	5.2	Quarterly Report 2	6d	100.00%
8	5.3	Quarterly Report 3	0d	0.00%
9	5.4	Final Report	0d	0.00%
10	6.0	Overall Work Complete	12M	29.00%



▬ 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			

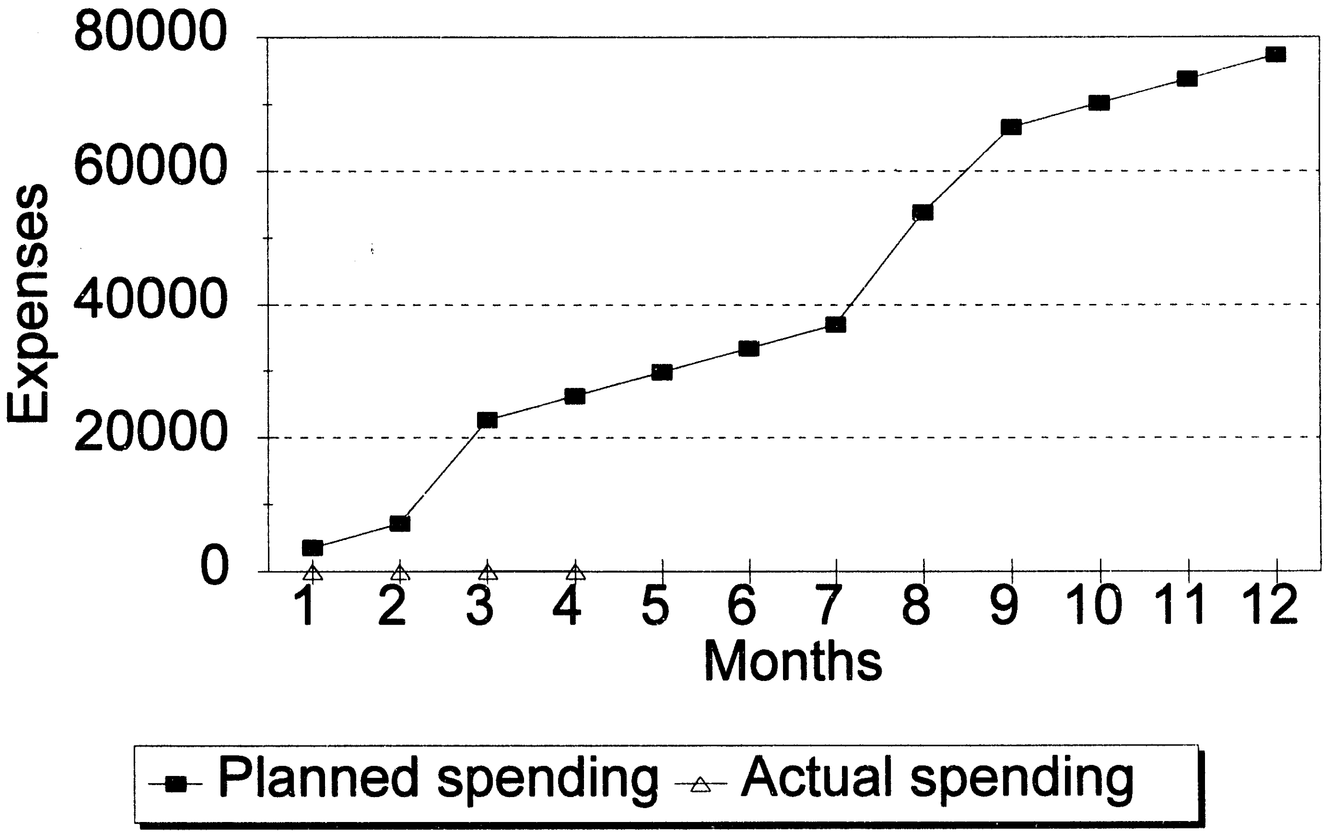
04/25/94

MC-2b
In-Situ Bioremediation

		1 December	2 January	3 February	4 March	5 April	6 May	7 June	8 July	9 August	10 September	11 October	12 November	Projected Totals	Actual Totals
W. Sack (p)	Planned spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$9,158.00	$9,158.00	$0.00	$0.00	$0.00	$18,316.00	
W. Sack (a)	Actual spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$0.00
A. Shiemke (p)	Planned spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$4,070.00	$0.00	$0.00	$0.00	$0.00	$4,070.00	
A. Shiemke (a)	Actual spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$0.00
Two Graduate Student (p)	Planned spending	$2,482.00	$2,482.00	$2,482.00	$2,482.00	$2,482.00	$2,482.00	$2,482.00	$2,482.00	$2,482.00	$2,482.00	$2,482.00	$2,482.00	$29,784.00	
Two Graduate Student (a)	Actual spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$0.00
Supplies (p)	Planned spending	$1,095.00	$1,095.00	$1,095.00	$1,095.00	$1,095.00	$1,095.00	$1,095.00	$1,095.00	$1,095.00	$1,095.00	$1,095.00	$1,095.00	$13,140.00	
Supplies (a)	Actual spending	$0.00	$0.00	$55.58	$68.25	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$123.83
Equipment (p)	Planned spending	$0.00	$0.00	$12,000.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$12,000.00	
Equipment (a)	Actual spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$0.00
Monthly Totals (Planned)		$3,577.00	$7,154.00	$22,731.00	$26,308.00	$29,885.00	$33,462.00	$37,039.00	$53,844.00	$66,579.00	$70,156.00	$73,733.00	$77,310.00	$77,310.00	
ACTUAL TOTALS		$0.00	$0.00	$55.58	$123.83	$123.83	$123.83	$123.83	$123.83	$123.83	$123.83	$123.83	$123.83		$123.83

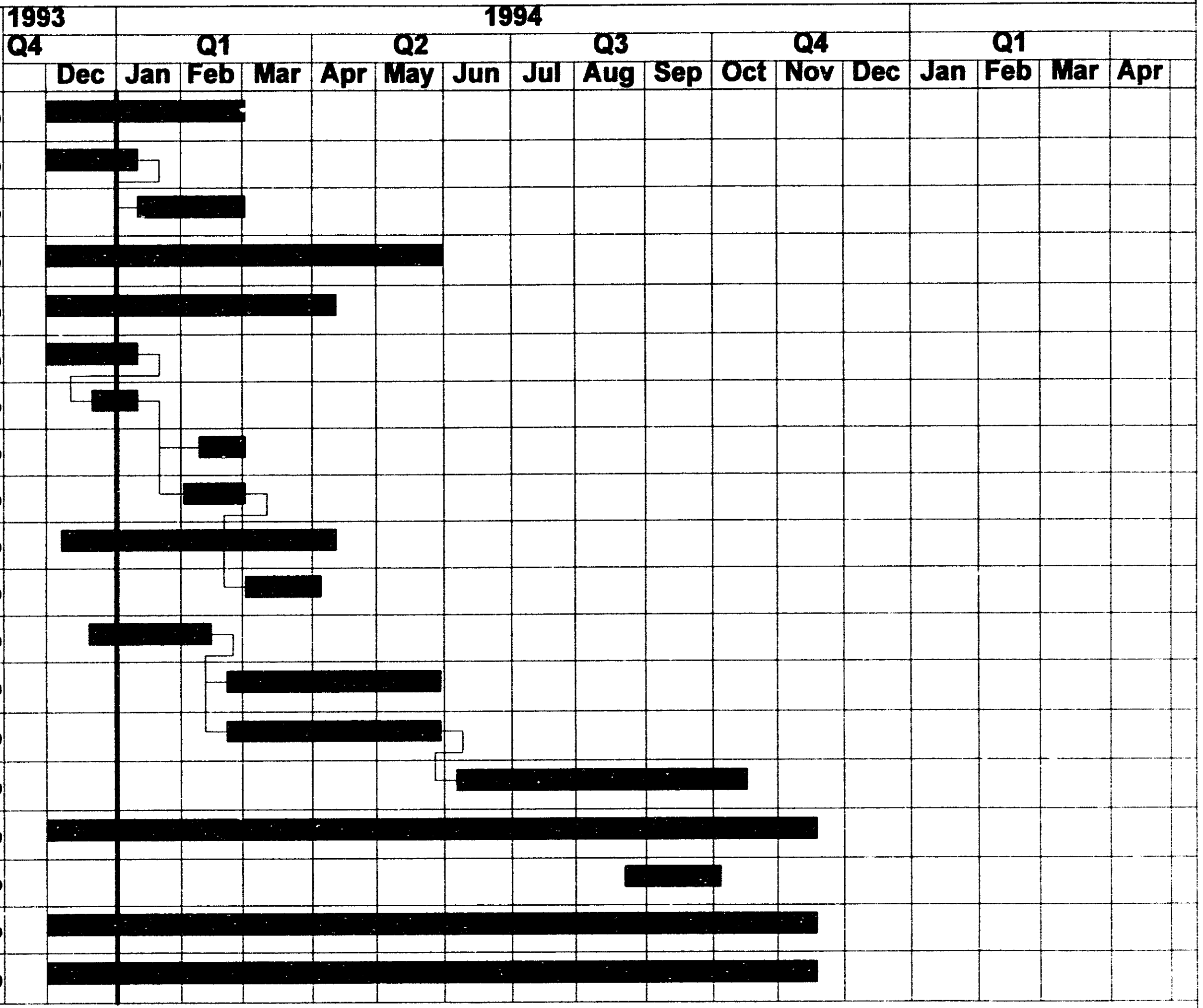
MC- 2b Expenses

In-Situ Bioremediation



MC-18 Microbial Enrichment

#	WBS	Task Name	Dura	%Compl
1	1.0	**Preliminary Research**	13w	75.00%
2	1.1	Research bioremediation	6w	75.00%
3	1.2	Technology evaluation	7w	75.00%
4	2.0	**Analytical Techniques**	26w	85.00%
5	3.0	**Preparation for Trials**	19w	64.29%
6	3.1	Hire and train tech.	6w	0.00%
7	3.2	Characterize soil	3w	100.00%
8	3.3	Soil analysis	3w	100.00%
9	3.4	Obtain HCs	4w	90.00%
10	3.5	Extraction techniques	18w	90.00%
11	3.6	Obtain inocula	5w	20.00%
12	3.7	Finalize QA/QC	8w	50.00%
13	4.0	**Bioremediation Trial 1**	14w	5.00%
14	5.0	**Bioremediation Trial 2**	14w	0.00%
15	6.0	**Trial Repeats (concurrent**	19w	0.00%
16	7.0	**Analysis & Reporting**	12M	25.00%
17	7.1	Analysis & Data Reduction	1.5M	0.00%
18	7.2	Reports & Manuscripts	12M	50.00%
20	8.0	**Overall Work Complete**	12M	36.33%



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▬ Noncritical
◇ Noncritical Milestone
▨ Total Float (+)
▲ Effort %Complete

▬ Complete
◆ Complete Milestone
▧ Total Float (-)

▭ Summary
◇ Summary Milestone
— Baseline

▬ External
◆ External Milestone
-------- Non-Resource

04/20/94

MC-18

Microbial Enrichment

	1 December	2 January	3 February	4 March	5 April	6 May	7 June	8 July	9 August	10 September	11 October	12 November	Projected Totals	Actual Totals
A. Sexstone (p) Planned spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$2,648.69	$2,648.69	$2,648.69	$0.00	$0.00	$0.00	$7,946.07	
A. Sexstone (a) Actual spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$0.00
C. Atkinson (p) Planned spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$3,076.85	$3,076.85	$3,076.85	$0.00	$0.00	$0.00	$9,230.55	
C. Atkinson (a) Actual spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$0.00
Technician (p) Planned spending	$3,178.86	$3,178.86	$3,178.86	$3,178.86	$3,178.86	$3,178.86	$3,178.86	$3,178.86	$3,178.86	$3,178.86	$3,178.86	$3,173.27	$38,140.73	
Technician (a) Actual spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$0.00
Supplies (p) Planned spending	$1,095.00	$1,095.00	$1,095.00	$1,095.00	$1,095.00	$1,095.00	$1,095.00	$1,095.00	$1,095.00	$1,095.00	$1,095.00	$1,095.00	$13,140.00	
Supplies (a) Actual spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$0.00
Subcontract (p) Planned spending	$608.33	$608.33	$608.33	$608.33	$608.33	$608.35	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$3,650.00	
Subcontract (a) Actual spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$0.00
Travel (p) Planned spending	$291.39	$291.39	$291.39	$291.39	$291.39	$291.39	$291.39	$291.39	$291.39	$291.39	$291.39	$291.41	$3,496.70	
Travel (a) Actual spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$0.00
Monthly Totals (Planned)	**$5,173.58**	**$10,347.16**	**$15,520.74**	**$20,694.32**	**$25,867.90**	**$31,041.50**	**$41,332.29**	**$51,623.08**	**$61,913.87**	**$66,479.12**	**$71,044.37**	**$75,604.05**	**$75,604.05**	
ACTUAL TOTALS	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**		**$0.00**

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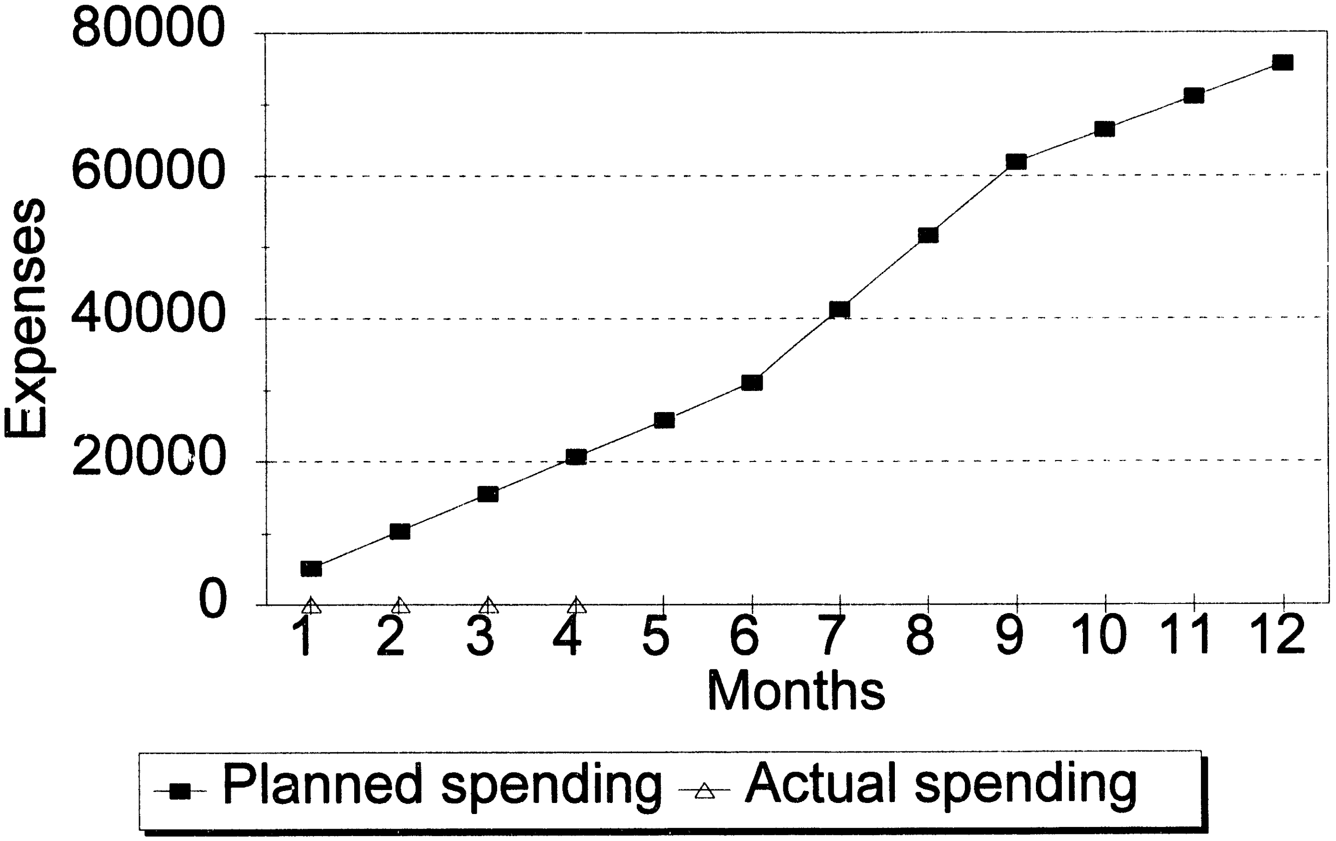
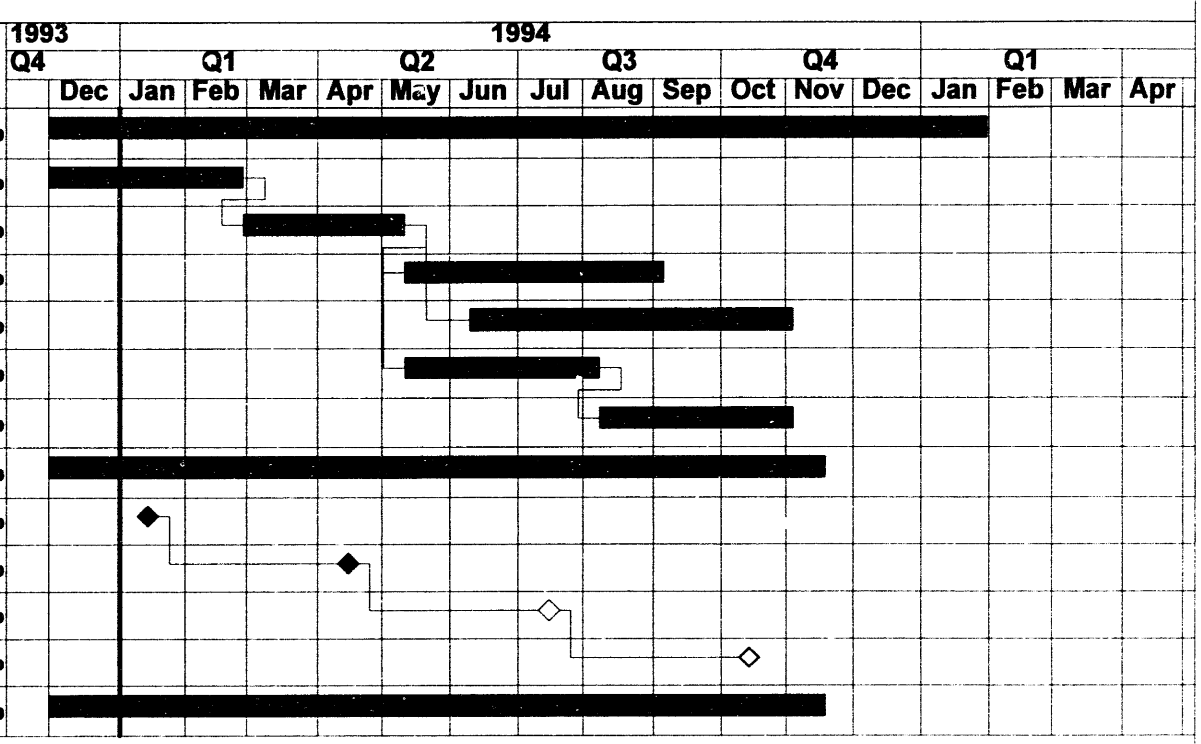
MC-18 Expenses

Microbial Enrichment



MC-20 VOC Treatment

#	WBS	Task Name	Dura	%Compl
1	1.0	Study effects of Biologica	4.5M	38.75%
2	1.1	Equipment Procurement	3M	95.00%
3	1.2	Fabrication and Installatio	2.5M	60.00%
4	1.3	Study of VOC removal by	4M	0.00%
5	1.4	Study of VOC removal by	5M	0.00%
6	2.0	Study on the Effect of Initi	3M	0.00%
7	3.0	Laboratory studies for fiel	3M	0.00%
8	4.0	Report Preparation	12M	50.00%
9	4.1	Quarterly Report 1	0d	100.00%
10	4.2	Quarterly Report 2	0d	100.00%
11	4.3	Quarterly Report 3	0d	0.00%
12	4.4	Final Report	0d	0.00%
13	5.0	Overall Work complete	12M	22.19%



■ 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			

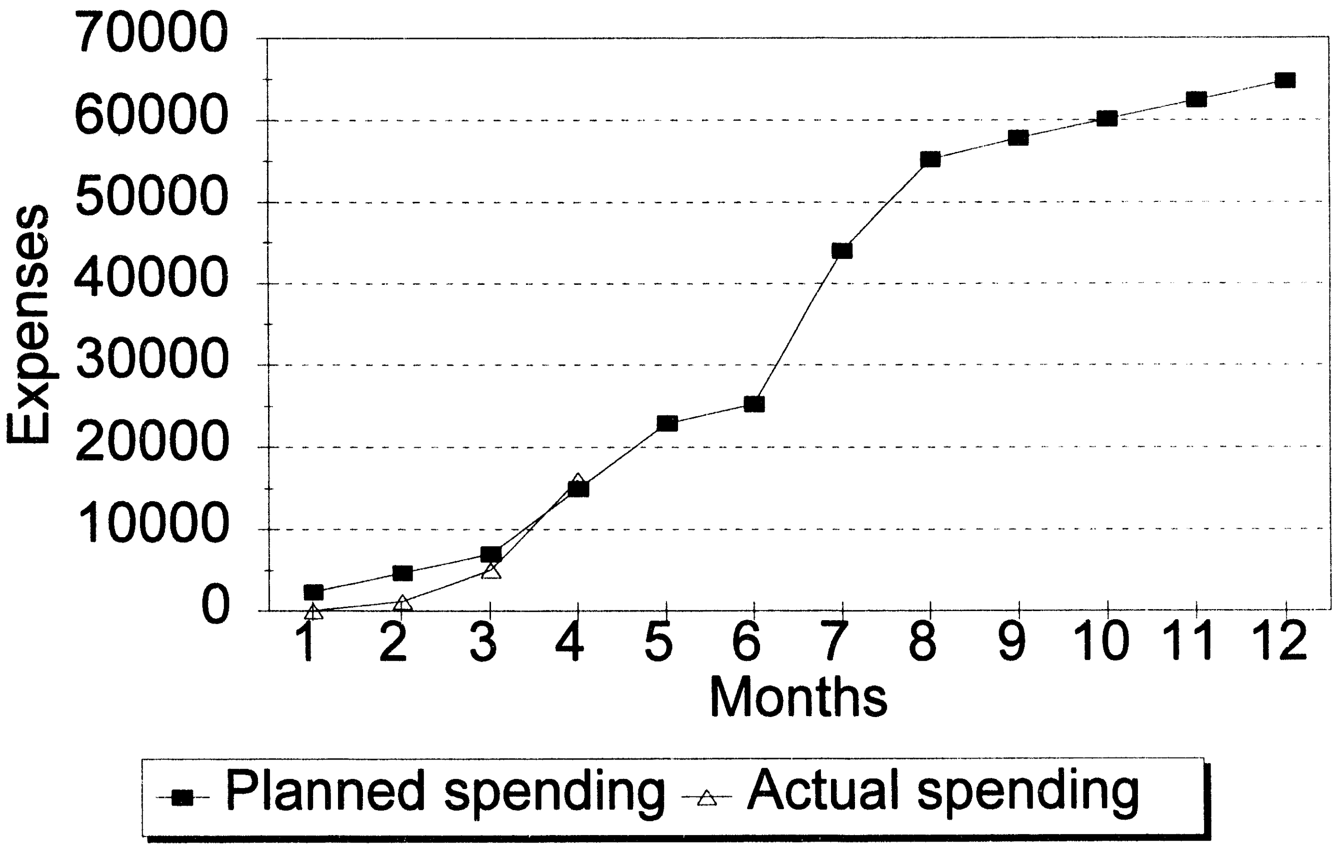
04/20/94

MC-20
VOC Treatment

	1	2	3	4	5	6	7	8	9	10	11	12		
	December	January	February	March	April	May	June	July	August	September	October	November	Projected Totals	Actual Totals
P. Carriere (p) Planned spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$4,716.97	$4,716.97	$0.00	$0.00	$0.00	$0.00	$9,433.94	
P. Carriere (a) Actual spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$0.00
S. Mohaghegh (p) Planned spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$9,485.83	$0.00	$0.00	$0.00	$0.00	$0.00	$9,485.83	
S. Mohaghegh (a) Actual spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$0.00
Graduate Student 1 (p) Planned spending	$1,167.88	$1,167.88	$1,167.88	$1,167.88	$1,167.88	$1,167.88	$1,167.88	$1,167.88	$1,167.88	$1,167.88	$1,167.88	$1,167.86	$14,014.54	
Graduate Student 1 (a) Actual spending	$0.00	$0.00	$2,482.00	$1,241.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$3,723.00
Graduate Student 2 (p) Planned spending	$1,167.88	$1,167.88	$1,167.88	$1.167.88	$1,167.88	$1,167.88	$1,167.88	$1,167.88	$1,167.88	$1,167.88	$1,167.88	$1,167.86	$14,014.54	
Graduate Student 2 (a) Actual spending	$0.00	$1,168.00	$1,168.00	$1,168.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$3,504.00
Supplies/Other (p) Planned spending	$0.00	$0.00	$0.00	$630.00	$630.00	$0.00	$0.00	$0.00	$200.00	$0.00	$0.00	$0.00	$1,460.00	
Supplies/Other (a) Actual spending	$0.00	$0.00	$191.80	$324.49	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$516.29
Equipment (p) Planned spending	$0.00	$0.00	$0.00	$5,000.00	$5,000.00	$0.00	$0.00	$2,000.00	$0.00	$0.00	$0.00	$0.00	$12,000.00	
Equipment (a) Actual spending	$0.00	$0.00	$0.00	$8,312.29	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$8,312.29
Travel (p) Planned spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$2,190.00	$2,190.00	$0.00	$0.00	$0.00	$0.00	$4,380.00	
Travel (a) Actual spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$0.00
Monthly Totals (Planned)	**$2,335.76**	**$4,671.52**	**$7,007.28**	**$14,973.04**	**$22,938.80**	**$25,274.56**	**$44,003.12**	**$55,245.85**	**$57,781.61**	**$60,117.37**	**$62,453.13**	**$64,788.85**	**$64,788.85**	
ACTUAL TOTALS	**$0.00**	**$1,168.00**	**$5,009.80**	**$16,055.58**	**$16,055.58**	**$16,055.58**	**$16,055.58**	**$16,055.58**	**$16,055.58**	**$16,055.58**	**$16,055.58**	**$16,055.58**		**$16,055.58**

MC-20 Expenses

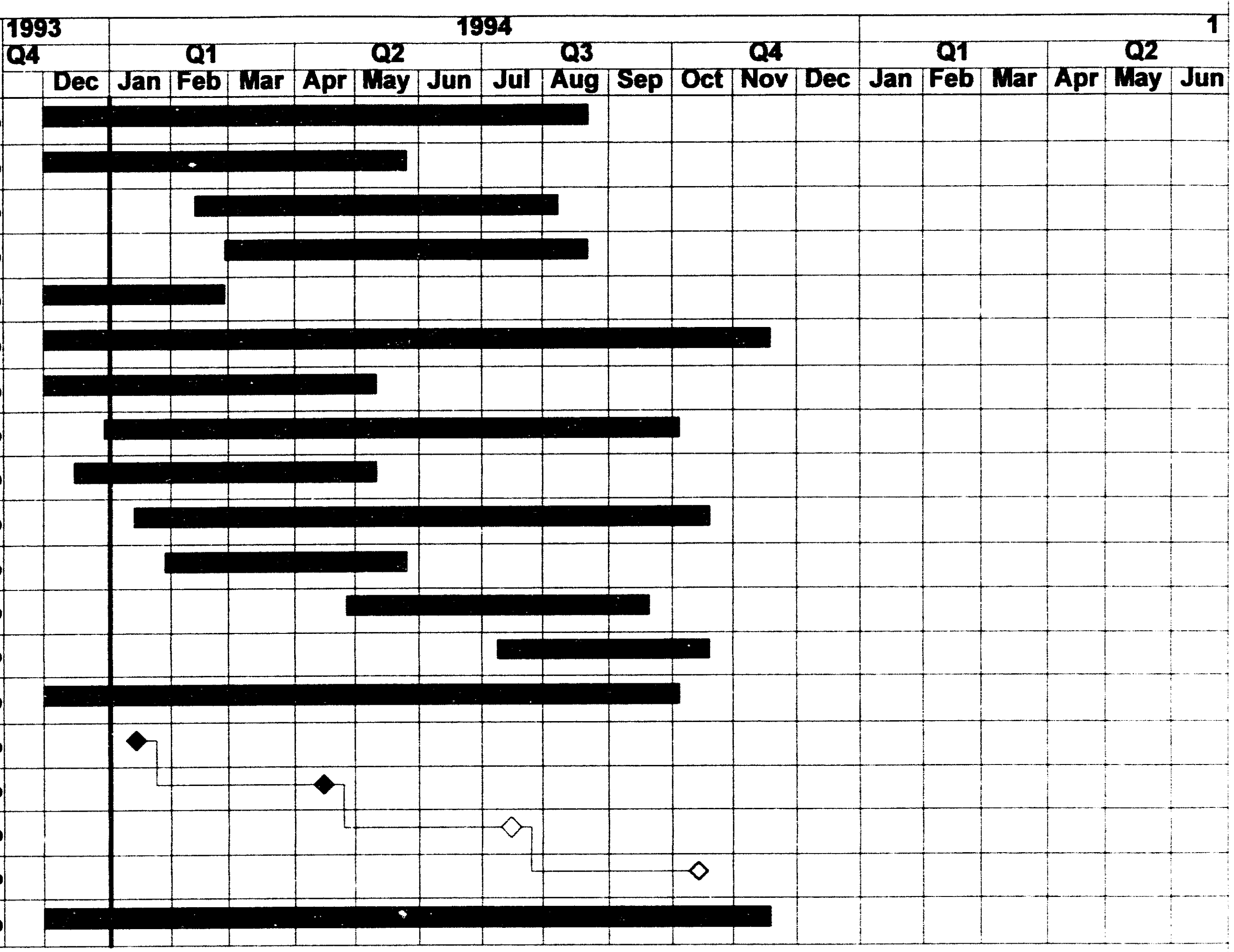
VOC Treatment



MISCELLANEOUS REMEDIATION TECHNOLOGIES

MC-2A Enhanced Soil Flushing

#	WBS	Task Name	Dura	%Compl
1	1.0	Column Testing	9M	50.00%
2	1.1	Long Term Efficien	6M	100.00%
3	1.2	Effect of Hydraulic	6M	25.00%
4	1.3	Effect of Confining	6M	25.00%
5	1.4	Retardation/Disper	3M	50.00%
6	2.0	Contaminant Reco	12M	58.33%
7	2.1	PVD Zone of Influe	5.5M	50.00%
8	2.2	Vacuum	9.5M	25.00%
9	2.3	Surcharge	5M	100.00%
10	3.0	Simulation Model	9.5M	25.00%
11	3.1	Sensitivity Study	4M	25.00%
12	3.2	Validation and Mo	5M	25.00%
13	3.3	Design Nomograp	3.5M	25.00%
14	4.0	Report and Field I	0.5M	50.00%
15	4.1	Quarterly Report/M	0d	100.00%
16	4.2	Quarterly Report/M	0d	100.00%
17	4.3	Quarterly Report/M	0d	0.00%
18	4.4	Final Report	0d	0.00%
19	5.0	Overall Work Com	12M	45.83%



▬ 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			

04/13/94

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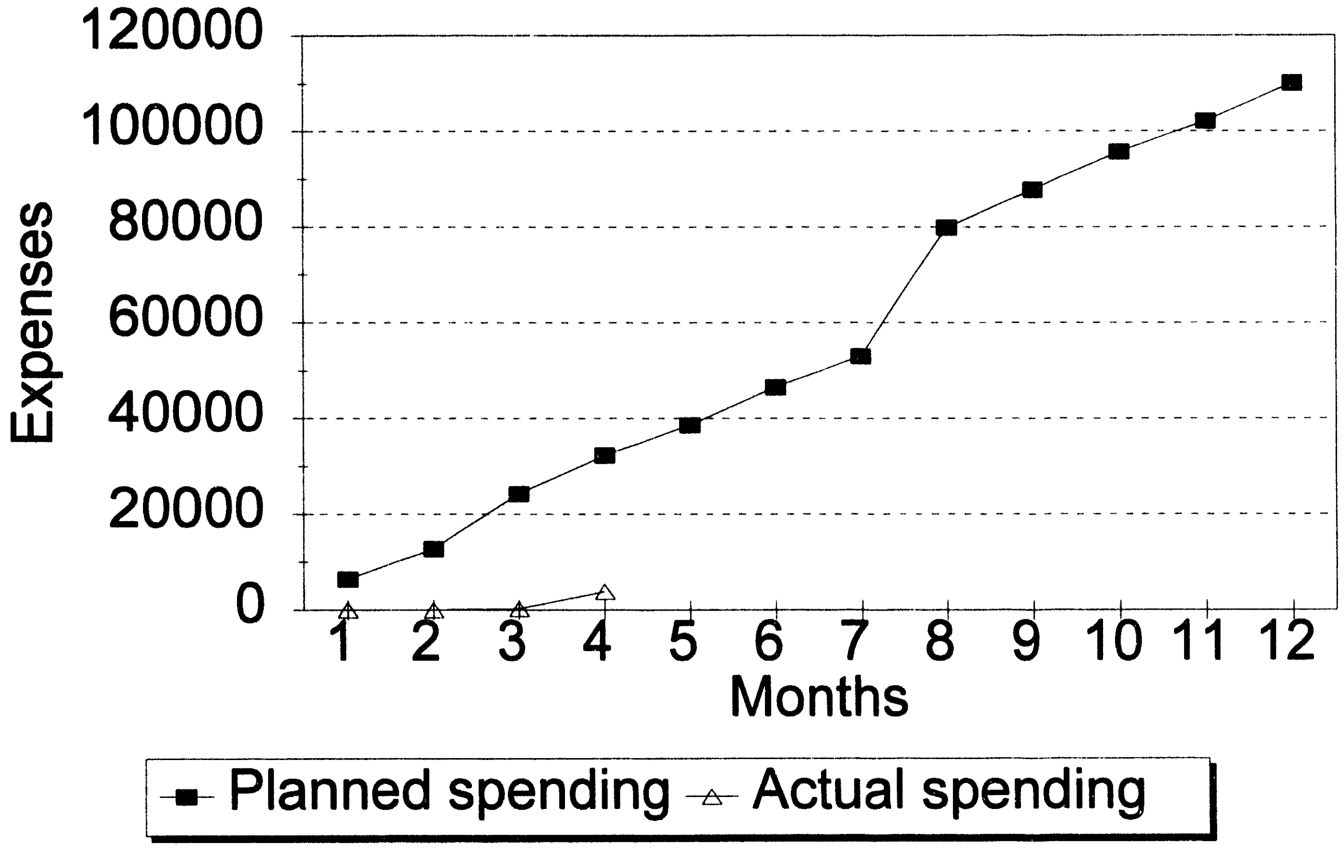
MC-2a
Enhanced Soil Flushing

		1 December	2 January	3 February	4 March	5 April	6 May	7 June	8 July	9 August	10 September	11 October	12 November	Projected Totals	Actual Totals
M. Gabr (p)	Planned spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$9,210.00	$0.00	$0.00	$0.00	$0.00	$9,210.00	
M. Gabr (a)	Actual spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$0.00
J. Bowders (p)	Planned spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$9,634.00	$0.00	$0.00	$0.00	$0.00	$9,634.00	
J. Bowders (a)	Actual spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$0.00
Post Doc. (p)	Planned spending	$1,460.25	$1,460.25	$1,460.25	$1,460.25	$1,460.25	$1,460.25	$1,460.25	$1,460.25	$1,460.25	$1,460.25	$1,460.25	$1,460.25	$17,523.00	
Post Doc. (a)	Actual spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$0.00
Two Graduate Student (p)	Planned spending	$2,482.00	$2,482.00	$2,482.00	$2,482.00	$2,482.00	$2,482.00	$2,482.00	$2,482.00	$2,482.00	$2,482.00	$2,482.00	$2,482.00	$29,784.00	
Two Graduate Student (a)	Actual spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$0.00
Undergraduate (p)	Planned spending	$730.00	$730.00	$730.00	$730.00	$730.00	$730.00	$730.00	$730.00	$730.00	$730.00	$730.00	$730.00	$8,760.00	
Undergraduate (a)	Actual spending	$0.00	$0.00	$208.80	$1,579.05	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$1,787.85
Supplies (p)	Planned spending	$973.00	$973.00	$973.00	$973.00	$973.00	$973.00	$973.00	$973.00	$973.00	$973.00	$973.00	$973.00	$11,676.00	
Supplies (a)	Actual spending	$0.00	$0.00	$0.00	$2,086.05	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$2,086.05
Other (p)	Planned spending	$730.00	$730.00	$730.00	$730.00	$730.00	$730.00	$730.00	$730.00	$730.00	$730.00	$730.00	$730.00	$8,760.00	
Other (a)	Actual spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$0.00
Equipment (p)	Planned spending	$0.00	$0.00	$5,200.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$5,200.00	
Equipment (a)	Actual spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$0.00
Travel (p)	Planned spending	$0.00	$0.00	$0.00	$1,582.00	$0.00	$1,582.00	$0.00	$1,582.00	$1,582.00	$1,582.00	$0.00	$1,582.00	$9,492.00	
Travel (a)	Actual spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$0.00
Monthly Totals (Planned)		$6,375.25	$12,750.50	$24,325.75	$32,283.00	$38,658.25	$46,615.50	$52,990.75	$79,792.00	$87,749.25	$95,706.50	$102,081.75	$110,039.00	$110,039.00	
ACTUAL TOTALS		$0.00	$0.00	$208.80	$3,873.90	$3,873.90	$3,873.90	$3,873.90	$3,873.90	$3,873.90	$3,873.90	$3,873.90	$3,873.90		$3,873.90

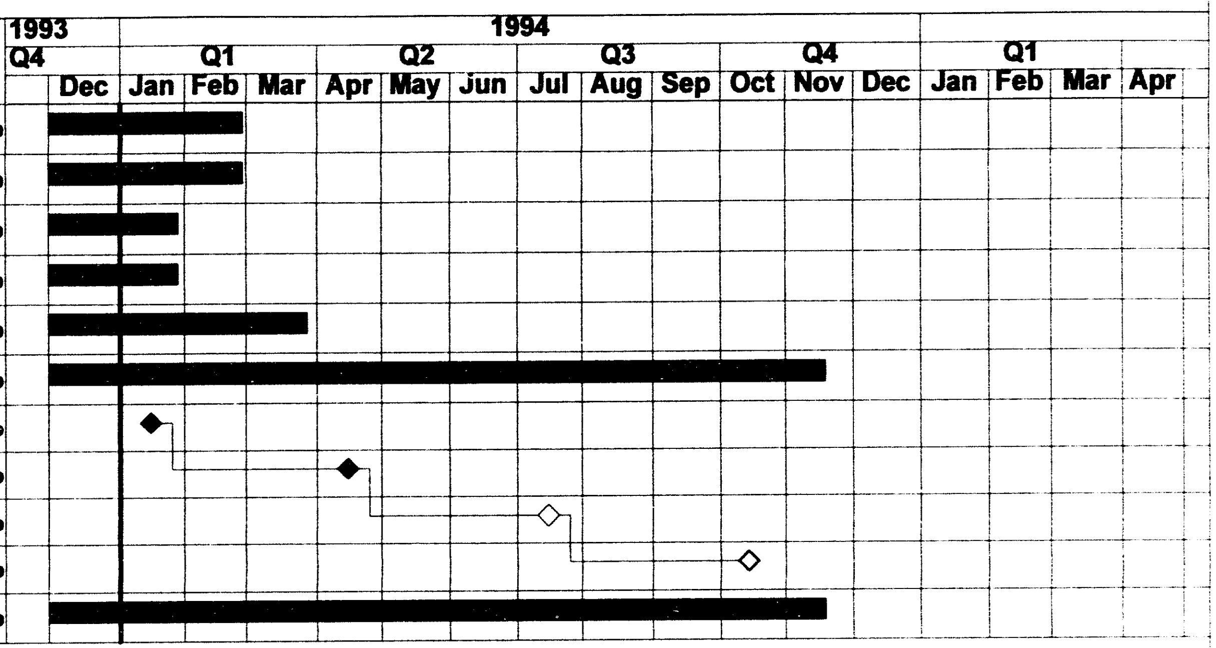
MC- 2a Expenses

Enhanced Soil Flushing



MC-6 Chemical Destruction

#	WBS	Task Name	Dura	%Compl
1	1.0	Synthesis of Triarylboran	3M	100.00%
2	2.0	Use of Triarylborane 6 as	3M	100.00%
3	3.0	Synthesis of Boron-Subst	2M	50.00%
4	4.0	Use of Boron-Substituted	2M	0.00%
5	5.0	Dechlorination by using F	4M	0.00%
6	6.0	Reports	12M	50.00%
7	6.1	Quarterly Report 1	0d	100.00%
8	6.2	Quarterly Report 2	0d	100.00%
9	6.3	Quarterly Report 3	0d	0.00%
10	6.4	Final Report	0d	0.00%
11	7.0	Overall Work Complete	12M	50.00%



▬ 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

04/20/94

MC-6
Chemical Destruction

		1 December	2 January	3 February	4 March	5 April	6 May	7 June	8 July	9 August	10 September	11 October	12 November	Projected Totals	Actual Totals
K. Wang (p)	Planned spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$15,387.00	$0.00	$0.00	$0.00	$0.00	$15,387.00	
K. Wang (a)	Actual spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$0.00
Post Doc. (P)	Planned spending	$3,579.00	$3,579.00	$3,579.00	$3,579.00	$3,579.00	$3,579.00	$3,579.00	$3,579.00	$3,579.00	$3,579.00	$3,579.00	$3,579.00	$42,948.00	
Post Doc. (a)	Actual spending	$0.00	$3,578.46	$3,578.46	$3,578.46	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$10,735.38
Two Graduate Student (p)	Planned spending	$1,387.00	$1,387.00	$1,387.00	$1,387.00	$1,387.00	$1,387.00	$1,387.00	$1,387.00	$1,387.00	$1,387.00	$1,387.00	$1,389.00	$16,646.00	
Two Graduate Student (a)	Actual spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$0.00
Supplies (p)	Planned spending	$1,216.00	$1,216.00	$1,216.00	$1,216.00	$1,216.00	$1,216.00	$1,216.00	$1,216.00	$1,216.00	$1,216.00	$1,219.00	$1,220.00	$14,599.00	
Supplies (a)	Actual spending	$0.00	$0.00	$592.15	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$592.15
Equipment (p)	Planned spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$1,095.00	$0.00	$0.00	$0.00	$0.00	$1,095.00	
Equipment (a)	Actual spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$0.00
Travel (p)	Planned spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$1,095.00	$0.00	$0.00	$0.00	$1,095.00	
Travel (a)	Actual spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$0.00
Monthly Totals (Planned)		$6,182.00	$12,364.00	$18,546.00	$24,728.00	$30,910.00	$37,092.00	$43,274.00	$65,938.00	$73,215.00	$79,397.00	$85,582.00	$91,770.00	$91,770.00	
ACTUAL TOTALS		$0.00	$3,578.46	$7,749.07	$11,327.53	$11,327.53	$11,327.53	$11,327.53	$11,327.53	$11,327.53	$11,327.53	$11,327.53	$11,327.53		$11,327.53

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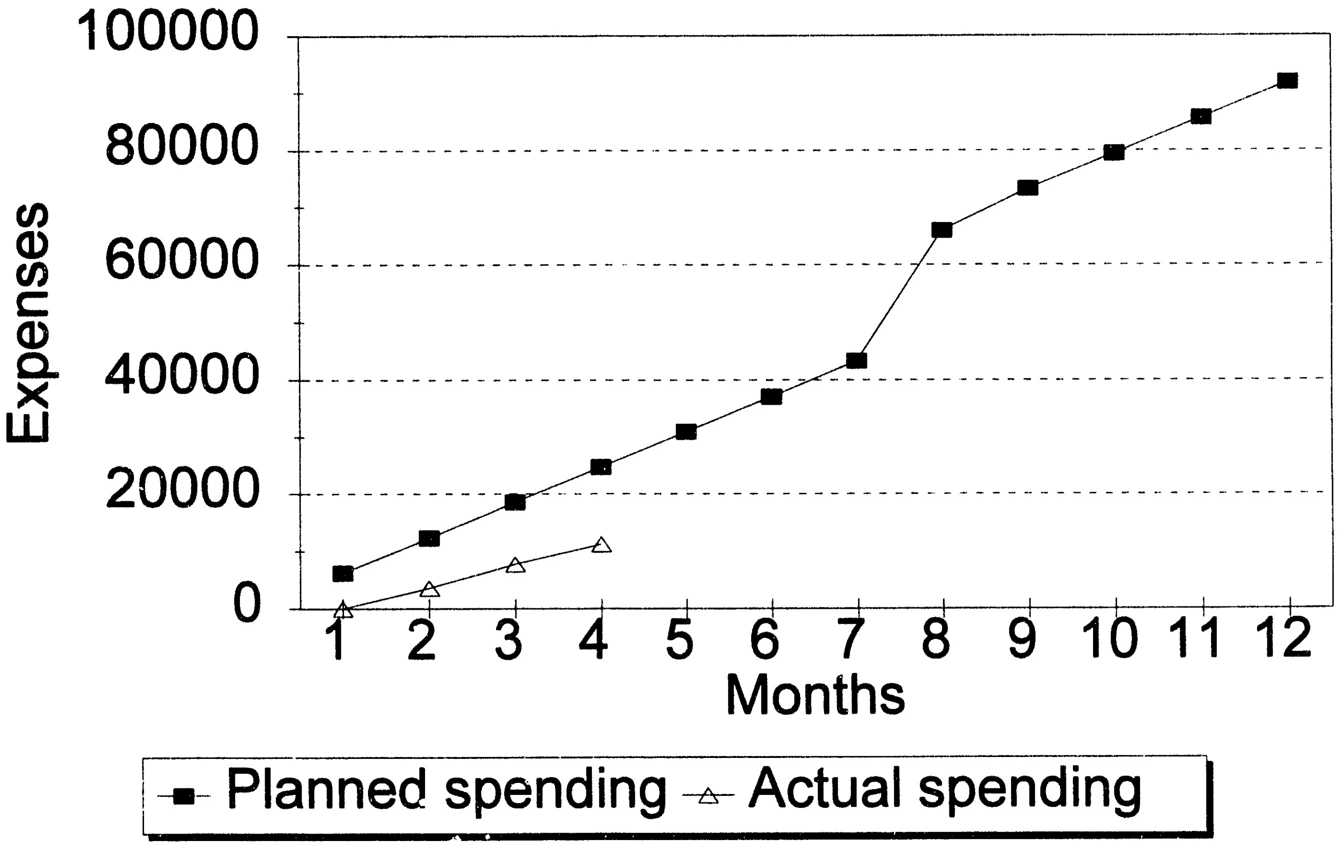
MC-6 Expenses

Chemical Destruction



MC-11
REMEDIATION OF HAZARDOUS SITES WITH STEAM REFORMING

Form EIA-459E
0/90)

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

FORM APPROVED
OMS No. 1900-0127
Page of

[1] Program/Project Identification No. DE-FC21-92MC29467	[2] Program/Project Title Decontamination Systems Information and Research Program	[3] Reporting Period January - March 1994
[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 September 30, 1994

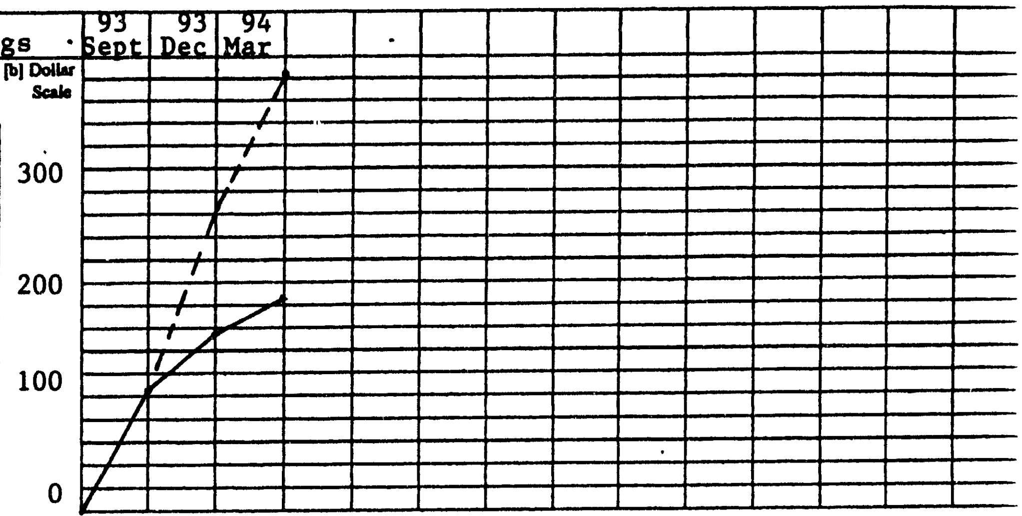
[7] FY 94 [8] Months or Quarters: Quarterly Endings — 93 Sept, 93 Dec, 94 Mar

[9] Cost Status [a] Dollars Expressed in Thousands [b] Dollar Scale

[10] Cost Chart

Fund Source		Quarter first	second	third	fourth	Cum. to Date	Tot. Plan
	P	105	160	122		387	387
	A	104	53	25		182	
	P						
	A						
	P						
	A						
	P						
	A						
Total P		105	160	122		387	
Total A		104	53	25		182	
Variance		1	107	97		205	

P = Planned A = Actual

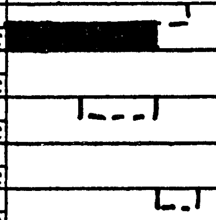


Cumulative Accrued Costs

	93 Sept	93 Dec	94 Mar
Planned	105	265	387
Actual	104	157	182
Variance	1	108	205

Total Planned Costs for Program/Project
Planned --------
Actual ________

Major Milestone Status		Units Planned / Units Complete
Task 1. System Modification	P	100%
	C	80%
Task 2. Testing & Analysis	P	100%
	C	80%
Task 3. Scale-up Design & Final Report	P	100%
	C	80%



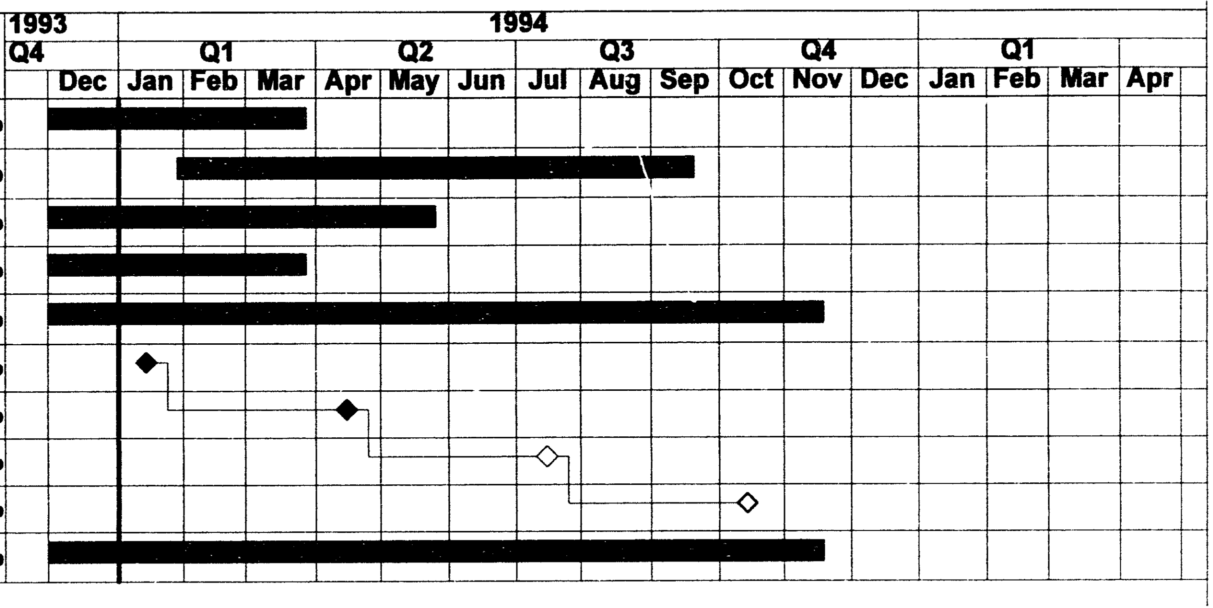
[12] Remarks Task 1 Slip - Due to replacement of some components with new units designed for pressurized operation.

[13] Signature of Recipient and Date 4/14/94
amir E Weslah for Babak Aghanohammadi

[14] Signature of DOE Reviewing Representative and Date

MC-19 Packed Flotation

#	WBS	Task Name	Dura	%Compl
1	1.0	**Sample Preparation**	4M	30.00%
2	2.0	**Laboratory Studies**	8M	20.00%
3	2.1	Data Evaluation	6M	0.00%
4	2.2	Process Modeling	4M	0.00%
5	3.0	**Report Preparation**	12M	50.00%
6	3.1	Report 1	0M	100.00%
7	3.2	Report 2	0M	100.00%
8	3.3	Report 3	0M	0.00%
9	3.4	Final Report	0M	0.00%
10	4.0	**Overall Work Complete**	12M	33.33%



▬	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						

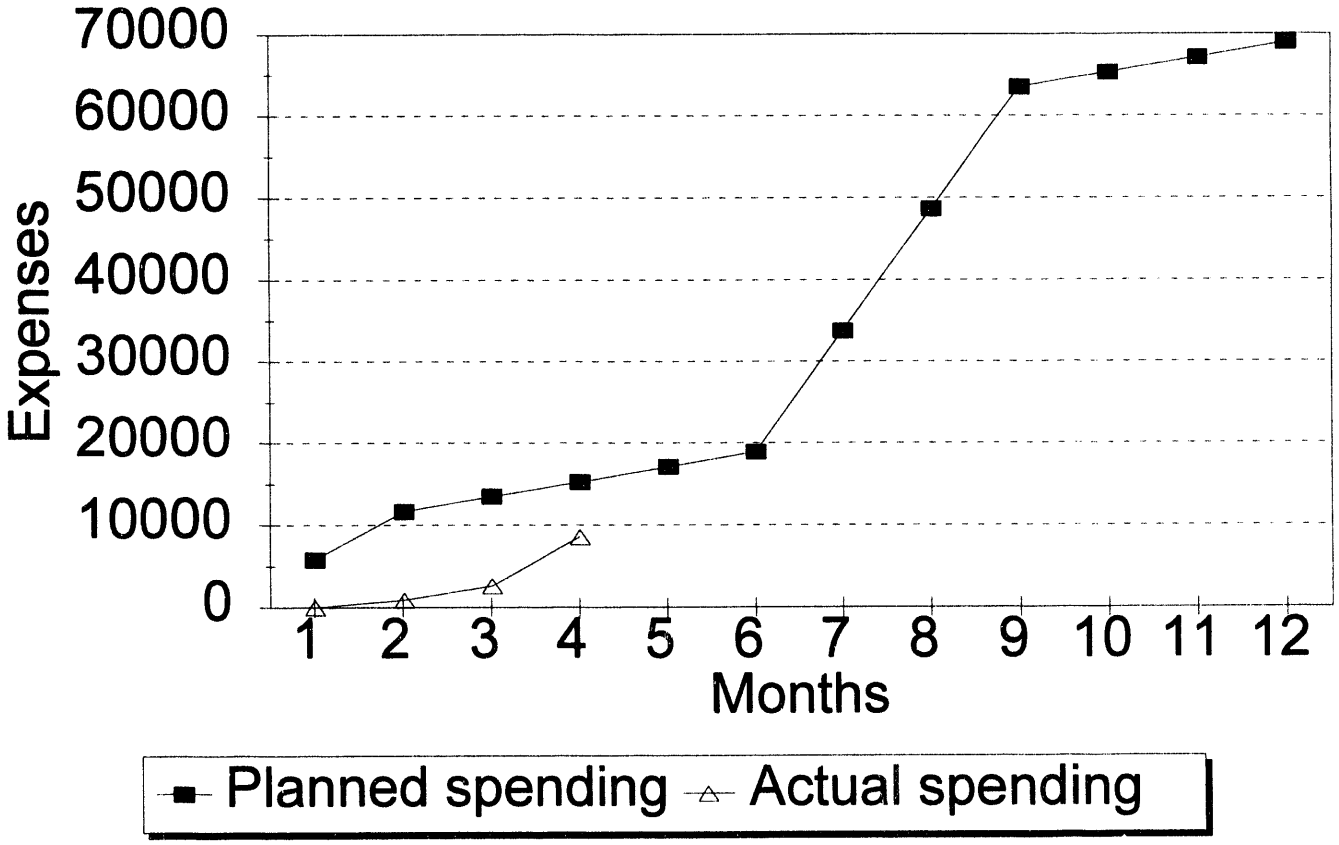
04/20/94

MC-19
Packed Flotation

		1 December	2 January	3 February	4 March	5 April	6 May	7 June	8 July	9 August	10 September	11 October	12 November	Projected Totals	Actual Totals
E. Cho (p)	Planned spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$3,349.94	$3,349.94	$3,349.94	$0.00	$0.00	$0.00	$10,049.82	
E. Cho (a)	Actual spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$0.00
F. Peng (p)	Planned spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$2,772.36	$2,772.36	$2,772.37	$0.00	$0.00	$0.00	$8,317.09	
F. Peng (a)	Actual spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$0.00
D. Yang (p)	Planned spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$6,930.91	$6,930.91	$6,930.92	$0.00	$0.00	$0.00	$20,792.74	
D. Yang (a)	Actual spending	$0.00	$866.36	$1,732.73	$1,732.73	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$4,331.82
Graduate Student (p)	Planned spending	$1,208.88	$1,208.88	$1,208.88	$1,208.88	$1,208.88	$1,208.88	$1,208.88	$1,208.88	$1,208.88	$1,208.88	$1,208.88	$1,208.88	$14,506.56	
Graduate Student (a)	Actual spending	$0.00	$0.00	$0.00	$2,920.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$2,920.00
Supplies/Other (p)	Planned spending	$425.83	$425.83	$425.83	$425.83	$425.83	$425.83	$425.83	$425.83	$425.83	$425.83	$425.83	$425.87	$5,110.00	
Supplies/Other (a)	Actual spending	$0.00	$0.00	$0.00	$974.73	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$974.73
Equipment (p)	Planned spending	$4,000.00	$4,000.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$8,000.00	
Equipment (a)	Actual spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$0.00
Travel (p)	Planned spending	$182.50	$182.50	$182.50	$182.50	$182.50	$182.50	$182.50	$182.50	$182.50	$182.50	$182.50	$182.50	$2,190.00	
Travel (a)	Actual spending	$0.00	$0.00	$0.00	$375.72	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$375.72
Monthly Totals (Planned)		$5,817.21	$11,634.42	$13,451.63	$15,268.84	$17,086.05	$18,903.26	$33,773.68	$48,644.10	$63,514.54	$65,331.75	$67,148.96	$68,966.21	$68,966.21	
ACTUAL TOTALS		$0.00	$866.36	$2,599.09	$8,602.27	$8,602.27	$8,602.27	$8,602.27	$8,602.27	$8,602.27	$8,602.27	$8,602.27	$8,602.27		$8,602.27

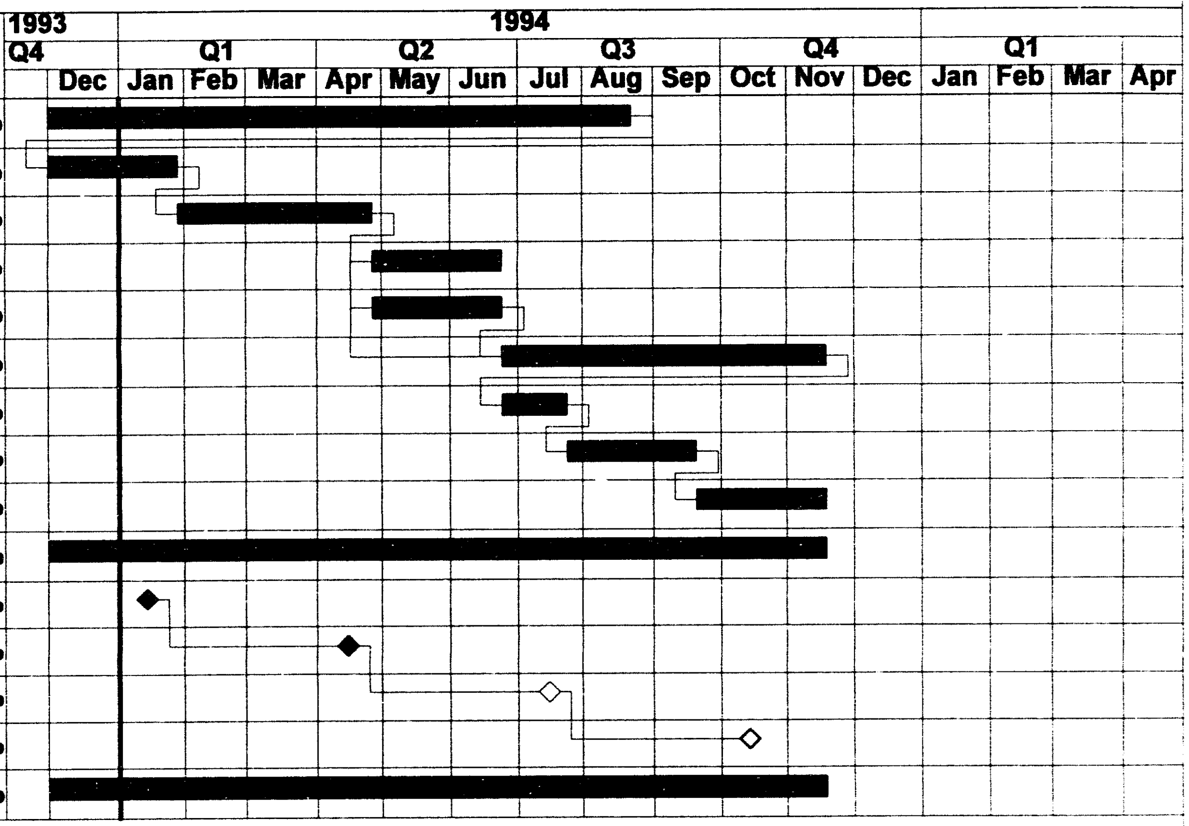
MC-19 Expenses

Packed Flotation



MC-21 Granular Activated Carbon

#	WBS	Task Name	Dura	%Compl
1	1.0	GAC Columns for Metal & O	9M	37.50%
2	1.1	Waste Acquirement and Carb	2M	100.00%
3	1.2	Activated Column Operation	3M	25.00%
4	1.3	Pilot-Scale Testing	2M	25.00%
5	1.4	Economic Analysis	2M	0.00%
6	2.0	Removal of Radionuclides b	5M	62.50%
7	2.1	Carbon Selection	1M	100.00%
8	2.2	GAC Column Testing	2M	25.00%
9	3.0	Treatment of an Aqueous Mi	2M	0.00%
10	4.0	Reporting	12M	50.00%
11	4.1	Quarterly Report 1	0d	100.00%
12	4.2	Quarterly Report 2	0d	100.00%
13	4.3	Quarterly Report 3	0d	0.00%
14	4.4	Final Report	0d	0.00%
15	5.0	Overall Work Complete	12M	37.50%



▬ 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

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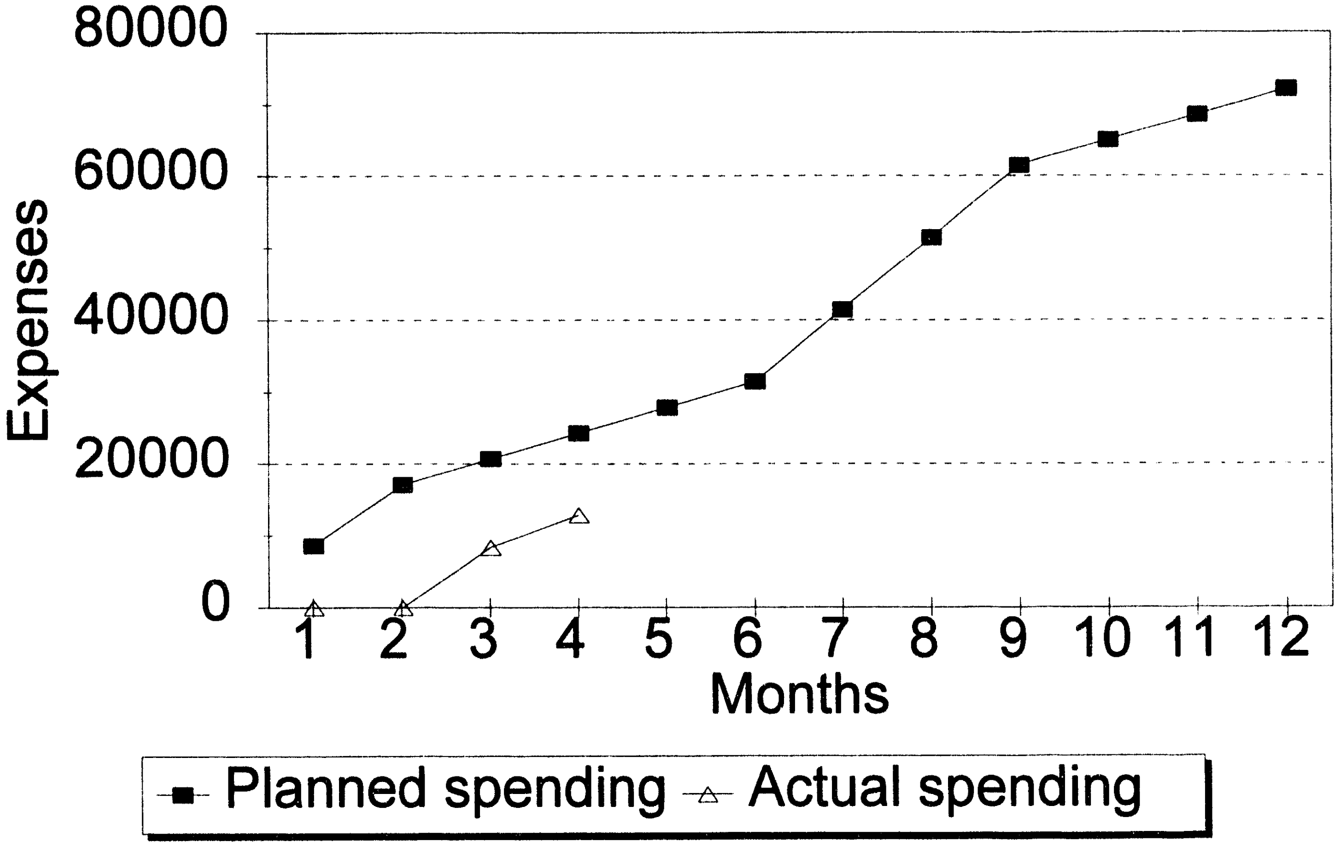
MC-21
Granular Activated Carbon

		1 December	2 January	3 February	4 March	5 April	6 May	7 June	8 July	9 August	10 September	11 October	12 November	Projected Totals	Actual Totals
P. Carriere (p)	Planned spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$3,487.43	$3,487.43	$3,487.43	$0.00	$0.00	$0.00	$10,462.29	
P. Carriere (a)	Actual spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$0.00
B. Reed (p)	Planned spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$2,929.31	$2,929.31	$2,929.32	$0.00	$0.00	$0.00	$8,787.94	
B. Reed (a)	Actual spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$0.00
PhD Student (p)	Planned spending	$1,460.00	$1,460.00	$1,460.00	$1,460.00	$1,460.00	$1,460.00	$1,460.00	$1,460.00	$1,460.00	$1,460.00	$1,460.00	$1,460.00	$17,520.00	
PhD Student (a)	Actual spending	$0.00	$0.00	$8,319.38	$4,531.25	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$12,850.63
Student (p)	Planned spending	$292.00	$292.00	$292.00	$292.00	$292.00	$292.00	$292.00	$292.00	$292.00	$292.00	$292.00	$292.00	$3,504.00	
Student (a)	Actual spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$0.00
Supplies/Other (p)	Planned spending	$1,216.67	$1,216.67	$1,216.67	$1,216.67	$1,216.67	$1,216.67	$1,216.67	$1,216.67	$1,216.67	$1,216.67	$1,216.67	$1,216.63	$14,600.00	
Supplies/Other (a)	Actual spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$0.00
Equipment (p)	Planned spending	$5,000.00	$5,000.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$10,000.00	
Equipment (a)	Actual spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$0.00
Travel (p)	Planned spending	$608.33	$608.33	$608.33	$608.33	$608.33	$608.33	$608.33	$608.33	$608.33	$608.33	$608.33	$608.37	$7,300.00	
Travel (a)	Actual spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$0.00
Monthly Totals (Planned)		$8,577.00	$17,154.00	$20,731.00	$24,308.00	$27,885.00	$31,462.00	$41,455.74	$51,449.48	$61,443.23	$65,020.23	$68,597.23	$72,174.23	$72,174.23	
ACTUAL TOTALS		$0.00	$0.00	$8,319.38	$12,850.63	$12,850.63	$12,850.63	$12,850.63	$12,850.63	$12,850.63	$12,850.63	$12,850.63	$12,850.63		$12,850.63

MC-21 Expenses

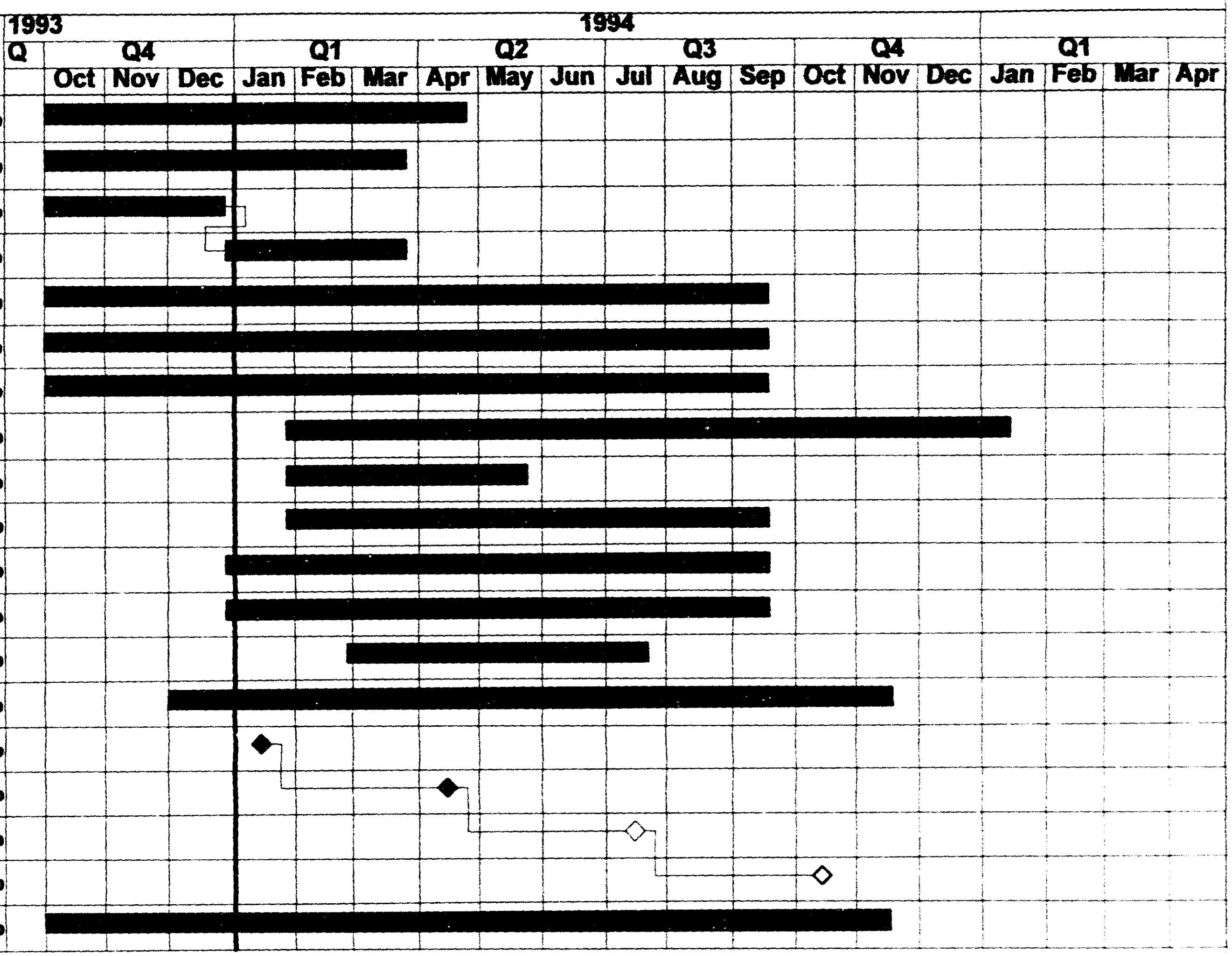
Granular Activated Carbon



INSTRUMENTATION

MC-7 MONOLAYER FILMS

#	WBS	Task Name	Dura	%Compl
1	1.0	Microbalance Syst	7M	95.00%
2	2.0	Vapor Generator	6M	100.00%
3	2.1	Construction	3M	100.00%
4	2.2	Testing	3M	100.00%
5	3.0	Polyion Multilayer	12M	50.00%
6	3.1	Model Substrates	12M	50.00%
7	3.2	SAW Crystals	12M	50.00%
8	4.0	Polyion Coating R	12M	60.00%
9	4.1	Non-coordination	4M	80.00%
10	4.2	Coordinating Coun	8M	40.00%
11	5.0	PolyionMultilayer	9M	2.50%
12	5.1	Non-coordinating	9M	5.00%
13	5.2	Coordinating Coun	5M	0.00%
14	6.0	Reporting	12M	50.00%
15	6.1	Quarterly Report 1	0d	100.00%
16	6.2	Quarterly Report 2	0d	100.00%
17	6.3	Quarterly Report 3	0d	0.00%
18	6.4	Final Report	0d	0.00%
19	7.0	Overall Work Com	14M	59.58%



▬ Critical
◇ Critical Milestone
▩ Free Float
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▬ Noncritical
◇ Noncritical Milestone
▨ Total Float (+)
▲ Effort %Complete
▬ Complete
◆ Complete Milestone
▧ Total Float (-)
▭ Summary
◇ Summary Milestone
— Baseline
▬ External
◆ External Milestone
-------- Non-Resource

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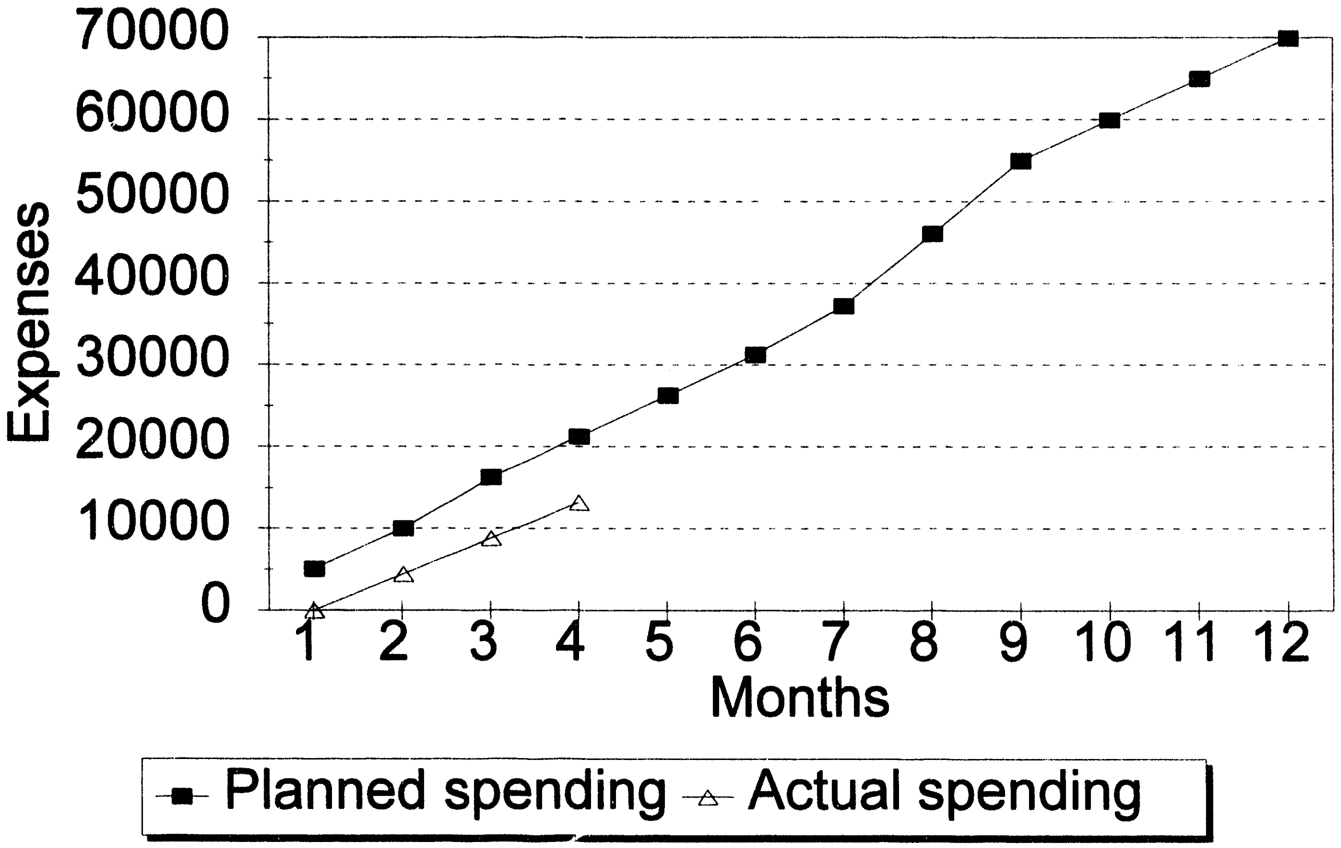
MC-7
Monolayer Films

		1 December	2 January	3 February	4 March	5 April	6 May	7 June	8 July	9 August	10 September	11 October	12 November	Projected Totals	Actual Totals
H. Finklea (p)	Planned spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$3,876.00	$3,876.00	$0.00	$0.00	$0.00	$7,752.00	
H. Finklea (a)	Actual spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$0.00
Res. Assistant (p)	Planned spending	$2,938.00	$2,938.00	$2,938.00	$2,938.00	$2,938.00	$2,938.00	$2,938.00	$2,938.00	$2,938.00	$2,938.00	$2,938.00	$2,938.00	$35,256.00	
Res. Assistant (a)	Actual spending	$0.00	$2,943.75	$2,943.75	$2,943.75	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$8,831.25
Graduate RA (p)	Planned spending	$1,460.00	$1,460.00	$1,460.00	$1,460.00	$1,460.00	$1,460.00	$1,460.00	$1,460.00	$1,460.00	$1,460.00	$1,460.00	$1,463.00	$17,523.00	
Graduate RA (a)	Actual spending	$0.00	$1,460.00	$1,460.00	$1,460.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$4,380.00
Supplies (p)	Planned spending	$608.00	$608.00	$608.00	$608.00	$608.00	$608.00	$608.00	$608.00	$608.00	$608.00	$608.00	$612.00	$7,300.00	
Supplies (a)	Actual spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$0.00
Equipment (p)	Planned spending	$0.00	$0.00	$1,250.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$1,250.00	
Equipment (a)	Actual spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$0.00
Travel (p)	Planned spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$876.00	$0.00	$0.00	$0.00	$0.00	$0.00	$876.00	
Travel (a)	Actual spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$0.00
Monthly Totals (Planned)		$5,006.00	$10,012.00	$16,268.00	$21,274.00	$26,280.00	$31,286.00	$37,168.00	$46,050.00	$54,932.00	$59,938.00	$64,944.00	$69,957.00	$69,957.00	
ACTUAL TOTALS		$0.00	$4,403.75	$8,807.50	$13,211.25	$13,211.25	$13,211.25	$13,211.25	$13,211.25	$13,211.25	$13,211.25	$13,211.25	$13,211.25		$13,211.25

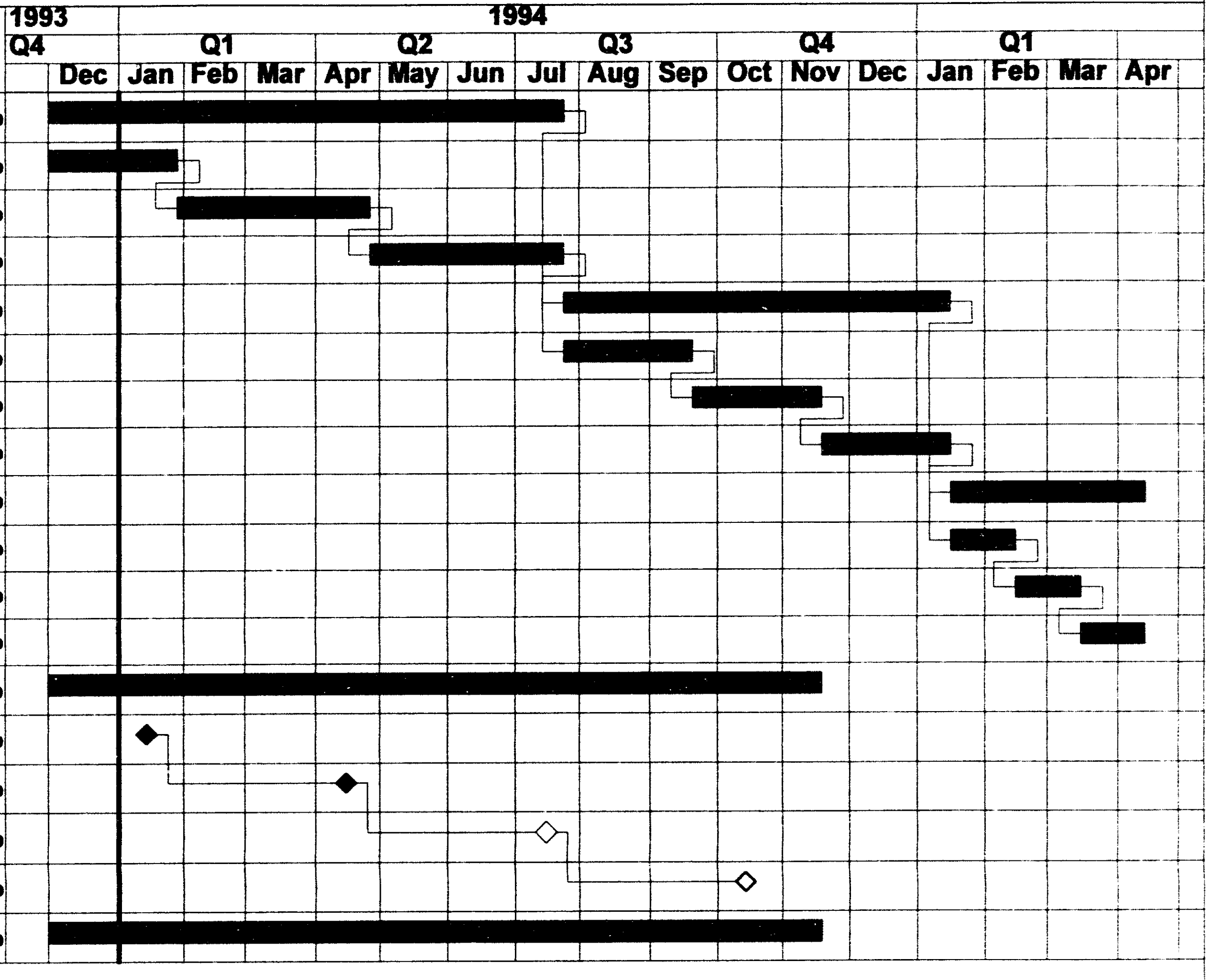
MC-7 Expenses

Monolayer Films



MC-22 Compact Mercuric iodide Detector

#	WBS	Task Name	Dura	%Compl
1	1.0	Literature Survey, Feasibi	8M	58.33%
2	1.1	Literature Survey	2M	100.00%
3	1.2	Feasibility Study	3M	75.00%
4	1.3	Detector Modeling	3M	0.00%
5	2.0	Processing the Detector	6M	0.00%
6	2.1	Chemical Etching	2M	0.00%
7	2.2	Annealing	2M	0.00%
8	2.3	Vacuum Exposure and Agi	2M	0.00%
9	3.0	Sensor Fabrication, Effici	3M	0.00%
10	3.1	Sensor Fabrication	1M	0.00%
11	3.2	Efficiency Study	1M	0.00%
12	3.3	Results and Recommendat	1M	0.00%
13	4.0	Report Writing	12M	50.00%
14	4.1	Quarterly Report 1	0d	100.00%
15	4.2	Quarterly Reoprt 2	0d	100.00%
16	4.3	Quarterly Report 3	0d	0.00%
17	4.4	Final Report	0d	0.00%
18	5.0	Overall Work Complete	12M	27.08%



■ 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			

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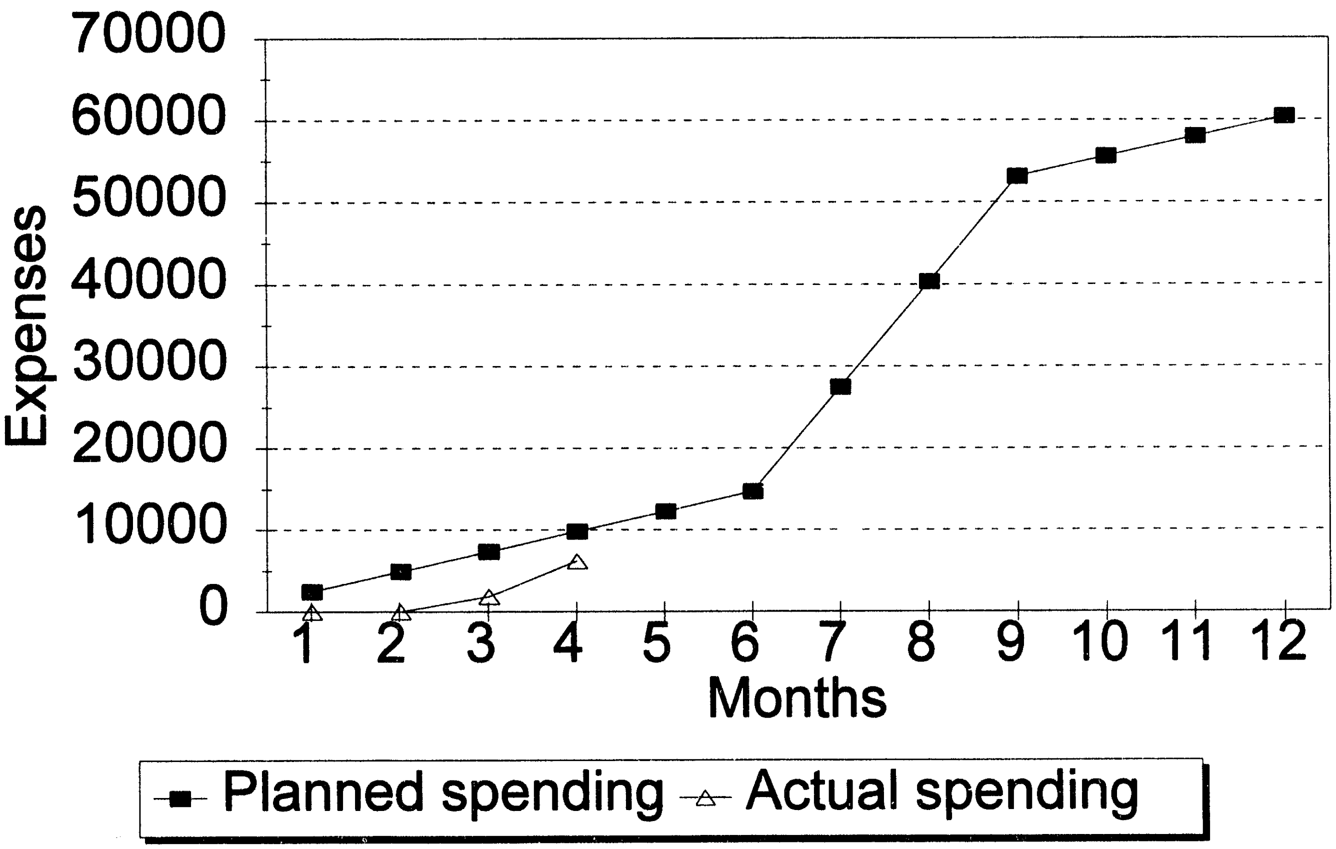
MC-22
Compact Mercuric Iodide Detector

		1 December	2 January	3 February	4 March	5 April	6 May	7 June	8 July	9 August	10 September	11 October	12 November	Projected Totals	Actual Totals
G. Nandi (p)	**Planned spending**	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$7,534.23	$7,534.23	$7,534.22	$0.00	$0.00	$0.00	$22,602.68	
G. Nandi (a)	**Actual spending**	$0.00	$0.00	$0.00	$2,904.90	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$2,904.90
D. Lyons (p)	**Planned spending**	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$2,825.10	$2,825.10	$2,825.10	$0.00	$0.00	$0.00	$8,475.30	
D. Lyons (a)	**Actual spending**	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$0.00
Graduate Student (p)	**Planned spending**	$1,168.37	$1,168.37	$1,168.37	$1,168.37	$1,168.37	$1,168.37	$1,168.37	$1,168.37	$1,168.37	$1,168.37	$1,168.37	$1,168.31	$14,020.38	
Graduate Student (a)	**Actual spending**	$0.00	$0.00	$1,740.00	$870.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$2,610.00
Supplies (p)	**Planned spending**	$608.33	$608.33	$608.33	$608.33	$608.33	$608.33	$608.33	$608.33	$608.33	$608.33	$608.33	$608.37	$7,300.00	
Supplies (a)	**Actual spending**	$0.00	$0.00	$0.00	$581.73	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$581.73
Other (p)	**Planned spending**	$304.17	$304.17	$304.17	$304.17	$304.17	$304.17	$304.17	$304.17	$304.17	$304.17	$304.17	$304.13	$3,650.00	
Other (a)	**Actual spending**	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$0.00
Travel (p)	**Planned spending**	$365.00	$365.00	$365.00	$365.00	$365.00	$365.00	$365.00	$365.00	$365.00	$365.00	$365.00	$365.00	$4,380.00	
Travel (a)	**Actual spending**	$0.00	$0.00	$103.60	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$103.60
Monthly Totals (Planned)		**$2,445.87**	**$4,891.74**	**$7,337.61**	**$9,783.48**	**$12,229.35**	**$14,675.22**	**$27,480.42**	**$40,285.62**	**$53,090.81**	**$55,536.68**	**$57,982.55**	**$60,428.36**	**$60,428.36**	
ACTUAL TOTALS		**$0.00**	**$0.00**	**$1,843.60**	**$6,200.23**	**$6,200.23**	**$6,200.23**	**$6,200.23**	**$6,200.23**	**$6,200.23**	**$6,200.23**	**$6,200.23**	**$6,200.23**		**$6,200.23**

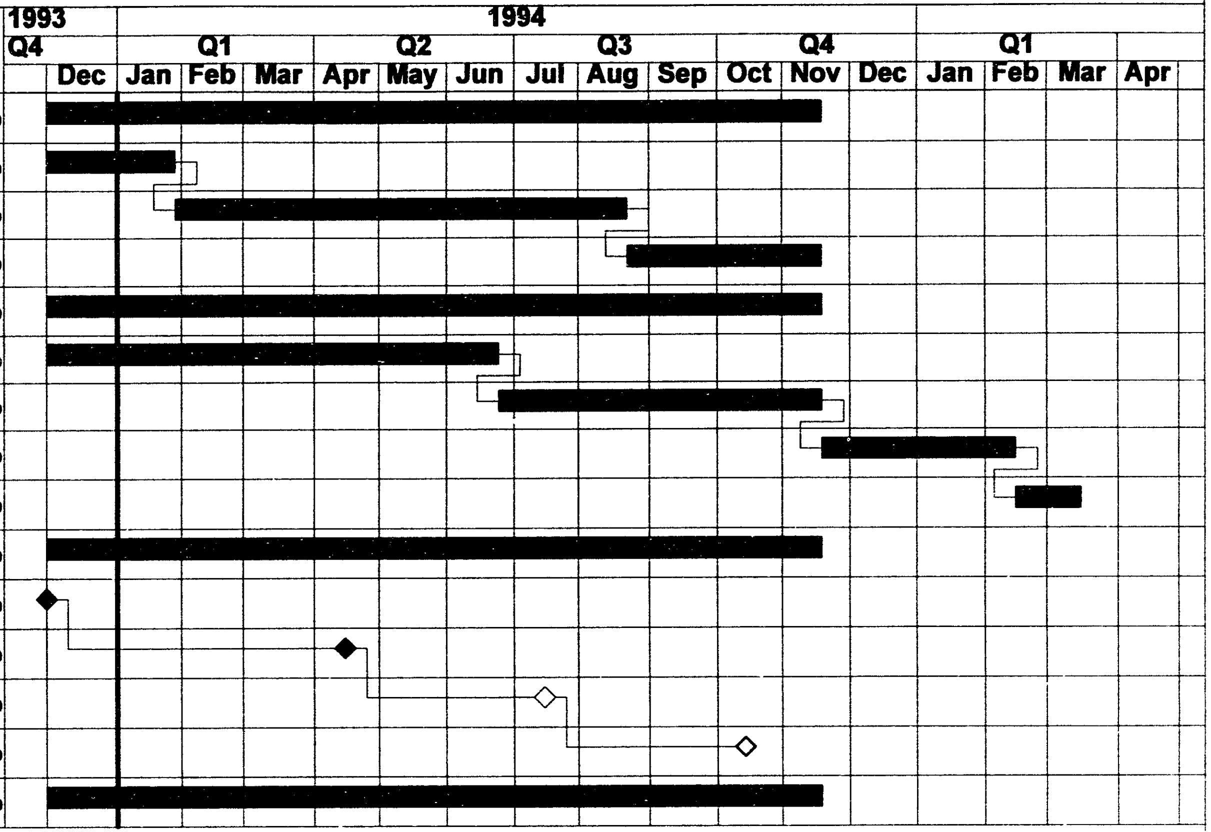
MC-22 Expenses

Compact Mercuric Iodide Detector



MC-23 IR and Mass Spec.

#	WBS	Task Name	Dura	%Compl
1	1.0	Evaluation of the IR spect	12M	33.33%
2	1.1	Literature Survey	2M	100.00%
3	1.2	Evaluation of the current li	7M	0.00%
4	1.3	Preparation of the report b	3M	0.00%
5	2.0	Performance evalution of	12M	62.50%
6	2.1	Precision	7M	100.00%
7	2.2	Quantitative Performance	5M	25.00%
8	3.0	Comparison of the IR and	3M	10.00%
9	4.0	Preparation of the Final R	1M	0.00%
10	5.0	Report Writing	12M	50.00%
11	5.1	Quarterly Report 1	0d	100.00%
12	5.2	Quarterly Report 2	0d	100.00%
13	5.3	Quarterly Report 3	0d	0.00%
14	5.4	Final Report	0d	0.00%
15	6.0	Overall Work Complete	12M	31.17%



▬ 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			

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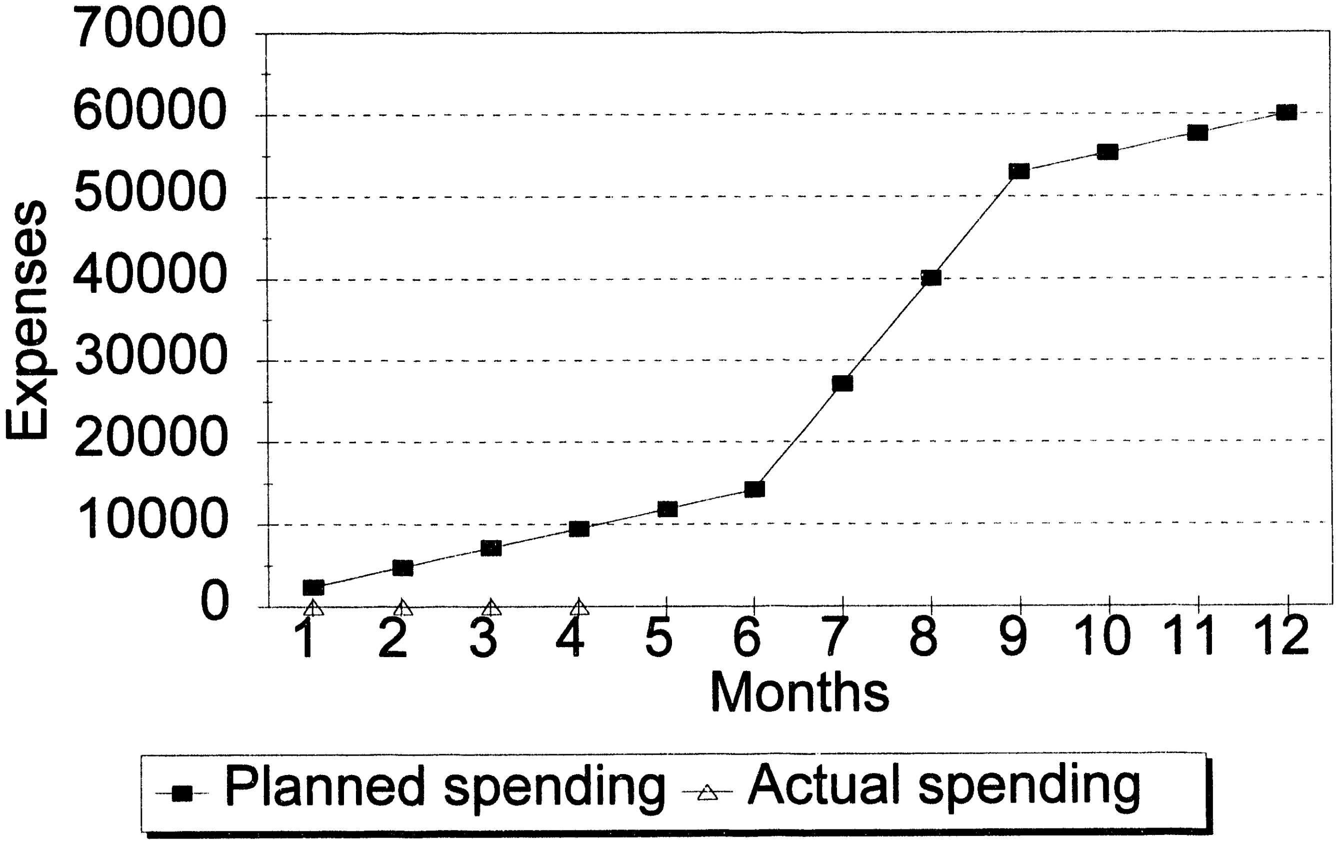
MC-23
IR and Mass Spec.

	1 December	2 January	3 February	4 March	5 April	6 May	7 June	8 July	9 August	10 September	11 October	12 November	Projected Totals	Actual Totals
M. Seehra (p) Planned spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$6,757.64	$6,757.64	$6,757.64	$0.00	$0.00	$0.00	$20,272.92	
M. Seehra (a) Actual spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$0.00
F. King (p) Planned spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$3,773.08	$3,773.08	$3,773.07	$0.00	$0.00	$0.00	$11,319.23	
F. King (a) Actual spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$0.00
Graduate Student 1 (p) Planned spending	$1,460.00	$1,460.00	$1,460.00	$1,460.00	$1,460.00	$1,460.00	$1,460.00	$1,460.00	$1,460.00	$1,460.00	$1,460.00	$1,460.00	$17,520.00	
Graduate Student 1 (a) Actual spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$0.00
Graduate Student 2 (p) Planned spending	$608.33	$608.33	$608.33	$608.33	$608.33	$608.33	$608.33	$608.33	$608.33	$608.33	$608.33	$608.37	$7,300.00	
Graduate Student 2 (a) Actual spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$0.00
Other (p) Planned spending	$121.67	$121.67	$121.67	$121.67	$121.67	$121.67	$121.67	$121.67	$121.67	$121.67	$121.67	$121.63	$1,460.00	
Other (a) Actual spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$0.00
Travel (p) Planned spending	$182.50	$182.50	$182.50	$182.50	$182.50	$182.50	$182.50	$182.50	$182.50	$182.50	$182.50	$182.50	$2,190.00	
Travel (a) Actual spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$0.00
Monthly Totals (Planned)	**$2,372.50**	**$4,745.00**	**$7,117.50**	**$9,490.00**	**$11,862.50**	**$14,235.00**	**$27,138.22**	**$40,041.44**	**$52,944.65**	**$55,317.15**	**$57,689.65**	**$60,062.15**	**$60,062.15**	
ACTUAL TOTALS	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**		**$0.00**

MC-23 Expenses

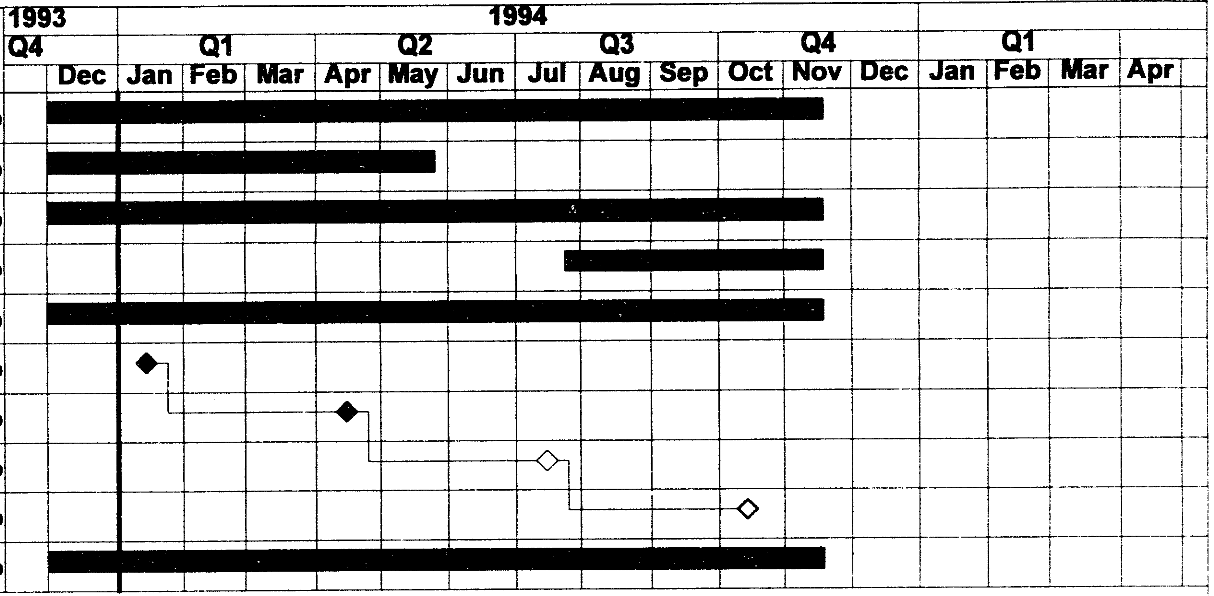
IR and Mass Spec.



TECHNOLOGY ASSESSMENTS

MC-1 Systematic Database

#	WBS	Task Name	Dura	%Compl
1	1.0	Data Collection	12M	50.00%
2	2.0	Software Development	6M	80.00%
3	3.0	Evaluation of Available D	12M	30.00%
4	4.0	Assessment of this Effort	4M	0.00%
5	5.0	Reporting	12M	50.00%
6	5.1	Quarterly Report 1	0d	100.00%
7	5.2	Quarterly Report 2	0d	100.00%
8	5.3	Quartlerly Report 3	0d	0.00%
9	5.4	Final Report	0d	0.00%
10	6.0	Overall Work Complete	12M	42.00%



- ▬ 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

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MC-1
Systematic Database

		1 December	2 January	3 February	4 March	5 April	6 May	7 June	8 July	9 August	10 September	11 October	12 November	Projected Totals	Actual Totals
Berg (p)	Planned spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$9,082.00	$0.00	$0.00	$0.00	$0.00	$9,082.00	
Berg (a)	Actual spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$0.00
Grad. Assist. (p)	Planned spending	$1,240.00	$1,240.00	$1,240.00	$1,240.00	$1,240.00	$1,240.00	$1,240.00	$1,240.00	$1,240.00	$1,240.00	$1,240.00	$1,240.00	$14,880.00	
Grad. Assist. (a)	Actual spending	$0.00	$0.00	$616.25	$3,081.25	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$3,697.50
Undergrad. (p)	Planned spending	$365.00	$365.00	$365.00	$365.00	$365.00	$365.00	$365.00	$365.00	$365.00	$365.00	$365.00	$365.00	$4,380.00	
Undergrad. (a)	Actual spending	$0.00	$0.00	$556.80	$600.30	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$1,157.10
Travel (p)	Planned spending	$0.00	$1,460.00	$0.00	$1,460.00	$0.00	$1,460.00	$0.00	$1,460.00	$0.00	$1,460.00	$0.00	$1,460.00	$8,760.00	
Travel (a)	Actual spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$0.00
Monthly Totals (Planned)		$1,605.00	$4,670.00	$6,275.00	$9,340.00	$10,945.00	$14,010.00	$15,615.00	$27,762.00	$29,367.00	$32,432.00	$34,037.00	$37,102.00	$37,102.00	
ACTUAL TOTALS		$0.00	$0.00	$616.25	$4,254.30	$4,854.60	$4,854.60	$4,854.60	$4,854.60	$4,854.60	$4,854.60	$4,854.60	$4,854.60		$4,854.60

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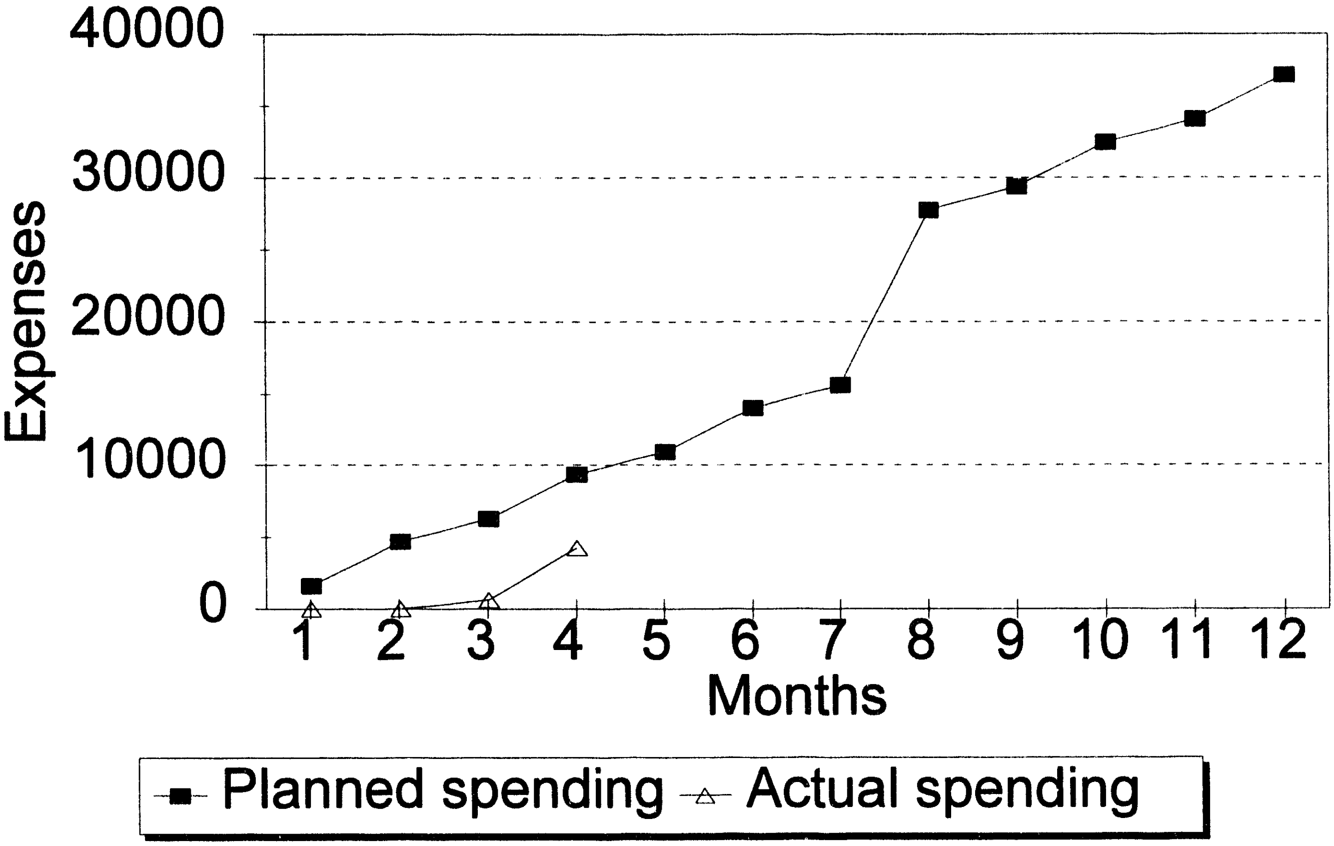
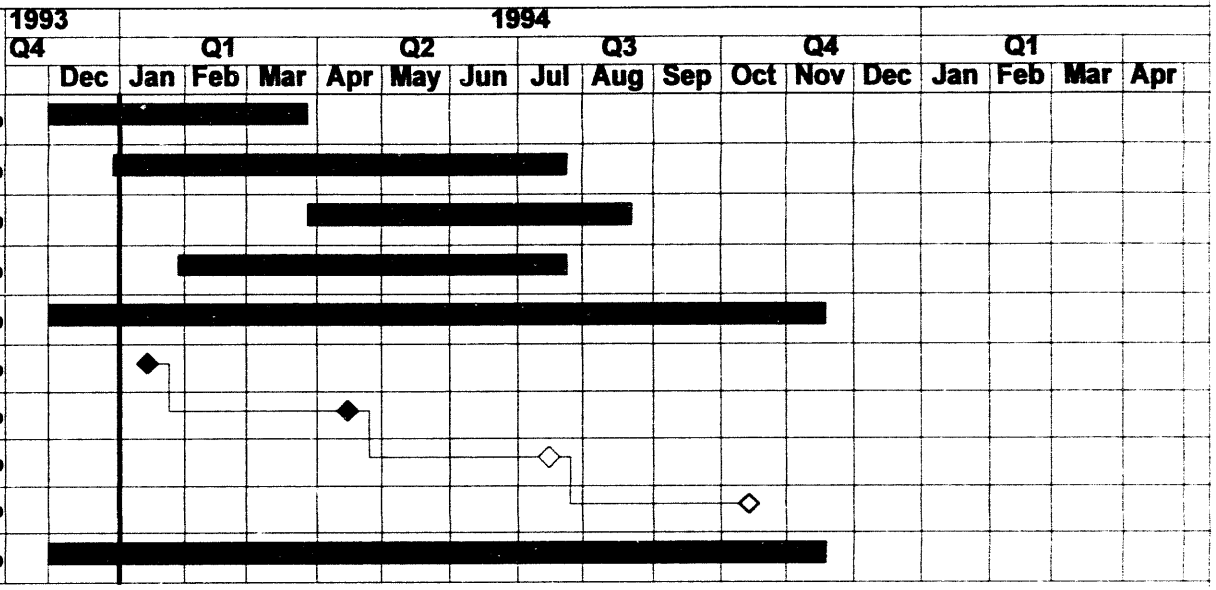
MC- 1 Expenses

Systematic Assess. Haz. Waste Clean-Up



MC-4 Duct Control Methods

#	WBS	Task Name	Dura	%Compl
1	1.0	Development of innovativ	4M	80.00%
2	2.0	Development of dust and	7M	40.00%
3	3.0	Development of mobile e	5M	10.00%
4	4.0	Development of dust/gas	6M	20.00%
5	5.0	Reporting	12M	50.00%
6	5.1	Quarterly Report 1	0d	100.00%
7	5.2	Quarterly Report 2	0d	100.00%
8	5.3	Quarterly Report 3	0d	0.00%
9	5.4	Final Report	0d	0.00%
10	6.0	Overall Work Complete	12M	40.00%



▬ 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			

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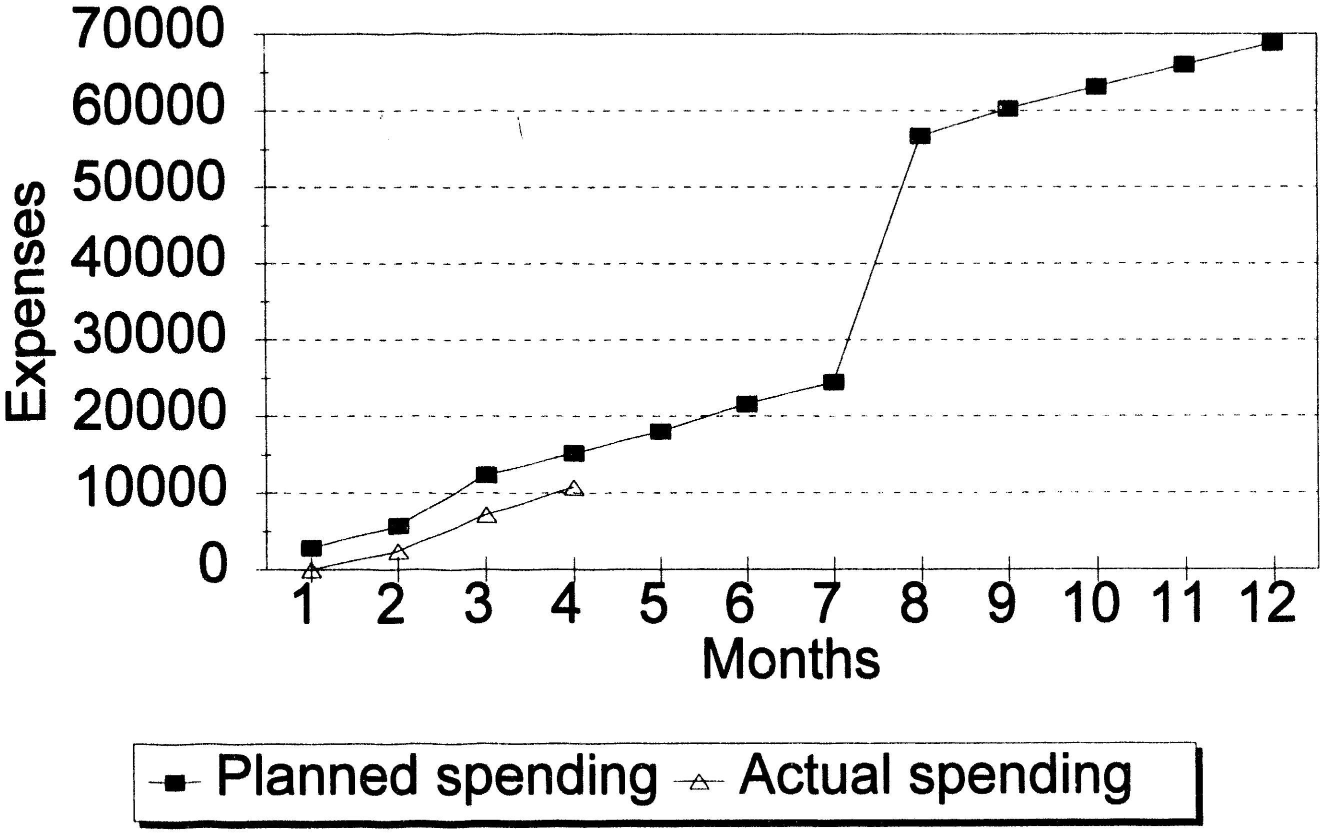
MC-4
Dust Control Methods

		1	2	3	4	5	6	7	8	9	10	11	12		
		December	**January**	**Fabruary**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**Projected Totals**	**Actual Totals**
S. Peng (p)	Planned spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$14,649.00	$0.00	$0.00	$0.00	$0.00	$14,649.00	
S. Peng (a)	Actual spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$0.00
F. Peng (p)	Planned spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$14,713.00	$0.00	$0.00	$0.00	$0.00	$14,713.00	
F. Peng (a)	Actual spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$0.00
Three Graduate Student (p)	Planned spending	$2,482.00	$2,482.00	$2,482.00	$2,482.00	$2,482.00	$2,482.00	$2,482.00	$2,482.00	$2,482.00	$2,482.00	$2,482.00	$2,482.00	$29,784.00	
Three Graduate Student (a)	Actual spending	$0.00	$2,409.00	$4,745.00	$3,577.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$10,731.00
Supplies (p)	Planned spending	$377.00	$377.00	$377.00	$377.00	$377.00	$377.00	$377.00	$377.00	$377.00	$377.00	$377.00	$377.00	$4,524.00	
Supplies (a)	Actual spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$0.00
Equipment (p)	Planned spending	$0.00	$0.00	$3,000.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$3,000.00	
Equipment (a)	Actual spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$0.00
Travel (p)	Planned spending	$0.00	$0.00	$730.00	$0.00	$0.00	$730.00	$0.00	$0.00	$730.00	$0.00	$0.00	$0.00	$2,190.00	
Travel (a)	Actual spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$0.00
Monthly Totals (Planned)		**$2,859.00**	**$5,718.00**	**$12,307.00**	**$15,166.00**	**$18,025.00**	**$21,614.00**	**$24,473.00**	**$56,694.00**	**$60,283.00**	**$63,142.00**	**$66,001.00**	**$68,860.00**	**$68,860.00**	
ACTUAL TOTALS		**$0.00**	**$2,409.00**	**$7,154.00**	**$10,731.00**	**$10,731.00**	**$10,731.00**	**$10,731.00**	**$10,731.00**	**$10,731.00**	**$10,731.00**	**$10,731.00**	**$10,731.00**		**$10,731.00**

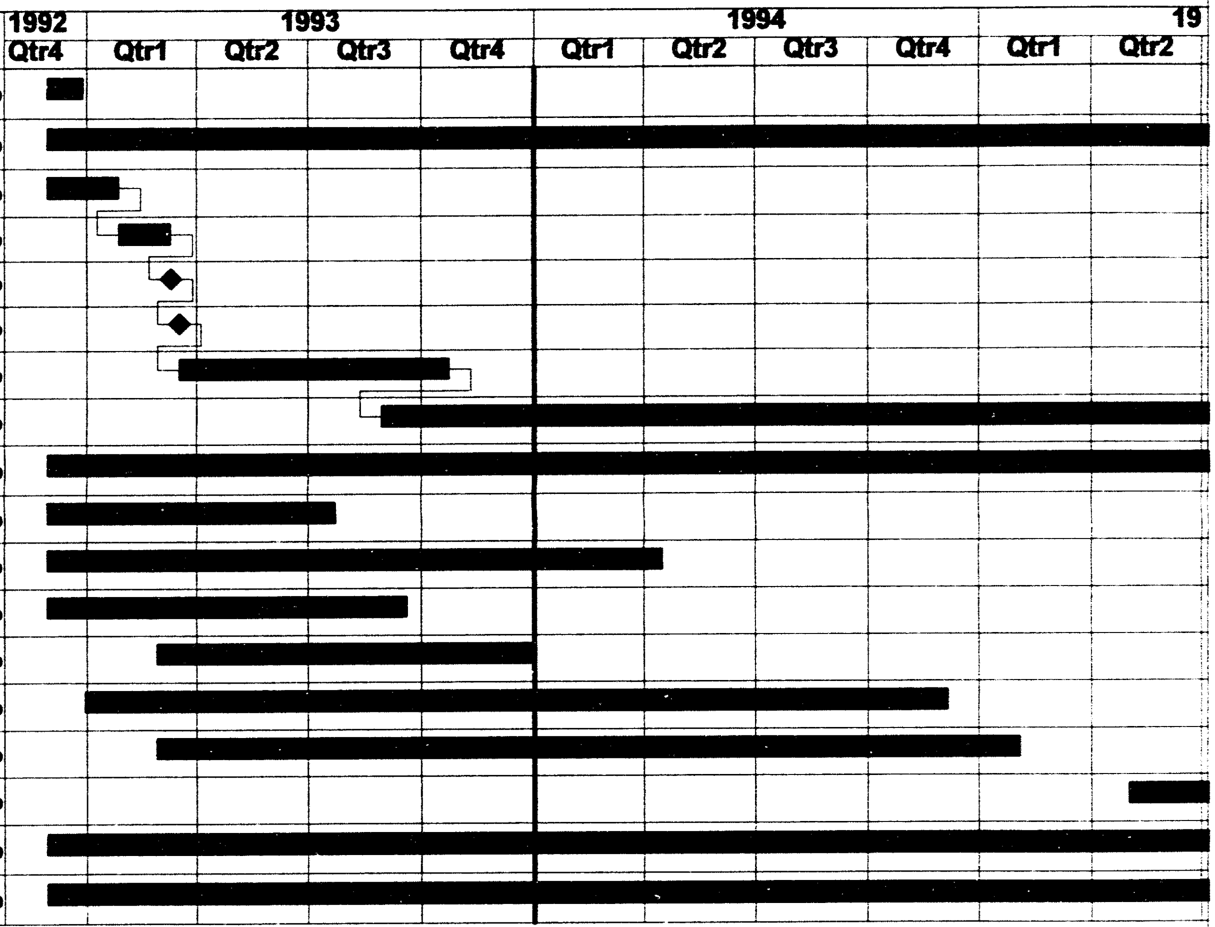
MC- 4 Expenses

Dust Control Methods



MC-9 Winfield Lock & Dam

#	WBS	Task Name	Dura	%Compl
1	1.0	**NEPA Documentation**	1M	100.00%
2	2.0	**Resource Group Develop**	60M	46.67%
3	2.1	**Gather Members**	2M	100.00%
4	2.1.1	Contact members	6w	100.00%
5	2.1.2	Send Formal requests	0d	100.00%
6	2.1.3	Meet with menbers	0d	100.00%
7	2.2	**Gather resources**	7.5M	20.00%
8	2.3	**Maintain Resource Group**	48M	20.00%
9	3	**WINFIELD**	60M	32.86%
10	3.1	**Eval. Baseline Risk**	8M	30.00%
11	3.2	**Eval. Storage Plans**	7.1M	100.00%
12	3.3	**Eval. Decon/Demo Plans**	10M	0.00%
13	3.4	**Eval. Removal Risk Analys**	.43M	100.00%
14	3.5	**Eval. Excav. & Storage Pla**	24M	0.00%
15	3.6	**Eval. Remedial Action Fea**	24M	0.00%
16	3.7	**Eval. Remed. Action Plan**	28M	0.00%
17	4.0	**Reports**	60M	27.62%
18	5.0	**Overall work Complete**	60M	51.79%



▬ 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

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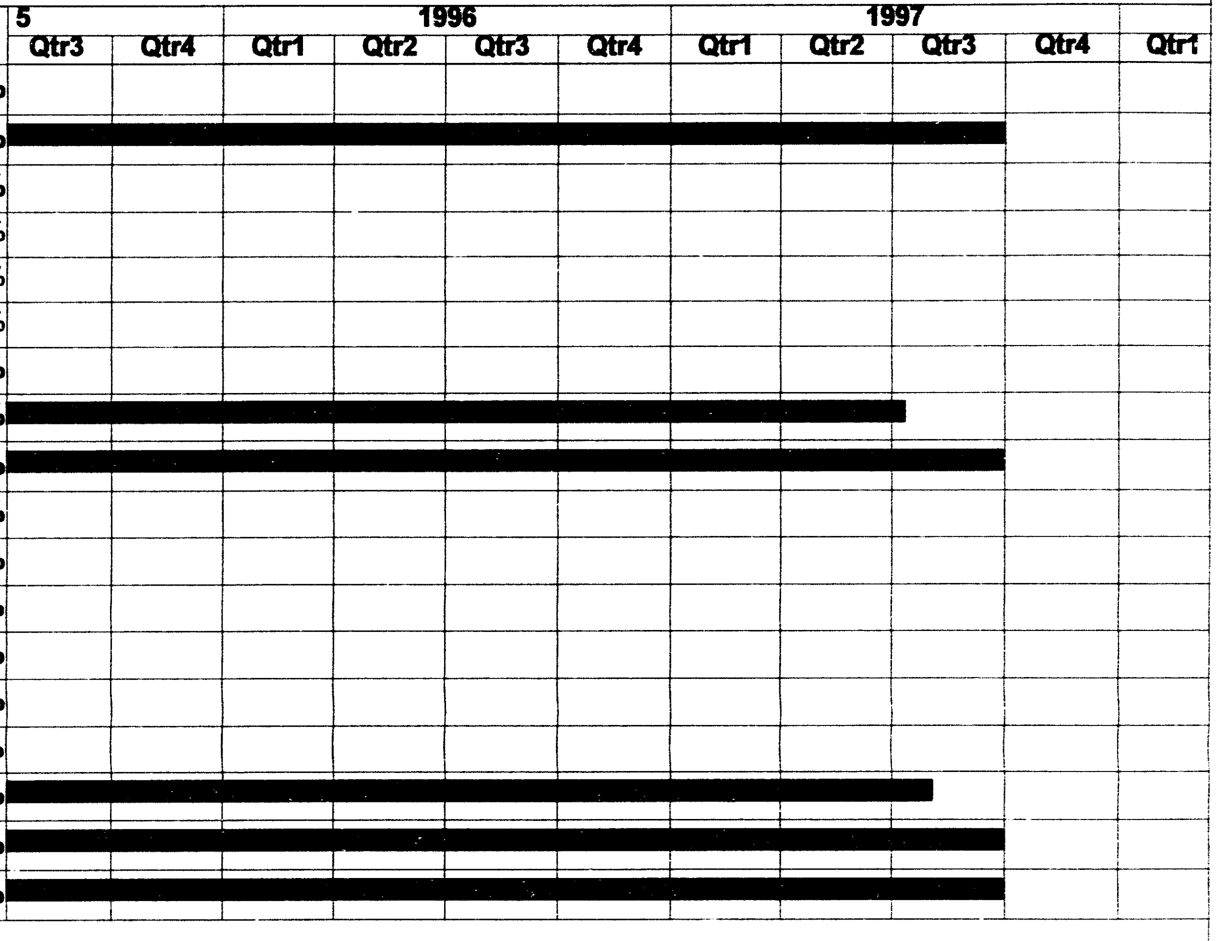
MC-9 Winfield Lock & Dam

#	WBS	Task Name	Dura	%Compl
1	1.0	**NEPA Documentation**	1M	100.00%
2	2.0	**Resource Group Develop**	60M	46.67%
3	2.1	**Gather Members**	2M	100.00%
4	2.1.1	Contact members	6w	100.00%
5	2.1.2	Send Formal requests	0d	100.00%
6	2.1.3	Meet with menbers	0d	100.00%
7	2.2	**Gather resources**	7.5M	20.00%
8	2.3	**Maintain Resource Group**	48M	20.00%
9	3	**WINFIELD**	60M	32.86%
10	3.1	**Eval. Baseline Risk**	8M	30.00%
11	3.2	**Eval. Storage Plans**	7.1M	100.00%
12	3.3	**Eval. Decon/Demo Plans**	10M	0.00%
13	3.4	**Eval. Removal Risk Analys**	.43M	100.00%
14	3.5	**Eval. Excav. & Storage Pla**	24M	0.00%
15	3.6	**Eval. Remedial Action Fea**	24M	0.00%
16	3.7	**Eval. Remed. Action Plan**	28M	0.00%
17	4.0	**Reports**	60M	27.62%
18	5.0	**Overall work Complete**	60M	51.79%



■ 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			

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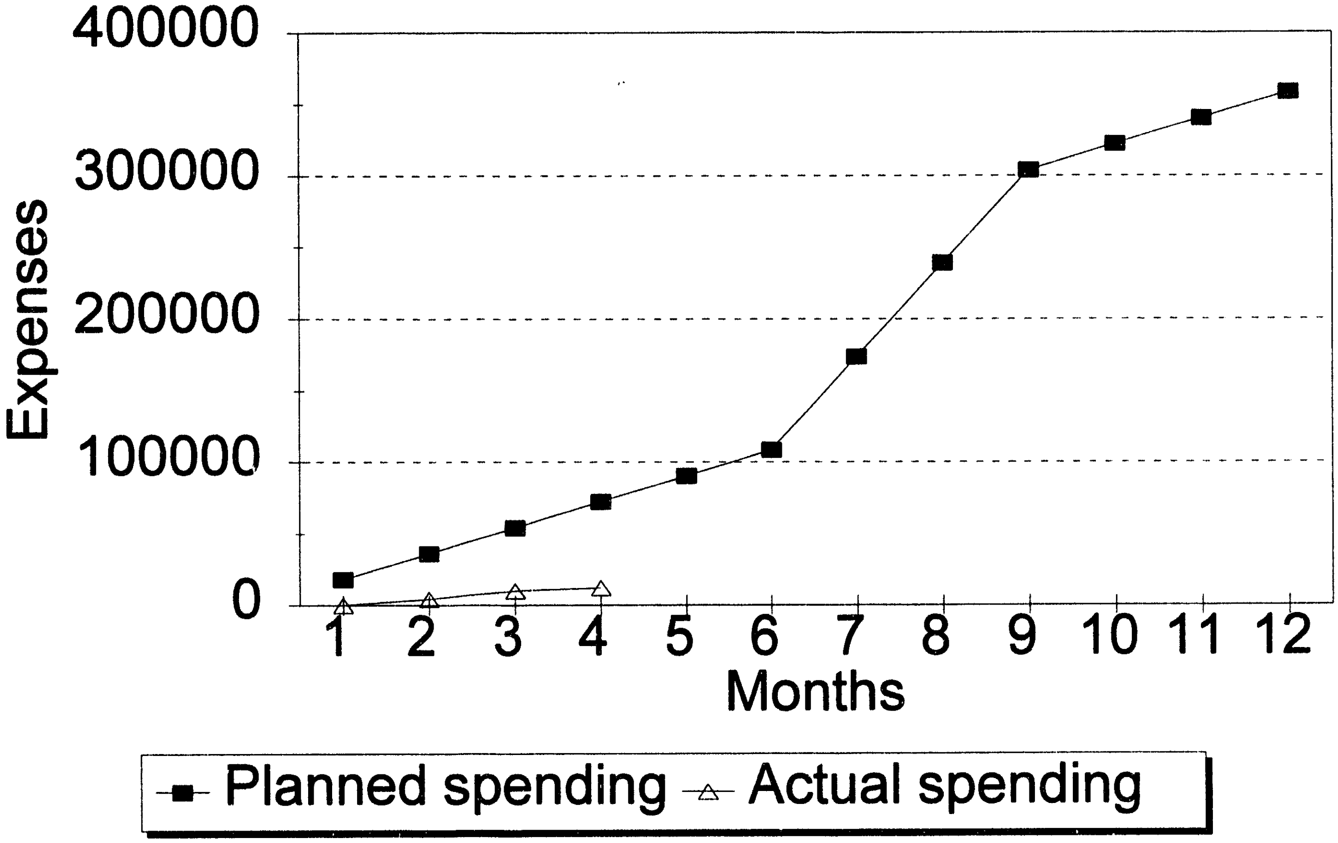
MC-9
Winfield Lock & Dam

		1 December	2 January	3 February	4 March	5 April	6 May	7 June	8 July	9 August	10 September	11 October	12 November	Projected Totals	Actual Totals
R. Lovett (p)	Planned spending	$5,191.00	$5,191.00	$5,191.00	$5,191.00	$5,191.00	$5,191.00	$5,191.00	$5,191.00	$5,191.00	$5,191.00	$5,191.00	$5,191.00	$62,292.00	
R. Lovett (a)	Actual spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$0.00
N. Reese (p)	Planned spending	$3,179.00	$3,179.00	$3,179.00	$3,179.00	$3,179.00	$3,179.00	$3,179.00	$3,179.00	$3,179.00	$3,179.00	$3,181.00	$3,181.00	$38,152.00	
N. Reese (a)	Actual spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$0.00
Resource Group (p)	Planned spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$47,085.00	$47,085.00	$47,085.00	$0.00	$0.00	$0.00	$141,255.00	
Resource Group (p)	Actual spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$0.00
Students (p)	Planned spending	$940.00	$940.00	$940.00	$940.00	$940.00	$940.00	$940.00	$940.00	$940.00	$940.00	$940.00	$942.00	$11,282.00	
Students (a)	Actual spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$0.00
Supplies/Other (p)	Planned spending	$3,102.50	$3,102.50	$3,102.50	$3,102.50	$3,102.50	$3,102.50	$3,102.50	$3,102.50	$3,102.50	$3,102.50	$3,102.50	$3,102.50	$37,230.00	
Supplies/Other (a)	Actual spending	$0.00	$2,148.18	$972.28	$1,396.02	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$4,516.48
Travel (p)	Planned spending	$5,675.75	$5,675.75	$5,675.75	$5,675.75	$5,675.75	$5,675.75	$5,675.75	$5,675.75	$5,675.75	$5,675.75	$5,675.75	$5,675.75	$68,109.00	
Travel (a)	Actual spending	$0.00	$2,254.94	$4,850.70	$459.40	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$7,565.04
Monthly Totals (Planned)		**$18,088.25**	**$36,176.50**	**$54,264.75**	**$72,353.00**	**$90,441.25**	**$108,529.50**	**$173,702.75**	**$238,876.00**	**$304,049.25**	**$322,137.50**	**$340,227.75**	**$358,320.00**	**$358,320.00**	
ACTUAL TOTALS		**$0.00**	**$4,403.12**	**$10,226.10**	**$12,081.52**	**$12,081.52**	**$12,081.52**	**$12,081.52**	**$12,081.52**	**$12,081.52**	**$12,081.52**	**$12,081.52**	**$12,081.52**		**$12,081.52**

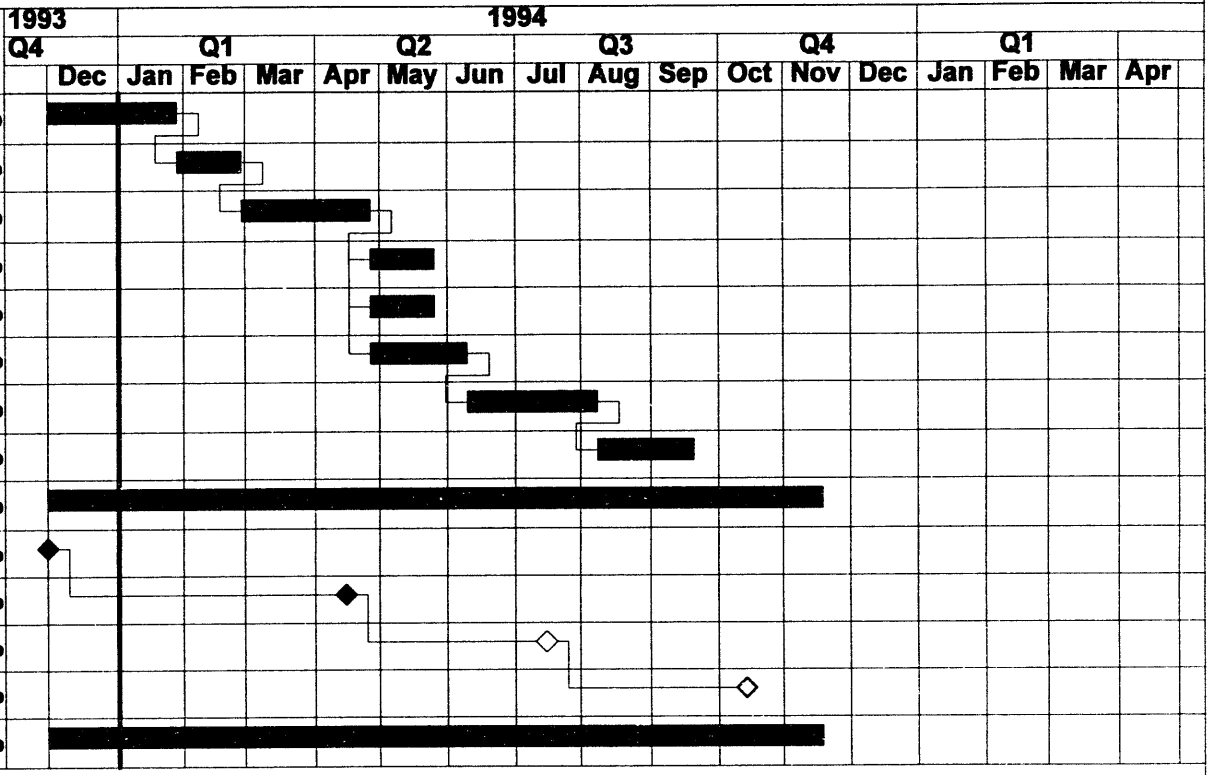
MC-9 Expenses

Winfield Lock and Dam



MC-24 Economic Assessment

#	WBS	Task Name	Dura	%Compl
1	1.0	Develop comprehensive li	2M	50.00%
2	1.1	Identify what is currently a	1M	50.00%
3	2.0	Assess the ability to ident	2M	1.67%
4	2.1	Determine the extent to wh	1M	5.00%
5	2.2	Evaluate the feasibility of	1M	0.00%
6	2.3	Identify any additional res	1.5M	0.00%
7	3.0	Specify characteristics of	2M	0.00%
8	3.1	Prepare a proposal for a c	1.5M	0.00%
9	4.0	Report Writing	12M	50.00%
10	4.1	Quarterly Report 1	0d	100.00%
11	4.2	Quarterly Report 2	0d	100.00%
12	4.3	Quarterly Reoprt 3	0d	0.00%
13	4.4	Final Report	0d	0.00%
14	5.0	Overall Work Complete	12M	25.42%



▬ 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

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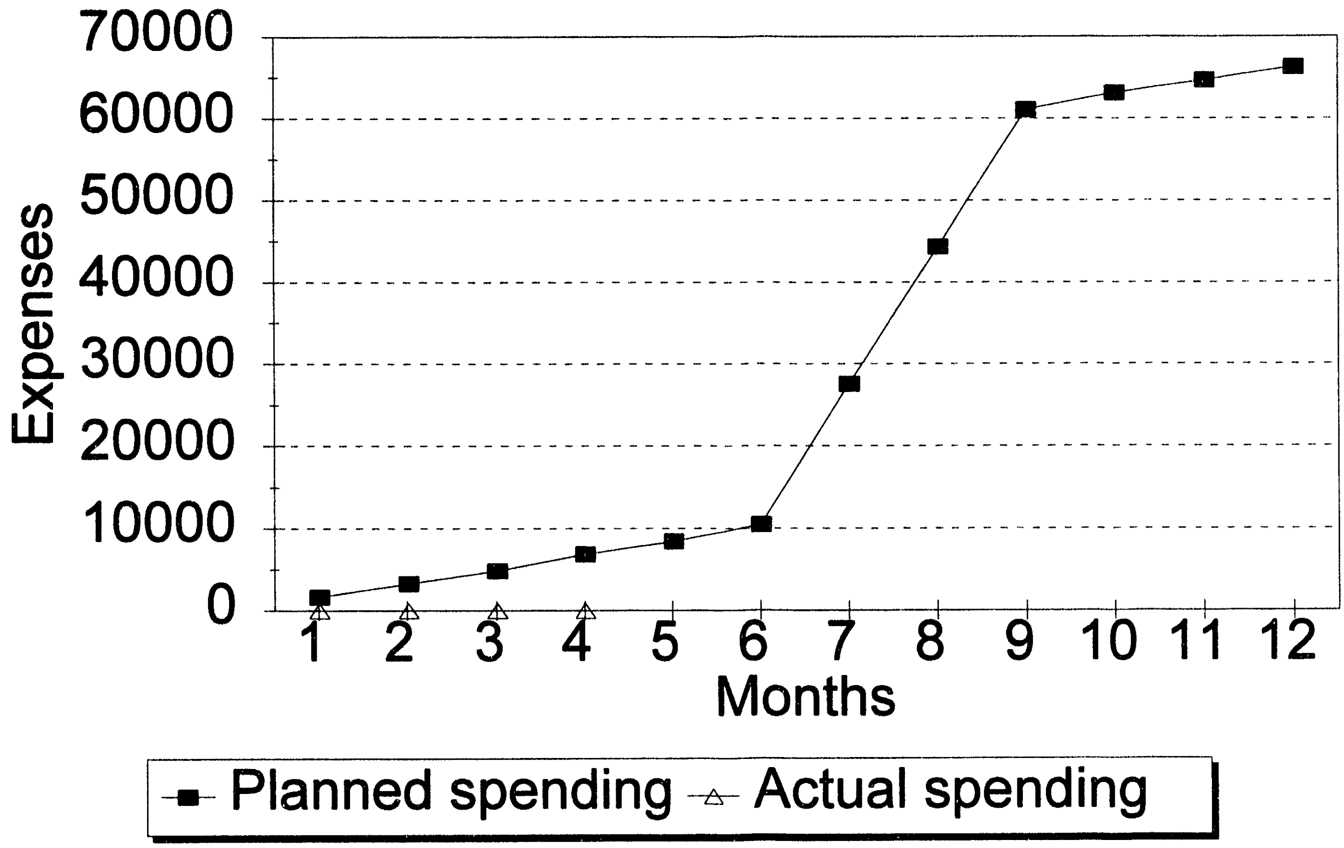
MC-24
Economic Assessment

		1	2	3	4	5	6	7	8	9	10	11	12		
		December	January	February	March	April	May	June	July	August	September	October	November	Projected Totals	Actual Totals
J. Fletcher (p)	Planned spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$3,658.82	$3,658.82	$3,658.82	$0.00	$0.00	$0.00	$10,976.46	
J. Fletcher (a)	Actual spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$0.00
A. Isserman (p)	Planned spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$4,507.60	$4,507.60	$4,507.60	$0.00	$0.00	$0.00	$13,522.80	
A. Isserman (a)	Actual spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$0.00
W. Trumbull (p)	Planned spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$6,976.11	$6,976.11	$6,976.11	$0.00	$0.00	$0.00	$20,928.33	
W. Trumbull (a)	Actual spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$0.00
Graduate Student (p)	Planned spending	$1,255.60	$1,255.60	$1,255.60	$1,255.60	$1,255.60	$1,255.60	$1,255.60	$1,255.60	$1,255.60	$1,255.60	$1,255.60	$1,255.60	$15,067.20	
Graduate Student (a)	Actual spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$0.00
Student (p)	Planned spending	$243.33	$243.33	$243.33	$243.33	$243.33	$243.33	$243.33	$243.33	$243.33	$243.33	$243.33	$243.58	$2,920.21	
Student (a)	Actual spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$0.00
Supplies (p)	Planned spending	$121.66	$121.66	$121.66	$121.66	$121.66	$121.66	$121.66	$121.66	$121.66	$121.66	$121.66	$121.74	$1,460.00	
Supplies (a)	Actual spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$0.00
Travel (p)	Planned spending	$0.00	$0.00	$0.00	$365.00	$0.00	$365.00	$365.00	$0.00	$0.00	$365.00	$0.00	$0.00	$1,460.00	
Travel (a)	Actual spending	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00		$0.00
Monthly Totals (Planned)		**$1,620.59**	**$3,241.18**	**$4,861.77**	**$6,847.36**	**$8,467.95**	**$10,453.54**	**$27,581.66**	**$44,344.78**	**$61,107.90**	**$63,093.49**	**$64,714.08**	**$66,335.00**	**$66,335.00**	
ACTUAL TOTALS		**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**		**$0.00**

MC-24 Expenses

Economic Assessment



QUARTERLY TECHNICAL PROGRESS REPORTS

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BIO-REMEDIATION

IN SITU BIOREMEDIATION OF CHLORINATED ORGANIC SOLVENTS
(MC-2b)

Quarterly Technical Progress Report
for Period January 1 through March 31, 1994

Work Performed Under
Contract Number: 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
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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 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.

TCE degradation studies under aerobic conditions in microcosms were continued. The degradation of TCE was monitored using aerobic cultures with a minimum detection limit of 5 ppb during this quarter. The use of control samples ensured that biodegradation is occurring. Three sets of samples (Set 3, Set 4, and Set 5) were used to determine TCE degradation rates for a maximum period of 1069 hours. Attention was focused on the determination of degradation rates. Sample results for sets 3, 4, 5, showed significant degradation of TCE. All samples, including headspace controls and killed cultures, showed that TCE disappearance occurred at a rate that decreased with time. The results from Set 5 where initial concentrations were varied indicate that the degradation rates of the viable (active) culture samples at the higher TCE concentration are much faster than at the lower TCE concentration. Future aerobic microcosm experiments will compare TCE removal rates when using methane, methanol or acetate as the energy source and to determine the optimum concentration of the selected energy source. Experiments for this quarter will also compare transformations by particulate and soluble forms of MMO.

Anaerobic microcosm studies (Set 5 and Set 6) were also continued for a period of 1800 hours (80 days) to better establish biodegradation and partioning of the TCE between the gas and liquid phases and sorption on the biological solids. The results showed some reductive dehalogenation and biodegradation of the TCE. The general trend experienced during microcosm studies 5 and 6 support successful anaerobic biological activity. Several short-term anaerobic microcosm experiments are planned to further evaluate removal rates using two different primary substrates.

The original column design as presented in last quarter report was modified somewhat to reduce dead space at the inlet and outlet. Most of the new fittings ordered as well as the necessary pumps have been received and operation of the anaerobic column is anticipated in early May.

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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 biodegration 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 RESULTS AND DISCUSSION

In order to accomplish project objectives in a timely manner, the research is being conducted in two complementary paths as will be discussed in detail in the following sections. Studies to enhance the aerobic degradation of target compounds by methanotrophs are being performed by Shiemke (biochemistry) while Sack and Carriere (environmental engineering) are working on anaerobic reductive dehalogenation using methanogens. Information gained from the separate aerobic and anaerobic research studies will then be combined to optimize sequential anaerobic/aerobic mineralization of the chlorinated solvents.

Data collection was hindered during the early part of this quarter due to GC optimization and maintenance. As was mentioned in the previous quarterly report, a consistent and steady increase in sensitivity of the new electrolytic conductivity detector with time was noted and unexplained. In addition, inclement weather delayed the replacement of the hydrogen gas cylinder allowing solvent to get into the reaction tube and significantly decreasing the detector signal. Due to difficulties with solvent clogging experienced while replacing the reaction tube, a service technician was called in from OI. During the two-day service call, the reaction tube was replaced, all solvent lines replaced and flushed, and GC conditions for TCE analysis at 5-200 ppb were improved. Further testing for the condition noted previously using TCE standards of known concentration revealed a consistent decrease rather than increase in detector sensitivity. This was shown to be caused by the use of screw cap vials for the standard solutions which were kept at room temperatures. This condition was

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remedied by the replacement of these vials with crimp-top, Teflon sealed vials. Though standard responses do vary with time, the amount of variation has been slight and not steady in either direction. The previous consistent increase noted remains unexplained by both project analysts and the OI service representative. The instrument is now performing well with careful attention being paid to variations and routine preventive maintenance of the equipment.

We are now able to measure TCE successfully in the Civil and Environmental Department after the purchase of a new detector and purge and trap for the GC. As noted in our last report, the Biochemistry lab had identified the need for a new detector and ordered the unit when the new funds became available. The new detector was recently received. Once the detector is installed and optimum conditions for TCE analysis are determined, sample analysis will begin at the Biochemistry Lab at an anticipated rate of five minutes per sample using direct aqueous injection.

5.1 Aerobic Batch Studies Using Methanotrophs to Evaluate Optimum Concentration of Growth Enhancing Agents in Both Liquid and Soil Cultures

The goal of our studies of aerobic biodegradation of TCE is to find conditions that enhance the rate of TCE degradation by methanotrophic bacteria. Our approach involves measuring the rate of TCE breakdown in pure cultures of methanotrophic bacteria, under various conditions. We are primarily interested in measuring the effect of compounds that are expected to enhance the metabolic rate of the bacteria. These include compounds that the bacteria can use as sources of reducing equivalents, such as methanol and formate, as well as peroxide as a source of oxygen. We will also investigate the effect of metal chelators that may alter the nature of the oxidative enzymes expressed by the bacteria, to determine which enzymes are most efficient for TCE degradation.

5.1.1 Aerobic TCE Degradation Rate Studies

The purge and trap gas chromatograph system in the Department of Civil Engineering continued to be the only available instrument for TCE concentration analysis during this quarter. Data acquisition and experimental implementation have been somewhat limited by the thirty minute per sample analysis period required by this system. Our current method of aqueous phase TCE analysis uses 0.5 ml sample injections into 5.0 ml purge water in order to fall within the range of concentrations for the standard curve. Standard curves were prepared using two primary standards diluted daily to secondary concentrations of 10 ppm. Portions of this secondary standard are injected into 5.0 ml purge water in order to generate a standard curve ranging from TCE concentrations of 5 ppb to 200 ppb. A total of eight standard curves were made over a two month period with a maximum curve slope deviation of twenty percent and maximum duplicate sample deviation of eight percent.

At least one standard within the expected sample TCE concentration ranges was run daily to ensure instrument consistency. Additional standards or standard curves were run following periods of expected power outages, gas cylinder changes and reaction tube replacement. TCE concentrations of unknowns were determined by applying the average of the equations for these standard curves to resulting chromatograph curve areas. The Department of Biochemistry has acquired just recently a stand alone, permanent electrolytic conductivity detector for the SRI gas chromatograph used previously for this project and is awaiting the accompanying installation and user's manual. Once installation is complete and optimum conditions for TCE analysis are determined using this instrument, sample analysis will begin at an anticipated rate of five minutes per sample analysis using direct aqueous injection.

Aerobic TCE degradation experiments are in progress using *Methylococcus capsulatus* bacteria grown in nitrate mineral salts medium (NMS), phosphate buffer solution, vitamins and copper sulfate under 20% methane by volume. Three sets of samples (sets three, four, and five) were prepared and TCE degradation rates were measured for a maximum period of 1069 hours (set three). Analysis of samples sets three, four, and five were initiated on February 9, 16, and 26, respectively. Analysis of all three sets is ongoing, with only one sample in set three reaching levels below the 5 ppb drinking water limit thus far. All microcosm samples were prepared in 125 ml autoclaved amber bottles with Teflon-lined silica rubber screw cap seals. Each set contained control samples with no bacteria (headspace controls) as well as control samples containing bacteria that had been killed by addition of 50 mg of sodium azide (killed cultures) and samples with viable bacteria cultures. A stock media of NMS was sterilized by autoclave and supplemented with filter sterilized phosphate buffer, vitamins and copper sulfate in proportions identical to those of the growth medium. Each sample bottle contained 25 ml of this solution. The remaining contents of each bottle were chosen according to the type of control or sample desired as summarized below.

SET 3 (5 samples)

Headspace Controls (C12): 25 ml micropure water

Methanotroph Samples (S12, S22): 25 ml M. capsulatus culture
(OD_{540}=1.5)

Killed Cultures (K12, K22): 25 ml M. capsulatus culture
(OD_{540}=1.5)
50 mg - sodium azide

A second headspace control sample from Set 3 was contaminated during preparation and was discarded. A syringe was used to deliver 20% methane by volume to each bottle through the Teflon-lined silica septa immediately after closing and sealing the bottle. The bottles were transferred immediately to the Engineering Sciences Building and 78.3 ul of a 1075 ppm solution of TCE in methanol was added to each bottle by syringe. Initial TCE concentrations were taken one hour after TCE addition to allow for headspace equilibration. Samples were analyzed periodically and maintained on a shaker at room temperature.

SET 4 (6 samples)

Headspace Controls (C13, C23): 25 ml micropure water

Methanotroph Samples (S13, S23): 25 ml M. capsulatus culture
(OD_{540}=1.0)

Killed Cultures (K13, K23): 25 ml M. capsulatus culture
(OD_{540}=1.0)
50 mg - sodium azide

As with Set 3, a syringe was used to deliver 20% methane by volume to each bottle through the Teflon-lined silica septa immediately after sealing the bottle. The bottles were transferred immediately to the Engineering Sciences Building and 78.3 ul of a 1075 ppm solution of TCE in methanol was added to each bottle. Results from TCE analysis of Set 3 suggested headspace equilibrium might not have been reached after one hour. For this reason, initial TCE concentrations were measured after 24 hours for these samples from Set 4. TCE concentrations were determined periodically and samples were maintained on a shaker at room temperature between analyses.

SET 5 (9 samples)

Headspace Controls (C14, C24, C34): 25 ml micropure water

Methanotroph Samples (S14, S24, S34): 25 ml M. capsulatus culture
(OD_{540}=1.7)

Killed Cultures (K14, K24, K34): 25 ml M. capsulatus culture
(OD_{540}=1.7)
50 mg - sodium azide

Methane was added at 20% by volume in the same manner previously described, and the microcosm bottles transferred immediately to the Engineering Science Building. 78.3 ul of a 1075 ppm solution of TCE in methanol was added to samples C14, C24, S14, S24, K14, and K24. Five-fold greater TCE concentrations were added to samples C34, S34 and K34c (391.5 ul of a 1075 ppm standard in methanol) to determine the effect of concentration on degradation rate. It has been found previously that the rate of degradation of organic compounds is directly proportional to their concentration (Riser-Roberts, 1992). Samples in Set 5 were analyzed after 15 hours for initial TCE concentrations. The concentrations of TCE in samples C34, S34 and K34 were determined from GC peak areas and corresponding concentrations of a 5-fold sample dilution (0.1 ml in 5 ml purge water). This concentration was multiplied by 5 to correct for the dilution. Although this inevitably introduced some level of error into the measured concentration values, it was required due to the high sensitivity of the purge and trap gas chromatograpy system.

Between analyses periods, all samples were inverted and maintained on a shaker at room temperatures ranging between 25 °C and 30°C. No additional methane was added after the initial injection of 20% by volume. There were three known power outages during this period. The duration of each is unknown and their effect on the experimental results has not been taken into account. The effect of temperature on TCE concentration in the aqueous phase was not monitored. It is known that with increased temperature, TCE concentration partitions preferentially into the vapor phase. Once analysis begins in the biochemistry lab, it will be feasible to maintain these microcosms on a shaker at constant temperature.

Sample results for Sets 3, 4, and 5 are plotted in Figures 1, 2, and 3, respectively. In all cases, samples with viable bacteria showed significant degradation of TCE. In fact, one of these samples demonstrated complete degradation to below 5 ppb over a 973 hour period. All samples, including headspace controls and killed cultures, showed TCE disappearance at a rate that decreased with time. TCE disappearance rates for these samples are listed in Table 1.

The rates of TCE degradation in viable cultures is proportional to the initial biomass in the cultures, as measured by the optical density at 540nm. Thus, the more bacteria available, the greater the rate of degradation. In contrast, the disappearance rates for the headspace controls and killed culture controls in all three sets remain constant between 0.70 and 0.93 ug/l.hour.

Set three (Figure 1) is the only set to demonstrate an initial increase in TCE aqueous phase concentration. This was originally attributed to phase equilibration, but could be due to improvement in the GC analysis methodology. In the viable M. capsulatus culture samples, the more rapid initial degradation rates in the first 300-400 hours can be attributed to the initial availability of methane which can serve as a growth substrate and a source of energy for the monooxygenase enzyme that catalyzes the initial oxidation of TCE.

The initial rate of TCE disappearance in the control and killed culture samples is significantly lower than in the viable culture samples, and stabilizes after approximately 150 hours. The continual decline in aqueous phase TCE concentration even after rate stabilization and growth substrate disappearance can possibly be tentatively attributed to three factors: 1) as 0.5 ml aqueous sample is removed per sample analysis (0.1 ml for samples S34, C34, K34), the sample headspace increases, and more TCE moves into the vapor phase, 2) as the septa seals are continuously punctured, the syringe holes become wider allowing for leakage, particularly of volatile components, and 3) adsorption of the TCE to the biomass of both the killed and viable cultures. Results of sample sets three and five (Figures 1 and 3) suggest that all of these factors contribute.
Subsequent to stabilization of the TCE disappearance rate after approximately 450 hours for set three

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and 240 hours for set five, the rates of aqueous phase TCE disappearance is greatest in the viable culture samples and least in the headspace controls.

Figure 4 shows the effect of a five-fold increase in initial TCE concentration. Initial degradation rates of the viable culture samples at higher TCE concentrations (S14, S24) are much faster than at the lower concentration (S34). Analysis of this data (Table 1) indicates a degradation of 6.70 ug/L/hour for the first 493 hours of the high concentration samples as compared to 2.40-2.10 ug/l/hour for lower concentration samples.

Table 1 : **Aqueous phase TCE disappearance rates in aerobic *M. capsulatus* cultures (S), headspace controls (C), and killed culture (K) microcosms.**

Sample	Initial Rate (ug/L·hr for first 500 hours)	Overall Rate (ug/L·hr for 980 hours)	Overall Rate (ug/L·hr for 1069 hours)
S12	1.68	*1.45	*1.45
S22	1.62	0.93	0.88
S13	1.14	0.84	-
S23	1.27	0.81	-
S14	2.40	-	-
C12	0.86	0.44	0.38
C13	0.72	0.53	-
C23	0.88	0.62	-
C14	0.37	-	-
C24	0.92	-	-
K12	0.88	0.61	0.54
K22	0.70	0.55	0.51
K13	0.85	0.66	-
K23	0.93	0.73	-
K14	1.45	-	-
K24	1.22	-	-
S34	6.70	-	-
C34	**4.29	-	-
K34	5.50	-	-

* Values after 900 hours were eliminated due to levels below the lower limit of the standard curve (5ppb)

** Inclusion of a questionably low initial value would change this value to no overall loss over a period of 493 hours.

Figure 1. TCE Degradation (ug/l) - Microcosm Set 3

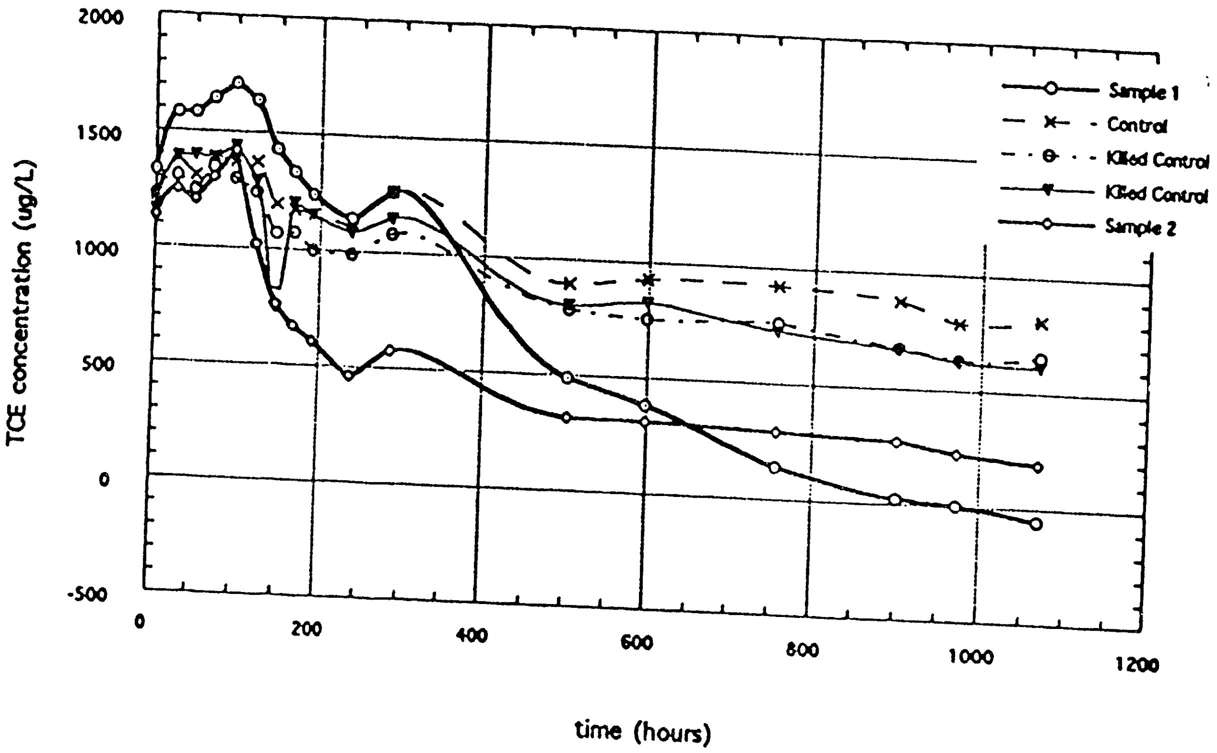


Figure 2. TCE Degradation (ug/l) - Microcosm Set 4

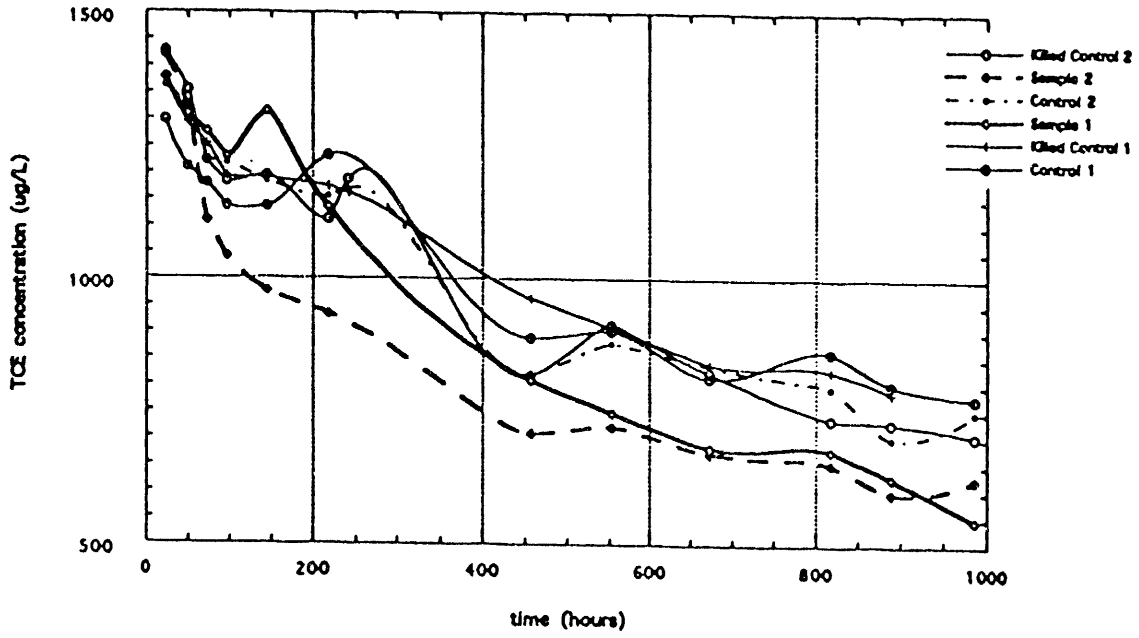


Figure 3. TCE Degradation (ug/l) - Microcosm Set 5

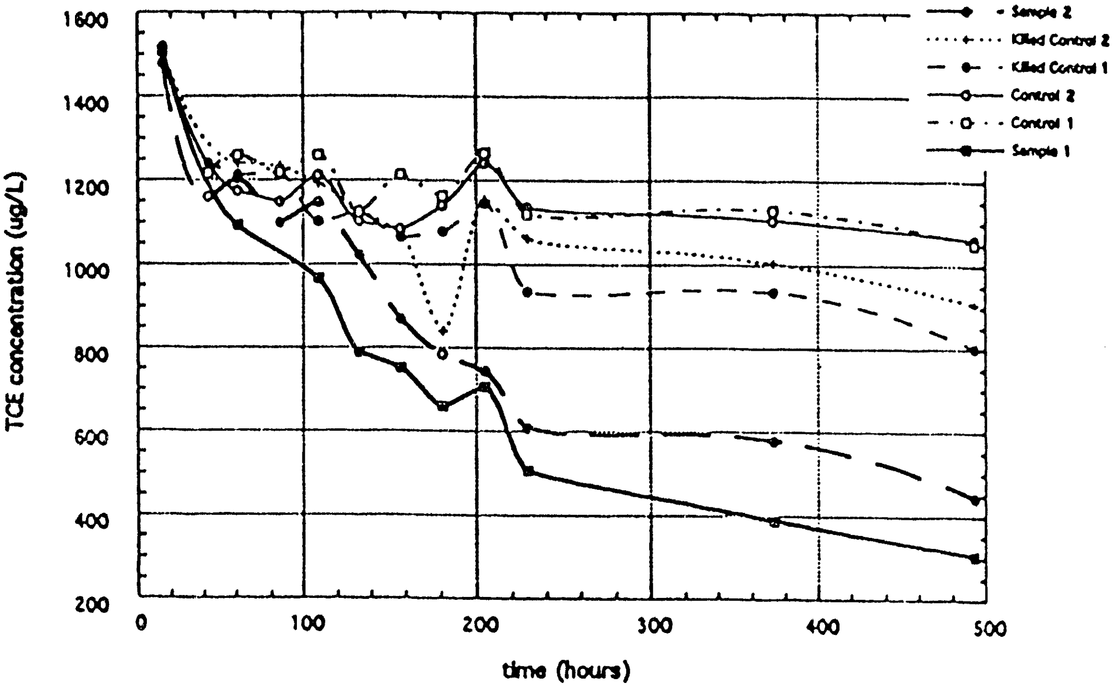
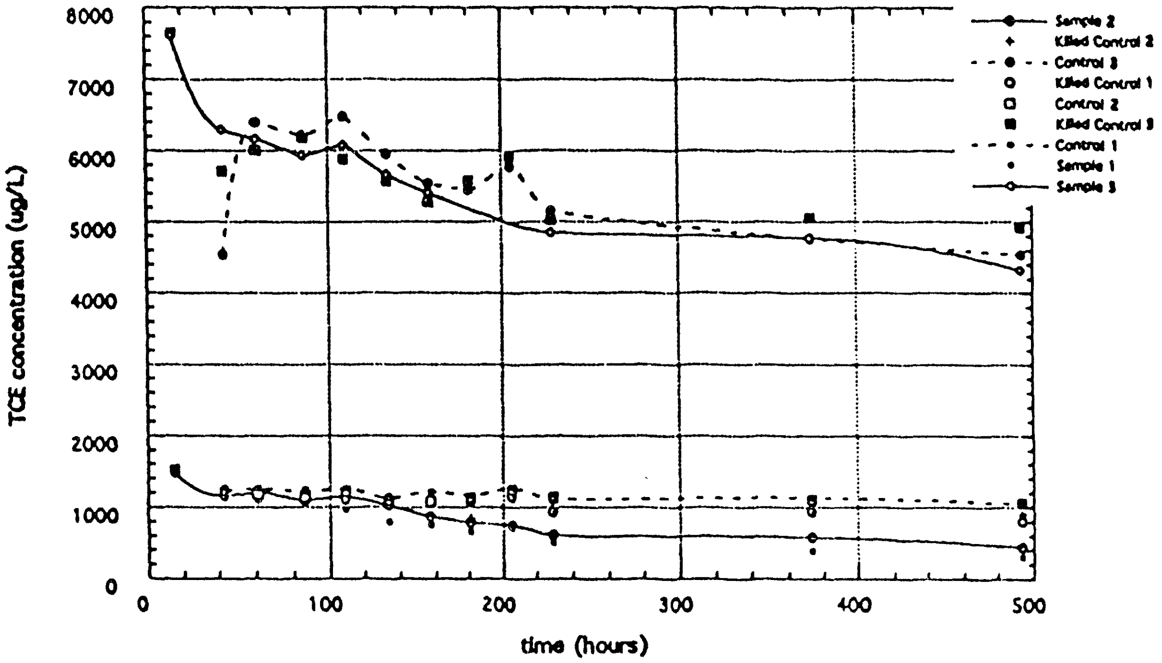


Figure 4. Effect of Concentration On Degradation Rate - Set 5



Additional peaks were observed at retention times that were lower than those of TCE, indicating the presence of lower molecular weight chlorinated organics that could be TCE daughter compounds. The areas of these unknown rgcks"wgrg"bgnow"vjg"svcnfcrf"cwrvg"rcngg"for"VCG, but were significantly above the noise level. Quality control standards samples containing tetrachloroethylene (PCE), TCE, 1,1-dichloroethylene (DCE), cis 1,2-DCE and vinyl chloride (VC) have been ordered at concentrations of 1000, 1000, 100, 100, and 100 ppb, respectively. According to published results, cis 1,2-DCE is the primary TCE degradation product found under methanogenic conditions (Chu, 1994 and Freedman, Gossett, 1989). The predominant byproduct of TCE degradation under methanotrophic conditions is unknown.""Oncg the quality convron standards arrive, standard curvgswknn"bg

5.2 Anaerobic Batch Studies Using a Mixed Consortia of Methanogens and Other Organisms to Accomplish Reductive Dehalogenation

Successful analysis of chlorinated aliphatic compounds (CAHs) has been accomplished under anaerobic conditions since the ELCD detector has been installed. Anaerobic microcosm studies (Sets 5 and 6) have been continued and are discussed below.

5.2.1 Microcosm Studies Sets 5 and 6 Microcosm studies (sets 5 and 6) from the last quarter were continued to better establish biodegradation and partioning of the TCE between the gas and liquid phases and sorption on the biological solids. As discussed in previous reports, TCE standardization was performed prior to microcosm sample analysis.

Microcosm Study Set 5:

During late November (11/29/93), the fifth set of anaerobic microcosm bottles was set-up to evaluate VOC partitioning and biodegradation rates and analysis was continued this quarter. Just as with past anaerobic experiments, maintenance reactor liquid was used to inoculate the active sample bottles. The maintenance reactor continues to operate successfully and displays good general system health and an adequate level of methanogenic activity. In addition to active sample bottles, water controls and killed culture controls were also prepared in triplicate and each of the serum bottles contained the following;

Active Samples (S): 100 ml Maintenance Reactor Liquid
50 mg/l Methanol
50 mg/l Acetate
~0.75 to 1.0 mg/l TCE

Water Controls (C):	100 ml Purged D.I. Water ~0.75 to 1.0 mg/l TCE
Killed Controls (K):	100 ml Maintenance Reactor Liquid (Autoclaved for 30 min. @ 250° F & 15 psi) ~0.75 to 1.0 mg/l TCE

Killed culture controls were added to the experiments in order to determine the mass of contaminant which is partitioned onto the biomass as compared to water controls. This will allow sorption coefficients to be calculated and an evaluation of potential active sample contaminant partitioning onto the biomass.

During microcosm study Set 5, stock solutions of methanol (100,000 ppm), acetate (100,000 ppm), and TCE (2128 ppm) were prepared with nitrogen purged organic free water. Serum bottles used in the fifth microcosm study were sealed with aluminum crimp caps and teflon lined septa. The fifth set of microcosm bottles were labeled, S5A, S5B, and S5C (Samples of Set 5, Bottle A, B, and C), C5A, C5B,C5C (Controls of Set 5, Bottle A, B, and C), K5A, K5B, K5C (Killed Control of Set 5, Bottle A, B, and C) and stored in the dark at 25° C, under quiescent conditions, with the liquid in contact with the septa.

As discussed in past quarterly reports, during refeeding of the microcosms the bottles are opened and maintained anaerobic by sparging with oxygen-free gas until sealed. They are fed fresh basal salts medium plus the organic substrates (50 mg/l methanol and 50 mg/l acetate) and finally respiked with the contaminant (0.75 - 1.0 mg/l TCE). Bottle C from the water controls, the killed controls, and active samples was not opened, but instead the active sample, S5C, was given organic substrates (50 mg/l methanol and 50 mg/l acetate) by syringe and the "C" bottles (C5C, K5C, and S5C) were stored undisturbed until the time of the next analysis. The bottles were maintained by using a syringe to introduce organic substrates and were not opened after the day 5 refeeding.

The results from Set 5 are presented in Table 2 and plotted in Figures 5, 6, and 7. The active sample results (Table 2) showed significant degradation of TCE for a period of 80 days when compared to the control and killed samples. Results for Set 5 indicate that the anaerobic biodegradation process is occurring.

The biodegradation rates for microcosm Set 5 are listed in Table 3. All the samples in Set 5 were spiked after 5 days. In the first 12 days (288 hours) after respiking the samples, the biodegradation rates for the active samples (S5A, S5B, and S5C) were observed to fall within 0.112 to 0.361 ppb/hr (average of 0.222 ppb/hr). The microcosms were not analyzed for 58 days (1392 hours) after respiking the samples due to GC repair as mentioned above.

Table 2. TCE Degradation (ppb) - Microcosm Set 5

Control Flasks

DAY	C5A	C5B	C5C
2	875.4	858.0	885.3
4	922.6	917.8	926.7
5	respiked	respiked	respiked
7	1049.7	985.1	980.0
9	1061.6	1062.1	1030.8
17	1024.4	970.9	985.7
75	852.2	915.2	926.7
78	937.9	940.5	968.0
80	841.2	862.6	904.4

Killed Culture Flasks

DAY	K5A	K5B	K5C
2	858.0	854.0	899.1
4	917.8	928.1	925.0
5	respiked	respiked	respiked
7	1046.2	1083.2	972.9
9	1054.3	1098.8	1081.8
17	1017.3	1023.5	940.6
75	893.9	865.9	742.2
78	913.6	933.0	849.8
80	825.5	855.6	702.8

Active Sample Flasks

DAY	S5A	S5B	S5C
2	801.1	791.9	790.5
4	845.0	806.1	778.6
5	respiked	respiked	respiked
7	924.9	948.4	827.8
9	992.6	976.6	822.1
17	892.6	844.5	772.6
75	408.6	380.3	256.5
78	375.7	397.8	276.7
80	300.4	297.9	167.5

$C5_A$ - Microcosm Water Control Bottles A
$K5_A$ - Microcosm Killed Control Bottles A
$S5_A$ - Microcosm Active Sample Bottles A
$C5_B$ - Microcosm Water Control Bottles B
$K5_B$ - Microcosm Killed Control Bottles B
$S5_B$ - Microcosm Active Sample Bottles B
$C5_C$ - Microcosm Water Control Bottle C
$K5_C$ - Microcosm Killed Control Bottle C
$S5_C$ - Microcosm Active Sample Bottle C

Figure 5. TCE Degradation (ppb) - Microcosm Set 5 For Water Control Samples

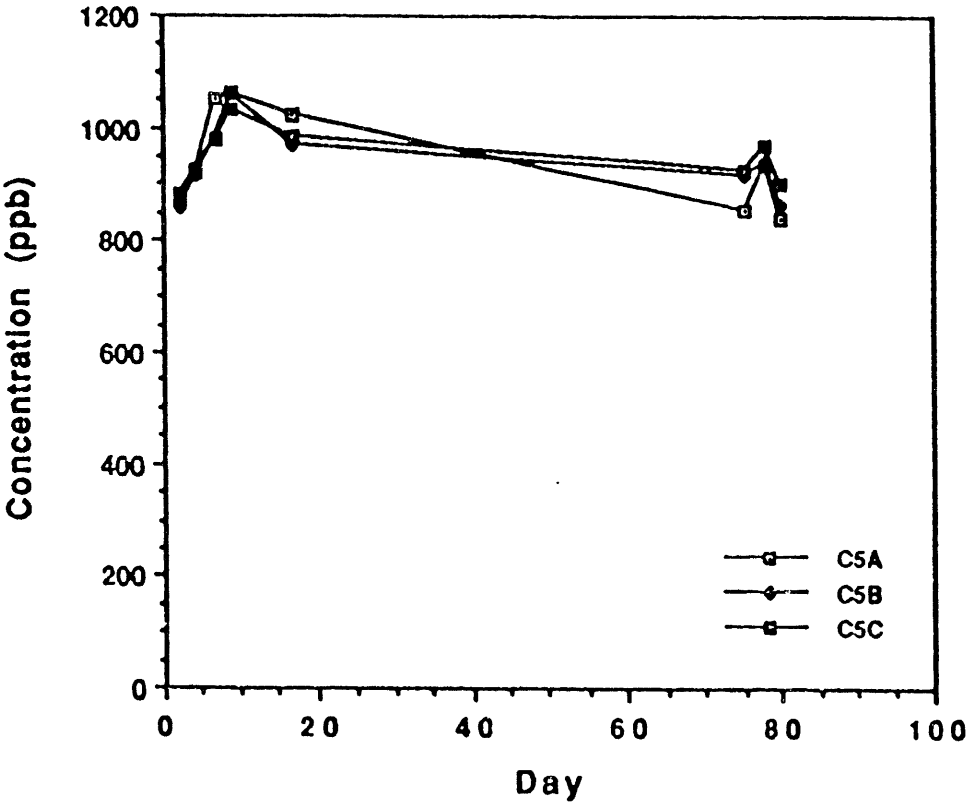


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Figure 6. TCE Degradation (ppb) - Microcosm Set 5
For Killed Control Samples

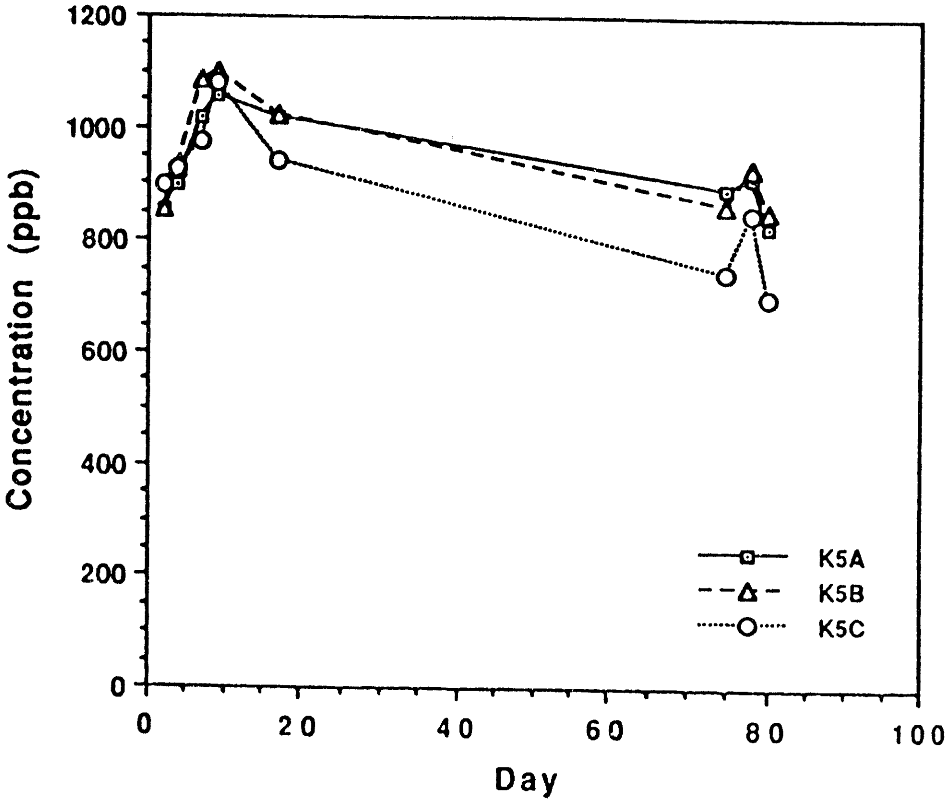

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Figure 7. TCE Degradation (ppb) - Microcosm Set 5
For Active Samples

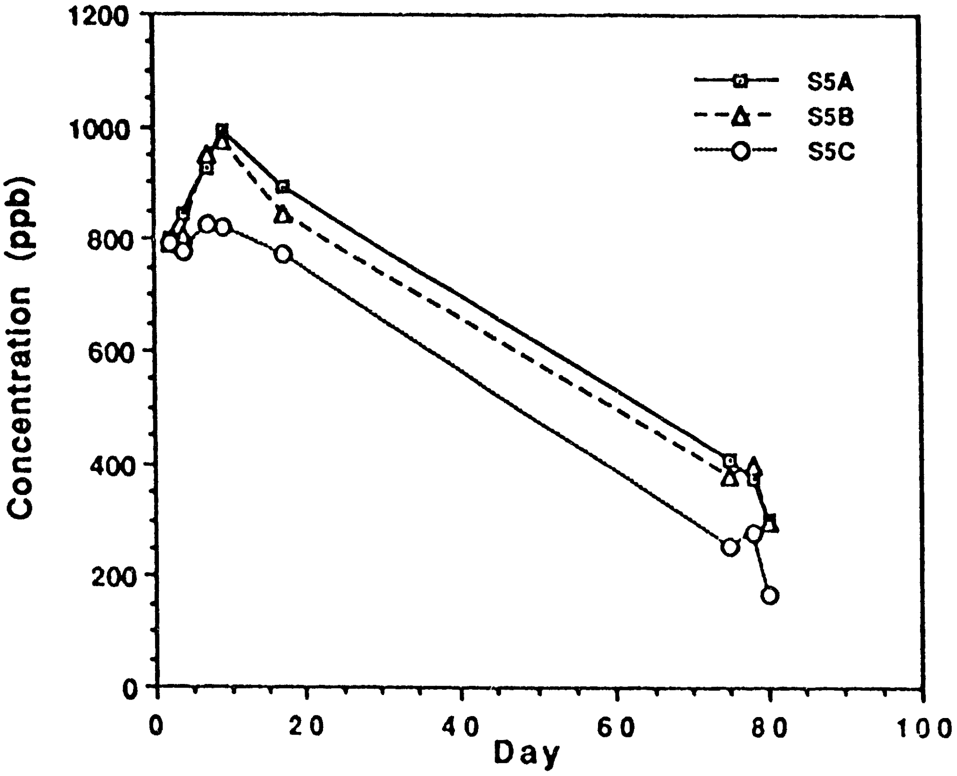

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Table 3. Biodegradation Rates - Microcosm Set 5

Sample	Rate 0-12 days (ug/l.hr)	Rate 12 -70 days (ug/l.hr)	Rate 70-75 days (ug/l.hr)
C5A	0.088	0.124	0.092
C5B	0.049	0.040	0.438
C5C	-0.020	0.042	0.186
K5A	-0.004	0.089	0.570
K5B	0.207	0.113	0.086
K5C	0.112	0.143	0.328
S5A	0.112	0.348	0.902
S5B	0.361	0.333	0.687
S5C	0.192	0.371	0.742

After 58 days, the biodegradation rates of Set 5 for the active samples (S5A, S5B, and S5C) were observed to fall within 0.333 to 0.371 ppb/hr (an average of 0.351 ppb/hr). Five days later, the active samples were again analyzed and the biodegradation rates fell within 0.687 to 0.902 ppb/hr which correspond to an average of 0.777 ppb/hr. These results showed an increase of biodegradation rates over time. The biodegradation of TCE into its daughter products 1,1 DCE, trans-1,2 DCE, cis-1,2 DCE, and vinyl chloride was observed, but not quantified because of lack of standards which were recently received. The loss of TCE for the water and killed control samples may be attributed to the release of TCE through the septa seals due to repeated puncturing, the removal of methane gas containing TCE from the headspace, and the removal of 0.5 ml per sample analysis.

Microcosm Study Set 6:

In addition to microcosm study Set 5, a sixth set of microcosm bottles was continued and analyzed. The sixth microcosm study began on 12/10/93 and the serum bottles were prepared identically to the fifth set as noted below:

Active Samples: 100 ml Maintenance Reactor Liquid
50 mg/l Methanol
50 mg/l Acetate
~0.75 to 1.0 mg/l TCE

Water Controls: 100 ml Purged D.I. Water
~0.75 to 1.0 mg/l TCE

Killed Controls: 100 ml Maintenance Reactor Liquid
(Autoclaved for 30 min. @ 250° F & 15 psi)
~0.75 to 1.0 mg/l TCE

Microcosm study Set 6 was intended to serve as a check for the fifth study and therefore experimental procedures and analytical techniques were consistent to the ones described for set #5 above.

The microcosm bottles were labeled S6A, S6B, S6C (Samples, Set#6, Bottle A, B, & C), C6A, C6B,C6C (Controls, Set 6, Bottle A, B, and C), K6A, K6B, K6C (Killed Control, Set 6, Bottle A, B, and C) and stored in the dark at 25° C, under quiescent conditions, with the liquid in contact with the septa.

The results of microcosm study Set 6 TCE analysis are presented in Table 4 and plotted in Figures 8, 9, and 10.

The active sample results (Table 4) showed significant degradation of TCE for a period of 78 days compared to the control and the killed samples. Results for Set 6 demonstrate the occurrence of anaerobic biodegradation.

The biodegradation rates for microcosm Set 6 are listed in Table 5. For the first 8 days, the biodegradation rates for the active samples were observed to fall within 0.380-0.448 ppb/hr (avg. 0.392 ppb/hr). The results from Set 6 showed increase in TCE concentrations for both the control and the killed culture controls. The samples were not analyzed from day 9 to day 62 because the GC was being repaired as mentioned above. The analysis of microcosm Set 6 was resumed on day 63 and the test was terminated on day 78. The biodegradation rates of the active samples during this time were observed to fall within 0.161-0.452 ppb/hr(avg. 0.270ppb/hr). The general trend experienced during microcosm studies 5 and 6 support successful anaerobic biological activity.

5.2.2 Columns and Equipment Procurement The Chromatography columns, 5.0 cm in diameter and 30.5 cm long, were purchased for use in the column experiments. Each column has an empty bed volume of 600 cm^3 and will be operated at a flowrate ranging from 6.25 ml/hr to 25 ml/hr (1 to 4 day detention time). A Cole Parmer, Masterflex peristaltic pump is selected to deliver the groundwater containing nutrients for the methanogens. The media chosen for the column is on Ottawa sand (20 -30 mesh).

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TABLE 4. TCE Degradation (ppb) - Microcosm Set 6

Control Flasks

DAY	C6A	C6B	C6C
1	1012.1	995.7	994.1
3	954.1	957.7	956.5
5	1028.7	992.0	1017.1
8	1049.3	1069.8	1062.1
63	842.7	792.6	845.8
66	954.9	974.5	963.3
68	948.9	910.3	960.9
78	677.7	678.5	688.8

Killed Culture Flasks

DAY	K6A	K6B	K6C
1	1043.5	1141.1	1111.4
3	1000.7	1074.0	1052.9
5	1013.1	1100.8	1057.0
8	1166.8	1080.4	1118.0
63	916.3	919.0	970.8
66	873.2	879.9	869.6
68	804.7	838.0	793.1
78	625.0	671.9	600.7

Active Sample Flasks

DAY	S6A	S6B	S6C
1	1026.5	983.1	992.9
3	896.9	902.2	913.2
5	915.3	915.1	928.9
8	940.4	909.4	920.0
63	326.4	148.0	334.6
66	413.3	391.4	393.1
68	372.7	334.4	359.7
78	268.6	228.7	263.3

$C6_A$ - Microcosm Water Control Bottles A
$K6_A$ - Microcosm Killed Control Bottles A
$S6_A$ - Microcosm Active Sample Bottles A
$C6_B$ - Microcosm Water Control Bottles B
$K6_B$ - Microcosm Killed Control Bottles B
$S6_B$ - Microcosm Active Sample Bottles B
$C6_C$ - Microcosm Water Control Bottle C
$K6_C$ - Microcosm Killed Control Bottle C
$S6_C$ - Microcosm Active Sample Bottle C

Figure 8. TCE Degradation (ppb) - Microcosm Set 6
For Water Control Samples

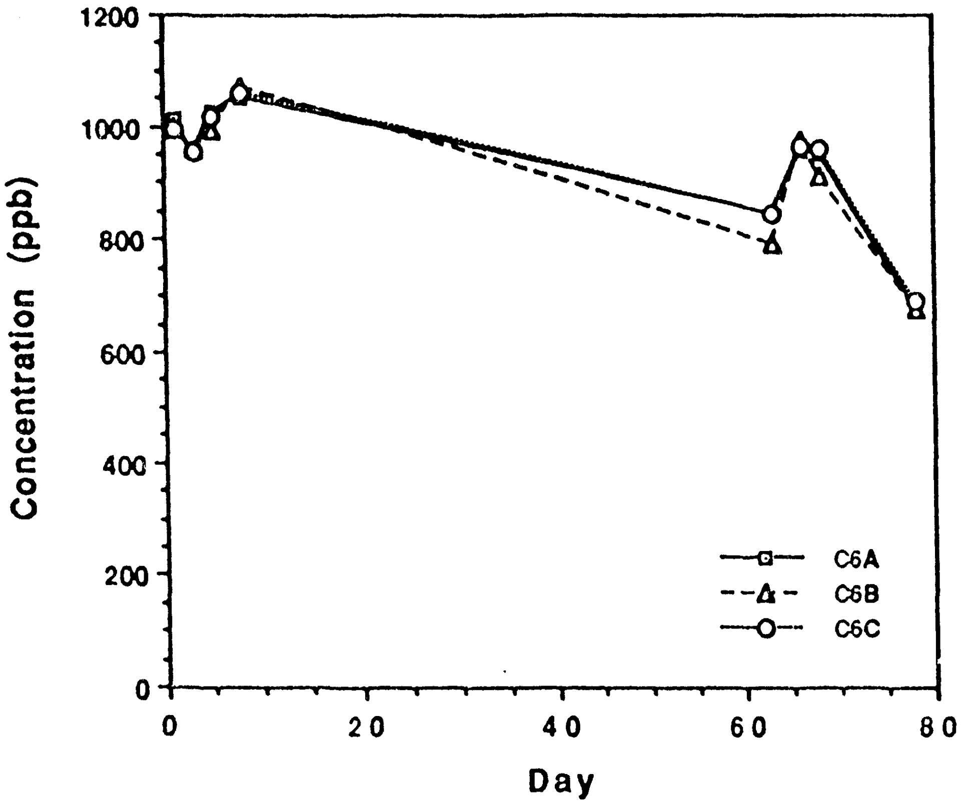

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Figure 9. TCE Degradation (ppb) - Microcosm Set 6
For Killed Control Samples

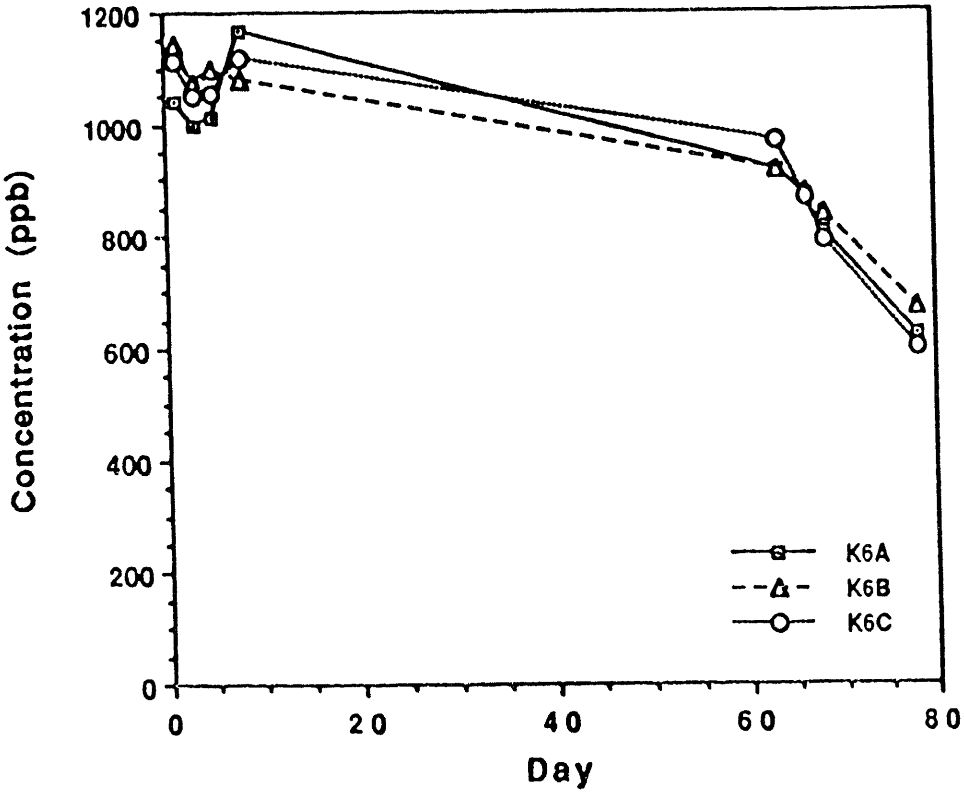

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Figure 10. TCE Degradation (ppb) - Microcosm Set 6
For Active Samples

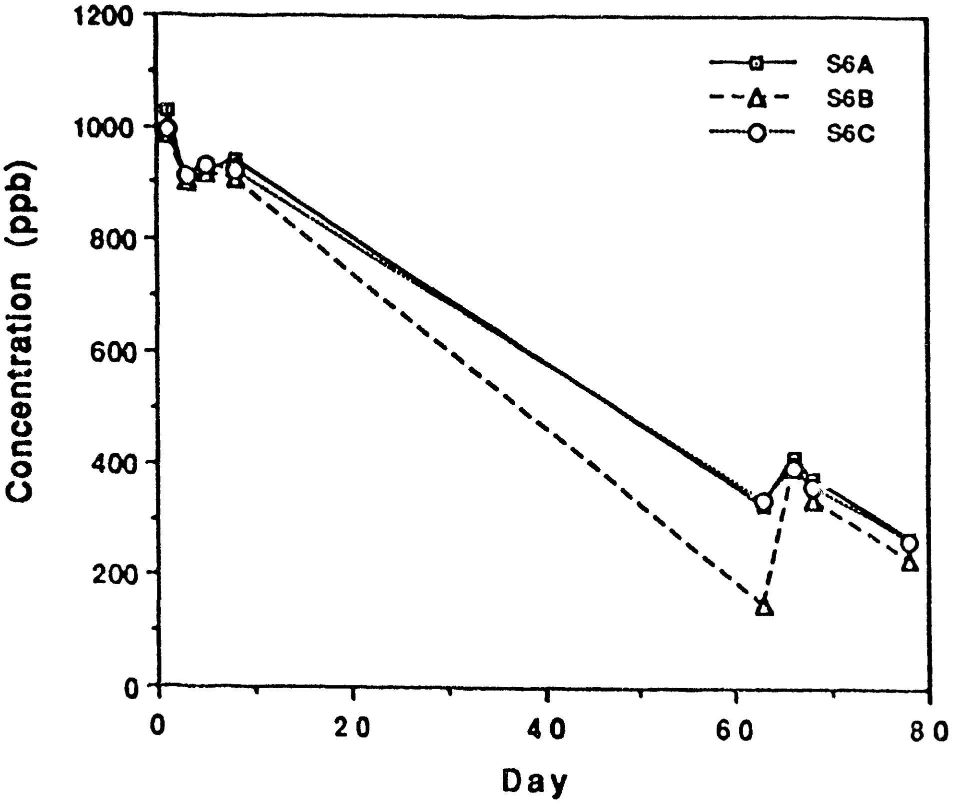

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Table 5. Biodegradation Rates for Microcosm Set 6

SAMPLE	Rate 0-8 days (ppb/hr)	Rate 9-62 days (ppb/hr)	Rate 63-78 days (ppb/hr)
C6A	-0.194	0.159	0.458
C6B	-0.346	0.214	0.317
C6C	-0.354	0.167	0.436
K6A	-0.642	0.193	0.809
K6B	0.316	0.124	0.686
K6C	-0.034	0.114	1.028
S6A	0.448	0.474	0.161
S6B	0.384	0.400	0.452
S6C	0.380	0.452	0.198

The grain size distribution of the media is presented in Table 6. A Scilog piston pump, Accu FM-40, with ceramic wetted parts to avoid corrosion was selected for the recycling effluent. It is capable of flows from 1 to 690 ml/hr at 100 psi. After a careful review of the original column setup, the column was redesigned to reduce dead space at the inlet and outlet and several new parts were ordered. A Cole Parmer, single channel syringe pump was selected to deliver TCE to the column. This pump has a flow range of 0.02 - 500 ml/hr, 0.5% accuracy and 0.2% precision.

Table 6. Grain Size Analysis Standard Ottawa Sand

SIEVE NO.	DIAMETER (MM)	WT. RETAINED (G) (CUM/INDV)	% RETAINED (CUM/INDV)	% PASSING
10	2.00	0	0	100
16	1.18	0	0	100
20	0.85	552.08/552.08	50.23/50.23	49.77
30	0.60	1094.2/542.12	99.54/49.32	0.45
40	0.43	1097.67/2.52	99.77/0.23	0.22
60	0.25	1097.67/2.52	99.86/0.09	0.13
PAN	----	1098.17/0.50	99.91/0.05	0.00

5.3 Research Planned for Next Quarter

5.3.1 TCE Degradation Rate Evaluation

In the studies described above the samples with live bacteria exhibit a rapid TCE degradation for the first 3-4 days of analysis. The rate then decreases until it is similar to that of the control samples which contain no live organisms. Thus it appears that the initial disappearance of TCE is biological, whereas the slower rate at long time periods represents the non-biological disappearance of TCE due to the factors discussed above. Thus, our future experiments will focus on only the degradation of TCE during this initial period.

Our set of experiments will compare the relative rates of TCE disappearance with methane, methanol, or formate as the source of energy substrate for TCE degradation we will then undertake a series of experiments to determine its optimum concentration. Similar methodology will be used to compare the relative rates of TCE degradation for the soluble and membrane-bound forms of methane monooxygenase (MMO). Two batches of cells will be grown, one expressing the soluble MMO and the other expressing the membrane bound MMO. One of the above energy substrates will be added to microcosms containing the same biomass from each bacteria. In all these studies the initial rate of TCE disappearance (over 2-3 days) will be used as the criterion for determining the efficiency of the energy substrate and the different forms of MMO. We will then progress to use of a soil column, in order to more effectively mimic the conditions of the subsurface. The optimum conditions determined from the microcosms will serve as the starting point for the column studies. Conditions in the column will be manipulated to optimize the initial rate of TCE degradation.

5.3.2. Operation of Columns for VOC Biotransformation- Engineering and Biochemistry

As noted in the last quarterly report, the phase 3 soil column studies will use upflow glass chromatography columns. The groups in Engineering and Biochemistry will utilize the same type of columns. The Engineering columns will be initially operated anaerobically while the columns in Biochemistry will be aerobic. After initial data is generated, a combined anaerobic-aerobic system will be operated.

Side ports used for sampling purposes will be fitted with a miniature inert 2-way valve with teflon connections and luer-lock fittings. A 5 ml gastight luer-lock syringe will be used to withdraw samples from the column during operation. Sampling design was selected in order to minimize flow interruption and avoid unnecessary loss of volatiles. All connections, fittings and tubing will be made of teflon in order to minimize contaminant adsorption. During column operation necessary measures will be taken in order to maintain ambient temperatures and a dark environment. As noted earlier, the original column design was modified in February so as to reduce dead space at the inlet and outlet and several new fittings were ordered. Most of the new parts have arrived and it is anticipated that the anaerobic column will be in operations in early May.

The aerobic columns will be innoculated with methanotrophic bacteria and TCE or PCE. The column will be flushed either continuously or intermittently with a carbon source and an oxygen source, and samples will be taken periodically for analysis of TCE, its degradation products, and bacterial growth. A control column flushed with nitrogen gas will also be examined to insure that the gas is not volatilizing the TCE. In this way, the relationship between the rate of growth and rate of TCE degradation as a function of substrate and oxygen addition under field-simulated conditions may be determined.

The anaerobic columns will be initially innoculated with organisms from the maintenance reactor to establish a consortia of organisms to carry out reductive dehalogenation (RD) of PCE and TCE. Appropriate primary substrates will be added to the groundwater based on the microcosm studies and recirculation will be practiced. It is anticipated that the column will be operated at an initial empty bed detention time of 24 to 96 hours. Samples will be taken over time to evaluate the biotransformation of the highly chlorinated solvents by RD to its degradation products. Initial contaminated groundwater flow rates 10 to 15 ml/hour and recycle rates of 25 to 50 ml/hour are planned.

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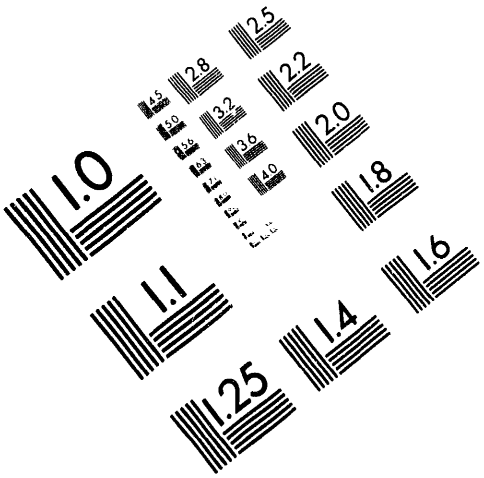

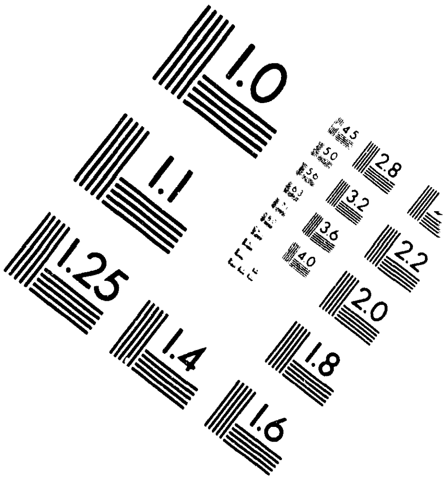

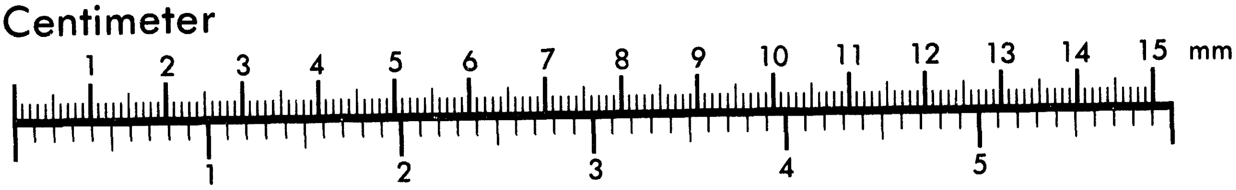

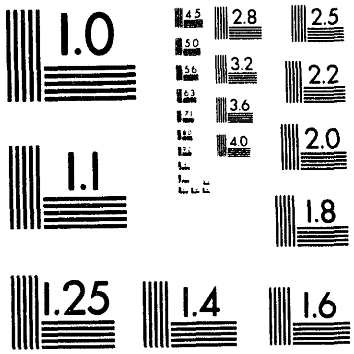

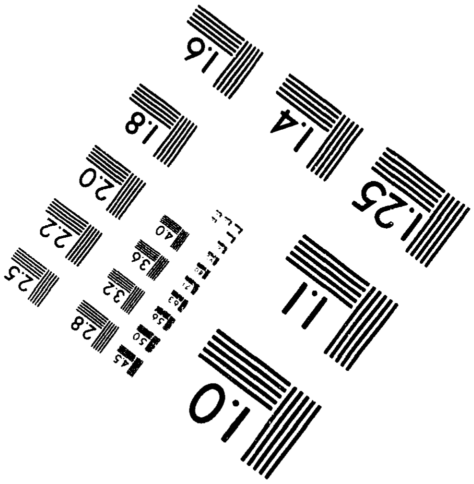

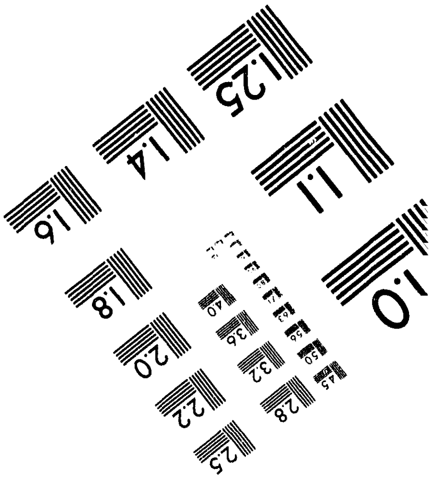

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MICROBIAL ENRICHMENT FOR ENHANCING BIODEGRADATION OF HAZARDOUS ORGANIC WASTES IN SOIL
(MC-18)

Quarterly Technical Progress Report
for Period January 1 through March 31, 1994

Work Performed Under
Contract Number: 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
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May 1994

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1.0 Problem and Research Objectives

The purpose of the current proposed study will be to develop a reliable *in vitro* assay to directly compare selected commercially available microbial inocula for enhancing biodegradation of mixed organic wastes by soil composting. The products to be initially will be taken from compilations provided by the EPA National Contingency Plan Product Schedule (NCPPS) or the EPRI Advanced Bioremediation Assessment and Technology Evaluation Program (ABATE). While both programs have identified microbial products, neither has directly compared efficacy for inoculation in soil composting. Inocula identified from the lists will be obtained directly from the remediation firms which produce them and used in replicated laboratory experiments to determine treatment effects on the rate and extent of biodegradation and formation of characteristic degradation byproducts. The products will be tested in both a surface and subsurface soil which have been excavated and amended for waste composting. Soils will be contaminated with a model mixed waste containing hydrocarbons, solvents, and polynuclear aromatic hydrocarbons. Biodegradation of the pollutants will be monitored in the presence and absence of inoculation. A specific objective of the work will be to compare the efficacy of bioaugmentation in a surface and subsurface soil. The working hypothesis to be tested is whether positive effects of bioaugmentation are greatest in the subsurface soil due to reduced microbial competition in this environment. Results of the initial one year study will generate specific comparisons of bioaugmentation products in a model test system. Our intention is to develop a more generalized testing procedure and expertise, which we can employ to examine bioaugmentation / biodegradation of a variety of wastes and / or waste sites. During the course of the year we will expand our contacts within the field of bioremediation, making specific expertise in this field available locally to WVU / NRCCE / METC.

2.0 Project Status

This is the second quarter of our study. Rather than hiring a technician as originally envisioned, we have decided to hire a post-doctoral research associate. Dr. Pradeep Saini will join us during the coming quarter, and will assume a major role in day to day oversight of the project. Dr Saini has an excellent background in soil microbial transformations, as well as soil and analytical chemistry. We expect that his enthusiasm and expertise will enhance our ability to pursue our stated research objectives. During the past quarter Mr Jay Winger, a graduate student, has worked out the waste extraction protocol and is currently initiating the first of our *in vitro* bioremediation studies. We have formulated our artificial mixed organic waste and have developed appropriate analytical protocols (Figure 1). We have continued to work with crude oil as a waste surrogate in preliminary biodegradation experiments (Figure 2). With hydrocarbon wastes, extraction efficiency from soil held in flasks is now greater than 85% using TCTFE or tBME as the extracting solvent. Using a centrifugation / extraction procedure we can increase this efficiency to 93%, however at a greater cost in sample processing time. Results of a preliminary study examining the effects of fertilizer application on crude oil biodegradation are reported (Table 1). In this study lower N treatments appeared to show greater biodegradation rates (statistical analysis of these data are not yet complete)

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perhaps due to a soil pH effect caused by fertilizer application (Table 2). We have begun the necessary acquisition of microbial inocula and have sub-cultured some strains in the laboratory. In this regard we have assisted METC cooperators Dr Shahab Mohaghegh and Patrick Carriere by helping them to prepare microbial inocula for their VOC biofilters.

FIGURE 1: Gas Chromatographic Method for the Separation of Model Waste Components.

```
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Run File   : C:\STAR\MODULE18\CMAS001.RUN
Method File : C:\MCKAIN\CMA2.MTH
Sample ID  : CMA

Injection Date: 19-MAR-94 1:03 AM  Recalculation Date: 19-MAR-94 2:34 PM

Operator   : dlm              - Detector Type: ADCB (1 Volt)
Workstation:                    Bus Address  : 18
Instrument : Varian Star #2       Sample Rate  : 10.00 Hz
Channel    : A = FID             Run Time     : 75.002 min

*********** Varian GC Star Workstation *********** Version 3.0 ***************
Run Mode       : Analysis
Peak Measurement: Peak Area
Calculation Type: Percent

                     Retention  Time              Width
Peak   Peak           Result    Time    Offset     Area      Sep.  1/2
No.    Name            (%)      (min)    (min)    (counts)   Code  (sec)
---  ------------   ---------- ------- -------   -------- --  -----
 1                   0.0019   3.955                1189      0.0
 2 TOLUENE          99.3476   5.139   0.000    62823952     61.8
 3 TC1               0.0288   6.687   0.019       18215      0.0
 4 CHLOROBENZEN0.0530   6.959   0.000       33505      0.0
 5 TC2               0.2377   7.471   0.018      150287      0.0
 6 TC3               0.2231   7.762   0.018      141106      0.0
 7 TC4               0.0045   8.471   0.048        2816      0.0
 8 TC6               0.0021  12.004   0.136        1305     13.0
 9 TC7               0.0011  21.361   0.030         678      9.3
10 TC8               0.0015  25.845   0.025         919      6.5
11 HEXADECANE 0.0438  29.237  -0.000       27717      3.9
12 PRISTANE          0.0461  31.692   0.000       29179      4.3
13                   0.0012  33.377                 776      0.0
14                   0.0009  34.073                 544      0.0
15                   0.0020  36.559                1247      0.0
16                   0.0013  42.081                 811      6.9
17 TC9               0.0010  47.873   0.024         613      0.0
18                   0.0007  48.996                 460      9.6
19                   0.0019  49.746                1179      8.8
--- ------------  ========== ------- =======  ======== -- -----
   Totals:         100.0000           0.318  63236500

Total Unidentified Counts :     6206 counts

Detected Peaks: 20      Rejected Peaks: 1    Identified Peaks: 12

Amount Standard: 1.000000  Multiplier: 1.000000  Divisor: 1.000000
```

Figure 2. Gas chromatographic analysis of a W.V. crude oil provided by Trio Oil and Gas Corporation: A) West Virginia crude, B) oil extracted from contaminated soil, and C) extract of an uncontaminated soil.

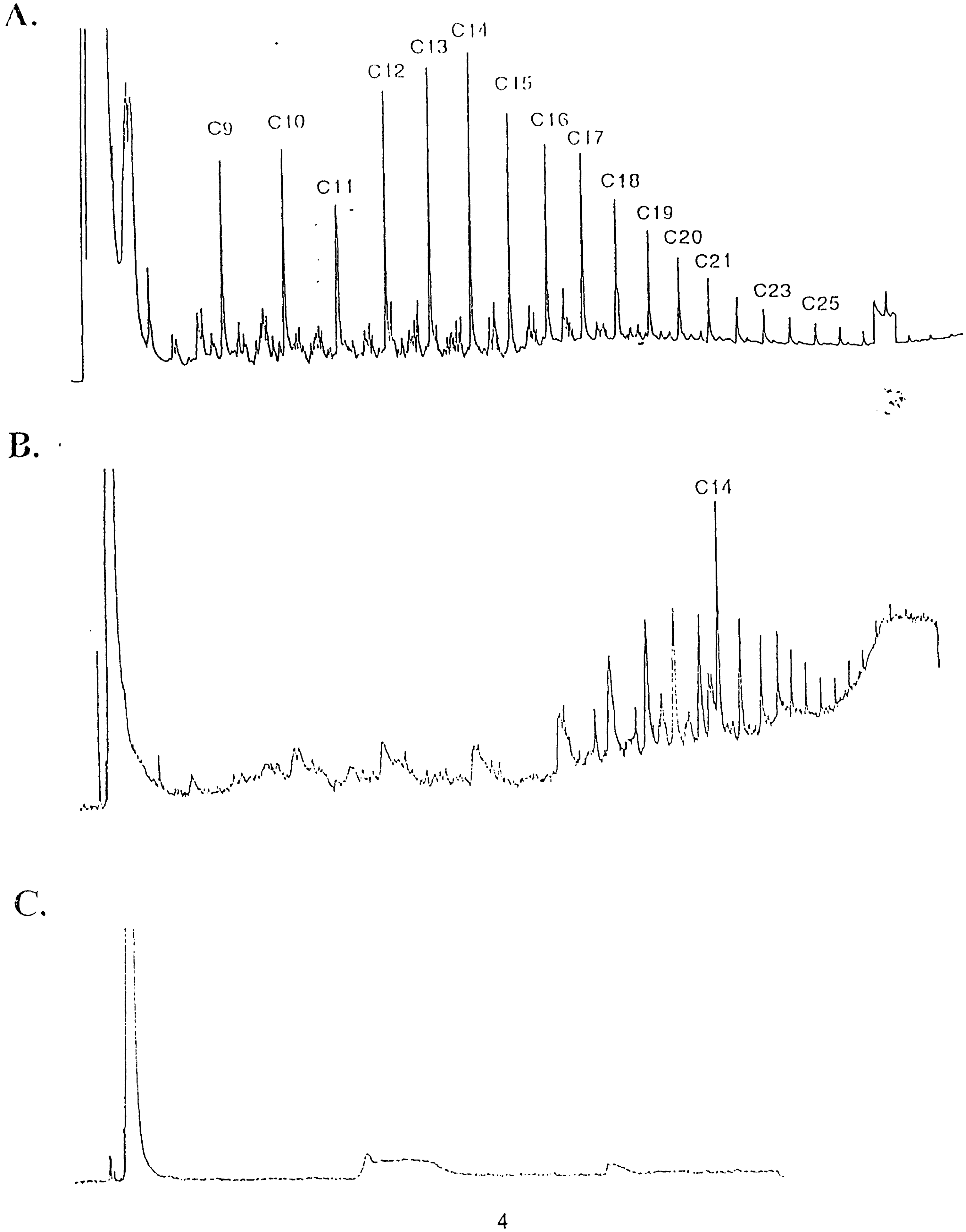

Table 1. Gravimetric oil recovery during 120 days following oil application to soils amended with N and P.

Treatment[a]		0 to 3 inch soil depth					3 to 9 inch soil depth	
		0	14	30	60	120	60	120
N treatment	P Treatment			(Days)				
control	control	.275 (100)[b]	.180[c] (66)[d]	.150 (54)	.109 (40)	.137 (50)	.004 (1.5)	.014(5.1)
30:1	control	.275 (100)	.117 (43)	.143 (52)	.098 (36)	.134 (49)	.020 (7.3)	.015 (5.5)
60:1	control	.275 (100)	.088 (32)	.108 (39)	.121 (44)	.102 (37)	.003 (1.1)	.007 (2.3)
120:1	control	.275 (100)	.154 (56)	.132 (48)	.075 (27)	.105 (38)	.008 (2.9)	.013 (4.7)
control	400:1	.275 (100)	.096 (35)	.118 (43)	.081 (29)	.155 (56)	.027 (9.8)	.014 (5.1)
30:1	400:1	.275 (100)	.121 (44)	.135 (49)	.107 (39)	.099 (37)	.004 (1.5)	.008 (2.7)
60:1	400:1	.275 (100)	.178 (65)	.102 (37)	.092 (34)	.075 (27)	.014 (5.1)	.010 (3.6)
120:1	400:1	.275 (100)	.162 (59)	.110 (40)	.076 (28)	.108 (39)	.017 (6.2)	.011 (3.9)
control	800:1	.275 (100)	.200 (73)	.114 (42)	.071 (26)	.121 (44)	.017 (6.2)	.007 (2.3)
30:1	800:1	.275 (100)	.128 (47)	.160 (57)	.086 (31)	.118 (43)	.004 (1.5)	.010 (3.6)
60:1	800:1	.275 (100)	.174 (63)	.104 (38)	.101 (37)	.089 (32)	.007 (2.5)	.026 (9.4)
120:1	800:1	.275 (100)	.163 (59)	.123 (45)	.094 (34)	.097 (35)	.013 (4.7)	.017 (6.3)
control	1200:1	.275 (100)	.137 (50)	.116 (42)	.090 (33)	.126 (46)	.010 (3.6)	.016 (5.9)
30:1	1200:1	.275 (100)	.121 (44)	.094 (36)	.124 (45)	.127 (46)	.017 (6.2)	.029 (10.6)
60:1	1200:1	.275 (100)	.143 (52)	.113 (41)	.082 (30)	.082 (30)	.025 (9.1)	.017 (6.3)
120:1	1200:1	.275 (100)	.170 (62)	.150 (55)	.080 (29)	.082 (30)	.012 (4.4)	.019 (7.0)

a Expressed as C:N or C:P ratio assuming 78% C in the applied oil.
b Calculated from original oil application to a soil depth of 3 inches.
c Oil weights are means of 3 replicates and are corrected for 93% oil extraction efficiency.
d Numbers in parentheses indicate % oil recovery.

Table 2. Soil acidification in nitrogen amended soils during 120 days following oil contamination.

Soil treatment	soil pH				
	(days)				
C / N	0	14	30	60	120
30:1	-	5.9	5.8	5.8	5.7
60:1	-	5.8	6.1	5.7	5.8
120:1	-	6.3	6.2	6.3	6.4
control	6.9	6.6	6.5	6.5	6.6

TREATMENT OF VOLATILE ORGANIC COMPOUNDS (VOCs) USING BIOFILTERS
(MC-20)

Quarterly Technical Progress Report
for Period January 1 through March 31, 1994

Work Performed Under
Contract Number: 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

By

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May 1994

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EXECUTIVE SUMMARY

The principal objective of this research is to investigate the performance of biofilters for removing Volatile Organic Compounds (VOCs), known to be potentially hazardous to public health. The Biofiltration is an innovative Air Pollution control technology in which off gases containing biodegradable VOCs are passed through a biologically activated material. The results obtained in terms of removal efficiency and economics will be compared with those of conventional technologies. There is limited engineering data available in the literature on this novel technology which is the primary objective of the current research.

The literature was reviewed and the laboratory setup was designed. The necessary process equipment and materials are procured. The frame for mounting the process equipment is fabricated. The process equipment are currently under hook up for conducting the study.

The software and hardware for the existing Varian 3410 model GC are upgraded. Trial runs on GC were performed to check the detector performance using test samples and the contaminants independently. The respective peaks were identified which confirmed proper functioning of the detector.

Activated carbon samples were obtained from M/S Calgon Carbon, PA to conduct adsorption isotherm studies. M/S Norit, GA expressed willingness to cooperate in the biofiltration research. They have supplied the sample of activated carbon.

After conducting thorough literature survey, the microorganisms capable of affecting degradation of organic compounds are identified to be (i) Acinetobacter Sp. Genospecies 11 and (ii) Nocardia Paraffinae, which were obtained from ATCC, Maryland. The freeze dried cultures received were rehydrated and incubated at the suggested temperatures. The growth studies of the microorganisms are to be conducted by a respirometer. The microorganisms are to be acclimated to the BTEX environment to avoid the lag phase before mixing with the support media.

This research will facilitate to understand the mechanism of biofiltration in the laboratory scale before conducting pilot plant studies and their commercial application to the existing air pollution concern of removing and controlling VOCs.

INTRODUCTION

Presently, the Army Corps of Engineers has many environmental cleanup concerns such as VOCs at the Winfield and Lock Dam site. The volatile organic chemicals pose a risk to public health due to their mobility in the soil and solubility in water. The COE has proposed an environmental cleanup to be accomplished in two phases: (1) Excavation of the contaminated soil and placement in a containment facility, and (2) Decontamination of soil. During the first phase of this cleanup process, the movement of the contaminated soil will accelerate the release of VOCs and semi-volatile organics into the atmosphere. Due to potential risks imposed by VOC emissions, the atmospheric release of these compounds must be controlled. Conventional technologies that have been used to control VOCs include: (1) Adsorption onto porous material such as activated carbon, (2) Absorption into a liquid stream followed by stripping of the liquid and (3) Combustion or incineration. These technologies present several problems involving disposal of generated wastes, cost of equipment and materials and energy required for operation.

The Clean Air Act amendments of 1990 made several significant changes in the clean air program and one of the key elements of the amendments was the inclusion of an operating permit program in title V. Under this act "all major sources of air pollution will need permits to operate". About 1200 sites have been targeted for clean up under Superfund, 4000 sites need remediation under corrective action of Resource Conservation and Recovery Act(RCRA). Tens of thousands more sites including under ground storage tanks and chemical or oil spills are expected to require treatment. Biofiltration a relatively recent air pollution control technology is the removal and oxidation of organic gases, Volatile Organic Compounds from contaminated air by beds of compost or soil where in microorganisms in a moist, oxygen rich environment oxidize organic compounds to CO_2 and H_2O. As compared to other options biofiltration is economical, reliable and represents more natural approach for control of VOCs.

This research will facilitate to understand the mechanism of biofiltration in the laboratory scale before conducting pilot plant studies and their commercial application to the existing air pollution concern of removing and controlling VOCs. An attempt will be made in this phase to address the known and frequently mentioned deficiency in this discipline, namely **limited engineering data.**

GOAL AND OBJECTIVE

The goal of the research proposed is to study the Biofiltration technology for VOC removal. The study is accomplished in 3 tasks. The specific objectives of the project are:

Task 1: To study the effect of biologically activated carbon on VOC removal.

Task 2: Effect of initial VOC concentration on removal efficiency which requires extensive research.

Task 3: To study the VOC removal efficiency with different types of Activated carbon.

TECHNICAL BACKGROUND

Biofiltration, a relatively recent air pollution control technology (APC), is the removal and oxidation of organic gases, Volatile Organic Compounds (VOCs) from contaminated air by beds of compost or soil, wherein microorganisms in a moist, oxygen rich environment oxidize organic compounds to CO_2 and H_2O. As compared to other options biofiltration is economical, reliable and represents a more natural approach for control of VOCs.

While a successful technology in Europe, biofiltration in the United States is held at arms length by EPA and industry, mostly because engineering data is limited. There are a few installations in the U.S. and Canada and their primary application is odor control. As companies tighten their budgets even some tried technologies will face competition and will opt for maximum achievable "ideally affordable" control technologies. The future of VOC control and where innovation must lie will be in technologies that control low concentrations of VOCs[1]. Gases are inherently more biodegradable than solids and liquids because they are molecularly dispersed.

The removal and oxidation rates depend on the biodegradability and reactivity of the gases. The VOCs can be classified according to their biodegradability. They are (i) rapidly degradable VOCs like alcohols, aldehydes, ketones, ethers, esters etc. (ii) slowly degradable VOCs like hydrocarbons, phenols and methylene chloride. (iii) very slowly degradable VOCs like halogenated hydrocarbons, polyaromatic hydrocarbons etc[2].

Incineration is a common and effective method for the destruction of the VOCs in air streams. There are many different types of incinerations such as thermal incineration, catalytic incineration, boilers and heaters. Incineration has draw backs like secondary control devices may be required to treat combustion products. Gas Adsorption involves passing a gas stream through a porous solid material. Gas molecules are removed from the stream by a combination of physical and chemical adsorption. The major disadvantage is that the secondary wastes are generated and off site treatment plant may be required in addition to its high costs. Absorption or scrubbing is a process in which one or more components in a gas stream are selectively transferred or absorbed into a relatively non volatile liquid. This process has disadvantages like some types of additives to the scrubbing water may be expensive. Scrubbing may not be effective on streams that contain a mixture of many dissimilar species of pollutants. Condensation separates one or more volatile components from a vapor mixture by saturation and subsequent phase change.The induced phase change can occur either by increasing the system pressure at a constant temperature or by reducing the temperature at a constant pressure. Condensation is not cost effective for the streams with low VOC concentrations. Vapor phase advanced oxidation is the technology that uses strong oxidizing agents and intense ultra violet radiation for the photo chemical stimulation of oxidation reactions. The by-product of oxidation of chlorinated VOCs is gaseous HCl and a fume scrubber may be required to treat this gas[3].

Biofiltration provides maximal contact and allows sufficient time for VOCs to react with soils. The low cost of biofiltration is due to its use of natural rather than synthetic sorbents or chemical oxidation. Due to low operating costs, biofiltration can provide significant economic advantages over other APC technologies if applied to off-gases that contain readily biodegradable pollutants in low concentrations (typically less than 1000 ppm). The development of biofiltration in West Germany, most of which took place in the late 1970s and the 1980s, was brought about by a combination of increasingly stringent regulatory requirements and financial support from federal and state governments.

Biofiltration is likely to find more widespread application in the US in the near future. In addition to a few existing installations, several full-scale projects are currently in the planning stage or under construction. Presently most biofilters have been built as open single bed systems. The biofilters originally built in the US were mostly soil beds for which biologically active mineral soils were used as filter materials. Due to the low biodegradation capacity of soils alternative support media need to be investigated.

Biofilters operate under moist rather than dry conditions. And even though water competes with most VOCs for sorption, it increases the sorption of water soluble gases. In appropriately designed biofilters, the VOCs remain long enough for microbes to oxidize them. If the amounts of VOCs are excessive or the reaction time too short, the VOCs are carried through the bed and released to the atmosphere rather than accumulating in the beds. Soil and compost have relatively low sorption capacities for gases. Biofiltration relies instead on continuous oxidation of the sorbed VOCs by microorganisms to CO_2 and water. The oxidation regenerates the sorption capacity, resulting in a steady-state removal of the incoming air pollutants.

EXPERIMENTAL METHODOLOGY

The process followed to determine the VOCs removal efficiency by employing the biofiltration technology is continuous. The contaminant mixture is passed through the column, which is packed with activated carbon. The activated carbon serves as the support media for the microorganisms which are instrumental in degradation of the contaminants.

The contaminant mixture of Benzene, Toluene, Ethylbenzene and Xylene is injected into the gas reservoir which is filled with air. As the contaminants are known for their volatility, as soon as vacuum is created they will be vaporized. The mixture is pumped to the column through a humidifying column. The humidifying column is employed to increase the water content of the contaminants which otherwise may dry up the column bed. In the humidifying column the water will be sprinkled from the top to maintain the water content of the mixture. The contaminant mixture is recycled to get a consistent concentration before passing through the column. Once after achieving the consistent concentration the air contaminant mixture is then passed through the column. Before the mixture enters the column a sample is drawn for the analysis, which determines the influent concentration. The effluent sample is collected at the outlet of the column and analyzed which gives the effluent concentration. The necessary nutrients for the microorganisms will be supplied from the top of the column. The drainage from the column is collected at the bottom portion of the column and is monitored continuously for the nutrient concentration. The chemical analysis of the contaminant mixture is carried out by employing the Gas Chromatography.

RESULTS

The tasks accomplished in the period are;

1. Literature review

Literature was thoroughly reviewed and the suitable microorganisms for the biodegradation of VOCs were identified. The materials (Teflon) which are resistant to the contaminants were identified.

2. Process Design and Equipment procurement

The engineering design was completed and the necessary process equipment was procured as per the design. The schematics of the biofiltration process experimental setup is placed at Figure 1. The frame for mounting the equipment was fabricated. The capillary column for the GC was procured and installed, trial runs were conducted with the test samples.

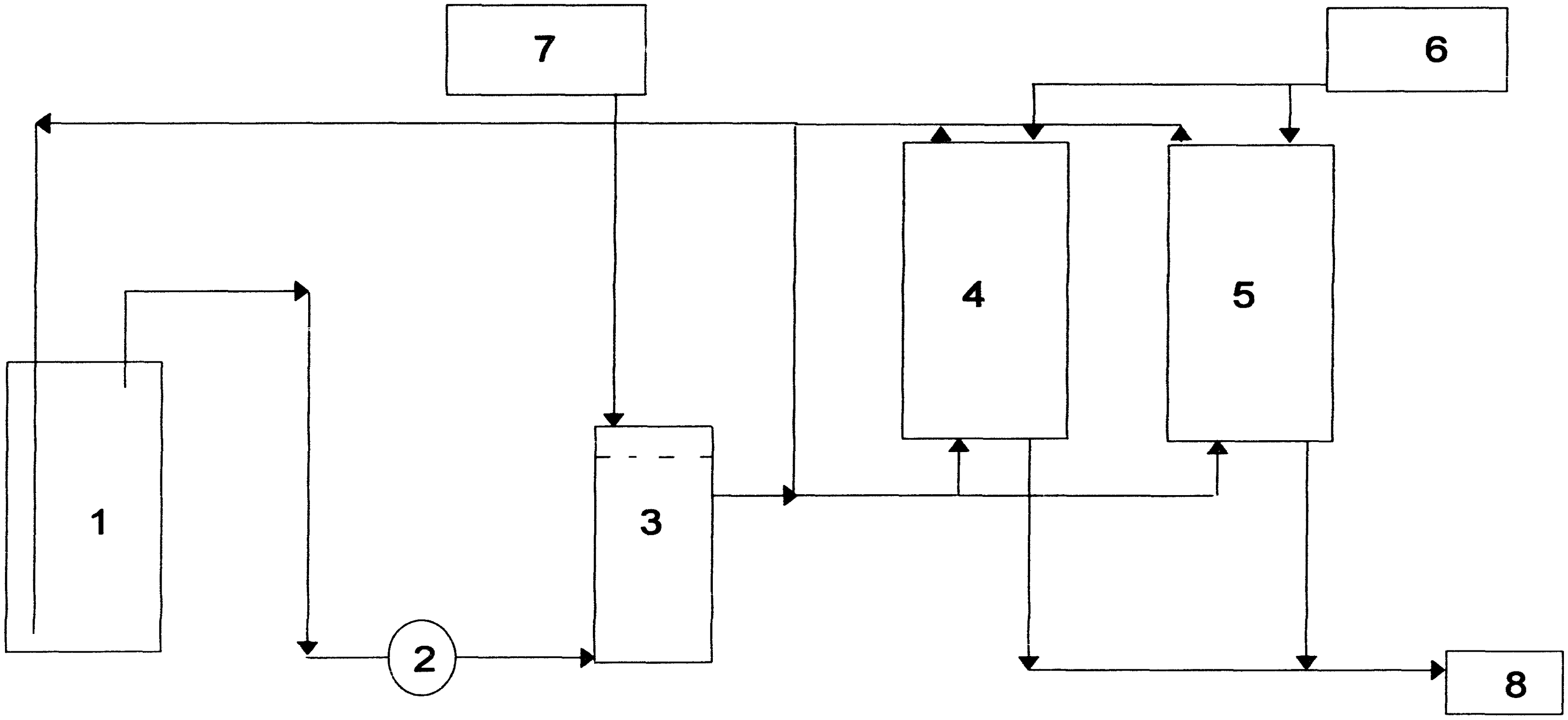
Description of Process Equipment Procured

(i) Column

The reaction column (chromatographic column) is to be used for the Activated Carbon Adsorption studies. The column will be packed with a specific type of Activated carbon which exactly suits the requirement of adsorbing Volatile Organic compounds Benzene, Toluene, Ethyl Benzene and Xylene. The contaminant mixture will be passed through the column upwards with the help of a pump. The column is provided with two openings one at the bottom and another at the top to facilitate packing of the column. Both top and bottom openings are gas tight. The column has one inlet at the bottom for the contaminant gases and an outlet for the nutrient solutions. The top section also consists of one inlet for the nutrient solution and one outlet for the treated gases. The column is also provided with three sample ports placed 6" apart with the

Figure 1

Biofiltration Process Experimental Setup



1. Gas Reservoir
2. Pump
3. Humidifying column

4 & 5. Reaction columns
6. Nutrient reservoir
7. Water tank

8. Drain Tank

first port at 1/3 height from the bottom, to draw the samples for further analysis. The sample ports are provided with gas tight septa to avoid gas leakage. Glass beads will be placed at both top and bottom of the carbon bed to achieve uniform distribution of gases and nutrient solutions over the area of the bed.

Material of the column: Glass

Dimensions of the Column: 24" Length and an ID of 2".

Supplier: ACE GLASS INC., NJ

(ii) Gas Reservoir

The gas reservoir is employed for the purpose of mixing and storing of contaminants. The reservoir will be filled with atmospheric air before adding the contaminant mixture. The gas reservoir is provided with a gas tight opening to facilitate filling the reservoir with air. The gas reservoir has one inlet and one outlet. The inlet will be for the recirculating mixture which will be extended to the bottom section of the reservoir. The outlet is for the contaminant gases which will be curtailed at the top of the reservoir. The contaminants will be injected into the reservoir through a gas tight septum. This gas reservoir will be placed at an higher elevation to increase the head for the pump.

Material of the Reservoir: Glass

Capacity of the reservoir: 5000 ml

Supplier: ACE GLASS INC., NJ

(iii) Gas Pump

The pump is employed for pumping the contaminant mixture through the column. The pump sucks the mixture from the gas reservoir and pumps to columns through a humidifying column. All the parts are made up of materials which are resistant to the contaminants mixture. The pump can be operated at variable speeds and the discharge range is from 5 to 1100 ml/min. The pump is also equipped with a digital Gas flow meter for measuring the rate of mixture being pumped in.

Material : Ceramic Piston, Plastic Cylinder case and Sintered Carbon liner.

Supplier: M/s Pump Express.

(iv) Humidifying Column

The humidifying column is placed between the pump and the column. The contaminants which are pumped from the gas reservoir will be in the gaseous phase and this mixture should be humidified before being passed through the column bed, to avoid complete drying of the bed. The gas from the pump enters the humidifier at the lower portion and gets humidified by the water being sprayed from the top. The mixture exits through the outlet at the top of the column. The column is provided with a circular glass perforated plate to achieve the spraying action of the water. The top of the column is connected to a water tank for continuous supply of water. The water from the column will be drained out at the bottom of the column.

Material of the Humidifier: Glass

Capacity: 2 L

Number of Humidifiers: 1

(v) Tubing

A flexible tubing connects all units of the set-up. Its a 1/4" ID Teflon tube which is resistant to the contaminant gases. The tube is fixed to all the units with compatible adopters.

Material of the Tube: Teflon

Dimensions of the Tube: 1/4" ID, 3/8" OD.

Set up of Gas Chromatograph

The GC, with a flame Ionization Detector (FID), suitable for detecting the VOCs, is required for the precise analysis. The existing GC was updated with Star Chromatography software, and the necessary hardware was procured and installed subsequently. The gases were obtained as per the requirement.

Helium	Carrier gas and Make up gas
Hydrogen & Air	Detector gases

Trial runs were conducted with the test samples and also with the contaminant gases. The respective peaks were identified.

3. Culturing of microorganisms

The microorganisms which are effective in biodegrading the VOCs were identified and the same were procured.

Microorganisms

The microorganisms will be employed to study the Biological removal of VOCs in the columns. The microorganisms cited in the literature for the purpose of degradation of aromatic compounds are Pseudomonas, Acinetobacter and Nocardia. The technical details were discussed with the suppliers ATCC, Maryland. These microorganisms need to be acclimated in the BTEX environment for achieving better growth rate and removal efficiencies.

Supplier : ATCC, Maryland.

Culturing of microorganisms:

Reactivation of the cultures received from ATCC

(a) Acinetobacter sp. Genospecies 11 (ATCC 11171) :

The media suggested by supplier for this species of the microorganism is medium 3 of the Difco catalogue which is Nutrient agar maintained at a temperature of 37°C. The microorganisms received as freeze dried sample needs to be rehydrated in the nutrient agar and incubated in the nutrient broth at the above mentioned temperature. 1.15 g (23 gm/liter) of the nutrient agar is weighed and transferred in to a 250 ml Erlenmeyer flask and 50 ml of millipore water (deionized distilled water) is added. The contents are then heated to dissolve the agar thoroughly and 8 ml of the agar solution is transferred into each of the 5 test tubes. The test tubes are then autoclaved at a pressure of 20 psi and temperature of 250°F for about 15 minutes. The test tubes after injection of the microorganism serve as slants (stock, working and spare) for future use or storage for a longer period at a temperature of 13°C. On the other hand 0.4g of nutrient broth (8 g/liter) is weighed for preparing 50 ml the solution in a similar way as agar solution but only in 3 test tubes of 5 ml each and autoclaved. The test tubes after injection of the microorganism are to be cultured at the above mentioned temperature of 37°C. The vials received need to be broken under the hood and transferred to these test tubes as recommended by the supplier ATCC.

(b) Nocardia Paraffinae (ATCC 21509)

The media suggested by supplier for this species of the microorganism is medium 196 of the Difco catalogue which is Yeast Malt (YM) Extract agar to be maintained at a temperature of 26°C. The microorganisms received as freeze dried sample needs to be rehydrated in the YM agar and incubated in the nutrient broth at the above mentioned temperature of 26°C.

2.05 g (41 g/liter) of the YM extract agar is weighed and prepared 50 ml of the agar solution as above and transferred 8 ml into each of the 5 test tubes (slants). The YM extract broth is not readily available with the Environmental Microbiology laboratory. However the following is the composition of the YM extract broth suggested by the Difco catalogue.

Ingredient	**Weight for 1 liter**
Bacto yeast extract	3 g
Malt Extract Difco	3 g
Bacto Peptone	5 g
Bacto Dextrose	10 g

The above ingredients are weighed for preparing 50 ml of the YM extract agar and transferred to a 250 ml EM flask, subsequently transferred 5 ml to each of 3 test tubes and autoclaved. The vials received need to be broken under the hood and transferred to these test tubes as advised by the supplier ATCC.

4. Adsorption Isotherm studies

The adsorption isotherm studies are underway. Adsorption is the collection of a substance onto the surface of the adsorbent solids, where as Absorption is the penetration of the collected substance in to the solid. Adsorption may be Physical and Chemical. Physical adsorption is primarily due to Van der waals' forces and is reversible occurrence. The phenomenon of Physical adsorption can be observed on the surface of Activated Carbon. Activated Carbon has numerous capillaries within the carbon particles and the surface available for adsorption includes the surface of the pores in addition to the surface of particles, moreover for activated carbon the ratio of total surface area to the mass is extremely large. In chemical adsorption a chemical reaction occurs between the solid and the and the adsorbate and the reaction is irreversible.

Activated carbon is made from various materials like wood, sawdust, fruit pits and coconut shells. The manufacturing of activated carbon usually consists of carbonization of the solids followed by activation using hot air or steam. When a contaminated gas is passed through a bed of activated carbon the adsorption of the adsorbate occurs and its concentration decreases from an initial concentration of C_o to an Equilibrium value of C_e if the contact time is sufficient. With the help of tests it is possible to get a relationship between C_e and the amount of substance adsorbed (x) per unit mass of activated carbon(m). Freundlich Isotherm which is an empirical formulation as shown below,

$$x/m = KC^{e1/n}$$

where K and n are experimental constants.

This equation can be represented graphically by plotting a graph with $C_e$on X axis and x/m as ordinate on a log-log graph. The plot is a straight line, whose slope and intercept on Y axis are 1/n and K respectively.

5. Breakthrough Curve

The breakthrough curve for a column shows the curve with throughput volume on X axis and the effluent concentration on Y axis. The length of the column in which the adsorption occurs is called the adsorption zone Z_s.It is in this zone the effluent is transferred from the gas onto carbon. As the adsorption zone passes up the column the contaminant concentration in the effluent reduces and the breakthrough begins and as the adsorption zone disappears the column is exhausted. At complete exhaustion the contaminant concentration in the influent and effluent are equal.

Before a Breakthrough curve is determined a satisfactory flow rate Q_b in bed volumes per unit time, of the contaminants is selected (usually between 0.2-3 bed volumes/hour).

The bed volume of the design column is given by BV, Bed volume = Q/Q_b , where Q is the contaminant flow rate.

The Mass of the adsorbent M = BV x Density of adsorbent.

The volume at breakthrough V_b is the volume corresponding to the allowable effluent concentration.

The volume of the contaminant treated per unit mass of adsorbent $V_m i = V_b/M$

The mass of adsorbent exhausted per unit time can be given by $M_t = Q/V_m$

The breakthrough time is $T = M/M_t$

If the calculated breakthrough time is not acceptable column can be redesigned by changing the Q_b.

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MISCELLANEOUS REMEDIATION TECHNOLOGIES

DRAIN-ENHANCED SOIL FLUSHING (DESF) FOR ORGANIC CONTAMINANTS REMOVAL
(MC-2a)

Quarterly Technical Progress Report
for Period January 1 through March 31, 1994

Work Performed Under
Contract Number: 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
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May 1994

EXECUTIVE SUMMARY

While major strides in the hazardous waste management field have been made in minimizing the risks associated with the disposal of wastes being generated, hundreds of inactive and/or abandoned hazardous waste sites exist that require remediation. The required remediation approach varies from site to site, depending on the hazardous constituents and site conditions present. The proposed study is an initial step in what will be a continuing effort to develop an in situ method, namely PV drain-enhanced soil flushing, to remove PAHs and other organic compounds from the contaminated subsurface. Because there is little or no experience with using PV drains as part of the soil flushing process, the proposed study will provide fundamental and basic information on performance characteristics of the DESF process as a mean of removing contaminants from sites containing fine grained soils.

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

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

Work conducted in this research investigates major parameters affecting the efficiency of contaminant extraction using PV drains. A single polycyclic aromatic hydrocarbon (PAH), in this case naphthalene ($C_{10}H_8$), is chosen as the study contaminant. Analysis to be conducted include naphthalene (by GC method 8100, USEPA, SW-846). The testing program includes column and batch studies to estimate appropriate environmental and engineering parameters for the soils, contaminants, and surfactant under consideration. In addition, several pilot scale systems (Contaminant Recovery Cells, CRC) in which the recovery efficiency of the PV drains will be evaluated.

The naphthalene removal from sand and a kaolinite/sand mix using an anionic surfactant, sodium dodecylsulfate (SDS) was evaluated. Laboratory tests included batch type experiments with three different surfactant concentrations. Column flushing tests were performed utilizing flexible wall permeameters to model in-situ conditions on two types of soils. The adsorptive capacity of the kaolinite dominated the removal kinetics of the SDS surfactant. The partition coefficients for the kaolinite soil was evaluated and its variation was found to be related to the concentrations of the SDS used. The use of 10, 50, and 100 mM SDS solutions resulted in partition coefficients of

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1.55, 0.165, and 0.155 L/mg, respectively, with the greater partition coefficients observed at SDS concentrations close to the Critical Micelle Concentration (CMC). Permeability tests using SDS as permeant liquid resulted in a two-orders-of-magnitude reduction in the values of the hydraulic conductivity. Flushing of naphthalene from the sand/kaolinite soil took 2.5 months to attain a removal level of 94% while the same removal level was attained in the case of sand only in a period of four days. In addition, 86% fewer pore volumes were permeated through the sand sample, to attain the 94% removal level, as compared to the kaolinite/sand samples

In addition, Major parameters affecting the feasibility and efficiency of liquid extraction using Prefabricated Vertical Drains (PVD) in conjunction with a vacuum system were investigated. Laboratory tests for this purpose included flexible wall permeability tests on soil specimens with and without a PVD installed in the middle of the specimens. In addition, pilot scale tests (0.67m X 0.67m X 1.0m - length/thickness/depth of soil) using Contaminant Recovery Cells (CRC) were conducted. soil samples were prepared from a mixture of 80% Ottawa sand and 20% kaolinite. The measured permeabilities for the study soil in accordance to ASTM D5084 decreased from $3x10^{-4}$ cm/sec for water content of 7% to approximately $2x10^{-5}$ cm/sec for molding water content of 11%. It was possible to replicate the $3x10^{-4}$ cm/sec permeability in the bench-scale reactors by controlling the moisture content and the compaction effort. Results from flexible column tests on specimens with PVD indicated a flow rate as high as 6 ml/sec can be obtained as compared to 0.25 ml/sec measured for specimens with no PV drains. Long term (4 weeks) clogging test on the PVD indicated a steady state flow rate of 0.12 ml/sec under a vacuum of 19 kPa with no apparent decreasing trend. Using four PVD, the volume of the retrieved fluid increased as a function of the vacuum level and was approximately 0.5 ml/sec. This indicated a recovery efficiency of 100% under vacuum magnitude of approximately 14 kPa. Using the observed drawdown of approximately 70 mm, total flow rate predicted using the well equation is 0.96 ml/s for a specific yield (S_y) value of 0.3. This value was approximately twice the rate measured using the PVD/vacuum system. However, using $S_y=0.07$ resulted in a total flow rate of 0.5 ml/sec which matched the flow rate retrieved using the PVD/vacuum system.

Analytical predictive model for contaminants transport with PVD installation is formulated. The results of a parameter study indicated that the model is robust. Expanded parameter study is currently being conducted.

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1.0 INTRODUCTION

Significant research effort is currently being conducted in the U.S. and the world for remediation of contaminated soils and groundwater. The Department of Energy (DOE) is responsible for approximately 3000 sites at which contaminants such as carbon tetrachloride (CCL), trichloroethylene (TCE), perchloroethylene (PCE), nonvolatile and soluble organics and insoluble organics (PCBs and pesticides) are encountered. Recently, the United States Environmental Protection Agency (USEPA) evaluated the progress of 112 sites where groundwater extraction was an integral part of containment and/or restoration activities (USEPA 1989a,b,c). The majority of the 112 sites were contaminated with organic compounds. The type and concentration of these organic compounds were found to be extremely diverse. In general, chemicals such as TCE, creosote, and PCBs have been reported as contaminants of concern (USEPA 1989d). In addition to the variety of contaminants and concentrations that prevail at these sites, wide variations in soil type, geological formation, and hydrogeologic conditions exist. A "typical" contaminated soil is difficult to define and remediation measures are usually developed on a site-specific basis.

There are a number of approaches to remediation that are used at contaminated sites. Examples are in-situ bioremediation, vacuum or air stripping, immobilization, and soil washing/flushing. In the case of in-situ bioremediation, organic compound(s) are biochemically degraded within the contaminated subsurface. Air or steam stripping are feasible if the Henry's Law constant of the organic compound(s) is greater than 3×10^{-3} atm/m^3 mol. In the case of immobilization techniques, contaminants are tightly bounded within a solid matrix that minimizes their migration. Solidification, stabilization, and vitrification are the principal immobilization techniques. Contrary to immobilization, the soil washing/flushing approach promotes contaminant solubilization and migration in the liquid phase so that the contaminants can be easily flushed from the soil matrix. Soil washing refers to ex-situ remediation of soils whereas soil flushing refers to in-situ extraction of contaminants (i.e., pump and treat technology). Considering all remediation approaches, only soil flushing and stripping remove contaminant(s) from the contaminated zone without excavating the soil. Of these two, soil flushing is the process of investigation in this research program.

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

However, in the case of fine grained soils, the efficiency of the soil flushing process can be enhanced by using Prefabricated Vertical Drains (PVD), also referred to as wick drains. The PVD's can be used to decrease the flow path and travel time between injection and extraction

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points and therefore expedite the remediation process.

The improvement of flushing solution movement in relatively low permeability soils (10^{-4} to 10^{-3} cm/s) is the subject of this research program. The feasibility of using PVD for enhanced soil flushing is presented. Major parameters affecting the mechanism and efficiency of liquid extraction using PV drains in conjunction with a vacuum system are investigated. A creosote contaminated site has been selected as the object of remediation. The chemical composition of creosote is approximately 85 percent polycyclic aromatic hydrocarbons (PAHs), 10 percent phenolic compounds and 5 percent others (N, S, and O heterocyclic compounds). Thus, a single polycyclic aromatic hydrocarbon (PAH), in this case naphthalene ($C_{10}H_8$), was chosen as the study contaminant. While remediation research must address diverse conditions, the main focus of this research project is the improvement of the liquid movement phenomenon of the soil flushing process and therefore, the choice of naphthalene is deemed appropriate for this purpose. It is tacitly assumed that the PV drain-enhanced soil flushing method will improve the efficiency of the pump and treat process regardless of the specific organic contaminant(s). Soil samples for this study are prepared from a mixture of Ottawa sand and kaolinite species of clay.

Research work to investigate the use of PVD for enhanced soil flushing include bench scale laboratory tests, pilot-scale laboratory tests, data analysis and the development of analytical contaminant transport model. Laboratory work is conducted to evaluate the potential of naphthalene removal from sand and kaolinite/sand soils by use of an anionic surfactant, sodium dodecyclsulfate (SDS). Batch type experiments with three different surfactant concentrations are conducted and adsorption/desorption behavior of the study soil is characterized. Improvement in liquid retrieval due to the installation of the PVD is investigated using flexible wall column tests on soil specimens with and without a PVD installed in the middle of the specimens. The flexible wall permeameters were selected to avoid problems with sidewall leakage and to model in-situ stress conditions. Specimens for the column tests are prepared using compaction procedures according to ASTM D698, method A. Column flushing tests are also performed according to ASTM D5084. In addition, pilot scale tests using large scale reactors, will be referred to as Contaminant Recovery Cells (CRC), are conducted. Long term efficiency of the PVD operating under a vacuum system is investigated. Retrieved flow rates as a function of the vacuum level are presented. Applicability of the well's theory to predicting flow rates for the PVD/vacuum system is discussed. A predictive contaminant transport model to analytically simulate full-scale operation of PV drain-enhanced soil flushing system is developed. A parameter study is conducted and the overall feasibility and performance of the PV drain-enhanced soil flushing technique is presented.

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2.0 BACKGROUND

In this section a brief discussion on PAHs contaminated sites, and the fate of PAHs in the subsurface (adsorption, desorption, biodegradation, and volatilization) and the use of surfactnat for contaminant soluablization is included. Background information on the conventional soil flushing system, the use of PV drains to improve liquid movement in the subsurface, and how PV drains will be used to improve the soil flushing process, is presented. Because the focus of this research is on improving the movement and extraction of the flushing solution through the contaminated zone, the literature review is focused on liquid and mass transport in the subsurface.

2.1 EXAMPLES OF PAHS CONTAMINATED SITES

In examining contaminated sites, a wide variety of PAHs (and other organic contaminants) are present in widely ranging concentrations. There are over 2000 wood preserving sites in the United States requiring remediation with over 50 of these sites on the National Priority List (NPL), Stinson et al. (1991). The MacGillis and Gribbs Superfund site in New Brighton, Minnesota, is heavily contaminated with creosote, pentachlorophenol, and fuel oil. PAH concentrations as high as 407 mg/kg have been reported (Stinson et al. 1991). At the Pine Street Canal Superfund site in Burlington, Vermont, PAH concentrations of 2,800, 240, and 10 mg/kg for peat, soils, and sediments, respectively, have been reported by Weir and McLane (1991). Christiansen et al. (1991) reported PAH concentration exceeding 1900 mg/kg at an undisclosed Texas site. PAH concentrations exceeding 3,000 mg/kg and 20,000 mg/kg have been reported at the Bayou Bonfouca (Slidell, Louisiana) and the Jennison-Wright (Granite City, Illinois) sites, respectively, as stated by Halloran et al. (1991).

2.2 PAH ADSORPTION AND DESORPTION, DEGRADATION, AND VOLATILIZATION

The fate of contaminants in the subsurface is influenced by the extent with which the contaminant adsorbs and desorbs, degrades, and volatilizes. Each of these topics will be discussed separately. The majority of the review focuses on adsorption and desorption because during the performance of the proposed research, steps will be taken to minimize degradation and volatilization.

2.2.1 Adsorption and Desorption

PAHs, the study contaminant, readily accumulates on soil particles. The concentration of the soil-bound contaminant can be related to the solution concentration through a number of isotherms (Freundlich, Langmuir, and B.E.T). In this study it is assumed that the soil has been contaminated thus, adsorption of the PAH will not be examined to a large extent. However, the adsorption of the surfactant-PAH onto clean soil will be investigated. It is conceivable that the contaminated flushing solution will pass through areas of the subsurface that are not contaminated and thus, it is possible that readsorption can occur. Desorption or solubilization

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of the contaminant from the soil in the presence of surfactant will be studied.

2.2.2 Biodegradation

A large number of organic compounds are subject to biochemical degradation. Biological treatment of contaminated sites has been named as the remediation technique in about 15 percent of the Records of Decision (ROD) (Christiansen et al. 1991). Naphthalene, the simplest PAH, is considered relatively degradable with a BOD5/COD ratio of < 0.2 (USEPA 1985). Christiansen et al. (1991), reported that the half-lives of total and carcinogenic PAHs in a soil-sludge slurry reactor were between 16 and 88 days. Weir and McLane (1991) reported that PAHs of low molecular weight (e.g., naphthalene and 2-methylnaphthalene) were biodegradable in soils, but higher weight PAHs were not. Berg et al. (1991) demonstrated that the composting of PAH contaminated soils was a viable treatment alternative. Total PAH soil concentration was decreased from approximately 300 mg/kg to less than 50 mg/kg in 14 weeks. Thus, it is apparent that PAHs, especially those with lower molecular weights, are susceptible to biochemical degradation. Measures to deter or account for biodegradation in laboratory experiments will be implemented.

2.2.3 Volatilization

PAHs are classified as semivolatile and generally have a Henry's constant lower than 10^{-4} atm/m^3 mol. Organic compounds having a Henry's law constant greater than 3×10^{-3} atm/m^3 mol are candidates for air stripping (Holden et al. 1989). While volatilization of PAHs is possible, transfer of the contaminant to the gas phase is not an efficient process. However, during the conduct of this research, the loss of PAHs from the soil via volatilization is accounted for by using a controlled experiments environment. Naphthalene has a Henry's law constant of 4.9×10^{-4} atm/m^3 mol.

2.3 SOIL FLUSHING AS A REMEDIATION TECHNIQUE

Soil washing/flushing processes normally utilize water as the primary washing fluid; chemical additives are carried by the water to promote contaminant solubilization. Non-ionic and ionic surfactant, acids, and solvents are examples of chemical additives. While soil flushing is the focus of this research, much information can be gained by examining the effectiveness of chemical additives in extracting soil-bound contaminants in the soil washing process. Soil washing refers to the ex-situ remediation of soils, whereas soil flushing refers to the in-situ extraction of contaminants. Use of these two methods has been limited. However, of these two methods, there has been a greater amount of study conducted on soil washing systems, especially in Europe (USEPA, 1988a).

The conventional soil flushing process involves a number of steps. Each step must be considered separately when assessing the overall effectiveness. The four steps are:

1) contaminant solubilization by the wash fluid (surfactant),

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2) extraction of the solubilized contaminants from the subsurface,
3) treatment of the spent flushing water, and,
4) disposal/reuse of the treatment residuals.

A general schematic of the first two steps, which defines the scope of this proposed investigation, is shown in Figure 2.1 (Holden et al. 1989). Conditions adversely affecting the success of the soil flushing process are listed in Table 1. Hydrogeologic conditions of the contaminated area are extremely important to the success of the soil flushing process. USEPA (1988b) reported that soil flushing has been used at five Superfund sites for the removal of organics. The permeability of the soils at these sites was relatively high. Currently, the soil flushing option is difficult to implement at sites with low permeabilities.

Table 1. Characteristics Affecting the Soil Flushing Process

Characteristics	Reason for Potential Impact
Unfavorable Waste Characteristics Mixed waste types Variable Waste Composition	Washing solution difficult to formulate Frequent formulation of washing solution
Unfavorable Soil Characteristics Variable soil conditions Low permeability High soil humic content Soil-solvent interactions	Inconsistent flushing Movement of flushing solution hampered Desorption difficult Desorption inhibition
Unfavorable Flushing Solution Characteristics Difficult recovery of washing solution Poor treatability of washing solution Toxicity of washing solution Reduction of soil permeability	High costs Replacement of washing solution Health risks Flushing chemicals reduce porosity.

Source: Technology Screening Guide for Treatment of CERCLA Soils and Sludges, U.S. EPA, (1988b)

2.3.1 Use of Surfactant to Remove Soil-Bound Organics

Surfactant molecules have both a polar (hydrophilic) and nonpolar (hydrophobic) segment and thus they accumulate at polar-nonpolar interfaces. Above a certain concentration surfactant will form micelles (aggregates). The polar end of the molecule in the micelles is presented to the aqueous phase. The nonpolar end of the surfactant molecule faces inward, away from water molecules. The interior of the surfactant micelles is nonpolar and thus can solubilize nonpolar compounds that are sorbed onto soil particles. A large number of commercial surfactant that are environmentally safe and relatively inexpensive are available. Surfactant types can be categorized

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as ionic (anionic, cationic), nonionic, and amphoteric. Examples of surfactant and their characteristics are presented in Table 2 (USEPA 1985).

Table 2. Surfactant Types

Anionic	Cationic	Non-ionic	Amphoteric
Carboxylic acid salts	Long chain amines	Alcohol ethoxylates	pH sensitive
Sulfonic acid salts	Quaternary ammonium salts	Polyoxyethylenated alkylphenols	pH insensitive

The use of surfactant was first investigated by the Texas Research Institute (1979, 1985) as a method of recovering gasoline. Ellis et al. (1985) investigated the use of nonionic surfactant for removal of PCBs, chlorinated phenols, and petroleum hydrocarbons from soils. At surfactant concentrations of 1.5 percent (by volume) over 90 percent of the contaminants was removed from the soil. The use of surfactant increased removal by an order of magnitude over that observed for a water-only flush. A possible drawback to using nonionic surfactant in the soil flushing process is the difficulty encountered in separating the surfactant from the contaminated groundwater and subsequent surfactant reuse. Nash (1987) investigated surfactant enhanced soil flushing at the lab and field-scale using soil from the Volk Air National Guard Base, Wisconsin. Significant removal of organics in the lab-scale systems was reported. However, organic removal in the field-scale systems was less than that observed in the laboratory. The decrease in organic removal was attributed to the surfactant not penetrating the soil.

Liu et al. (1991) investigated the solubilization of several PAHs (anthracene, phenanthrene, and pyrene) by nonionic and anionic surfactant. Nonionic surfactant octyl- and nonyl-phenylethoxylates (9 to 12 ethoxylate units) were the most effective. A 1 percent (by volume) surfactant dosage was required to achieve 70-90 percent solubilization. Fountain and Hodge (1992) reported that several surfactant were able to increase the solubility of common chlorinated organics (e.g., perchloroethylene (PCE)) by several order of magnitudes. They also reported that, for PCE, several surfactant lowered interfacial tension between water and PCE to less than 1 dyne/cm causing downward vertical movement of the PCE. Thus, proper selection of surfactant mixtures is required if spreading of the contaminant downwards towards uncontaminated soils is to be minimized.

Dworkin et al. (1988) and Kuhn and Piotek (1989) reported favorably on the use of soil flushing for wood preserving contaminated sites. The relationship between the amount of contaminant that is solubilized and the surfactant concentration is approximately linear provided that the surfactant concentration is above the "critical" micelle concentration (CMC) as described by Gannon et al. (1989). At surfactant concentrations below the CMC contaminant solubilization does not occur. Gannon et al. (1989) reported that the CMC may be substantially reduced by the presence of a hydrophobic contaminant. However, Liu et al. (1991) reported that the solubilization of several soil-bound PAHs occurred at surfactant concentrations that were larger than the "clean-water" CMC.

In summary, a great deal of research on the development and use of surfactant to remove organic compounds from soils has been conducted. Based on results from lab-scale studies as well as full scale remediation systems, the use of surfactant in the remediation of contaminated soils appears to be promising.

2.4 PV DRAINS AND SUBSURFACE LIQUID MOVEMENT

Prefabricated vertical (PV) drains, also referred to as wick or strip drains, were originally developed as a substitute for the commonly used sand drains. They have been used extensively in the past for the expedient drainage and consolidation of low permeability soils under surface surcharge for the purpose of soil improvement. The design of prefabricated vertical drains varies according to a specific application. Key parameters usually addressed in the design include:

i. Equivalent diameter of the drain which dictates the size of the inflow surface; and,
ii. Discharge capacity of the drain.

PV drains shorten the drainage path of the flow and therefore would expedite the soil flushing process. Compared to conventional well fields and drains, the use of PV drains would reduce both labor and material costs. Because the installation process is relatively simple and inexpensive, fluid extraction using this process can prove to be practical and cost-effective. Figure 2.2 schematically shows a possible arrangement for the use of PVD system for recovery of subsurface pollutants in the field. Past applications of the PVDs and state-of the-art design and selection methods are presented below.

2.4.1 Past Field Applications of PVD

As described by Anon (1988) PV drains used in field applications consist of porous geotextiles wrapped around a plastic drainage core 3 to 4 inches wide and one quarter to 3/8 of an inch thick. PV drains are usually spaced in a manner to allow the dissipation of pore pressure generated due to the application of surcharge or hydraulic stresses on the system. They provide a conduit for flow under the induced hydraulic gradient. Typically they are arranged in a triangular or square grid pattern with 3 to 12 feet spacing. Installation rates reported in the literature are on the order of 1-3 feet per second excluding equipment mobilization and set-up time. Figure 2.3 illustrates the installation process of a typical PV drain configuration in a field situation.

The use of synthetic PV drains has evolved to many applications and several case studies were reported in literature. A theoretical study pertaining to the design and application of vertical drainage systems was conducted by Guido (1986). Recommendations for the selection of design spacing for band-shaped PV drains were examined. A comprehensive research program was carried out by New York State Department of Transportation (Suits et al 1986) to estimate the effectiveness of several types of PV drains. This research program included laboratory and field testing. Results indicated the suitability of using PV drains to accelerate the drainage of a given soil profile.

A successful implementation of PV drains was presented by Mattox (1987). In this project, construction of a 21.7 ft high embankment over weak marsh deposits in Mobile, Alabama, was accomplished through the use of geogrid reinforcing and PV drains. Installation of PV drains was necessary to reduce the time required for settlement of the embankment through accelerated drainage of the subsurface profile. Estimated savings due to the use of the innovative drainage technology was on the order of $600,000. In another application, Thacker et al (1988) presented a case in which PV drains were used in the construction of a coal refuse impoundment to allow complete pore pressure dissipation. Field measurements with pneumatic piezometers indicated that the use of PV drains in the drainage scheme was successful. The coal refuse impoundment met prudent engineering criteria with regard to stability even though a large portion of the dam was being built over hydraulically filled fine coal refuse. In a similar application, Saye et al (1988) presented a case in which PV drains, installed at spacing ranging from 3 feet to 5.5 feet, were used in order to facilitate drainage and strength gain of soft highly plastic clay deposited in a cutoff oxbow of the Missouri River.

In general, research work conducted to quantify the performance of the PV drains is mostly directed toward the drainage potential to accelerate the consolidation process, or compression of a soil profile due to expulsion of water. No research specifically addressed the quantity of flow being collected using a PV drainage scheme. Furthermore, no research was conducted to address the potential of using a PVD drainage scheme for the removal of pollutant substances from subsurface soils.

However, some research was conducted on the retrieval of tracers in agricultural applications through the use of subsurface drains. Everts and Kanwar (1990) presented the results of a study in which potassium bromide and calcium nitrate were used as tracers in sprinkler irrigation water. These tracers were applied to a field plot drained with a single subsurface drain line during two irrigations. Drain outflow was measured, and water samples were collected from drain discharge and analyzed for Nitrate (No^{-3}) and Bromide (Br^{-}) content. Results indicated that, transported on a mass basis, 24% and 12% of the bromide and 20% and 9% of the nitrate reaching the drain, respectively, during the two sprinkler irrigations. Although not directly related to the scope of the proposed work, the results of this study indicates the promising potential of using subsurface drains for collecting subsurface pollutants.

2.4.2 Theoretical Background: Vertical Drains

Originally, the vertical drains were constructed from sand. With the advent of material science, these have been largely replaced by the use of prefabricated vertical drains (PVD) that are manufactured from synthetic polymers. Theoretical description of flow mechanisms and associated volume changes for vertical drains was presented by Terzaghi's (1943) radial

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consolidation theory and Barron (1948). Hansbo (1979, 1981) adopted these theories for the analysis of PVDs. The basic concept in utilizing the PVD is that as a system of PVD is installed and gradient is induced through applying surface area surcharge or vacuum potential, the rate of drainage will be increased due to the decreased drainage path. Obviously the spacing of the drains greatly influences the rate of drainage. As illustrated in Figure 2 (a) each drain has a zone of influence which is defined by the drain spacing. This zone was originally given the shape of a square for square spacing patterns and a hexagon for triangular or staggered patterns. Replacing the polygonal zone of influence with a right circular cylinder of equal area simplified the problem by making it axisymmetric. The diameter of the zone of influence (deq) was defined by 1.13 times the spacing for square patterns and 1.05 for triangular patterns. This assumption has been shown to not introduce any significant errors into the calculations (Terzaghi, 1943). General boundary conditions were that the outer boundary of the zone of influence is an impermeable membrane, i.e., a no flow boundary, the lower surface is a no flow boundary, and excess water escapes only through the drain or through the top of the zone of influence.

Barron (1948) and Hansbo (1979, 1981) performed the seminal work in radial consolidation theory for vertical sand drains and its application to PVD installations, respectively. Richart (1957) conducted an extensive review of these theories and provided a discussion of numerical procedures to solve the various consolidation equations. The subsequent paragraphs primarily review the work of Barron (1948) and Hansbo (1979, 1981).

Barron's (1948) work formed the basis of all subsequent solutions for radial consolidation equations for PVD installations. Two extreme cases for vertical consolidation, free strain and equal vertical strain, were considered. Cases considered included ideal case and a case in which installation caused smear zone; will be referred to as the "well smear" case. In addition, resistance to upward flow inside the drains, referred to as "well resistance", was considered only for the equal vertical strain case. The difference in the solutions between the case of free strain and that of equal vertical strain is negligible as reported by Barron (1948) and Hansbo(1979) with the equal strain case solutions being simpler (Barron, 1948 and Richart, 1959). Observations of field conditions supported the assumption of equal vertical strain as presented by Hansbo (1979). Therefore the equal strain case is usually assumed in the design and analysis of vertical drains.

The general equation given by Barron (1948) for consolidation due to both radial and vertical flow with the presence of vertical drains is:

$$\frac{k_h}{\gamma_w}\left(\frac{1}{r}\frac{\delta u}{\delta r} + \frac{\delta^2 u}{\delta r^2}\right) + \frac{k_v}{\gamma_w}\left(\frac{\delta^2 u}{\delta z^2}\right) = \frac{a_v}{(1 + e)}\left(\frac{\delta u}{\delta t}\right) \qquad (1)$$

where: r and z = cylindrical coordinates

k_h = coefficient of permeability in the horizontal direction
k_v = coefficient of permeability in the vertical direction

γ_w = unit weight of water
a_v = coefficient of compressibility (-de/dp)
e = void ratio

Using the methodology outlined by Carrillo (1942) a solution to (1) is:

$$u_{r,z} = \frac{u_r u_z}{u_o} \qquad (2)$$

where: $u_{r,z}$ = excess pore pressure due to combined radial and vertical flow

u_r = excess pore pressure due to radial flow only
u_v = excess pore pressure due to vertical flow only
u_o = initial excess pore pressure

The above theory was developed for the design and analysis of sand drain installations and did not consider the effects of disturbance (smear) or of well resistance. Simple adaptations have made them applicable to the analysis of PVD installations.

2.4.3 Effect of Smear

Regardless of the installation process, some disturbance of the surrounding soil will occur. As stated previously this disturbance is often termed "smear". The classic example of smear is the case of a varved clay in which the varves consist of a clay overlying a coarser layer, e.g., silt. During installation the clay will be "smeared" down over the more permeable silt layers creating a zone of low permeability adjacent to the drain (Barron, 1948).

Obviously the larger the mandrel used in the installation process the larger the zone of disturbance will be. Casagrande and Poulos (1969) reported that, using the full displacement methods for sand drains installation, the zone of disturbance will extend a distance from the periphery equivalent to the area of the displaced area of the sand drain. The circular, hollow, closed-end mandrel then can be considered to create the largest zone of disturbance. In order to prevent excess disturbance the size of the mandrel for PVD installation must be as close as possible to the size of the drain itself.

In no case will the disturbed zone (smeared zone) be homogeneous with respect to either geometry or soil properties. However, Barron (1948) has assumed the zone to be homogeneous. In addition it was assumed that due to the proximity of the zone to the drain it will consolidate very rapidly. It was postulated that consolidation near the drains is expedited by high lateral pressures generated by drain installation, and by the high hydraulic gradients generated with the placement of fill (Casagrande and Poulos, 1969). These occur relatively quickly with respect to the undisturbed soil. Barron (1948) treated the soil in the disturbed zone as an incompressible material ignoring its consolidation relative to that in the remainder of the zone of influence.

2.4.4 Well Resistance

Heretofore all the solutions presented have assumed infinite permeability in the drains, i.e., no resistance to flow would occur in the drain. Reality however is that head losses will occur in the flow out of the drain. Well resistance is particularly significant for large flow volumes and/or when the diameter of the drain is small. The use of very thin geotextiles as filters on the PVD's may assist in partially eliminating this resistance but it remain as a major factor to be considered. In 1948 Barron developed solutions for well resistance. He considered both the presence and absence of a peripheral smear zone at the well. In both cases it was assumed that the vertical permeability of the consolidating soil to be zero.

2.4.5 Hydraulic Analysis of PVD's

Several modifications and approximations of the above theories are apropos to the design and analysis of PVD installations. Hansbo (1979) published a succinct presentation of these adaptations which has become the preferable design methodology in use today (Koerner, 1990). In 1981 Hansbo published more rigorous derivations of the solutions found in his 1979 work. Hansbo (1979) used only the equal strain theory of Barron (1948) citing the small differences in their results and the agreement of field observations with the equal strain theory. The average degree of consolidation (which is related to the dissipation of pore pressure and the volume of water expelled from the soil pore space) due to radial flow only was given by Hansbo (1979) as:

$$U_h = 1 - e^{\frac{-8T_h}{\mu}} \tag{3}$$

Recalling that:

$$T_h = \frac{c_h t}{D^2} \tag{4}$$

where c_h = coefficient of consolidation due to radial (horizontal) flow and D = length of the drainage path. It is a simple matter to solve for the time (t) for a certain degree of consolidation to occur as:

$$t = \frac{D^2\mu}{8c_h}\ln\left(\frac{1}{1 - U_h}\right) \tag{5}$$

The μ term is equivalent to Barron's term for F(n) used by others. Hansbo (1979) approximated μ as:
where n is the ratio of the radius of the zone of influence to the radius of the drain.

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$$\mu = \frac{n^2}{n^2-1}(\ln(n) - 0.75 + \frac{1}{n^2}) \qquad (6)$$

Graphical solutions were developed for Hansbo (1979) model which enable the user to directly obtain the maximum drain spacing for different drain diameters in order to achieve a given degree of consolidation. A major consideration in the application of radial consolidation theory for PVDs was the shape of the PVDs. Usually they are band shaped, having a thickness of about 4 mm and a width of about 100 mm (Kjellman, 1948;Hansbo, 1979;Koerner, 1990). In contrast the sand drains for which the theory was developed are circular. An equivalent diameter for the PVDs was therefore necessary.

Kjellman (1948) stated that the circumference of the drains was more critical than the diameter, i.e., the cross-sectional area. This assumption was verified using the finite element method by Runesson, Tägnfors and Wiberg (1977). Results of an experimental study by Singh and Hattab (1979) found results which tend to verify Kjellman's assumption. Using different shaped mandrels in examining the effects of installation and spacing they found that the highest rates of consolidation were obtained using a closed, cross-shaped mandrel. Such a shape provides a large circumference. Although they used a mandrel with a higher circumference (star shaped) the resulting angularity of this shape caused more disturbance thereby reducing the rate of consolidation below that obtained with the cross-shaped mandrel.

Consequently equivalent drain diameters for PVDs are based not on cross-sectional area but on equivalent circumferences. For example, a typical PVD having a thickness of 4mm and width of 100 mm has a circumference of 208mm. The resulting equivalent drain diameter, i.e., the

$$CIRCUMF = 208mm = 2\pi r \rightarrow d_{eq} = 66mm \qquad (7)$$

diameter a sand drain would have if it had the same circumference is:
or symbolically:

$$C = 2(b + t) = 2\pi r = \pi d_{eq}$$
$$\rightarrow d_{eq} = \frac{2(b + t)}{\pi} \qquad (8)$$

where: d_{eq} = the equivalent diameter of the PVD
b = width of the PVD
t = thickness of the PVD

Equation (8) does not allow for the throttle which occurs as flow lines come together rapidly, such as at the edge of a PVD. Atkinson and Eldred (1981) reported that the Delft Laboratory of Soil Mechanics in the Netherlands proposed a further reduction of ($\pi/4$), i.e., ¼ the circumference be applied to Equation (8). Because equivalent diameters range only from about 66 to 100 mm for the majority of PVDs currently available and drain spacings are generally no less than 0.8 m the ratio (n) of radius of zone of influence to drain radius is generally greater than 12. As a result a further approximation of μ, Barron's F(n), is justified (Hansbo, 1979):

$$\mu \approx \ln(n) - 0.75 \tag{9}$$

The modifications for well resistance and smear are similar to those of Barron (1948). Considering well resistance only, the term μ in Equation (6) should be replace with μ_r as follows:

$$\mu_r = \ln(n) - 0.75 + \pi z(2l-z)\frac{k_c}{q_w} \tag{10}$$

where:
l = length of drain, ½ length when the well is double draining
k_c = permeability of the undisturbed soil
q_w = discharge capacity of the well

In the case of PVDs with the ratio k_c/q_w less than about 3000 m^2, the effect of well resistance cannot be ignored (Hansbo, 1979). Determination of the discharge capacity is preferably accomplished by full scale field tests or alternately by laboratory tests which attempt to closely model field conditions (Hansbo, 1979, Hansbo, Jamiolkowski, and Lok, 1981), e.g., soil type, in situ stresses, hydraulic gradients, drain type.

The effects of smear can be accounted for by two methods, either by simply using a smaller diameter drain or by assuming a smeared zone of radius (r_s) and reduced permeability (k_c') to exist around the well. For PVD installation design and analysis a reduced equivalent diameter of 50 mm has been found to agree with observations (Hansbo, 1979, Davies and Humpheson, 1981). When using a reduced equivalent diameter (and assuming no well resistance) the solutions for the ideal case can be used without further modification. When considering a smeared zone to exist around the well the μ term should be replaced with μ_s as follows:

$$\mu_s \approx \ln\left(\frac{n}{s}\right) + \frac{k_c}{k_c'}\ln(s) - 0.75 + \pi z(2l-z)\left(\frac{k_c}{q_w}\right)\left\{1 - \frac{\frac{k_c}{k_c'} - 1}{\left(\frac{k_c}{k_c'}\right)\left(\frac{n}{s}\right)^2}\right\} \tag{11}$$

where: $s = r_s/r_{eq}$.

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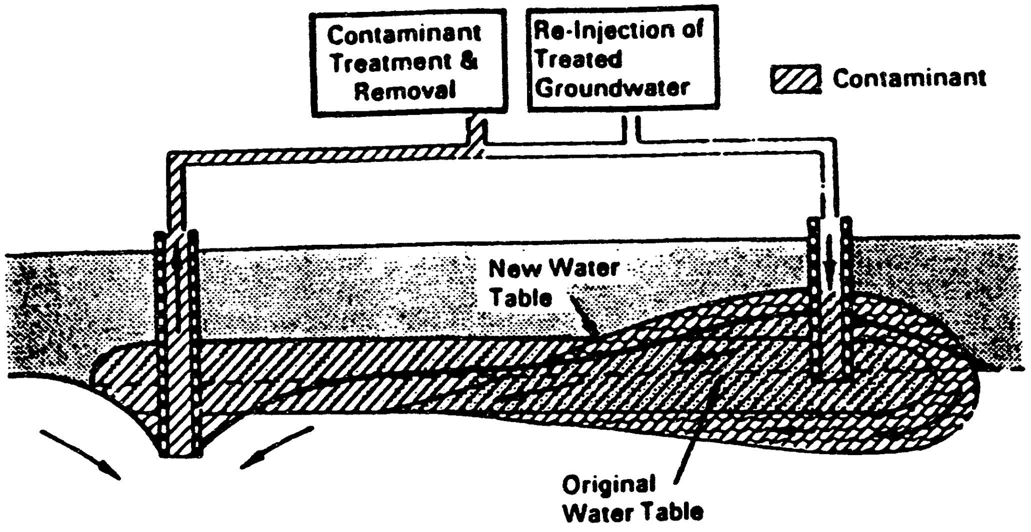
Unfortunately the values for s and k_c' are somewhat debatable. Values of s between 1.5 and 3 have been reported in the literature. Casagrande and Poulos' (1969) work for driven sand drains results in s value of 1.4. The range for k_c/k_c' is however less well defined (Hansbo, 1979). Barron (1948) assumed a value of k_c/k_c' to be 0.1. Later, Casagrande and Poulos (1969) concluded that the permeability in the smeared zone could be up to 3 orders of magnitude lower than in the undisturbed zone. Hansbo (1979) stated that the best agreement with Equation (11) has been by using the reduced equivalent diameter method.

In general the theory behind the use of PVD for soil improvement applications is well defined. However, several modifications and adaptation have to be conducted to render these theories usable for the application of soil flushing. In addition, a contaminant transport model has to be developed in order to analyze and investigate the effectiveness of using PVD for removal of subsurface contaminants.



Source: EPA/540/2-86/003(f)

Figure 2.1 Schematic of Conventional Soil Flushing Process

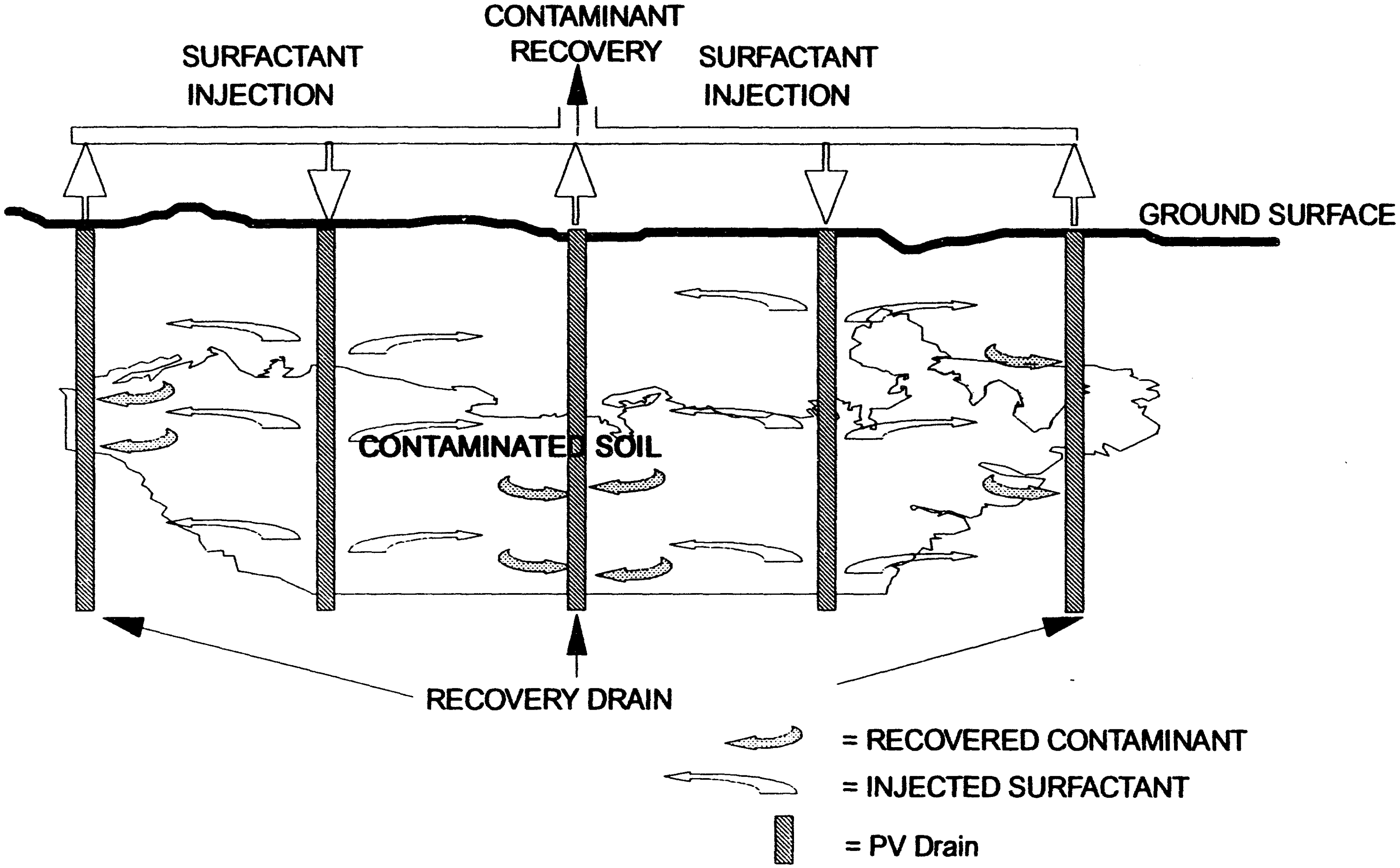
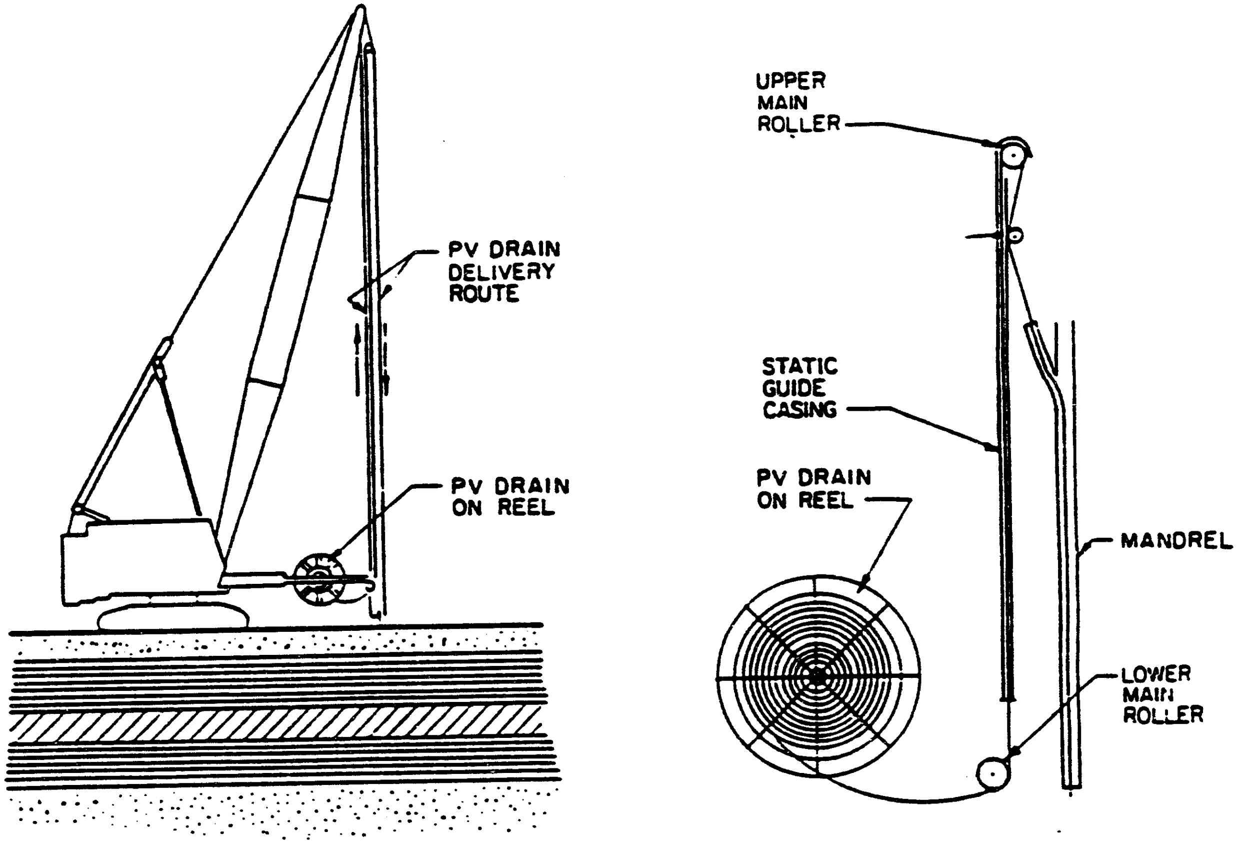


Figure 2.2 Proposed Field Configuration for Contaminant Recovery



(A) INSTALLATION RIG

(B) DRAIN DELIVERY ARRANGEMENT

Figure 2.2 Proposed Field Configuration for Contaminant Recovery

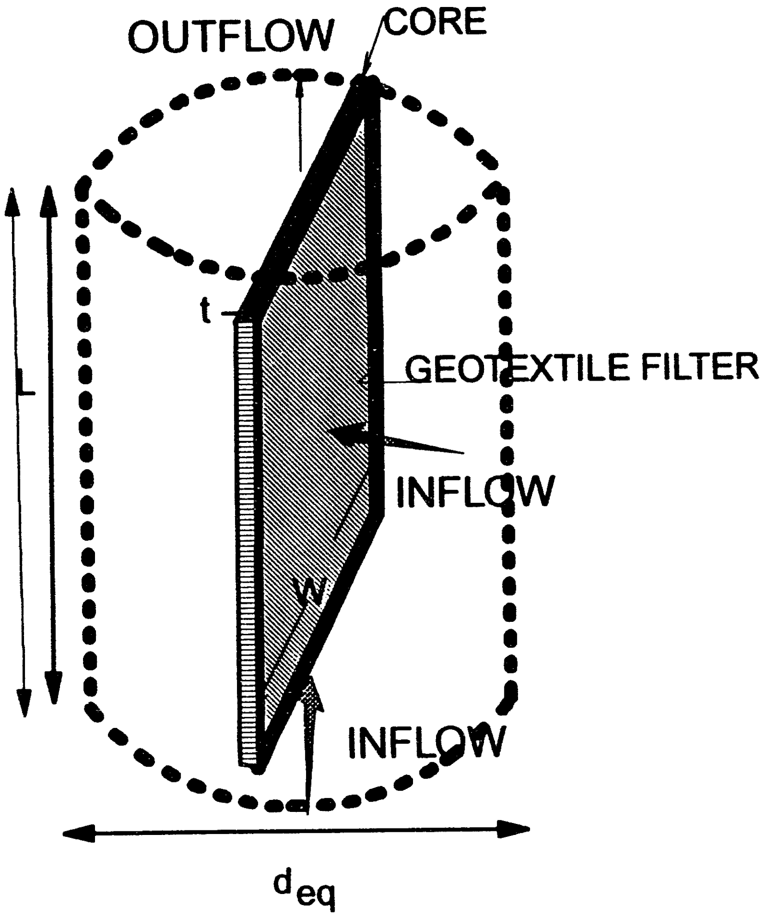


Figure 2.4 Idealization of PVD Dimensions and Zone of Influence

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3.0 EXPERIMENTAL PROGRAM AND RESULTS

The experimental research program consists of column and batch studies to determine appropriate environmental and engineering parameters for the soils, contaminants, and surfactant under consideration. In addition, several pilot scale tests using the Contaminant Recovery Cells (CRC) are conducted in order to evaluate the recovery efficiency (hydraulic only) of the PV drains.

A single polycyclic aromatic hydrocarbon (PAH), in this case naphthalene ($C_{10}H_8$), was chosen as the study contaminant. Analysis conducted as part of this study include naphthalene (by GC method 8100, USEPA, SW-846). Anionic aqueous solution of sodium dodecylsulfate (SDS) was chosen as the study surfactant. The anionic surfactant is negatively charged which will assist in minimizing sorption to the negatively charged kaolinite particles. A testing program was conducted to evaluate the proper mix of the soil to be used in the testing program. Compaction tests according to ASTM D698 and permeability tests according to ASTM D5084 were conducted using blends of kaolinite clay (hydrite-R) and Ottawa sand to select the appropriate soil mix for use in the experiments. The kaolinite has a specific gravity of 2.58, a cation exchange capacity (CEC) of 5 to 10, and a mean particle diameter of 0.77 microns. Based on the results of this testing program a soil blend consisting of sand and kaolinite was selected. These mixtures contained varying amounts of clay ranging from 0% to 20% kaolinite. A grain size distribution for 80/20 mix of the study soil is shown in Figure 3.1.

Major parameters affecting the feasibility and efficiency of liquid extraction using Prefabricated Vertical Drains (PVD) in conjunction with a vacuum system are investigated. Fundamental parameters of the recovery system are evaluated. Laboratory tests included batch isotherms and flexible wall soil flushing permeability tests. In addition, flexible wall permeability tests on soil specimens with and without a PVD installed in the middle of the specimens are conducted. Several pilot scale tests using (0.67m X 0.67m X 1.0m - length/thickness/depth of soil) Contaminant Recovery Cells (CRC) are conducted. Long term efficiency of the PVD operating under a vacuum system is investigated. Retrieved flow rates as a function of the vacuum level are evaluated.

3.1 BATCH ISOTHERMS

Batch isotherm studies are performed in order to evaluate the effectiveness of surfactant for contaminant removal from soil surfaces. A testing program was conducted to evaluate the solubilization of $C_{10}H_8$ using the anionic aqueous solution of sodium dodecylsulfate (SDS) which was chosen as the study surfactant. The empirical formula for SDS is as follows:

$H_3C\text{-}(CH_2)_{10}\text{-}CH_2OSO_3^- \, Na^+$

which has 12 carbon chains, one sulfate anion, and one sodium ion for each SDS molecule. This make up leaves the SDS molecule with a net negative (anionic) charge. Thus, it is postulated that sorption of the surfactant onto the clay soils, should be minimized as a result of the net negative charge of the kaolinite.

Laboratory analysis of naphthalene was performed using a Hewlett Packard Series II Gas Chromatograph (GC) model 5890. The GC was equipped with a flame ionization detector which allowed naphthalene to be detected at levels of greater than or equal to 1ppm. All liquid effluent analysis was prepared by a liquid-liquid extraction procedure outlined by EPA 3510. Soil analysis was done in accordance with EPA 3540 soxhlet extraction (USEPA 1992). The base solvent used for all analysis was *Fisher Brand* Pesticide Grade Methylene Chloride. The procedure for soil extraction is based on EPA Method 3540 Soxhlet Extraction with minor alterations to accommodate the University laboratory. Description of this procedure is as follows:

Materials:

Soxhlet Extractor: 37mm ID, with 250ml boiling flask and Allihn condenser (the cooling fluid will be the laboratory supplied cold water).

Kuderna-Danish Apparatus:
Concentrator Tube: 10ml graduated, with ground glass stopper.
Evaporator Flask: 250ml
Snyder Column: Three ball macro.
Boiling Chips: PTFE, 10/40 mesh.

Water Bath: Temp controlled bath under hood.

Paper Thimbles: 33mm x 80mm cellulose.

Reagents:

Distilled Water: Laboratory supplied.

Sodium Sulfate: Granular Anhydrous.

Methylene Chloride: Pesticide grade.

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Methanol: Pesticide grade.

Methods:

1. Mix 10g of sample with 10g of anhydrous Sodium Sulfate and place in the extractor thimble.

2. Place 175ml of Methylene Chloride into a 250ml boiling flask with boiling chips and attach to the Soxhlet extractor.

3. Attach an Allihn condenser to the extractor and install the cold water lines to the hose barbs.

4. Heat the solvent and allow to extract for 16 hrs.

5. After the extract has cooled, place the remaining solvent in to a Kuderna-Danish (K-D) concentrator.

6. Prewet the Snyder column with approx. 1ml of Methylene Chloride.

7. Place the concentrator in a water bath and allow the extract to evaporate until the volume left is 1ml. The temperature should be adjusted so this takes 15 min.

8. Remove the K-D concentrator from the bath and allow to cool.

9. Adjust the volume if necessary with Methylene Chloride to 2ml.

The procedure for contaminating the soil was accomplished by dissolving naphthalene into methylene chloride and mixing the resulting solution with the desired amount of soil. This mix was placed under a laboratory hood until the soil was dry (usually overnight). Although some naphthalene was lost during this procedure, the rapid volatilization of the methylene chloride minimized this loss to less than 20% of the original concentration.

Initial tests were conducted to establish the minimum size of soil samples whereby meaningful batch isotherms are obtained. Because of the nature of the test soil (80% ottawa sand and 20% kaolinite) and based on the results of initial tests, a minimum weight of 10 gm is needed for representative soil sample. For samples smaller than 10 gm the 80%:20% representation was not obtained and erroneous isotherms were measured.

3.1.1 Surfactant Analysis

In order to select the proper concentration of SDS, the solubility of naphthalene in SDS was investigated. Naphthalene-saturated solutions of SDS ranging from 0 mM to 250 mM were prepared by placing an excess of naphthalene into varying concentrations of SDS. These mixtures were agitated for 12 hours in order to reach equilibrium. Upon equilibrating, a sample was extracted for analysis. The results of this procedure are shown in Figure 3.2. As the SDS molarity increased the solubility of the naphthalene increased with a near linear

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relationship. This is due to the fact that the surfactant (its molecules are composed of hydrophobic and hydrophilic regions) forms micelles which solubilize with the hydrophobic naphthalene compound. Naphthalene solubility of 500 mg/l was measured for SDS concentration of 0.05 Mol and approximately 3300 mg/l for SDS concentration of 0.5 Mol.

Two different slopes as a function of the SDS molarity are clearly evident. The first horizontal slope ranging from 0 mM to 8mM shows no significant increase in naphthalene solubility as a function of increasing SDS concentration. The second slope shows a steady and linearly increasing function of naphthalene solubilization with increasing SDS concentration. The intersection of these two slopes is the critical micelle concentration (CMC). At approximately 8 mM SDS, micelles begin to form and dominate the naphthalene solubilization. The slope of the solubilization function from this point on is the Molar Solubilization Ratio (MSR). The value of the MSR was determined to be ≈ 9800 ppm of naphthalene/mole of SDS.

3.1.2 Adsorption Isotherms

To estimate adsorptive kinetics, batch isotherm tests were conducted in accordance with ASTM ES10-85. Initially the synthetic soil mix of 20% kaolinite and 80% Ottawa sand was to be used in evaluating the isotherms. However it was not possible to obtain a representative homogeneous small-size kaolinite/sand sample. Therefore, the isotherms were generated for the Ottawa sand and the kaolinite clay separately. Since the study soil was comprised of only these two components, individual adsorptive kinetics were related to the parent soil.

Naphthalene-saturated solutions of 10, 50, and 100 mM SDS were placed in a glass bottle with varying amounts of uncontaminated soil. The samples were then placed on a shaker table for 24 hrs. At that time a sample was drawn and centrifuged. The free SDS solution was then analyzed for naphthalene concentration.

The results of the adsorptive isotherms for the Ottawa sand showed that the naphthalene adsorption was below detectable levels for the analysis instrumentation. The kaolinite clay however showed distinctive adsorptive capabilities. The measured data for the three concentrations of SDS examined in this study are shown in Figure 3.3(a,b,c). The corresponding partition coefficients (K_p) were calculated for each of the SDS concentrations. The 10, 50, and 100 mM SDS/kaolinite solutions resulted in partition coefficients of 1.55, 0.165, and 0.155 L/mg, respectively.

3.1.3 Desorption Isotherms

Figure 3.4 (a,b) illustrates the desorption of several concentrations of naphthalene, into a 50 mM SDS solution, from kaolinite clay. The saturation concentration in this case was 500 mg/L. As evident from the isotherms, a maximum value of C_{eff}/C_{sat} for the SDS at equilibrium was measured to be approximately 0.65. In this case C_{eff} refers to the extracted naphthalene concentration in the surfactant and C_{sat} refers to the saturation level of naphthalene in the surfactant. The C_{eff}/C_{sat} value is less than expected. For example, in the case of the specimen size of 10 grams (gm), C_0 was equal to 100,000 mg/Kg and therefore 4000 mg/L of naphthalene concentration was available for desorption. In this case, it was anticipated that desorption of naphthalene would be approximately 500 mg/L; which is the saturation concentration. However, measured results indicated a desorption level of only 350 mg/L. While volatilization of some of the original naphthalene concentration was suspected, results from control tests indicated that less than______ mg/l volatilized during the 24-hour volatilization period. The less than maximum desorption concentration remains under study.

3.2 COLUMN STUDIES

Three series of column studies were conducted. A series was conducted on clean soil with water and with surfactant solution to evaluate the hydraulic properties of the study soil. These tests were used to obtain permeability characteristics of the soil, both, with water and with surfactant as permeating liquids. The second series was conducted on contaminated soil. The tests on contaminated soil were used to ascertain the effectiveness of the SDS surfactant in removing contaminants under a flow type situation and estimate the dispersion/advection characteristics of the system. A third series was conducted on soil specimens with a PVD installed in the middle of the specimens to investigate the increase in the magnitude of flow with the PVD in place. Specimen preparation technique for the columns study was as follows:

1. Specimens were prepared from a mixture of ottawa sand and 0%- 20% kaolinite.

2. Sieve analyses were conducted as a baseline to check the final integrity of the soil upon completion of a test.

3. Specimens were compacted using standard proctor according to ASTM D698, method A. The specimens were prepared at water content range of approximately 6% to 11% to achieve a permeability on the order of 1×10^{-3} cm/sec to 1×10^{-5} cm/sec. The relationship between compaction density and water content for the study soil is shown in Figure 3.5. Maximum density of approximately 125 pcf was achieved in a compaction mold using Standard Proctor test and at a moisture content of 9.5%. In addition, densities achieved for the samples prepared in the CRC's are presented in the figure.

4. Flow tests are conducted to a duration necessary to provide discharge of minimum of 5-7 pore volumes of permeant fluid.

3.2.1 Permeability Tests: No Drains, Clean and Contaminated Soils

Figure 3.6 (a,b) shows the variation of permeability as a function of effluent pore volume for the uncontaminated soil specimens. The flexible wall permeability test was conducted according to ASTM 5084 standards. The molding moisture content plays a significant role in controlling the density, and therefore the permeability, of the compacted soil. This can be explained by the diffuse double layer theory. At low water content, clay particles develop flocculated structures which lead to low compaction density. As the water content is increased, the structure of the soil matrix tend to disperse and high compaction densities are achieved.

The variation of the permeability as measured from the flexible wall test using ASTM 5084 standards, as a function of the molding water content is shown in Figure 3.7. These tests were performed using water as permeant and clean soil. As the results indicated and as reported by Lambe (1959) soils compacted dry of optimum tend to have high permeability while soils compacted wet of optimum tend to have low permeability. Measured permeabilities for the study

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soil decreased from 3×10^{-4} cm/sec for water content of 7% to approximately 2×10^{-5} cm/sec for molding water content of 11%. Table 3 presents the soil parameters for the different column tests.

Table 3. Flexible Wall Column Tests on Study Soil

Test	Molding w(%)	i	σ3 (psi)	γdry (pcf)	e	n	Initial S(%)
k-80/20-1	7.5	30	5.5	124.6	0.33	0.25	61
k-80/20-2	9.9	30	5.5	126.0	0.31	0.24	85
k-80/20-3	11.0	12	4.0	121.9	0.36	0.26	81
k-80/20-7	8.7	12	7.0	127.3	0.30	0.23	75
k-80/20-8	6.8	12	7.0	122.2	0.35	0.26	48
k-80/20-9	8.8	12	7.0	127.4	0.30	0.23	76
k-80/20-10	9.5	12	7.0	126.0	0.31	0.24	78
k-80/20-12	10.5	12	7.0	122.7	0.35	0.26	80
k-80/20-13	10.3	12	7.0	123.7	0.34	0.25	80

i = hydraulic gradient, σ3= confining pressure, e= void ratio, n= porosity, and S= degree of saturation

Figure 3.8 (a,b) shows the effect of the SDS surfactant on the permeability characteristics of clean sand and sand/kaolinite soils, respectively. In this case, permeability tests were performed using water and then SDS solution with concentrations between 0.0022 and 0.008 Mol as permeant liquids. The introduction of the SDS solution resulted in a slight reduction in the hydraulic conductivity values of the sand samples. However, the reduction in the hydraulic conductivity values was two orders of magnitude for the sand/kaolinite soil samples (Figure 3.8b) and deserves further investigation.

The study soil contains 20% clay of the kaolinite species. The kaolinite minerals, common in soils, have a 1:1 silica: alumina 2-sheet structure with alternating silica and octahedral sheets as shown schematically in Figure 3.9. Reduction in the hydraulic conductivity may be due to one or combinations of the following phenomena:

1. Migration of fine particles: the hydraulic conductivity depends more on the percent of clay particles in the soil mixture. A small percentage of fines can clog the pores of coarse fraction.

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2. Bonding of sulfate anions from the solution onto the positive edges of the clay particles: some types of negatively charged anions such as sulfate can be attracted to the edges of the clay particles, where broken bonds create net positive charge, and becomes part of the surface. This causes deflocculations and swelling and consequently decrease in hydraulic conductivity.

3. Sulfate compounds such as SDS causes rise in the pH which results in solutioning of the silica tetrahedral and alumina octahedral layers. Precipitation of this material can cause clogging of pores and therefore drop in the hydraulic conductivity.

Sectional grain size distribution on the soil samples was conducted to investigate potential migration of clay particles. Soil columns were sectioned along their length and grain size distributions were determined. All sections had the original 80% sand-20% kaolinite composition. Thus migration and deposition was not likely contributing to clogging and reduced hydraulic conductivity.

The reduction in the hydraulic conductivity of the test samples due to the introduction of the surfactant was observed to be reversible. As shown in Figure 3.10, The hydraulic conductivity of a sample that was tested for approximately 3 months (50 pore volumes were circulated through it) was reduced by two orders of magnitude, as compared to values obtained using water as permeant. Once saturated, the measured hydraulic conductivity was relatively steady with a value of approximately 2×10^{-7} cm/sec at 6 pore volumes. After approximately 8 pore volumes of flow, the hydraulic conductivity increased steadily until the end of the test at nearly 50 pore volumes. Thus, and as the circulation of flow continued, the hydraulic conductivity values were gradually increased back to values comparable to those obtained using water as permeant liquid.

In light of the observed 'recovery' of the hydraulic conductivity with increased volume of flow, two phenomenon are thought to be most likely for the observed behavior. The first is the precipitation of alumina or silica constituents and their subsequent re-solubilization (Bowders, 1989). The continued fresh supply of SDS facilitated the dissolutioning of these precipitates, and ultimately resulting in the higher hydraulic conductivity.

A second phenomenon is that of multiphase flow. The SDS solution must displace the indigenous soil pore water prior to freely flowing through the soil matrix. When the SDS solution is permeated into the water saturated or nearly saturated soil specimen, an SDS/water interface (meniscus) may be established. Surface tension and resulting capillary forces must be overcome in order for the SDS to permeate the specimen (Foreman and Daniel, 1985). As the SDS solution fills connecting soil pores, the flow rate increases, until which time the soil specimen is completely saturated with the SDS solution. Thus it is possible that either or both of the above described phenomena are causing the measured behavior of the hydraulic conductivity shown in Figures 3.9b and 3.10.

The flexible wall column tests results shown in Figure 3.10 are for a sample that was contaminated with naphthalene. In this case, the permeating solution was 10 mM SDS and initial naphthalene concentration was 6,000 mg/Kg. Final analysis of the soil revealed a residual naphthalene concentration of 360 mg/Kg. Total testing time was 2.5 months. The removal at the end of the testing period was 94%. A summary of the results from flushing tests performed on naphthalene-contaminated soil samples is shown in Table 4.

Table 4. Summary of Percent Removal of Naphthalene from Flexible Wall Column Tests

Sample	SDS Concent.	Initial Napth. Concent.	Final Napth. Concent.	% Removal	Pore Volume Passed	Testing Time
Sand	100 mM	9500 mg/Kg	63 mg/Kg	99.3	6.5	4 days
Sand	50 mM	9500 mg/Kg	400 mg/Kg	95.8	6.6	4 days
Sand	10 mM	9500 mg/Kg	825 mg/Kg	91.4	6.9	4 days
Sand	Water	9500 mg/Kg	1230 mg/Kg	87.2	8.2	4 days
80/20 Mix	10 mM	6000 mg/Kg	363 mg/Kg	94.0	49	2.5 months

3.2.2 Permeability Tests: Drains Installed

A series of tests was performed on soil specimens with 32mm-wide and 3mm thick PV drains installed in the middle of the specimens to investigate the increase in the flow rate due to the inclusion of the PVD's. The PVD's were wrapped with a nonwoven geotextile made from polypropylene with an apparent opening size of 0.075 mm. The PV drains were characterized as having an effective diameter of approximately 22 mm (circumference/π). Figure 3.11 schematically illustrates the set-up for these tests. The soil specimens were wrapped with filter fabric to maintain their integrity. An acrylic disk covered with a latex membranae was installed at the bottom of the specimens to prevent vertical flow. A similar disk was installed at the top of the specimens with the exception of being fitted with a 32 mm cut through which the PVD was inserted. The PVD, was then fitted into the top cap. This arrangement allowed the measurement of the radial flow capacity of the soil specimens with the PVD installed. Table 5 presents the density and water contents of the tested specimens along with hydraulic gradients used in the tests.

Table 5. Density and Water Content of Specimens used in the Permeability Tests

SPECIMEN	Water Cont. (%)	γ_{dry} (kN/m^3)	Hydr. Grad. (i)	Comments
DC1-1	8.5	111.5	9.5	central drain
DC1-2	8.0	111.5	9.5	central drain
DC2-1	9.1	118.6	9.5	central drain
DC2-2	9.1	118.6	9.5	central drain
DC2-3	9.5	119.3	9.5	central drain
NDC1 (H-1)	9.1	118.1	6.9	horizontally trimmed
NDC1 (H-1)	8.8	122.2	12	horizontally trimmed
NDC2 (H-1)	9.2	123	12	horizontally trimmed
NDC2(H-1)	8.9	126.2	6.9	horizontally trimmed

For the sake of comparison, four specimens without PVD's were tested in accordance with ASTM D5084. These specimens were trimmed from a soil sample that was compacted into a 0.67m x0.67m x1m box. The specimens were trimmed in the horizontal direction to allow comparison with results from specimens fitted with the PV drains. Properties of the soil specimens and test conditions are presented in Table3. An average flow rate of approximately 0.25 ml/sec was measured for the specimens with no PV drains. However, and as shown in Figure 3.12, the rate of flow was significantly increased by introducing the PVD in to the soil specimens.

Results from two of the tests on specimens with PVD indicated a flow rate of approximately 6 ml/sec. This flow rate is 25 times that measured for specimens with no PV drains. Results from the other three tests (DC2-1, DC2-2, DC2-3) indicated initial decrease of the flow rate during the first 25 pore volume of flow followed by an increase in the flow rate to 6 ml/sec. It is of interest to note that the specimens exhibited this behavior had a moisture content range of 9%-9.5% compared to 8% to 8.5% for the two specimens that did not exhibit such behavior. This initial decrease in the flow rate may be indicative of the filtration behavior of the PVD's filter fabric and the probable internal rearrangement of the fine particles around the drain.

A simple experiment was conducted to investigate the clogging potential of the drains. In this experiment, the soil was compacted into a 0.5 m in diameter and 0.67 m high column. A single 32mm-wide PVD was installed in the middle of the column. The column was saturated and a constant head of 0.3 m was maintained on the soil specimen. A vacuum system was attached to the PVD and a vacuum of 19 kPa was applied. Figure 3.13 shows the flow rate through the PVD under the applied vacuum and as a function of time. The flow rate reached a steady state value of approximately 0.12 ml/sec with no apparent decreasing trend over a period of four weeks.

3.3 CONTAMINANT RECOVERY CELLS

Four contaminant recovery cells (CRC's) were constructed and are currently used to assess the efficiency of the PV drain contaminant recovery system. The CRC's include a central section (0.67m X 0.67m X 1.0m - length/thickness/depth of soil) which is filled with the study soil. An upstream reservoir supply a base inflow into the soil while the downstream reservoir collect the base outflow. The reservoirs are used to pre-saturate the soil and to apply a constant base flow during water and contaminant recovery tests. For contaminant recovery purposes, PV drains will be installed into the soil. In order to quantify recovery efficiency, single and multiple drains will be used.

Figure 3.14 shows a photograph of one of the cells and Figure 3.15 shows a schematic diagram of one of the cells. Clay/geotextile mating was used as lining material to minimize side wall leakage. A dye was introduced to trace the flow path. No side wall leakage was observed. Saturation of the bottom 300 mm of the soil samples in the CRC's took approximately eight weeks to complete. Figure 3.16a shows the saturation levels, measured using monitoring wells, as a function of time. Figure 3.16b shows the location of the wells used to monitor the advancement of the saturation front.

Soil samples were compacted in the CRC's using a 10 Kg weight that was dropped from a height of approximately 670 mm two times to obtain a weight density of approximately 17 kN/m^3 and three times to obtain weight density of 19 kN/m^3. The soil was compacted in twelve layers in each CRC. Figure 3.17 shows the distribution of the in-place density measured using the sand cone test. The uniformity of density distribution increased as the work crew gained experience with mixing and preparing the soil samples. At this stage of the research it was decided that a density on the order of 110 pcf is desirable in order to allow the installation of the PVD with minimum disturbance. Therefore, and as shown in Figure 3.17, the molding water content was increased in preparing the sample for CRC #3 in order to achieve the target density of 110 pcf. The permeability values measured from the CRC's as a function of time are shown in Figure 3.18. The permeability values measured from the CRC's as a function of molding water content are shown in Figure 3.7 in conjunction with values estimated from the flexible wall column tests. The permeability values measured from the CRC's were on the order of 1×10^{-3} to 1×10^{-4} cm/sec.

Two systems of fluid recovery are feasible in this case. These include applying a vacuum to the drains and applying a surcharge on the surface of the soil. Both systems provide a driving force for fluid transport from the soil. Feasibility study of the retrieval system favored the use of vacuum mechanics over the use of surface surcharge load for inducing the required gradient for subsurface liquid retrieval. Disadvantages of using surcharge include the possibility that the surcharge be classified as contaminated material once it is installed on a contaminated site and the length of time required to construct the surcharge load and achieve a specific stress level. In this case, a rather extensive construction activity will be needed. This construction activity will be taking place in a contaminated site and elaborate health and safety consideration must be observed.

Therefore, the present focus for retrieval is on the use of the vacuum system. Several preliminary pilot scale tests using the CRC's and the vacuum system were conducted. Using four PVDs in a rectangular arrangement, the volume of the retrieved fluid increased as a function of the vacuum level as shown in Figure 3.19. The base inflow, controlled by the headwater and tailwater elevations, was measured to be approximately 0.55 ml/sec. For this case, the recovery efficiency for the mass flux was observed to be 100% under vacuum magnitude of approximately 14 kPa.

Nueman's solution for multiple wells in unconfined aquifers was used to predict the retrieved flow rate based on the observed drawdown. As presented by Freeze and Cherry (1979), the drawdown can be defined as:

$$s_t = \sum_{i=1}^{n} \frac{Q_i}{(4\pi T)} w_i(u_A, u_B, \eta) \qquad (12)$$

where:
$u_A = r_i^2 S/4Tt_i$,
$u_B = r_i^2 S_y/4Tt_i$,
s_t=total drawdown,
Q_i=retrieved flow rate,
T=transmissivity,
w_i=well function,
r_i=distance to point of observed drawdown,
S_y=specific yield
S=storativity,
n=number of drains,
η=unconfined well function = r_i^2/b^2 and b= depth of zone of saturation.

Observed drawdown at a point 156 mm from each of the drain and at the center of the rectangular formation was 70 mm after one hour of pumping. In this case, T is calculated as 3×10^{-3} cm^2/sec, S= 2.9×10^{-3} assuming aquifer compressibility of 1×10^{-6} m^2/N and aquifer thickness of 0.3 m, S_y= 0.07-0.3 (Freeze and Cherry, 1979), and t=3600 seconds, and the well function, $w_i(u_A,u_B,\eta)=1.1$ for $S_y=0.3$ and $w_i(u_A,u_B,\eta)=2$ for $S_y=0.07$.

Using the observed drawdown of 70 mm, the total flow rate predicted using the well equation is 0.96 ml/s for $S_y=0.3$. This value is approximately twice the rate retrieved using the PVD/vacuum system. However, using $S_y=0.07$, a total flow rate of 0.5 ml/sec was obtained.

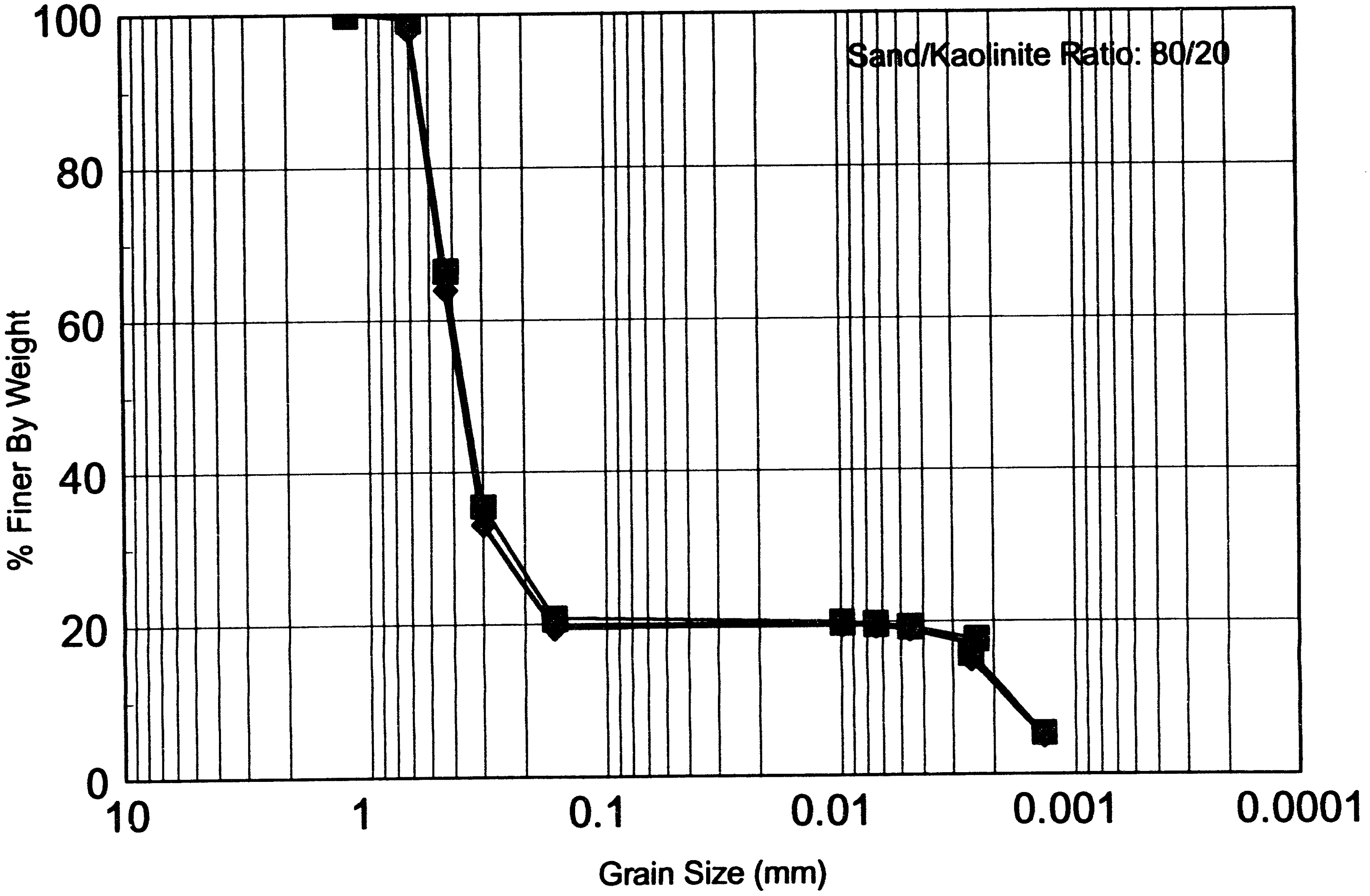

Figure 3.1 Grain Size Distribution of the Study Soil

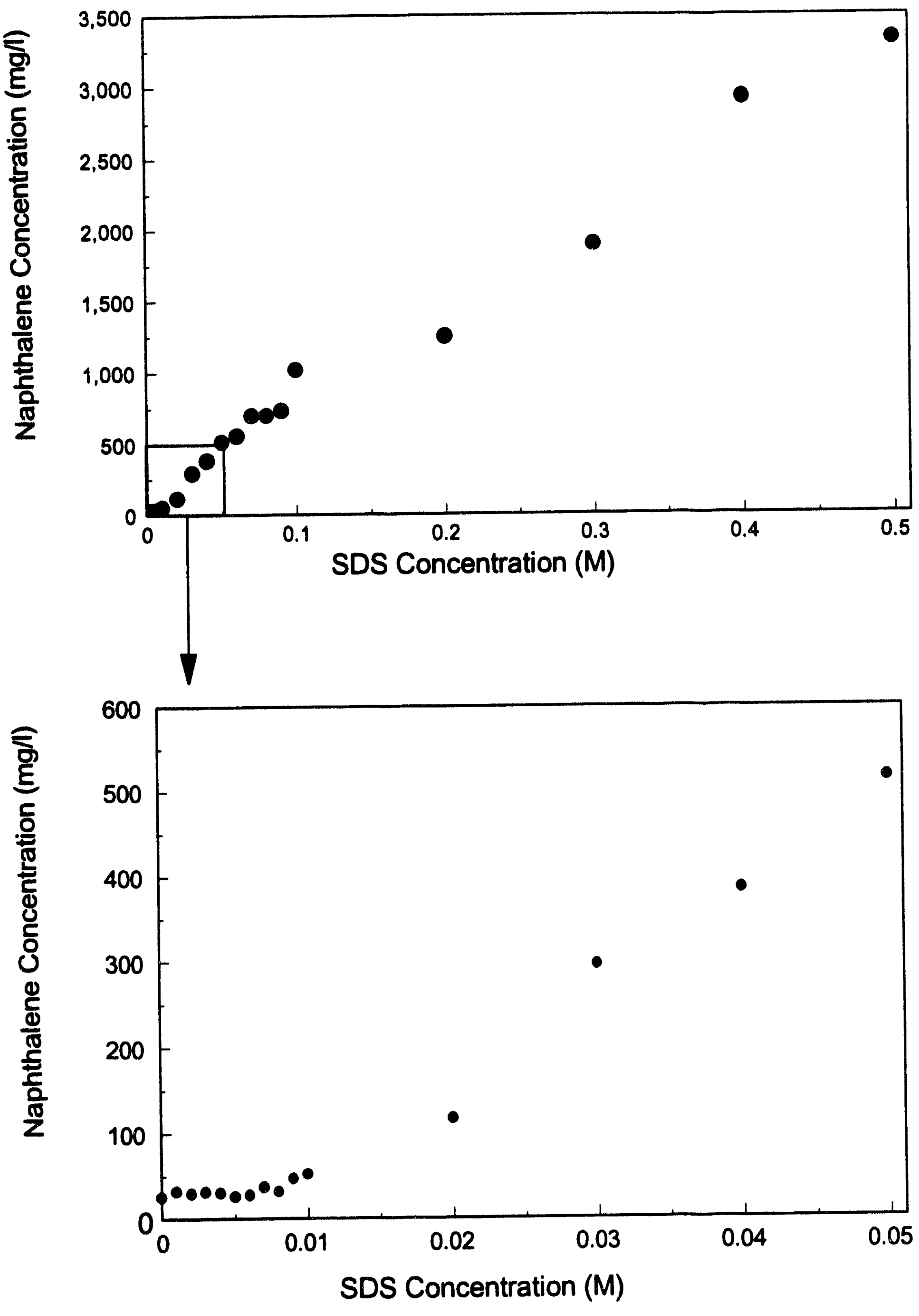

Figure 3.2 Soluability of Naphthalene Using SDS Surfactant Solution

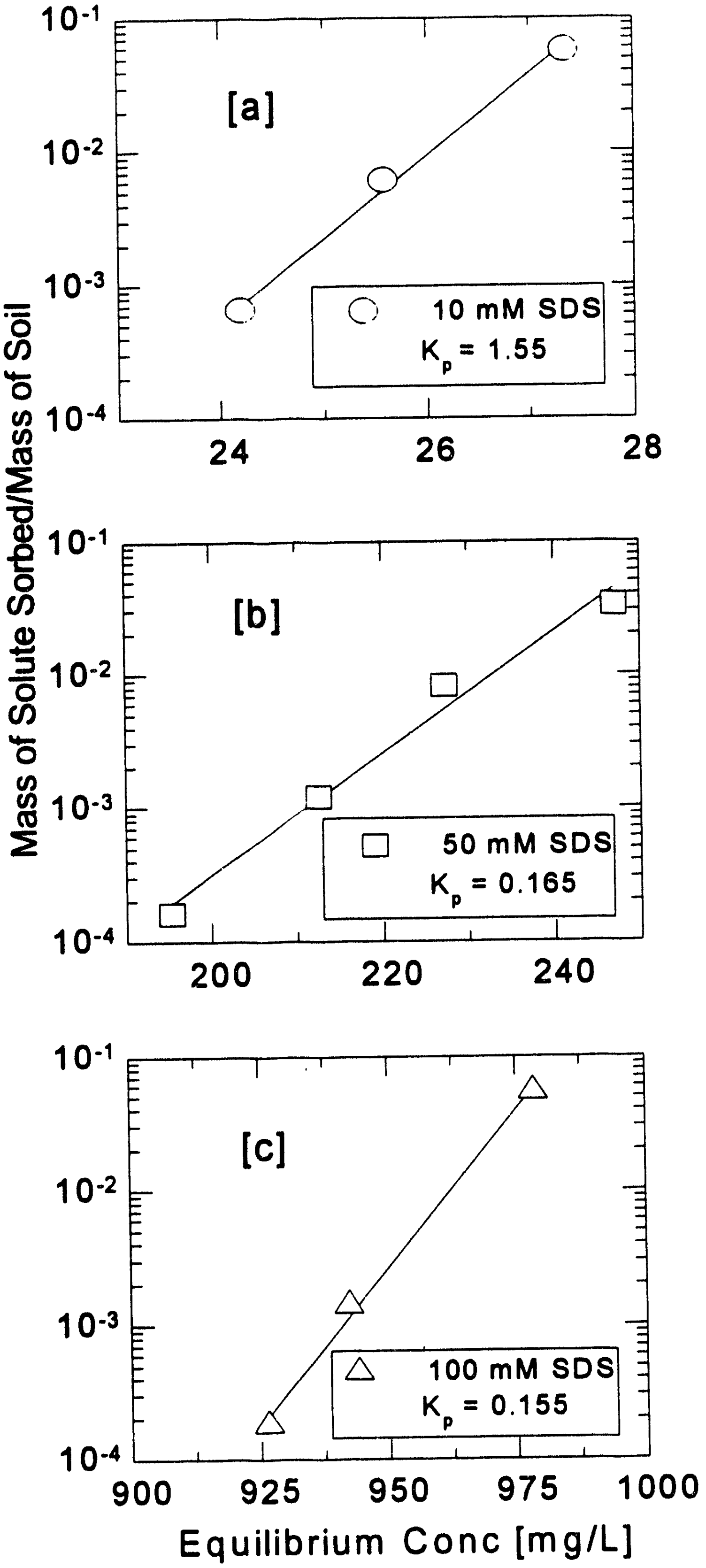

Figure 3.3 Isotherms for Naphthalene Saturated SDS and Kaolinite

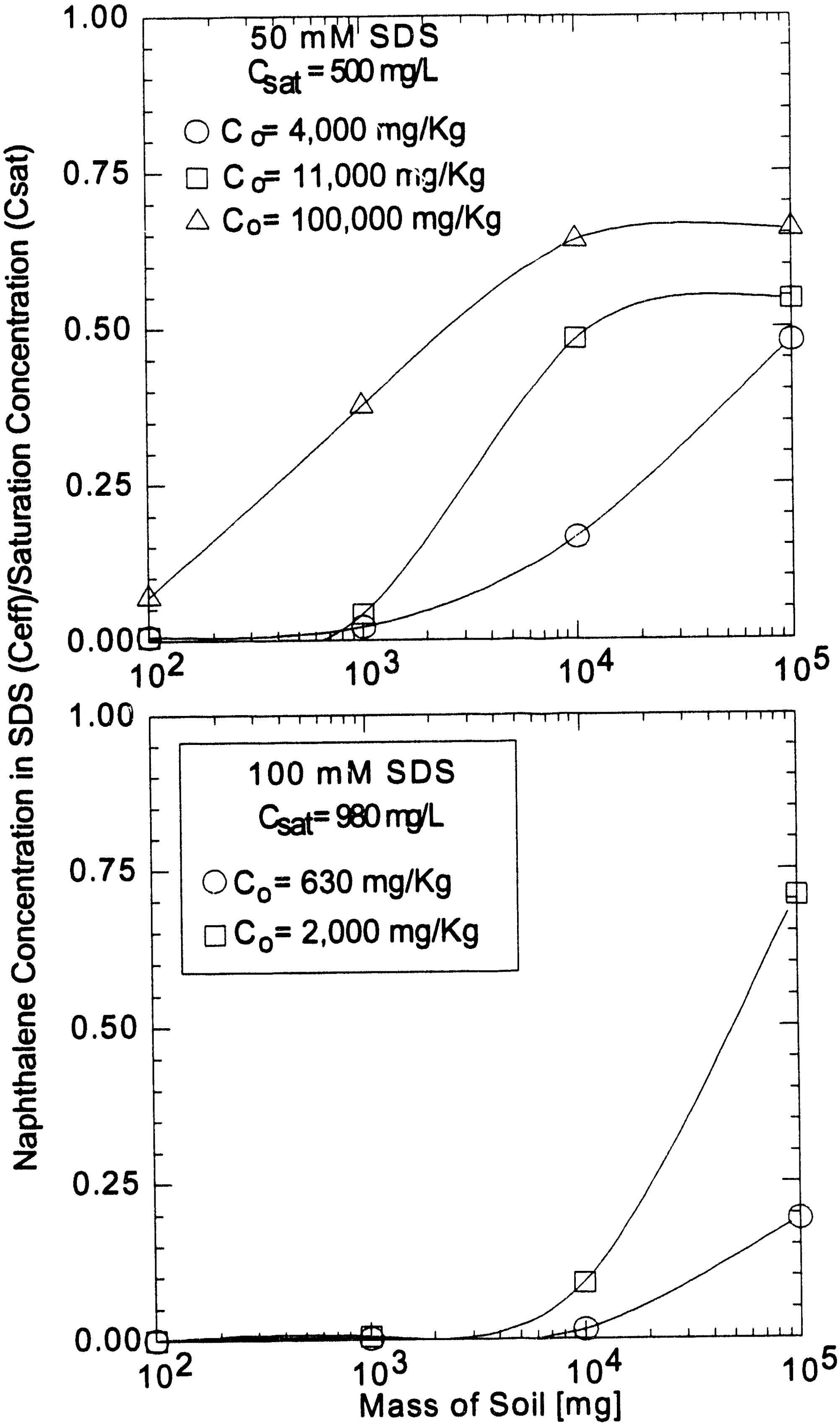

Figure 3.4 Desorption of Naphthalene-Contaminated Kaolinite with 50 mM and 100 mM SDS

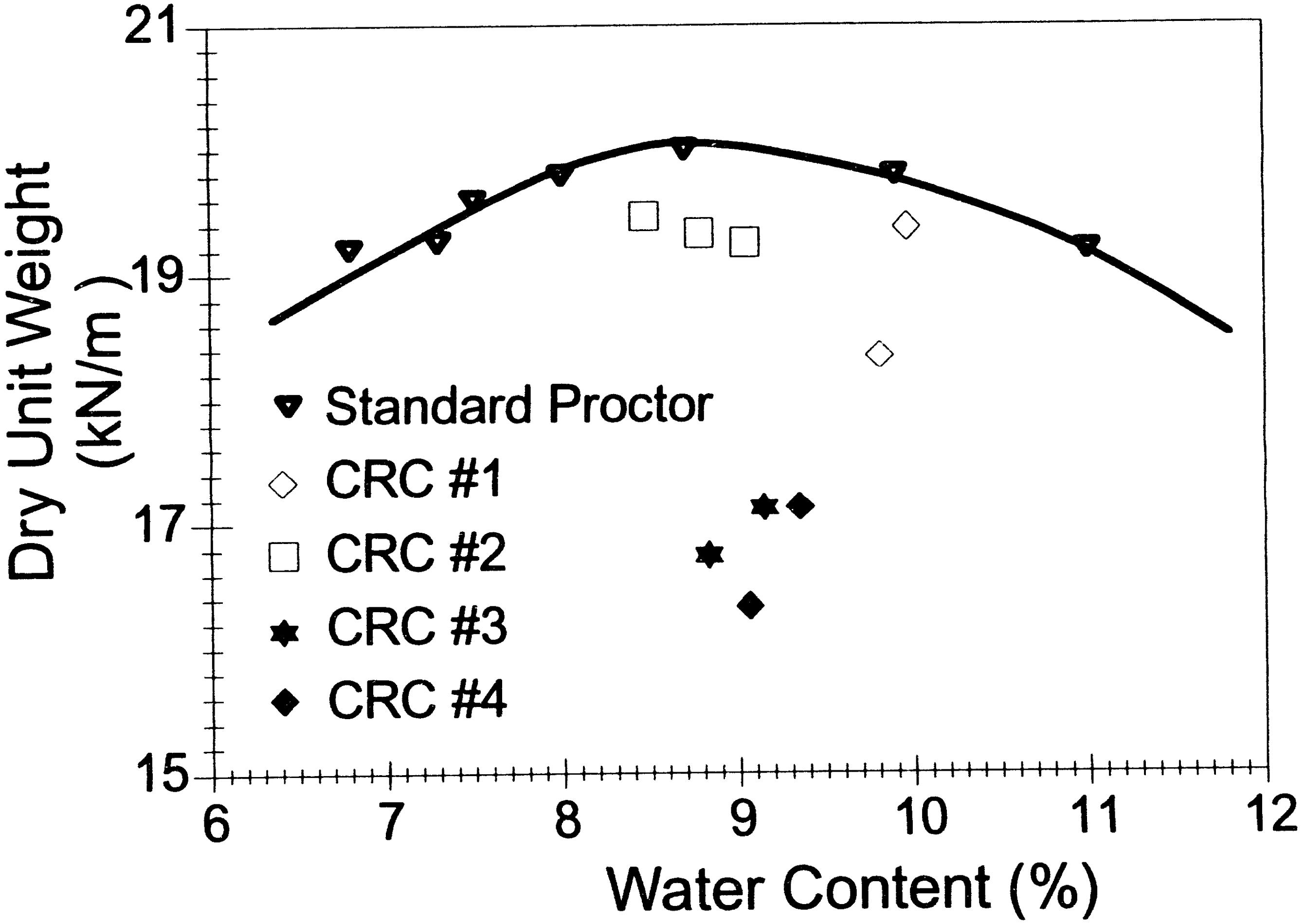

Figure 3.5 Dry Unit Weight vs. Molding Moisture Content

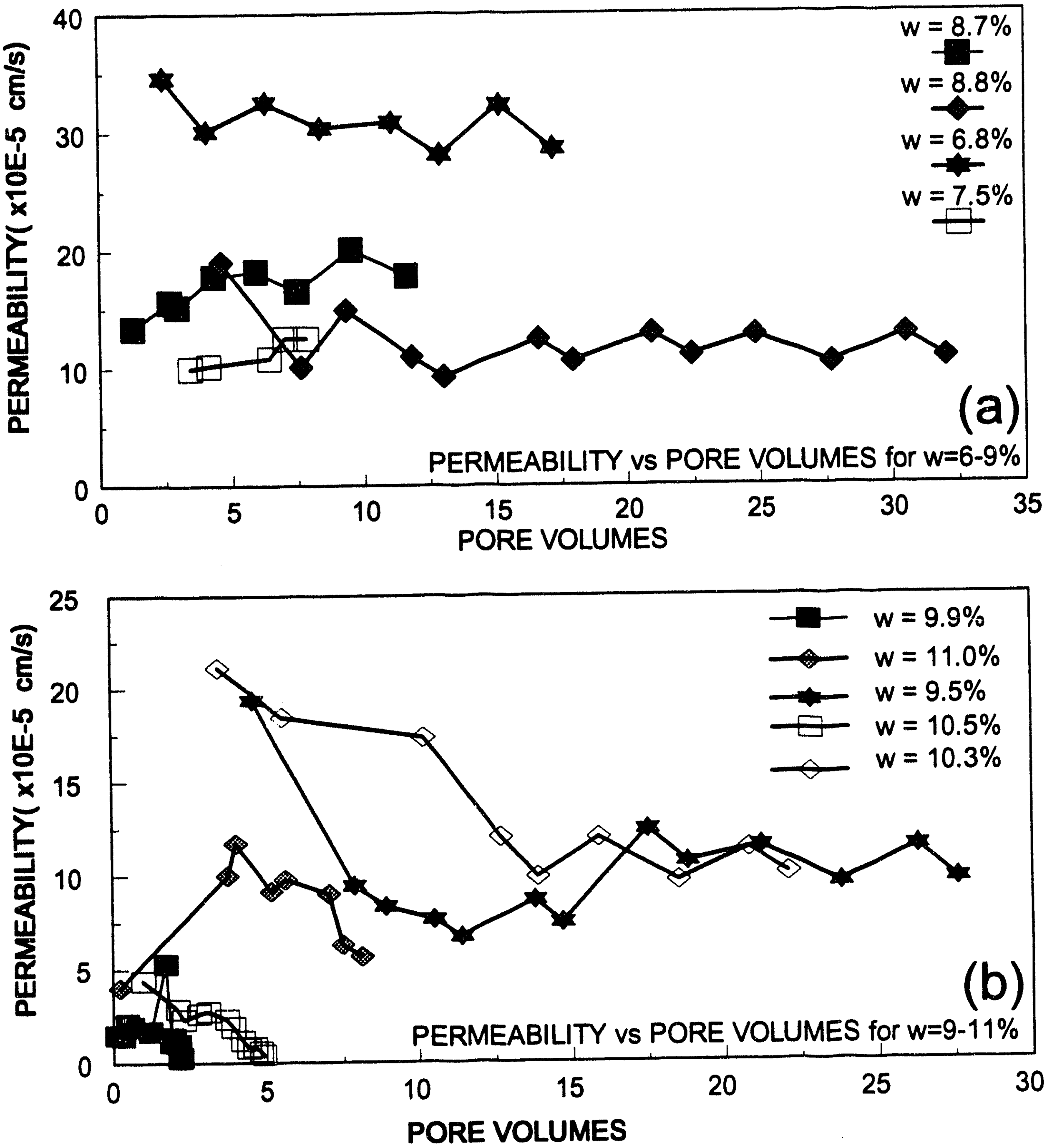

Figure 3.6 Results of the Flexible Wall Permeability Tests: a) w range of 6%-9% and b) w range of 9% to 11%

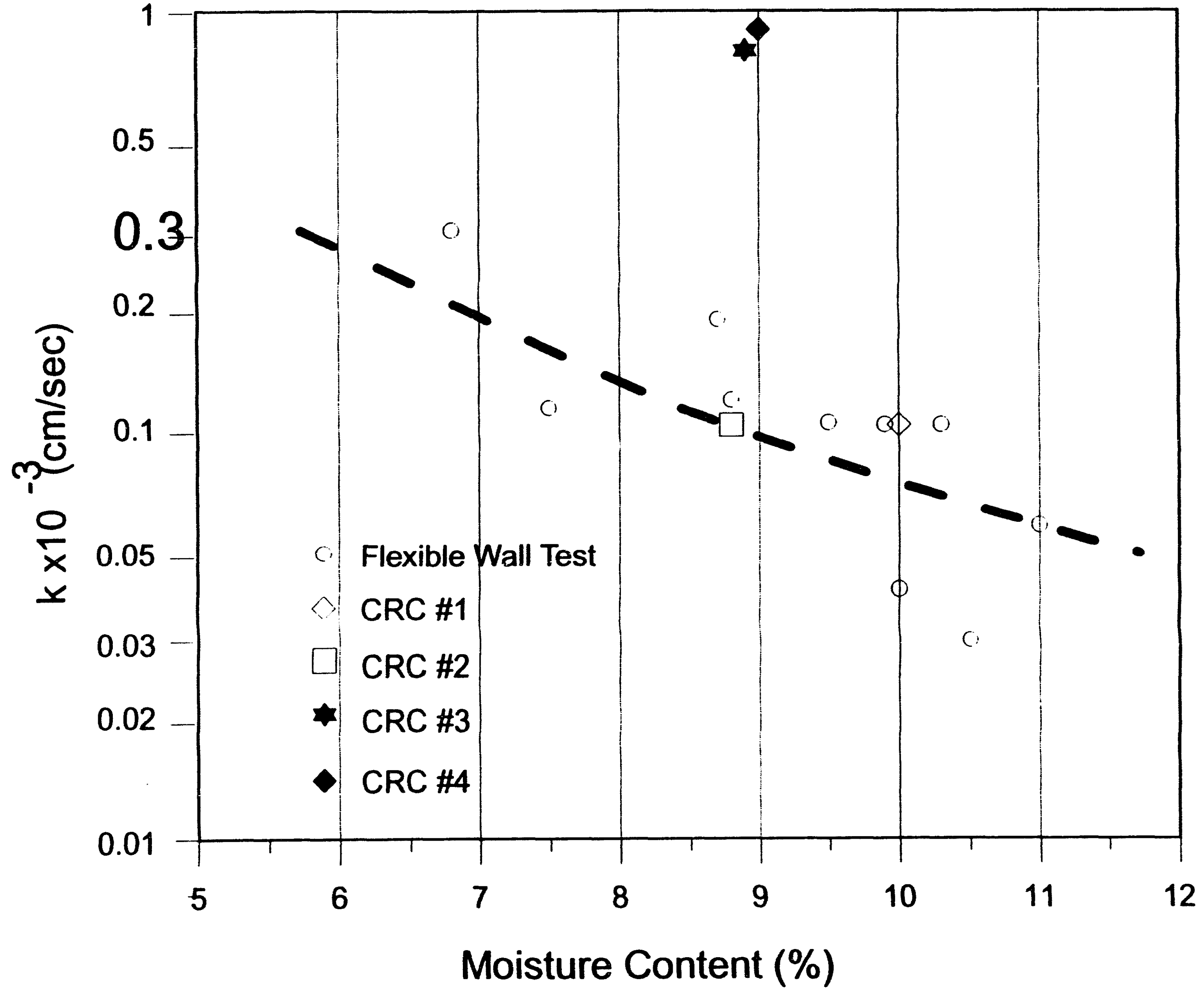

Figure 3.7 Variation of Permeability as a Function of Molding Water Content

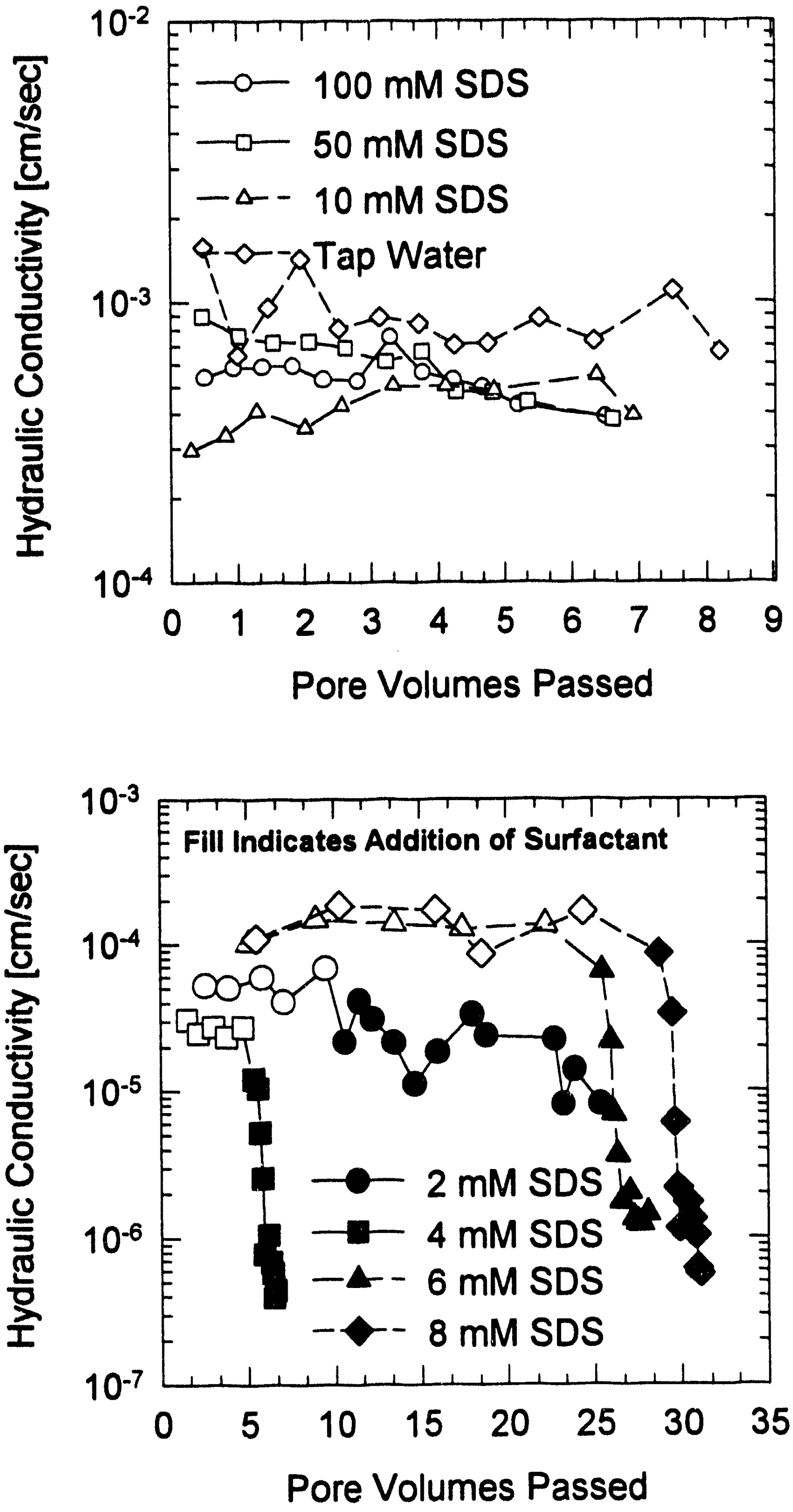

Figure 3.8 Variation of Hydraulic Conductivity as a Function of Surfactant Concentration for Uncontaminated Soil: a) Sand, and b) 80/20 Mix

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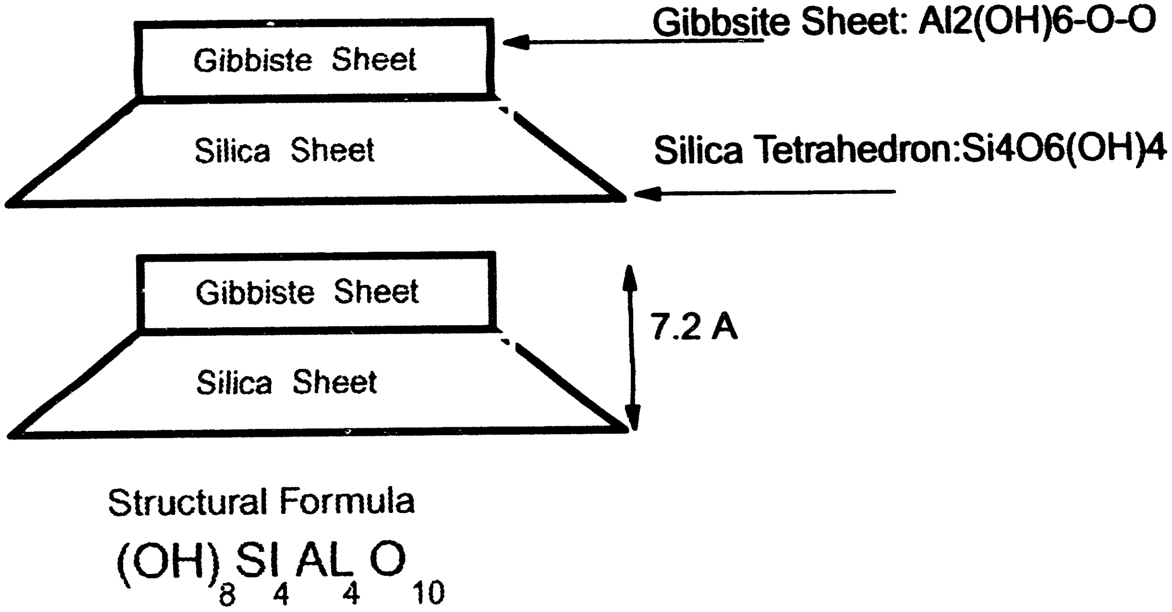

Figure 3.9 Structure of Kaolinite Clay Used in This Study

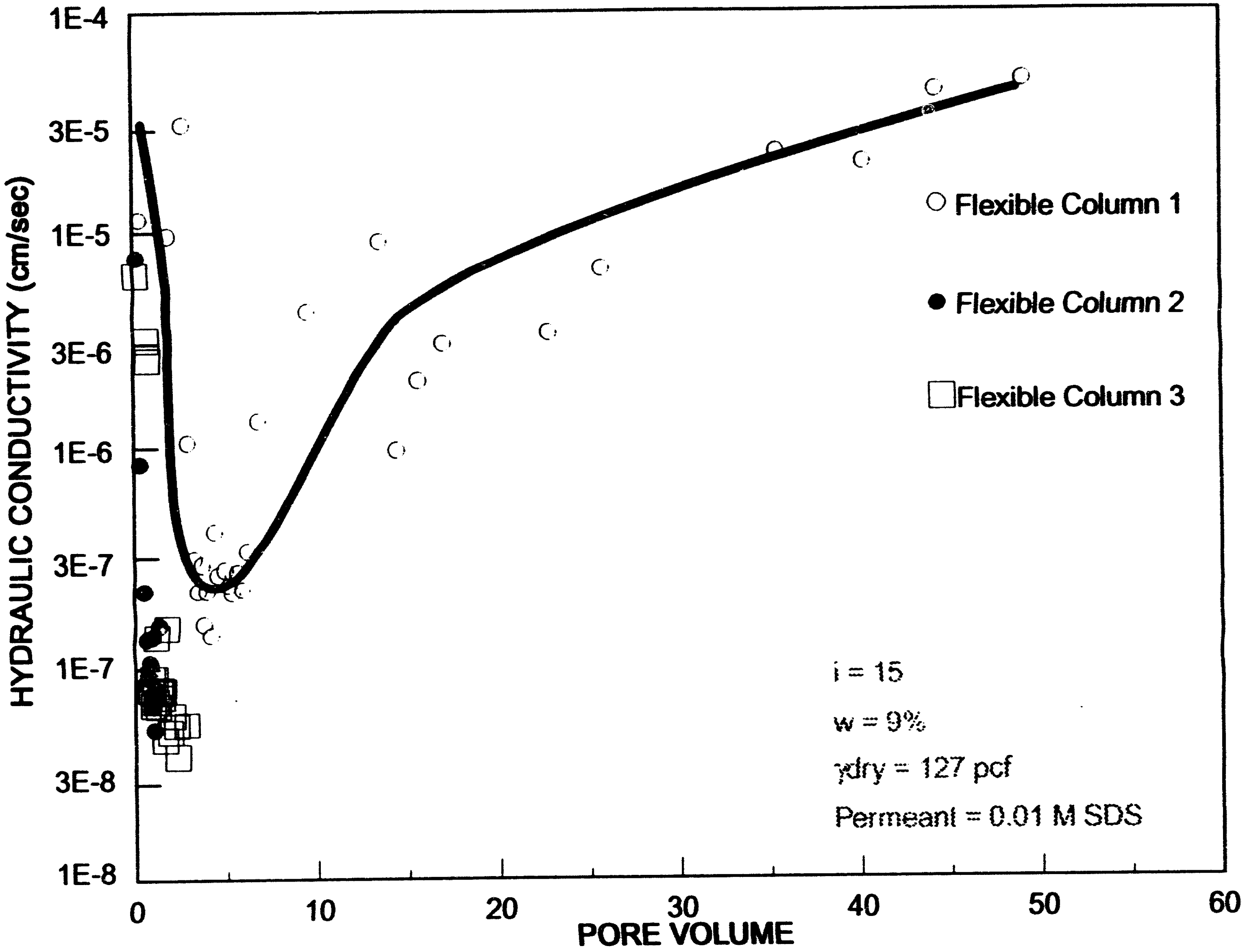

Figure 3.10 Long Term Variation in the Hydraulic Conductivity with Surfactant as Permeant Liquid: Contaminated Soil

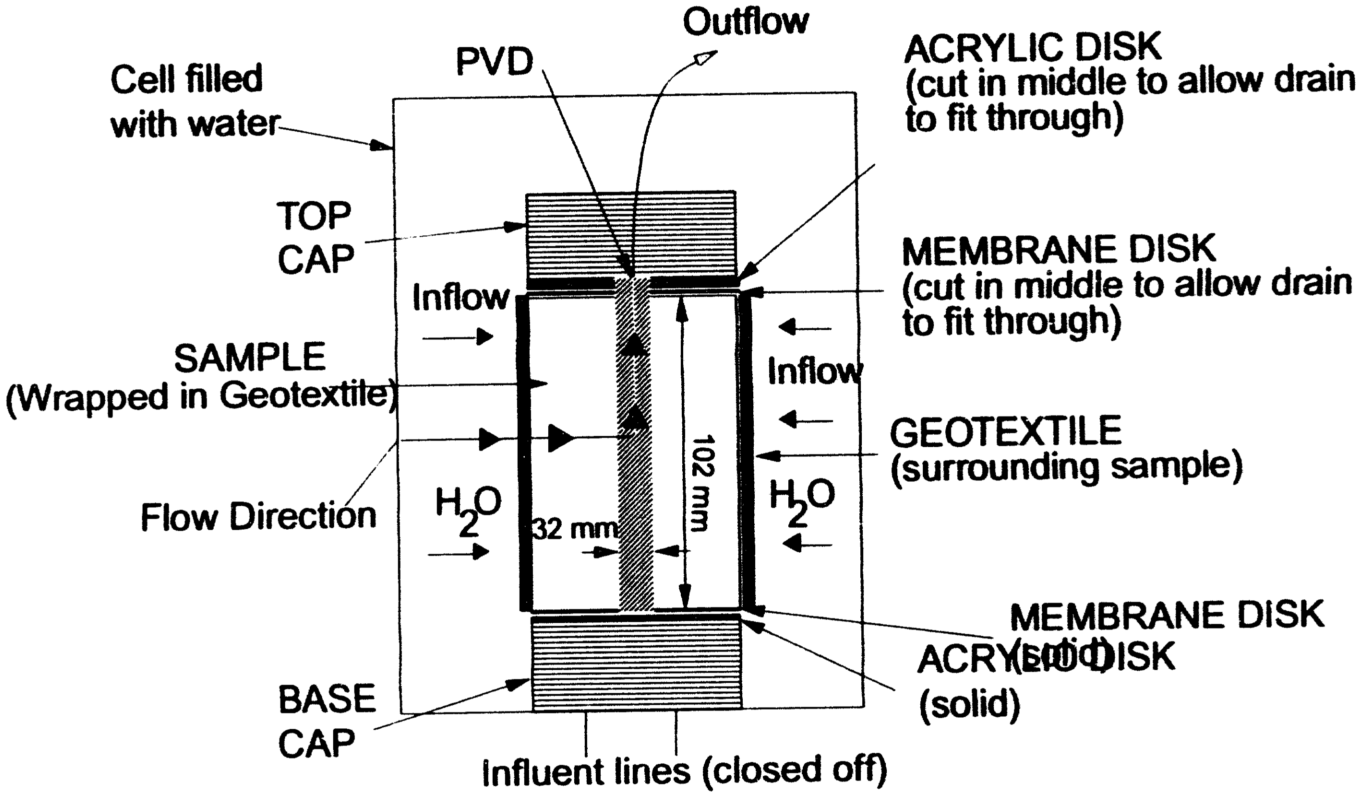

Figure 3.11 Experimental Set-Up for Radial Flow Permeability Test

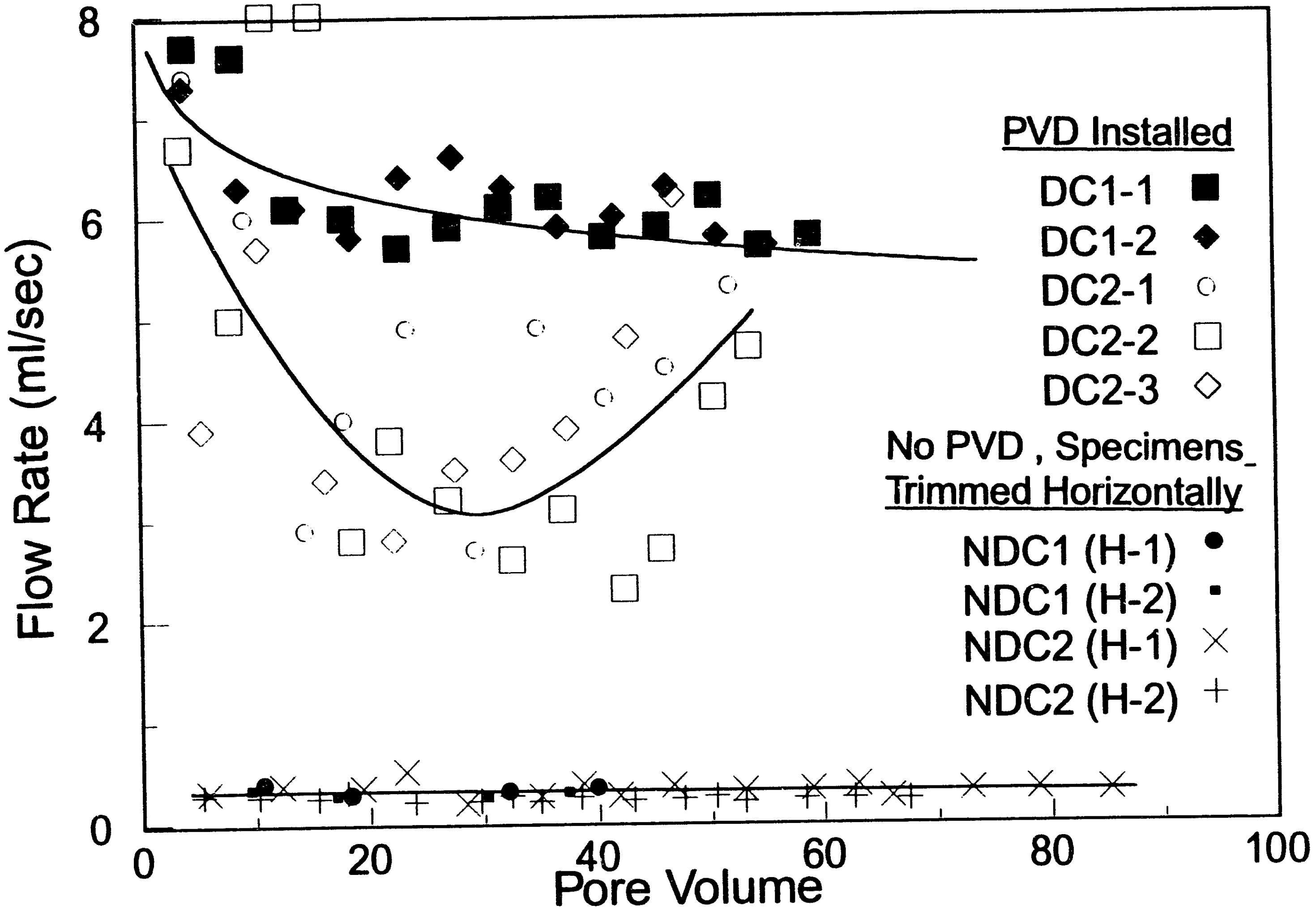

Figure 3.12 Rate of Flow With and Without PVD Installed

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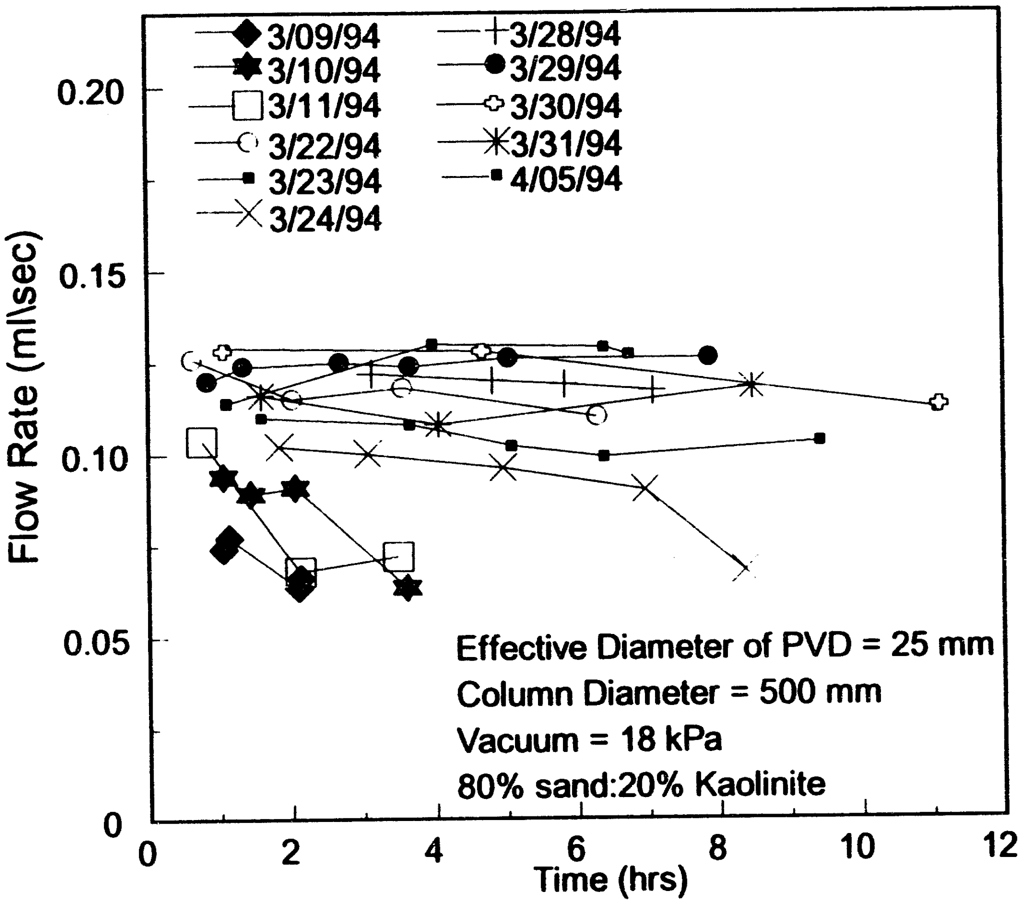

Figure 3.13 Long Term Flow Behavior of PVD with Vacuum System

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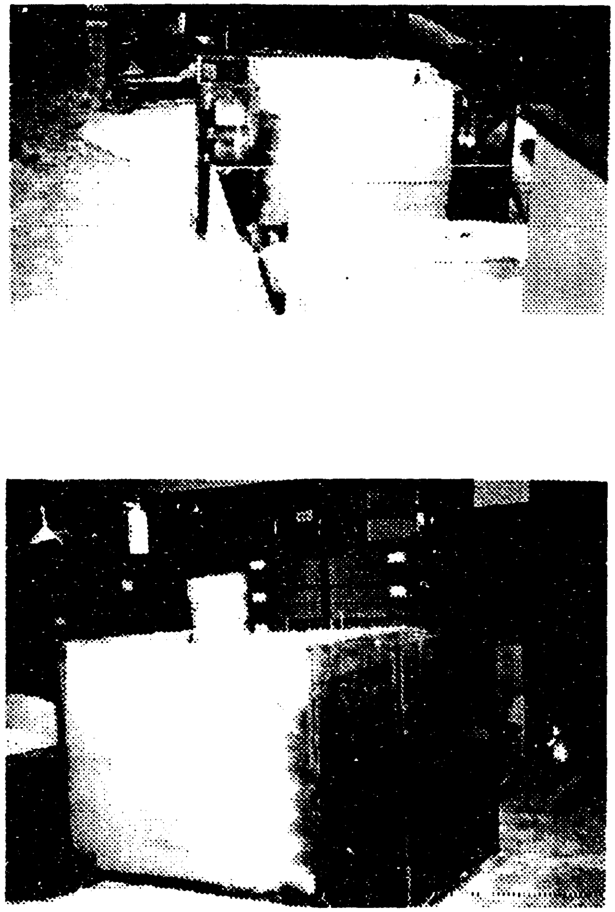

Figure 3.14 Photograph of Contaminant Recovery Cell (CRC)

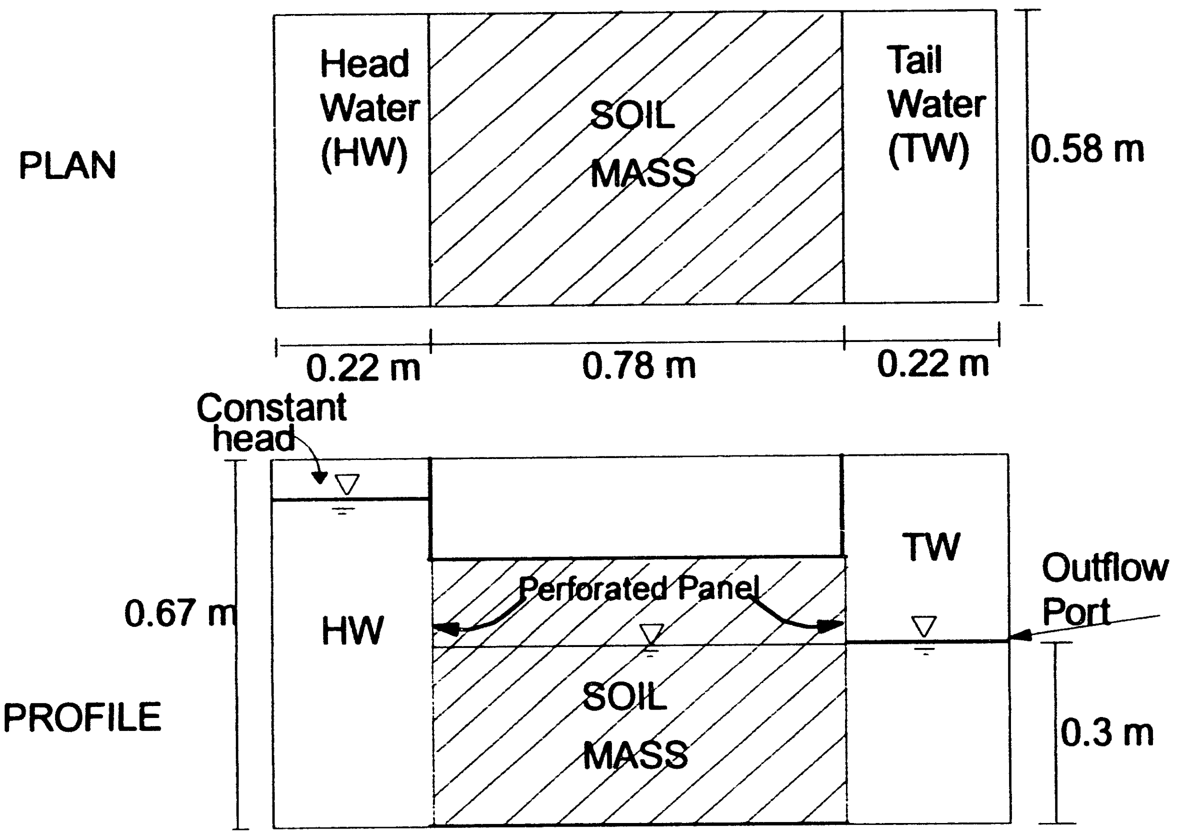

Figure 3.15 Schematic Diagram and Dimensions of CRC

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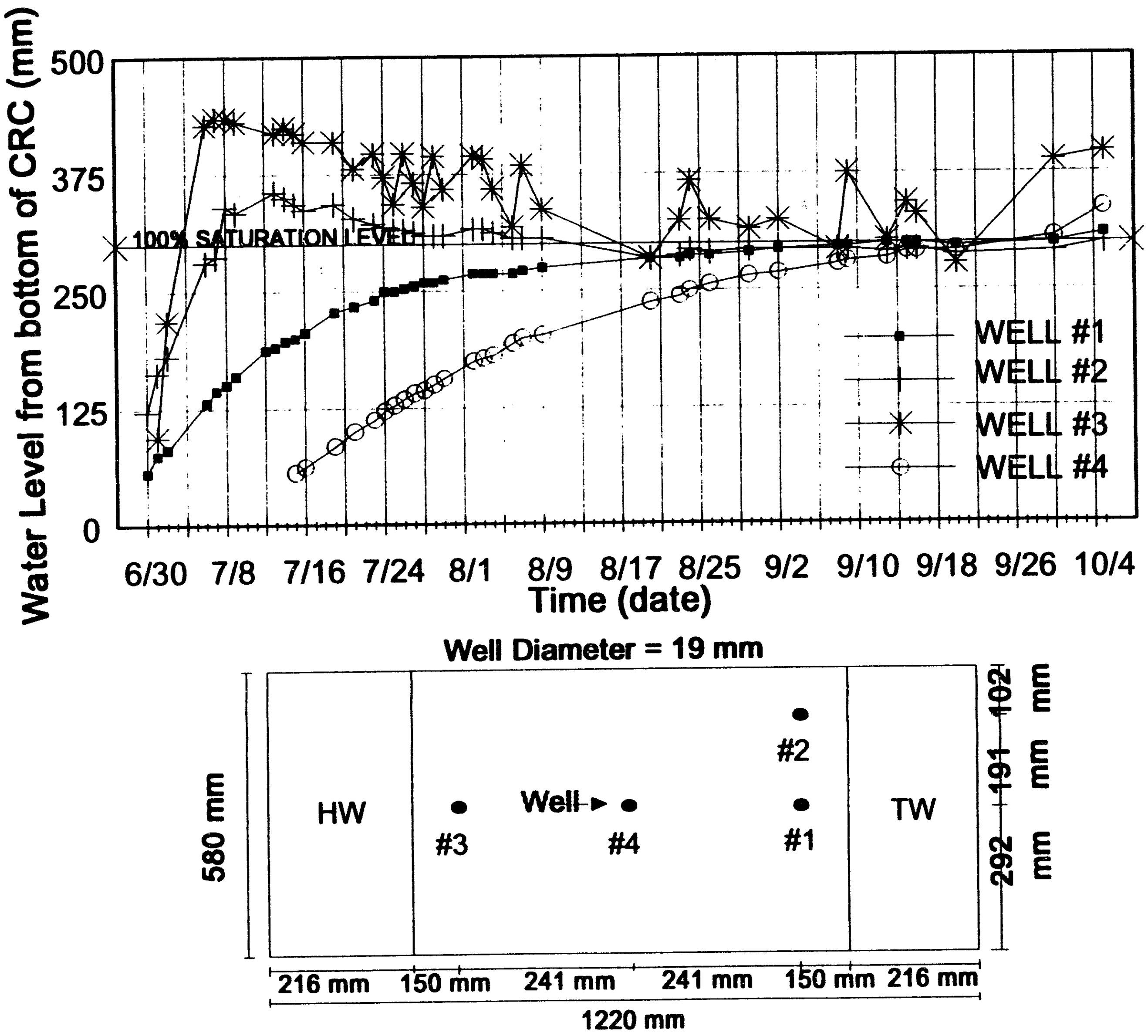

Figure 3.16 Advancement of Saturation Front for 80/20 Sample in the CRC

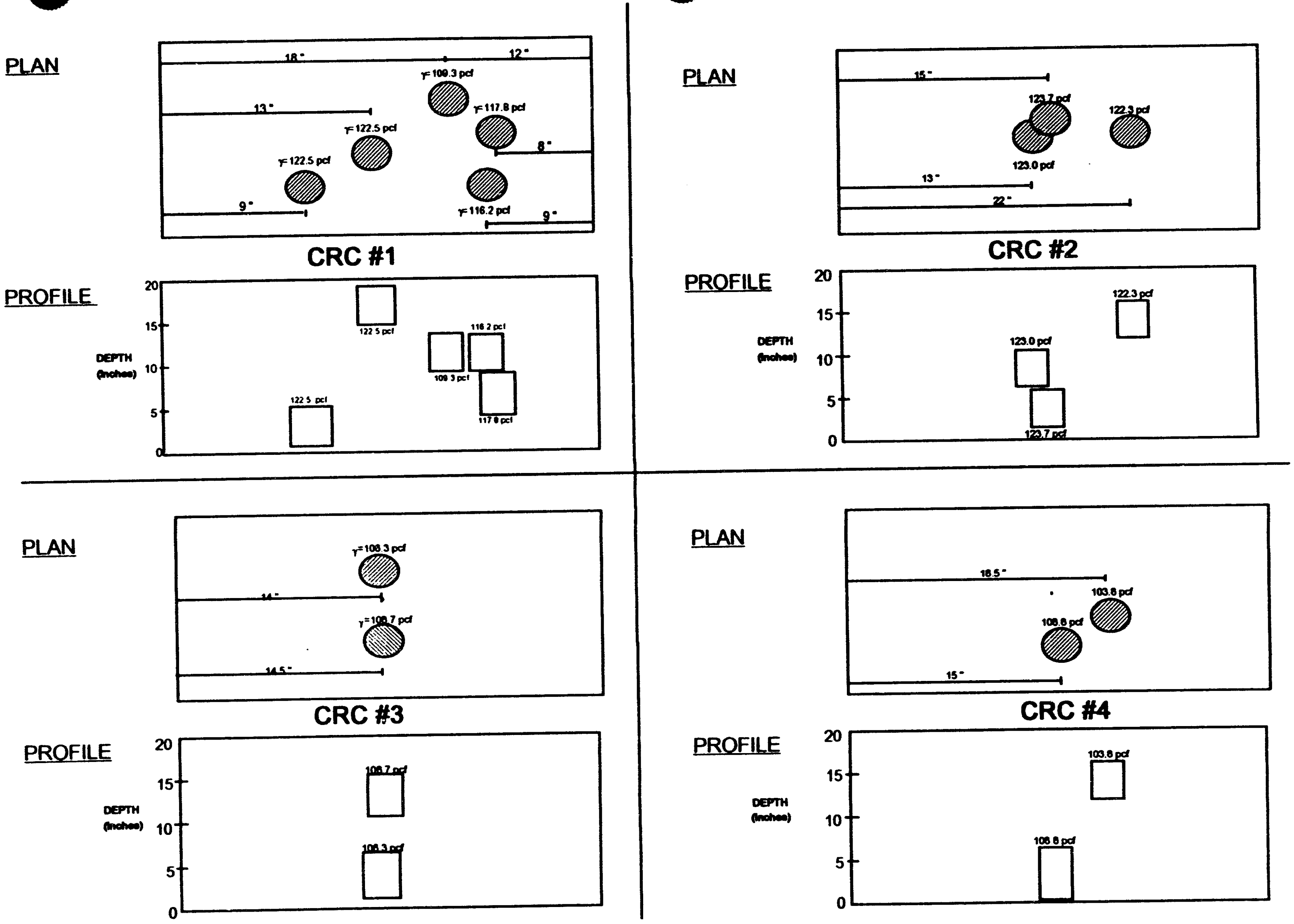

Figure 3.17 Measured In-Place Densities from Sand Cone Tests

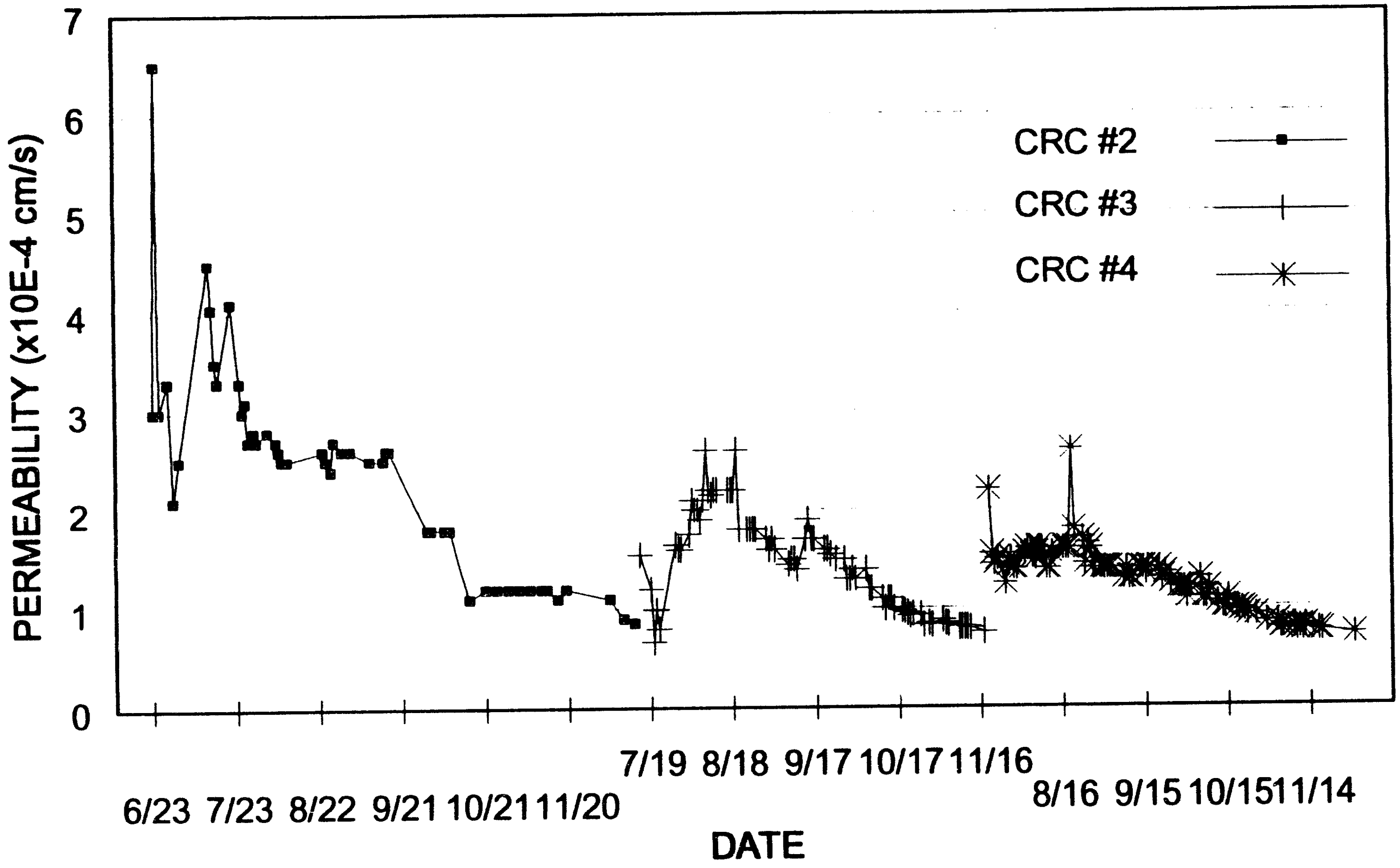

Figure 3.18 Variation of Hydraulic Conductivity Measured in the CRC as a Function of Time: Water as Permenat Liquid and 80/20 Clean Soil

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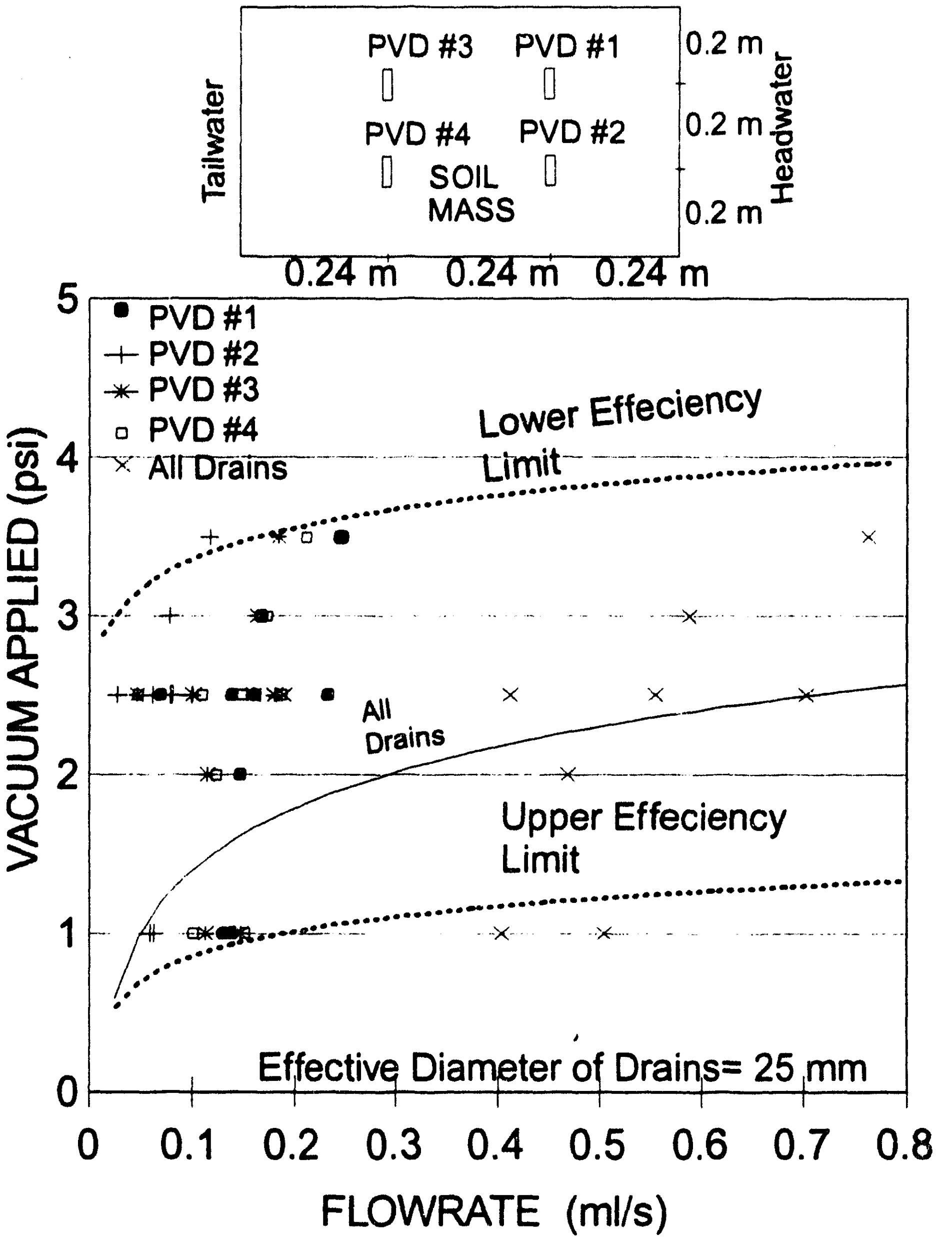

Figure 3.19 Retrieved Flow Rate as a Function of Vacuum Level: 80/20 Mix, Clean Soil

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4.0 LIQUID RETRIEVAL USING PVD: CONTAMINANT TRANSPORT MODEL

Analysis techniques for performance evaluation of the PVD focus on the ability to induce consolidation and therefore accelerate the rate of settlement at a given site with soft clay soils. However, the use of PVD for this project is to improve the soil washing process through the efficient retrieval of subsurface liquid in fine grained soils that may contain appreciable amount of cohesionless material.

4.1 Model Development

As shown in Figure 4.1, the installed PVD has a zone of influence with a radius r_{eq}. The governing differential equation for the solute transport assuming full saturation and no decay:

$$\frac{\partial C}{\partial t} = \frac{1}{r}\frac{\partial}{\partial r}(D_r r\frac{\partial C}{\partial r}) + D_z\frac{\partial^2 C}{\partial z^2} - \frac{1}{r}\frac{\partial}{\partial r}(\frac{r\, v_r C}{n}) - \frac{1}{n}\frac{\partial}{\partial z}(v_z C) - \frac{1}{n}\frac{\partial(\rho_d K_d C)}{\partial t} \qquad (13)$$

where:

C= concentration
r =equivalent radius
D_r and D_z = coefficient of vertical and radial dispersion: f(v_r and v_z)
v_r and v_z= radial velocity and vertical velocity
k_d=equilibrium distribution coefficient
ρ_b = bulk density
n= porosity of soil

Using Darcy's Law, the radial velocity of flow can be defined as:

$$V_r = -K\frac{d\varphi}{dr} = K\frac{ds}{dr} \qquad (14)$$

where K=coefficient of permeability; ψ = piezometric head, and s= induced stress which in this case provide for the action of the PVDs injection/retrieval and can be expressed as follows:

$$s = \frac{Q_0}{2\pi KH}\ln(\frac{r}{D}) \qquad (15)$$

where H=thickness of aquifer;
Q_0=total discharge of injection well which is assumed equal to retrieval rate;
D=radial distance between injection and vacuum drains.

Substitute Eq.15 into Eq.14, the following eqation can be obtained:

$$v_r=\frac{Q_0}{2\pi Hr} \tag{16}$$

Based on the radial velocity, the coefficient of radial dispersion is expressed as:

$$D_r=\alpha_r v_r=\frac{\alpha_r Q_0}{2\pi Hr} \tag{17}$$

where α_r=radial dispersivity. The vertical velocity in this case can be considered as constant (Sudicky, 1982) as is expressed as follows:

$$D_z=\alpha_z v_z \tag{18}$$

where α_z=vertical dispersivity. Substituting Eqs. 16, 17 and 18 into Eq.13, the following model equation for axisymmetric contaminant transport can be obtained:

$$\frac{\partial C}{\partial t}=\frac{Q_0\alpha_r}{2\pi Hr}\frac{\partial^2 C}{\partial r^2}+\alpha_z v_z\frac{\partial^2 C}{\partial z^2}-\frac{Q_0}{2\pi nHr}\frac{\partial C}{\partial r}-\frac{v_z}{n}\frac{\partial C}{\partial z}-\frac{1}{n}\frac{\partial(\rho_b K_d C)}{\partial t} \tag{19}$$

Analytical solution of above 2-order and 4-variable partial differential equation is obtained as followes:

Based on Carribo's solution (1952) for a similar model, C can be expressed as:

$$C(z,r,t)=C_z(z,t)\cdot C_r(r,t)=C_z\cdot C_r \tag{20}$$

where C_z and C_r represent vertical and radial concentration at a given location, respectively. Diffrentiating with respect to time:

$$\frac{\partial C}{\partial t}=C_z(z,t)\frac{\partial C_r(r,t)}{\partial t}+C_r(r,t)\frac{\partial C_z(z,t)}{\partial t}=C_z\frac{\partial C_r}{\partial t}+C_r\frac{\partial C_z}{\partial t} \qquad (21)$$

$$\frac{\partial^2 C}{\partial r^2}=C_z\frac{\partial^2 C_r}{\partial r^2} \qquad (22)$$

$$\frac{\partial^2 C}{\partial z^2}=C_r\frac{\partial^2 C_z}{\partial z^2} \qquad (23)$$

$$\frac{\partial C}{\partial r}=C_z\frac{\partial C_r}{\partial r} \qquad (24)$$

$$\frac{\partial C}{\partial z}=C_r\frac{\partial C_z}{\partial z} \qquad (25)$$

Substituting Equations 21 through 25 into Eq.19, the following general equation can be obtained:

$$(1+\frac{\rho_b K_d}{n})(C_r\frac{\partial C_z}{\partial t}+C_z\frac{\partial C_r}{\partial t})=\frac{Q_0\alpha_r}{2\pi Hr}C_z\frac{\partial^2 C_r}{\partial r^2}+\alpha_z v_z C_r\frac{\partial^2 C_z}{\partial z^2}-\frac{Q_0 C_z\frac{\partial C_r}{\partial r}}{2\pi nHr}-\frac{v_z}{n}C_r\frac{\partial C_z}{\partial z}$$

$$C_r(\frac{\partial C_z}{\partial t}-\frac{\alpha_z v_z n}{n+\rho_b K_d}\frac{\partial^2 C_z}{\partial z^2}+\frac{v_z\frac{\partial C_z}{\partial z}}{n+\rho_b K_d}=C_z(\frac{-\partial C_r}{\partial t}+\frac{Q_0\alpha_r n\frac{\partial^2 C_r}{\partial r^2}}{(n+\rho_b K_d)2\pi Hr}-\frac{Q_0\frac{\partial C_r}{\partial r}}{(n+\rho_b K_d)2\pi Hr}) \qquad (26)$$

Equation (26) can be separated to two equations representing vertical and radial conditions as follows: with initial and boundary conditions as follows:

$$\frac{\partial C_z}{\partial t}=\frac{\alpha_z v_z n}{n+\rho_b K_d}\frac{\partial^2 C_z}{\partial z^2}-\frac{v_z}{n+\rho_b K_d}\frac{\partial C_z}{\partial z} \qquad (27)$$

$$\begin{aligned} &C_z(z,0)=C_{z0}, && z\geq 0\\ &C_z(0,t)=0, && t>0 \qquad (28)\\ &C_z(\propto,t)=0, && t>0 \end{aligned}$$

and

$$\frac{\partial C_r}{\partial t}=\frac{\alpha_r Q_0 n}{(n+\rho_b K_d)2\pi H}\frac{1}{r}\frac{\partial^2 C_r}{\partial r^2}-\frac{Q_0}{(n+\rho_b K_d)2\pi H}\frac{1}{r}\frac{\partial C_r}{\partial r} \qquad (29)$$

with initial and boundary conditions as follows:

$$\begin{aligned} &C_r(r,0)=C_{r0}, && r\geq r_0\\ &C_r(r_0,t)=0, && t>0 \qquad (30)\\ &C_r(\propto,t)=0, && t>0 \end{aligned}$$

Using Laplace Transform and Laplace Inverse Transform (Marino, 1974a), Eq.27 can be solved utilizing initial and boundary conditions:

$$C_z(z,t)=\frac{C_{z0}}{2}[erf(\frac{\frac{v_z t}{n+\rho_b K_d}-z}{2\sqrt{\frac{\alpha_z v_z n t}{n+\rho_b K_d}}})+erf(\frac{\frac{v_z t}{n+\rho_b K_d}+z}{2\sqrt{\frac{\alpha_z v_z n t}{n+\rho_b K_d}}})] \qquad (31)$$

where

$$erf(x)=\frac{2}{\sqrt{\pi}}\int_0^x e^{-\xi^2}d\xi \qquad (32)$$

Using Laplace Transform and Laplace Inverse Transformation as described by Marino (1974b) and utilizing initial and boundary conditions, Eq.29 can be solved as follows:

$$C_r(r,t)=C_{r0}[1-erf(h)] \qquad (33)$$

where:

$$h=\frac{\dfrac{3Q_0 t\ \alpha_r n}{(n+\rho_b K_d)2\pi H}}{4(r-r_0)^3} \qquad (34)$$

Substituting Eq.31 and Eq.33 into Eq.20:

$$C(z,r,t)=C_z\cdot C_r=\frac{C_0}{2}\left[erf\left(\frac{\dfrac{v_z t}{n+\rho_b K_d}-z}{2\sqrt{\dfrac{\alpha_z v_z n t}{n+\rho_b K_d}}}\right)+erf\left(\frac{\dfrac{v_z t}{n+\rho_b K_d}+z}{2\sqrt{\dfrac{\alpha_z v_z n t}{n+\rho_b K_d}}}\right)\right][1-erf(h)] \qquad (35)$$

where $C_0=C_{r0}C_{z0}$; h and function erf are expressed by Eqs.32 and 34.

4.2 Parameter Study

A parameter study is conducted to investigate the influence of key contaminant, drain and soil parameters on the rate of soil flushing and the associated duration. In addition, the parameter study is used to check the robustness of the solution. The analysis parameters for the case used as the "base cas" are shown in Table 6. The results of the parameter study are presneted in the form of relative contaminant concentration as a function of time The modeled configuration is shown in Figure 4.2.

Table 6. Analysis Parameters for the Base Case

n	0.25
K_d	1×10^{-4} m^3/kg
ρ_b	2000 kg/m^3
H	10 m
α_r	5 m
α_z	1 m
v_z	0.05 m/h
Q_0	10 m^3/h
C_0	200 mg/kg

Predictions utilizing the above model for the base case are shown in Figure 4.3. Approximately 90% clean-up level was obtained at 3 m below the ground surface after one day and it took approximately 1 ½ days to reduce to the original concentration by 90% at depth of 7 m below the ground surface.

The results of the parameter study are presented in Figures 4.4 through 4.9. Discussion will be added in the next Progress Report.

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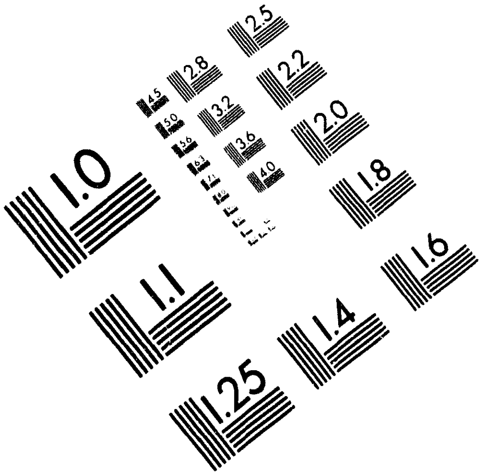

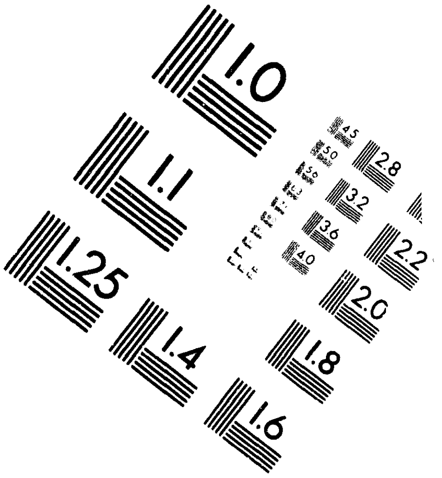

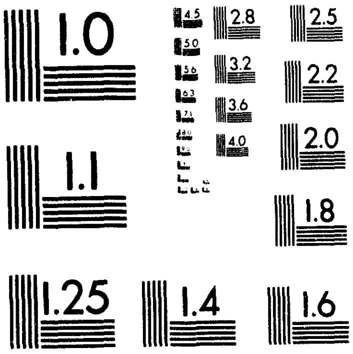

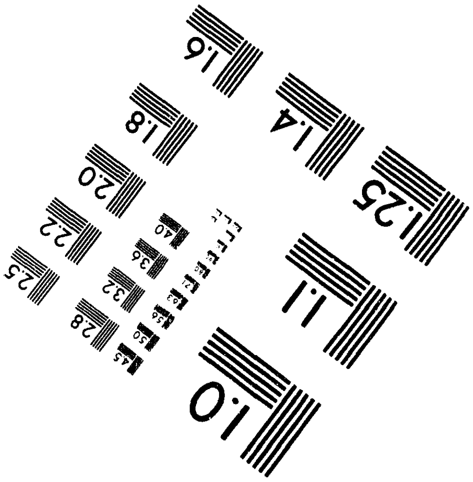

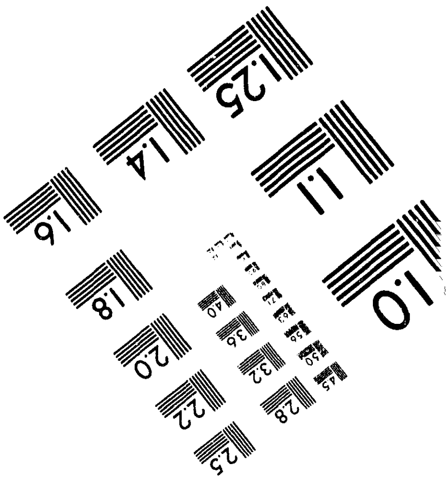

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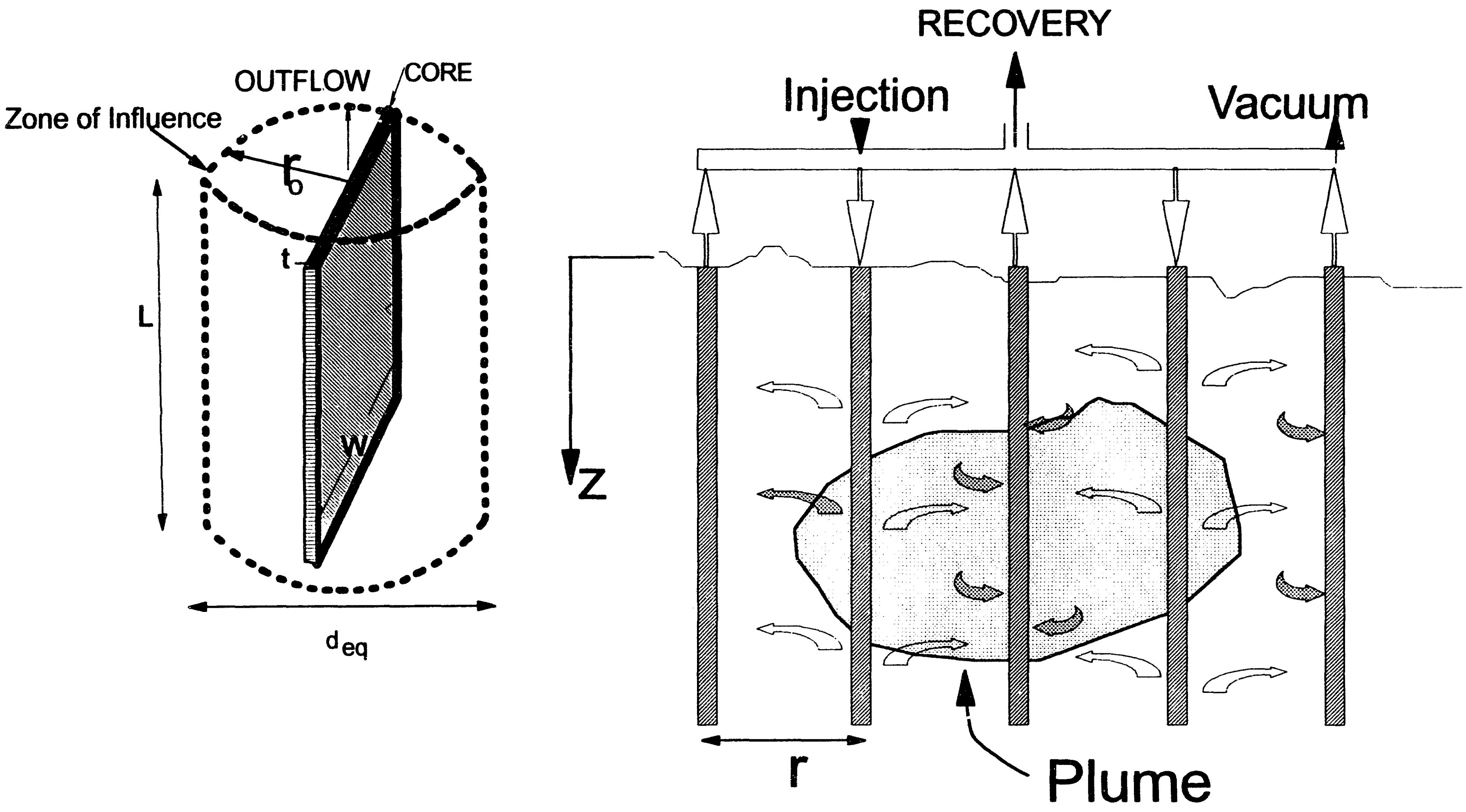

Figure 4.1 Idealized PVD Dimensions and Model Parameters

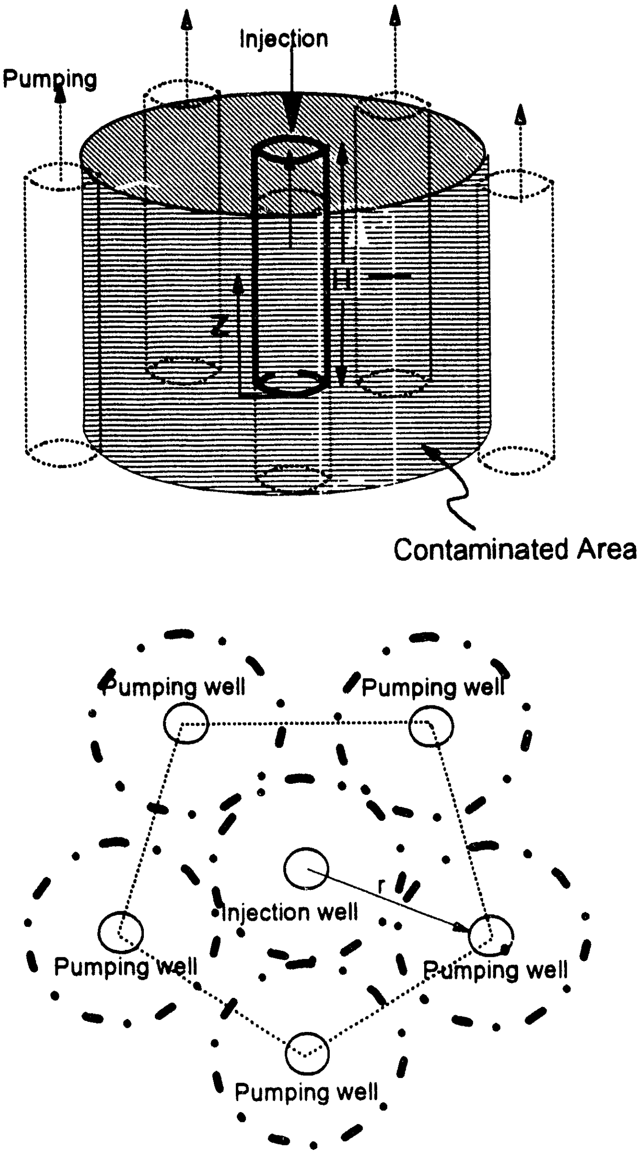

Figure 4.2 Well Pattern and Modeling Configuration

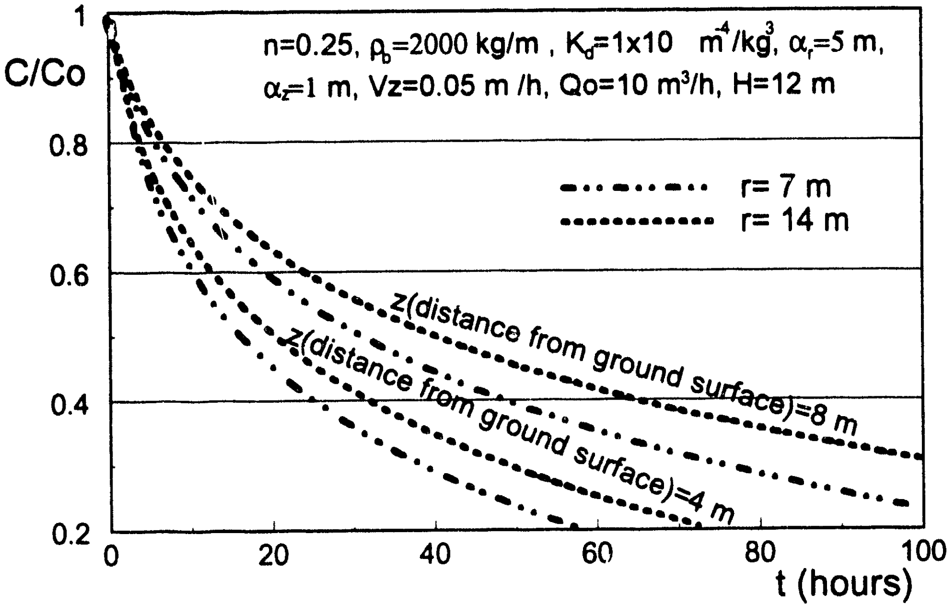

Figure 4.3 Relative Contaminant Concentration as a Function of Time for Different Radial Distances from the Injection PVD

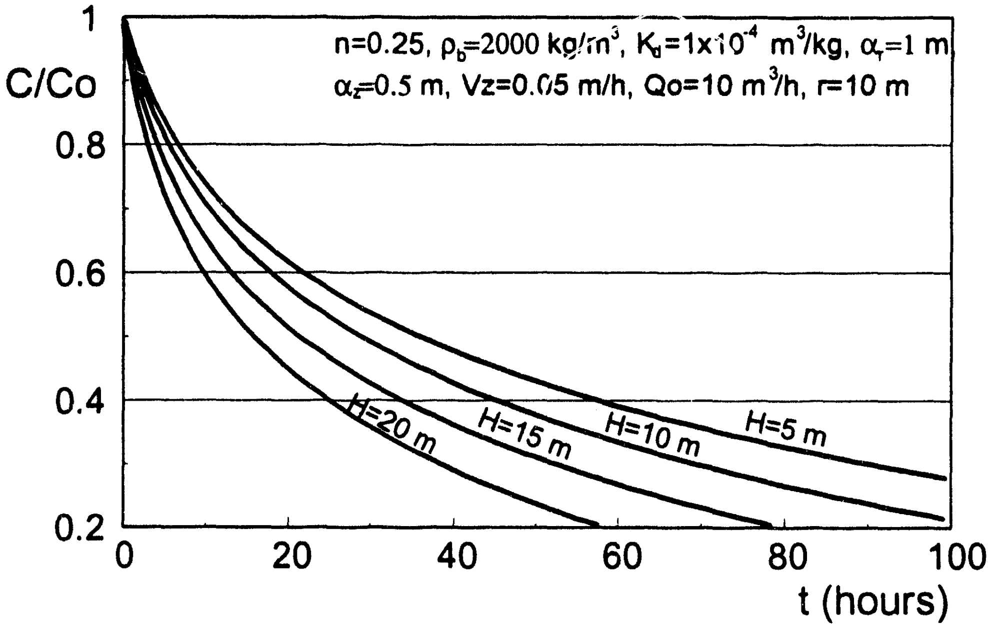

Figure 4.4 Effect of Depth of PVD Penetration and Aquifer Thichness

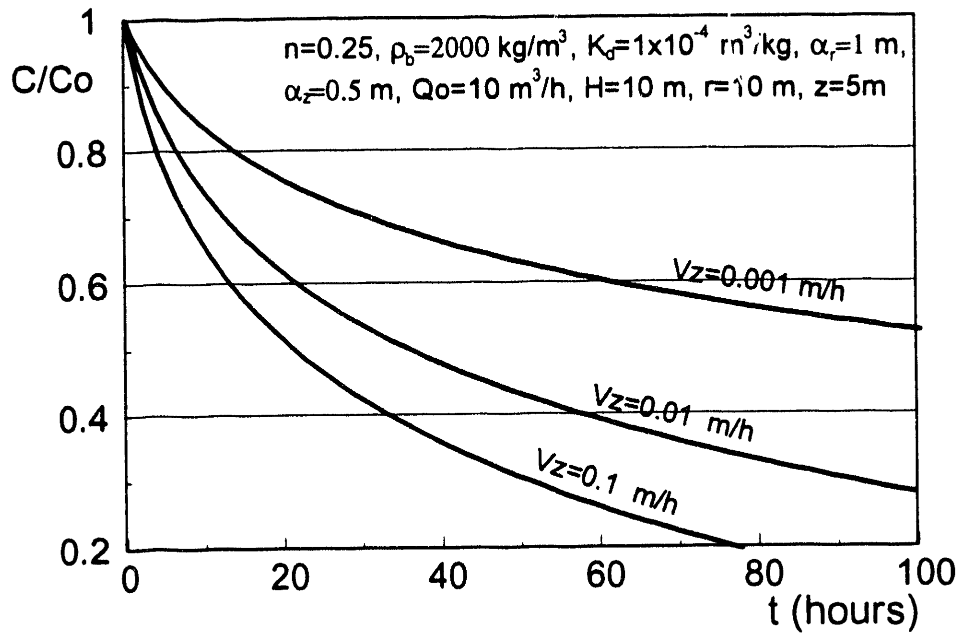

Figure 4.5 Effect of Vertical Velocity of Flow

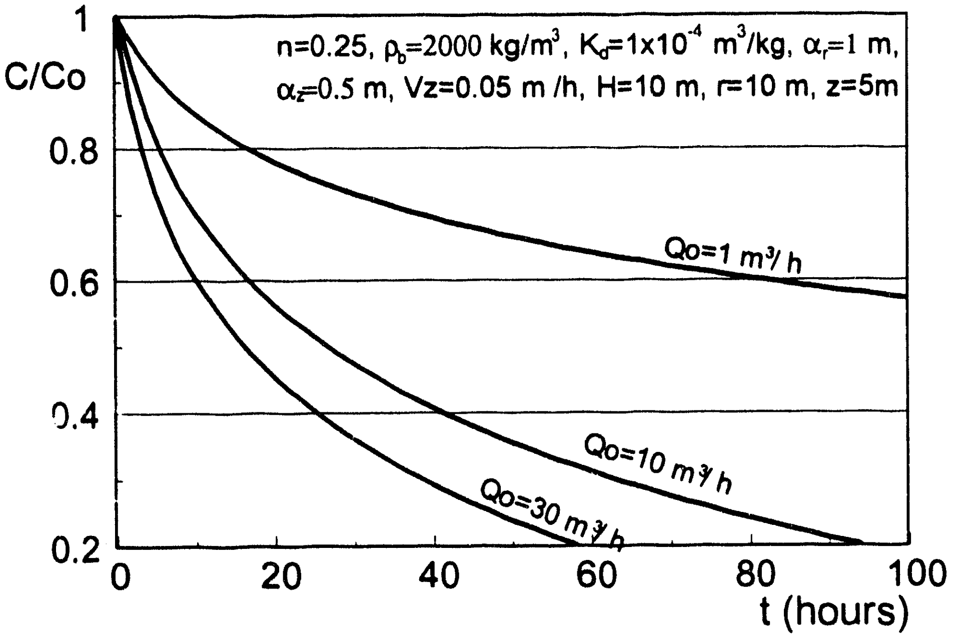

Figure 4.6 Effect of Pumping Rate

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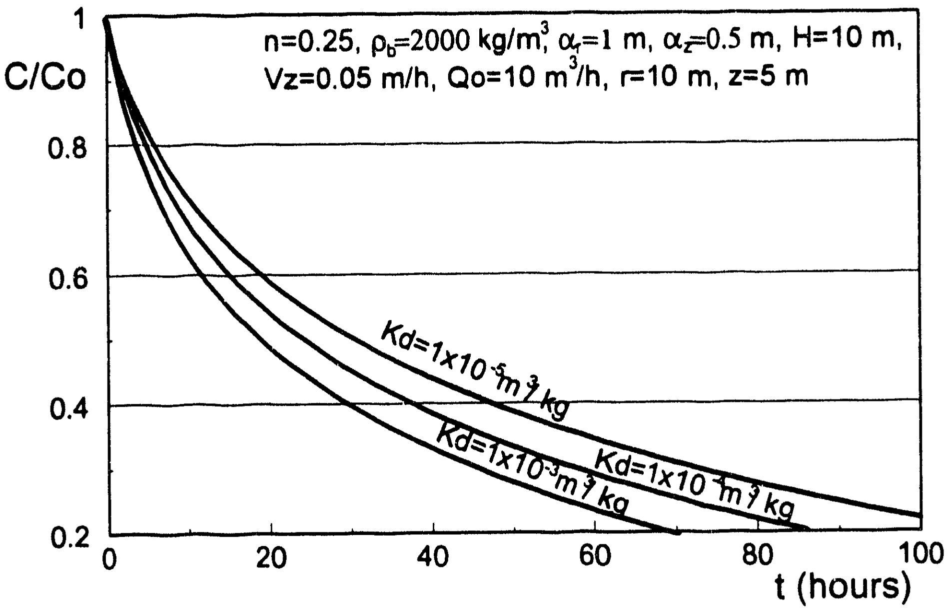

Figure 4.7 Effect of Coefficient of Partition

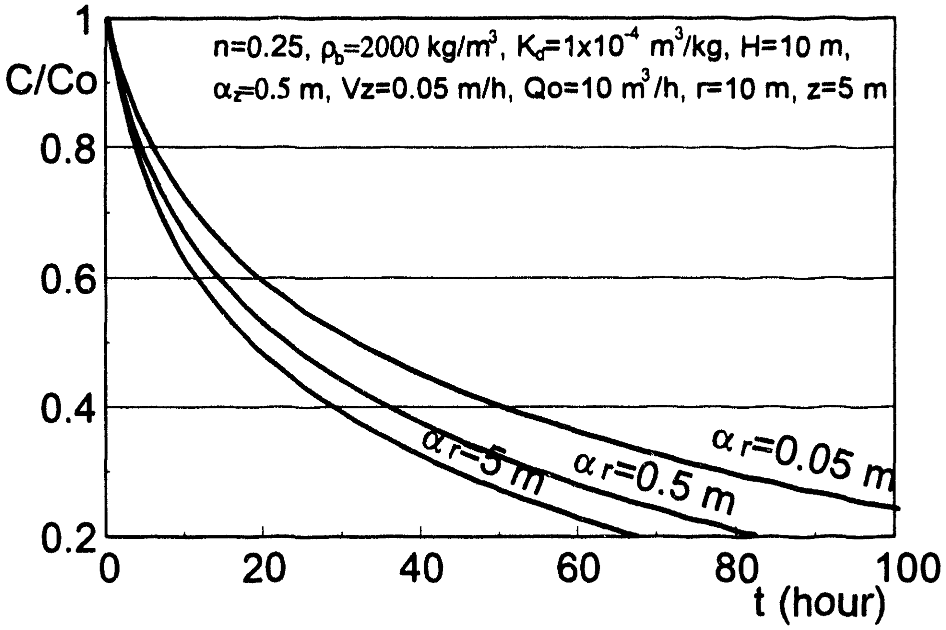

Figure 4.8 Effect of Coefficient of Radial Dispertion

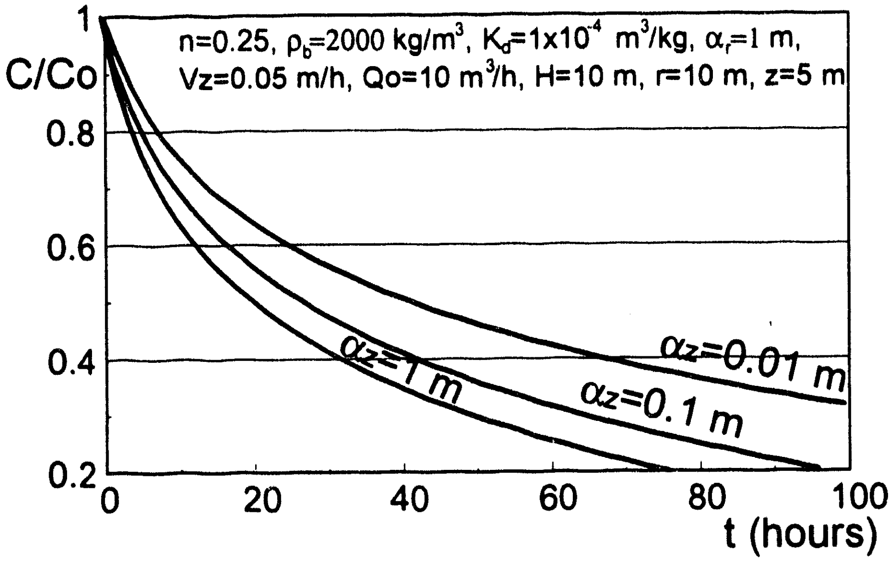

Figure 4.9 Effect of Coefficient of Verticla Dispertion

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5.0 SUMMARY AND CONCLUSIONS

The research concept presented in this report aims at enhancing the effectiveness of the soil flushing process by installing the PVD to shorten the drainage path of the flow and provide redundancy and wide coverage to capture the subsurface pollutants. The research work is progressing on budget and on time. Literature review was conducted to investigate the existing theories dealing with applications of PVD and their applicability to the soil type to be used in the project. Laboratory tests included batch type experiments with three different surfactant concentrations. Column flushing tests were done utilizing flexible wall permeameters, in accordance with ASTM 5084 procedure, to model in-situ conditions on two types of synthetic soils. The flexible wall permeability tests were conducted using soil specimens with and without a PVD installed. In addition, bench-scale tests using large scale reactors, referred to as Contaminant Recovery Cells (CRC), were conducted. Soil samples were prepared from a mixture of Ottawa sand and 0%- 20% kaolinite.

Permeability tests using solution of the study surfactant as permeant resulted in reduction on the order of two orders of magnitude in the values of the hydraulic conductivities and deserves further investigation. The study soil contains 20% clay of the kaolinite species. The kaolinite minerals, common in soils, have a 1:1 silica: alumina 2-sheet structure with alternating silica and octahedral sheets. Reduction in the hydraulic conductivity may be due to one or combinations of the following factors:

1. The hydraulic conductivity depends more on the percent of clay particles in the soil mixture. A small percentage of fines can clog the pores of coarse fraction.

2. Some types of negatively charged anions such as sulfate can be attracted to the edges of the clay particles, where broken bonds create net positive charge, and becomes part of the surface. This causes deflocculations and swelling and consequently decrease in hydraulic conductivity.

3. Sulfate compounds such as SDS causes rise in the pH which results in solutioning of the silica tetrahedral and alumina octahedral layers. precipitation of this material can cause clogging of pores and therefore drop in the hydraulic conductivity.

Sectional grain size distribution on the soil samples was conducted to investigate potential migration of clay particles. Soil columns were sectioned along their length and grain size distributions were determined. All sections had the original 80% sand-20% kaolinite composition. Thus migration and deposition was not likely contributing to clogging and reduced hydraulic conductivity.

The reduction in the hydraulic conductivity of the test samples due to the introduction of the surfactant was observed to be reversible. The hydraulic conductivity of a sample that was tested for approximately 3 months (50 pore volumes were circulated through it) was reduced by two orders of magnitude, and as the circulation of flow continued, the hydraulic conductivity values were gradually increased back to values comparable to those obtained using water as permeant liquid.

In light of the observed 'recovery' of the hydraulic conductivity with increased volume of flow, two phenomenon are thought to be most likely for the observed behavior. The first is the precipitation of alumina or silica constituents and their subsequent re-solubilization. The continued fresh supply of SDS facilitated the dissolutioning of these precipitates, and ultimately resulting in the higher hydraulic conductivity.

A second phenomenon is that of multiphase flow. The SDS solution must displace the indigenous soil pore water prior to freely flowing through the soil matrix. When the SDS solution is permeated into the water saturated or nearly saturated soil specimen, an SDS/water interface (meniscus) may be established. Surface tension and resulting capillary forces must be overcome in order for the SDS to permeate the specimen. As the SDS solution fills connecting soil pores, the flow rate increases, until which time the soil specimen is completely saturated with the SDS solution. Thus it is possible that either or both of the above described phenomena are causing the measured behavior of the hydraulic conductivity.

Based on the results of this study, the following conclusions can be advanced:

1. Variations of partition coefficients can be related to the concentrations of SDS used. Greater partition coefficients are observed at SDS concentrations close to the CMC. The 10, 50, and 100 mM SDS/kaolinite solutions resulted in partition coefficients of 1.55, 0.165, and 0.155 L/mg, respectively.

2. Maximum value of C_{eff}/C_{sat} for the SDS at equilibrium was measured to be approximately 0.65. This value is relatively less than expected. For the case of the specimen size of 10 gm, measured results indicated desorption of only 350 mg/L while approximately 500 mg/L would have been expected.

3. Hydraulic conductivity variations are clearly a result of physico/chemical interactions of the SDS with the kaolinite.

4. The adsorptive capacity of the kaolinite dominates the removal kinetics of SDS using a laboratory mixed soil. Compared to removal of over 90% for the sand in four days the kaolinite rich soil took 2.5 months to reach the removal level for the sand. In addition, 86% fewer pore volumes passed for the Ottawa sand sample as compared to the kaolinite rich soil.

5. The measured permeabilities for the study soil in accordance with ASTM D5084 decreased from $3x10^{-4}$ cm/sec for water content of 7% to approximately $2x10^{-5}$ cm/sec for molding water content of 11%. It was possible to replicate these permeabilities in the CRCs by controlling the moisture content and the compaction effort. It was necessary to compact the soil in twelve layers to achieve a uniform density across the soil sample. A weight density of approximately 17 kN/m^3 to 19 kN/m^3 was achieved for the soil samples in the CRC's.

6. Results from flexible column tests on specimens with PVD indicated a flow rate of approximately 6 ml/sec as compared to the 0.25 ml/sec that was measured for specimens with no PV drains.

7. A long term (4 weeks) clogging experiment on the PVD indicated that a steady state flow rate of 0.12 ml/sec was reached under a vacuum of 19 kPa with no apparent decreasing trend.

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8. Results from the CRC tests using four PVDs in a rectangular arrangement indicated that the volume of the retrieved fluid increased as a function of the vacuum level and was approximately 0.5 ml/sec. The base inflow, controlled by the headwater and tailwater elevations in thte CRC, was measured to be approximately 0.55 ml/sec which indicated a recovery efficiency of 100% under a vacuum magnitude of approximately 14 kPa.

9. Using the observed drawdown of approximately 70 mm at the center of the rectangle formed by the installed PVDs, the total flow rate predicted using the well equation is 0.96 ml/s for a specific yield (S_y) value of 0.3. This value was approximately twice the rate retrieved using the PVD/vacuum system. However, using S_y=0.07 resulted in a total flow rate of 0.5 ml/sec which matched the flow rate retrieved using the PVD/vacuum system.

A contact was established with the NILEX corporation, one of the largest installers of the PVD in the U.S. The Nilex Corporation indicated strong interest in the project and are fully involoved in the project as industrial partners. In addition to contaminant recovery, results from this research program will indicate the feasibility of using PVD system for collection and detection of leachate in cases where waste was placed in unlined areas. Furthermore, the feasibility of using the PVD system to deploy micro-organisms for in situ bioremediation will be postulated from the results of this research.

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CHEMICAL DESTRUCTION OF CHLORINATED ORGANIC COMPOUNDS
(MC-6)

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ABSTRACT

The general objective of this research is to first evaluate the existing technologies for destruction of polychlorinated biphenyls (PCBs) by chemical methods. Development of new chemical treatment procedures for dechlorination of PCBs will also be a major focus of this research project. The detailed reaction pathway for the dechlorination process will be carefully probed so as to gain fundamental understanding of the reaction mechanism. Such information will be invaluable in providing guidelines for designing an efficient and economical system.

In the first part of this report, the main focus will be on the assessment of the current technologies and the discussion of the basic chemical reactions behind these treatment procedures. The commercial processes as well as procedures recently published in the literature will be reviewed, including dechlorination of PCBs by sodium and other alkali metals, by the use of strong base, by catalytic dechlorination, and by photochemical degradation.

In the second part of this report, experimental results obtained from dechlorination of aromatic halides, including chlorobenzene, 4-chlorobiphenyl, Aroclor 1242, and Aroclor 1254, by sodium 1-dimethylaminonaphthalide (NaDMAN) will be discussed. The easy recovery of 1-dimethylaminonaphthalene from the reaction mixture by a simple acid extraction offers a significant advantage for its use as an electron carrier for sodium metal during the dechlorination process. However, as a reagent NaDMAN in tetrahydrofuran is not very stable. It is necessary to prepare NaDMAN at -10 °C and immediately prior to use. Storing NaDMAN solution at room temperature resulted in gradual loss of its reactivity over several days.

In the third part of this report, research efforts toward developing sterically hindered triarylboranes as potential electron carriers for sodium metal will be discussed. Because of the presence of an empty p-orbital on the boron atom which allows an electron from sodium metal to reside over it, triarylboranes are excellent electron carriers. Moreover the corresponding radical anions are stable over an extended period of time at room temperature, allowing dechlorination procedure to be carried out at ambient temperature. A sterically hindered triarylboran having an amino substituent was successfully synthesized to allow easy recovery after the dechlorination process was complete. Attaching a suitable electron carrier to a polymer backbone to allow easy separation is also being investigated.

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1. EXECUTIVE SUMMARY

It is the objective of this research to evaluate the existing technologies for destruction of polychlorinated biphenyls (PCBs) by chemical methods. We will also focus on establishing chemical treatment procedures for dechlorination of PCBs. We will probe into the detailed reaction mechanisms of various dechlorination processes so as to gain fundamental understanding of the reaction pathway. Such information will provide insight in designing an efficient and economical system.

In the first part of this report, the main focus will be on the assessment of the current technologies and the discussion of the basic chemical reactions behind these treatment procedures. Three commercial vendors listed with the Environmental Protection Agency (EPA) for their involvement in chemical dechlorination of PCBs have been contacted: (1) Trinity Environmental Technologies, Inc., (2) Chemical Waste Management, Inc., and (3) Roy F. Weston, Inc.

The Trinity Environmental Technologies, Inc. utilizes sodium metal to dechlorinate PCBs to inert biphenyl and sodium chloride. A general discussion of dechlorination of PCBs by sodium and other alkali metals is included in this report.

The Chemical Waste Management, Inc. utilizes a nucleophile-based process (the KGME process) that enables the destruction of halogenated aromatic compounds through the successive replacement of one or more halogen atoms with 2-methoxyethoxy moiety. A demonstration of this process was given at the ReSolve Superfund site at North Dartmouth, Massachusetts in the summer of 1992 under the sanction of EPA. Destruction of PCBs by nucleophilic displacement of chlorine atoms with a strong base is also reviewed in this report.

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 and has not been scaled up to pilot plant level. Other catalytic dechlorination processes are also discussed in this report.

The direct photodegradation of PCBs with UV or sunlight irradiation proceeds with low efficiency. However, the efficiency of photodegradation can be dramatically enhanced with appropriate photo-sensitizers and other additives. The basic reaction mechanism of the photodegradation process is discussed in this report.

In the second part of this report, experimental results obtained from dechlorination of aromatic halides, including chlorobenzene, 4-chlorobiphenyl, Aroclor 1242, and Aroclor 1254, by sodium 1-dimethylaminonaphthalide (NaDMAN) will be discussed. The easy recovery of 1-dimethylaminonaphthalene from the reaction mixture offers a significant advantage for its use as an electron carrier for sodium metal during the dechlorination process. However, as a reagent NaDMAN in tetrahydrofuran is not very stable. It is necessary to prepare NaDMAN at -10 °C and immediately prior to use. Storing NaDMAN solution at room temperature resulted in gradual

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loss of its reactivity over several days.

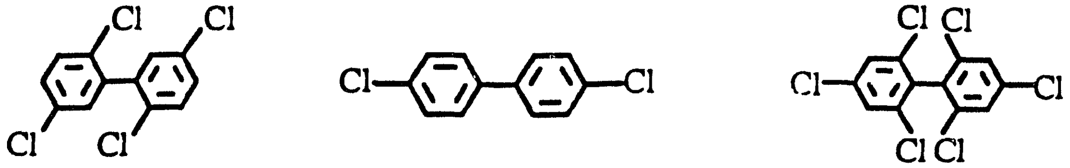
In the third part of this report, research efforts toward developing sterically hindered and chemically stable triarylboranes as potential electron carriers for sodium metal will be discussed. Because of the presence of an empty p-orbital on the boron atom which allows an electron from sodium metal to reside over it, triarylboranes are excellent electron carriers. Moreover the corresponding radical anions are stable over an extended period of time at room temperature, allowing dechlorination procedure to be carried out at ambient temperature. A sterically hindered triarylboran having an amino substituent was successfully synthesized to allow easy recovery after the dechlorination process was complete. Attaching a suitable electron carrier to a polymer backbone to allow easy separation is also being investigated.

2. INTRODUCTION

2.1 Background

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 effort 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.

2.2 Destruction of PCBs

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 will soon begin its test burn only after 13 years of planning and construction, more then 20 court cases, and even the intervention of the Vice President of the United States. In a recent 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.

2.3 Purpose and Scope of Report

It is the purpose of this report to first evaluate the existing technologies for the destruction of PCBs by chemical methods. We will focus mainly on the current commercial processes as well as procedures recently published in the literature, including dechlorination of PCBs by sodium and other alkali metals, by the use of strong base, by catalytic dechlorination, and by photochemical degradation. The basic chemical reactions behind these dechlorination processes will also be discussed. Experimental results obtained from dechlorination of aromatic chlorides by sodium 1-dimethylaminonaphthalide will also be discussed. Research efforts toward synthesizing sterically hindered and chemically stable triarylboranes as electron carriers for sodium metal are included in the report.

3. LITERATURE REVIEW OF CHEMICAL DESTRUCTION OF PCBS

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. Excellent review articles of the chemical processes are available in the literature.[4] In addition, a recent monograph by Mitchell D. Erickson covered broad issues concerning PCBs, especially the analytical procedures.[5] In this report, four general methods for chemical destruction of PCBs will be reviewed.

3.1 Dechlorination of PCBs by Sodium and Other Alkali Metals

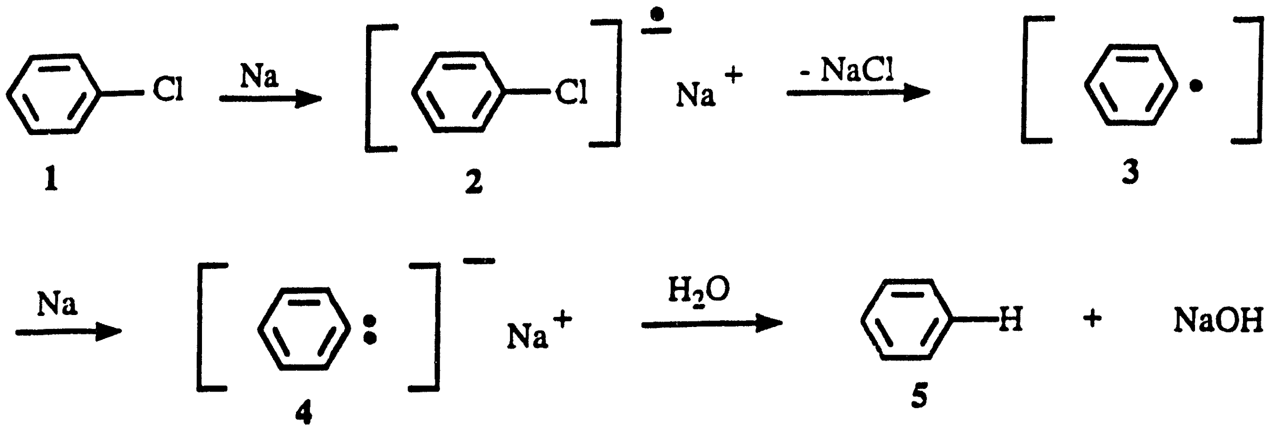
The Goodyear Tire and Rubber Company patented a sodium-naphthalide process for PCB destruction in 1981 and later released it for public use.[6] This process removes chlorine atoms from the PCBs and combines them with sodium to form sodium chloride (table salt).

The use of sodium metal for the dechlorination of aromatic compounds is well established in the literature.[7] The reaction mechanism is believed to involve first transferring an electron from sodium to the chlorinated aromatic compound, such as chlorobenzene (**1**) to form the corresponding radical anion, such as (**2**) (Fig. 2). The radical anion **2** then loses a chloride ion to form phenyl radical **3**, which then acquires an electron from sodium to form phenyl anion **4**. Subsequent quenching of **4** with water affords the dechlorinated adduct as benzene (**5**). In the

2.2-0

case of PCBs, such reaction cycle is repeated several times until all the chlorine atoms are removed. The resulting anions then are quenched with water.

Figure 2. Dechlorination of Chlorobenzene by Sodium



Because sodium metal is not very soluble in organic solvents, the Goodyear process uses naphthalene as an electron carrier to improve the efficiency of electron transfer. The process normally takes 2 hours at 60°C for complete dechlorination. However, to effectively remove low levels of PCBs (ca. 100 parts per million, ppm) from contaminated oil down to ca. 3 ppm, far lower than the requirement set by the Environmental Protection Agency (EPA), a large excess of the reagent is required. Typically, the reagent to chloride molar ratio must be from 25 to 500 to obtain significant reduction of the PCB concentration. Quenching the excess sodium-naphthalide reagent with water must be conducted slowly and with extreme caution. This is because generation of hydrogen gas will occur if sodium is contacted with water, creating a potentially dangerous situation for explosion.

In 1984, Goodyear disclosed an improved process with the elimination of the water quench step.[8] The difficulties and disadvantages associated with a water quench of the alkali metal aromatic radical anion reagent are overcome by utilizing carbon dioxide (CO_2) as the excess reagent quenching material. No hydrogen gas is involved and at no time does water enter the system. The exclusion of water from the process allows for the recovery of the reaction solvent, such as tetrahydrofuran, in pure, dry form, eliminating additional process step, does not generate a waste water stream for disposal, and improves overall process safety.

The Goodyear process uses naphthalene, which has been classified as a priority pollutant by EPA, and its use is restricted. A number of processes have since been developed, utilizing other compounds as substitute for naphthalene.[9-11] The Sunohio, Inc. of Canton, Ohio developed proprietary compounds to replace naphthalene in a sodium-based process for reclamation of transformer oils containing PCBs. The Sunohio procedure was reviewed preciously.[9]

In a recently patented procedure, ammonium salt was used to accelerate the reductive cycle of dechlorination and to serve as a proton source to hydrogenate and quench the dehalogenated polyhaloaromatics.[10] It was also reported in a separate patented procedure that liquid hydrosiloxane could facilitate the reductive dechlorination so that it will proceed to completion at room temperature in relatively short times.[11] It was claimed that PCBs are dechlorinated to biphenyl and its higher molecular weight oligomers with greater than 99% efficiency.

Currently, the sodium-based process is employed by the Trinity Environmental Technologies, Inc., using a modified version of the Goodyear process. It is claimed that this process is cost competitive compared to incineration for the treatment of PCB oils. However, this process will not be able to treat PCB contaminated soil. A block diagram of the Trinity process is given in Figure 3.

3.2 Destruction of PCBs by the Use of Strong Base

The use of strong base to attack PCBs has been investigated. The KPEG process, which uses potassium metal (K) and polyethyleneglycol (PEG) to destroy PCBs, is an example of such a treatment procedure.[4a] Potassium metal reacts with polyethyleneglycol, such as diethyleneglycol (**6**), to form the correspond alkoxide (**7**), a strong base, which than attacks PCBs by nucleophilic displacement (Fig. 4).

Figure 4. Destruction of PCBs by the KPEG Process

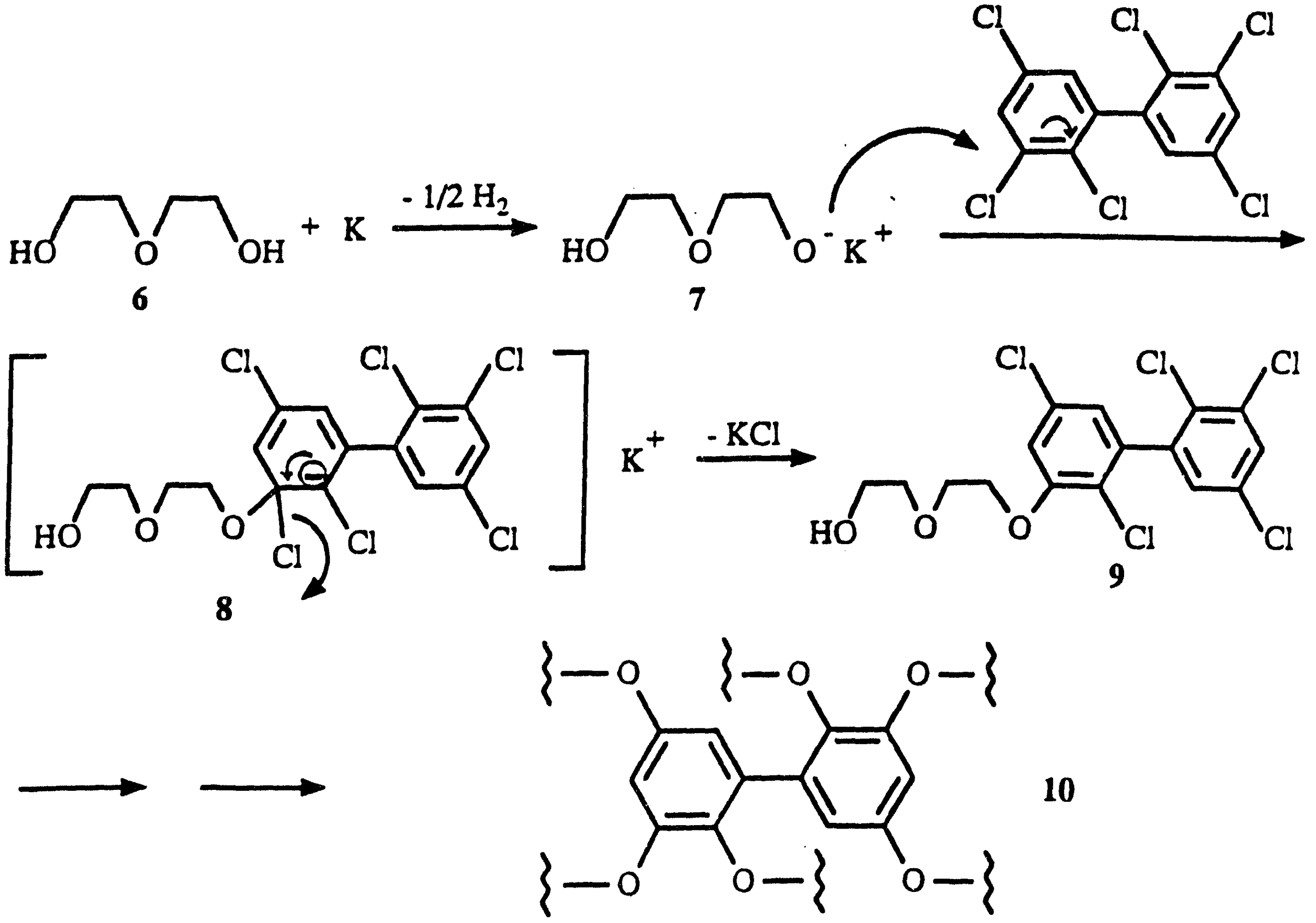
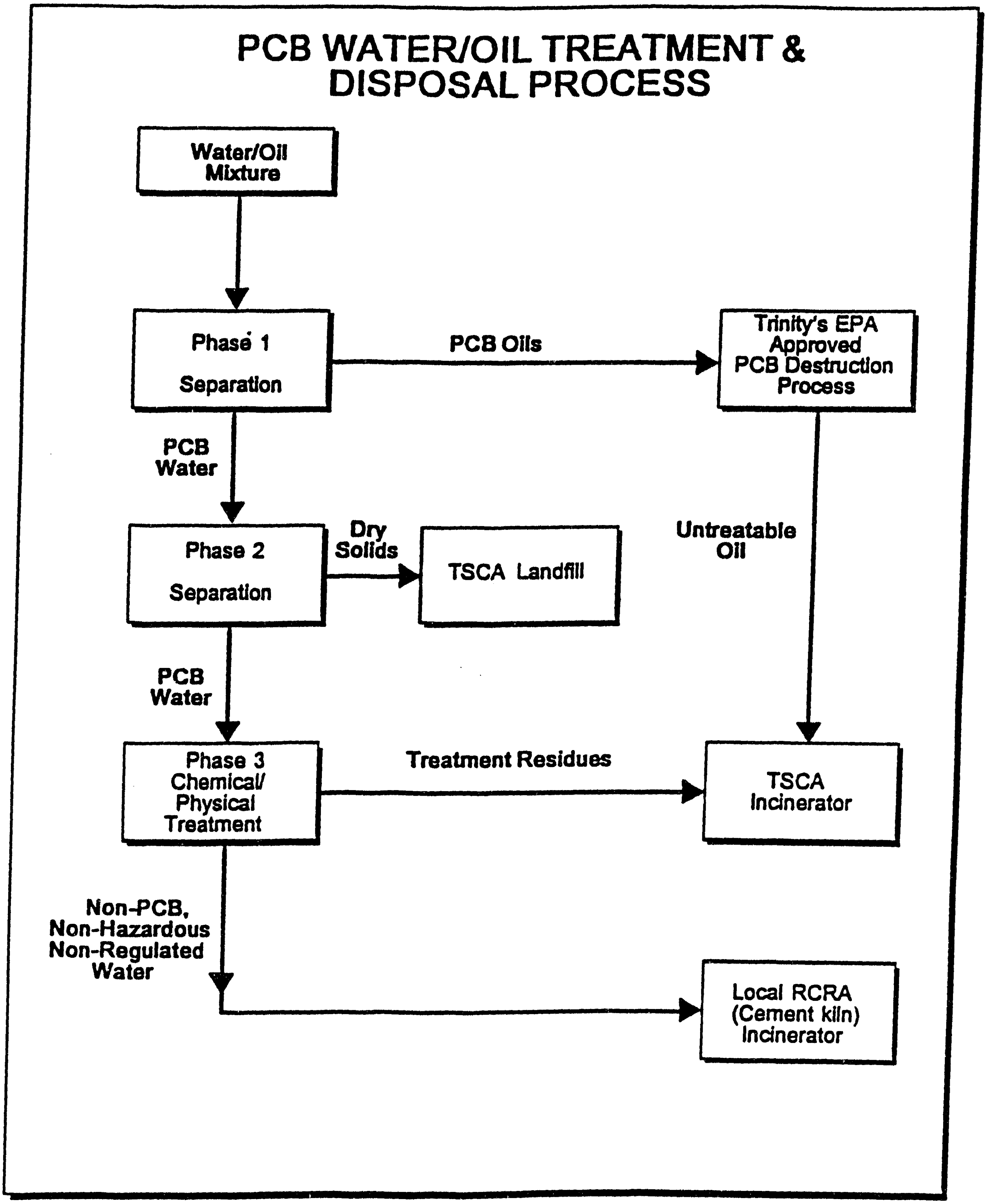


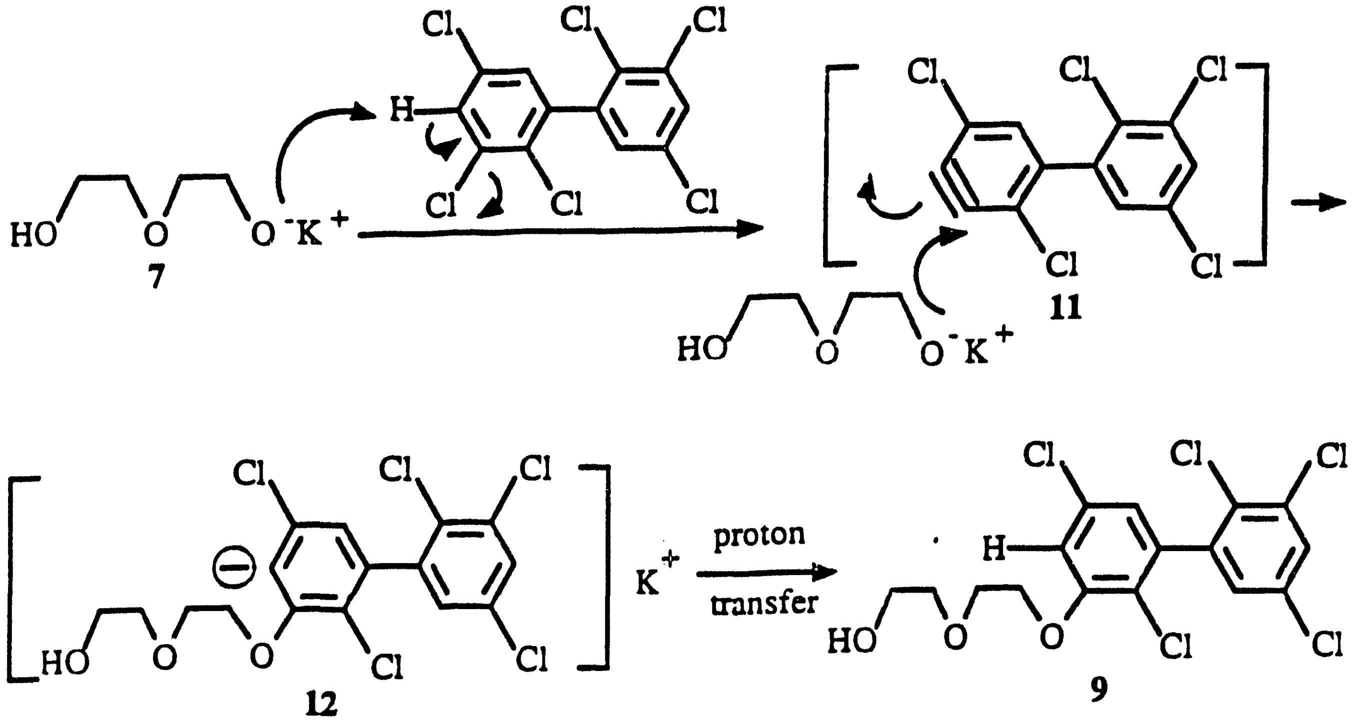
Figure 3. Block Diagram of the Trinity PCB Treatment Process



Although the exact reaction mechanism of the KPEG process probably has not been fully established. It can be speculated that for the highly chlorinated biphenyls, the electron deficient benzene ring could be attacked by **7** to form **8**. Subsequent loss of a chloride ion from **8** could lead to **9** with the net effect of replacing a chlorine atom with a polyethyleneglycol. After successive replacement of chlorine atoms with polyethyleneglycol, complete dechlorination to form polyhydroxylated biphenyls **10** could thus be achieved.

It is also possible that a competing reaction pathway involving the formation of a benzyne intermediate **11** may also be responsible for the dechlorination process (Fig. 5).[12]

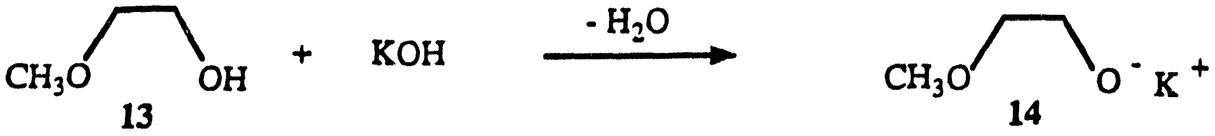
Figure 5. The KPEG Process via the Benzyne Pathway



Initial dehydrochlorination of PCBs to form benzyne **11** followed by the attack of **11** with an alkoxide would lead to **12**. Subsequent proton transfer could also result in the displacement of a chlorine atom by a polyethyleneglycol as shown in **9**.

Currently, a modified KPEG process is being utilized by the Chemical Waste Management, Inc. for the destruction of PCBs. The reagent, KGME (**14**), is generated in situ via the addition of KOH to 2-methoxyethanol (glycol methyl ether, GME, **13**), followed by azeotropic removal of water (Fig. 6). The use of KOH instead of potassium metal as in the KPEG process is an improvement which avoids the generation of hazardous hydrogen gas during reagent preparation.

Figure 6. Preparation of the KGME Reagent



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. Although a final report on the demonstration is not available at the present time, 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.

In early 1991, reports started to appear in the press indicating that quicklime, or calcium oxide (CaO), could destroy PCBs.[13] A success in such a process could mean a low cost remediation of PCB pollution. However, many researchers were skeptical of those reports because the basic chemical reaction between quicklime and water generates mainly $Ca(OH)_2$, which is a source of hydroxide ion. Hydroxide ion had not been shown to effectively destroy PCBs. Preliminary results from an independent study by the EPA's Risk Reduction Engineering Laboratory in Cincinnati suggest that the reduction of PCB content is mostly attributable to volatization and is not due to actual PCB destruction.[13,14]

3.3 Catalytic Dechlorination of PCBs

The catalytic dechlorination of PCBs at 180°C to biphenyl with 5% platinum or palladium on 60/80 mesh glass beads over hydrogen gas was reported by Berg *et al.* in 1972.[15] The use of 69% nickel on kieselguhr in the presence of sodium hydroxide and 50 atm of hydrogen gas at 115°C for 6 hours also effectively dechlorinated Aroclor 1248.[16] It was later discovered that sodium borohydride could replace hydrogen gas as the reducing agent.[17] One example of the study showed that 0.3 mmol of Aroclor 1254 could be most effectively reduced to biphenyl (97%) by treating with 2.0 mmol of $NiCl_2$ and 60 mmol of sodium borohydride in 2-propanol at ambient temperature and pressure. The disadvantage of this process is that a rather large ratio of sodium borohydride to PCBs is required to reach complete dechlorination.

In a process patented by the Union Carbide Corporation in 1983,[18] 100 mg of a commercial Aroclor in 1 mL of methanol was treated with 0.03 g of $NiCl_2$, 0.5 g triphenylphosphine, 0.25 g NaI and 1.0 g of zinc dust in 10 mL of wet *N,N*-dimethyl formamide (DMF) at 60°C for 4 hours. The zinc dust in the presence of sodium iodide serves as the reducing means to keep the nickel in a zero valance state for effective catalytic dechlorination.

Currently, the Roy F. Weston, Inc. uses a catalytic dehydrochlorination procedure to remediate soils, sludges, and sediments contaminated with PCBs. The process uses 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. However, this process has been tested only in the laboratory in gram quantity and has not been scaled up to pilot plant level.

3.4 Photochemical Dechlorination of PCBs

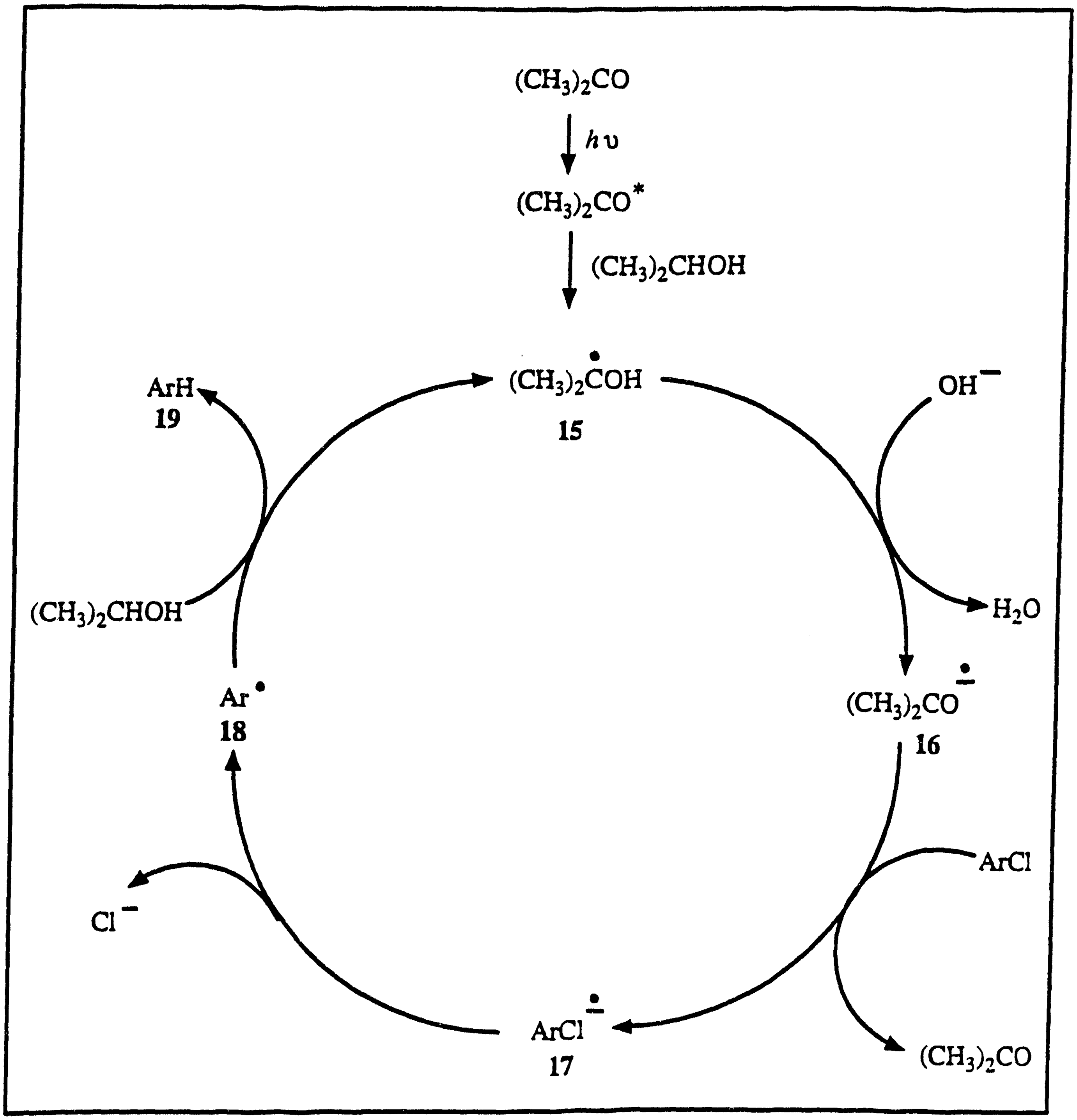
The use of photochemical methods for the destruction of PCBs have received considerable attention. The direct photodegradation of PCBs with UV or sunlight irradiation proceeds with low efficiency. This is because once the heavier chlorinated and more photo-sensitive biphenyls are depleted, the dechlorination process becomes very slow. Typically, only about 25% of Aroclor 1254 and 10% of Aroclor 1260 are reacted after 10 hours.[19a] However, the efficiency of photodegradation has been shown to be dramatically enhanced with appropriate photosensitizers and other additives. For example, it was reported that amines,[20] borohydrides,[19] alkaline alcohols,[21] and hydroquinones[22] greatly enhanced the rate of photodechlorination of PCBs in solution.

Recently, the use of acetone as a photosensitizing agent in alkaline 2-propanol has been shown to be particularly promising, allowing dechlorination of Aroclor 1254 at wavelengths compatible with those available from the sun.[23] Total disappearance of Aroclor 1254 and the formation of biphenyl occurred in less than 25 minutes.

A free radical chain reaction has been proposed to be the pathway of the photodechlorination process (Fig. 7). The acetone molecule is excited by irradiation to a high energy triplet state, T_1 (n,π^*), which then abstracts a hydrogen atom from 2-propanol to give the ketyl radical **15**. The ketyl radical then loses a proton to the alkaline medium, producing the ketyl radical anion **16**. The Aroclor in turn reacts with the ketyl radical anion through an electron-transfer process given unstable aryl radical anion **17** which releases a chloride anion, producing the aryl radical **18**. The aryl radical then abstracts a hydrogen atom from 2-propanol to furnish dechlorinated biphenyls **19** and the ketyl radical **15**, allowing the propagation cycle for dechlorination of PCBs to continue until all of the chlorine atoms are removed.

The acetone-induced photodegradation of PCBs is a very attractive method because of the low costs of the reagents. Unfortunately, under similar conditions photodechiorination of extracts of Aroclor 1254 contaminated soil proceeded with low efficiency. Clearly, continued research is needed to bring the photodegradation method to practical use.

Figure 7. Acetone-Induced Photochemical Degradation of PCBs



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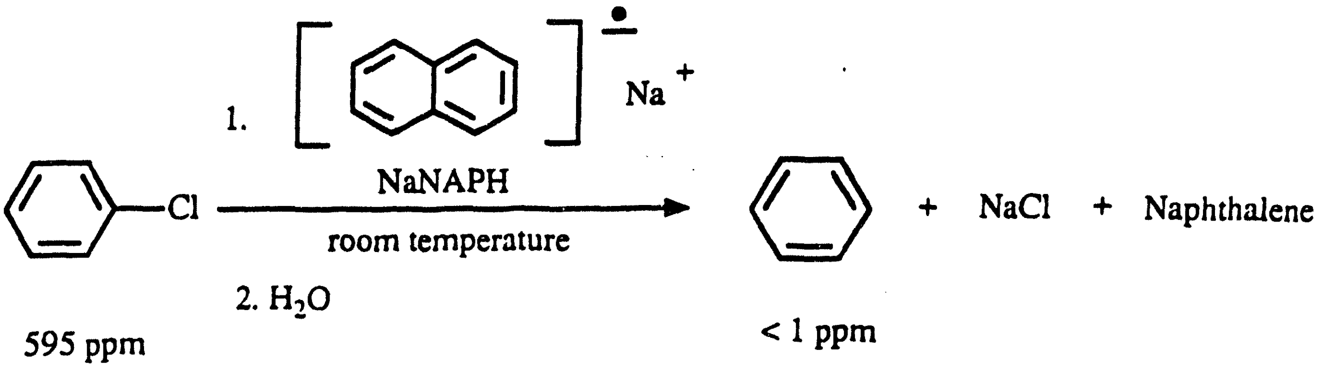
4. CHEMICAL DESTRUCTION OF CHLORINATED AROMATICS BY SODIUM 1-DIMETHYLAMINONAPHTHALIDE (NaDMAN)

The use of sodium metal in the presence of an appropriate electron carrier is potentially a good process for destruction of PCBs. We have selected this area to conduct our initial investigation because the process is simple and easy to carry out in the laboratory. It also provides an opportunity to establish an analytical procedure to determine the efficiency of the process for destruction of PCBs by sodium metal-based method and other processes in the subsequent studies.

We have first repeated the Goodyear process by using sodium metal in the presence of naphthalene as an electron carrier for PCB destruction. Chlorobenzene was used as a surrogate for PCBs and sodium naphthalide (NaNAPH) was prepared according to the published procedure.[6] Indeed the dechlorination process is very facile at room temperature. The reaction was followed by periodically withdrawing a small sample from the reaction mixture and quenching it with water. The extent of dechlorination was then analyzed by using a GC/MS. It was found that the reaction was essentially complete within a few minutes with reduction of chlorobenzene concentration from 595 ppm by weight in tetrahydrofuran to less than 1 ppm (Figure 8).

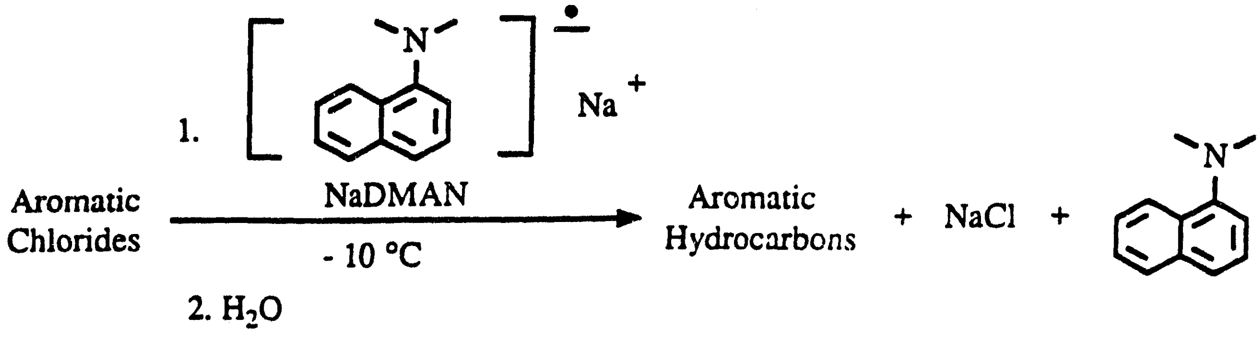
Figure 8. Dechlorination of Chlorobenzene by NaNAPH



With the establishment of the NaNAPH dechlorination condition as a baseline for comparison and a GC/MS method for following the reaction, we then turned our attention to finding an alternative electron carrier as a substitute for naphthalene. As indicated earlier, naphthalene has been classified as a priority pollutant by EPA, and its use is restricted. It is also difficult to separate naphthalene from other organic products after the dechlorination process is complete. A careful search of literature brought to our attention the use of 1-dimethylaminonaphthalene as a substitute for naphthalene.[24] Because of the presence of an amino functionality, 1-dimethylaminonaphthalene is very soluble in aqueous acidic solution and can be easily separated from other organic compounds. It can be regenerated by neutralizing the aqueous solution for easy recovery and reuse, minimizing pollution to the environment and reducing the cost of the dechlorination process.

Although the use of sodium 1-dimethylaminonaphthalide (NaDMAN) for dechlorination of aliphatic chlorides was reported,[24] extending the use of this reagent to aromatic chlorides had not been studied. It was gratifying to observe that sodium 1-dimethylaminonaphthalide was also very efficient in dechlorinating aromatic chlorides, such as chlorobenzene, 4-chlorobiphenyl, Aroclor 1242, and Aroclor 1254 (Figure 9). The efficiency of dechlorination is similar to that of NaNAPH. Recovery of 1-dimethylaminonaphthalene after the reaction was essentially quantitative.

Figure 9. Dechlorination of Aromatic Chlorides by NaDMAN

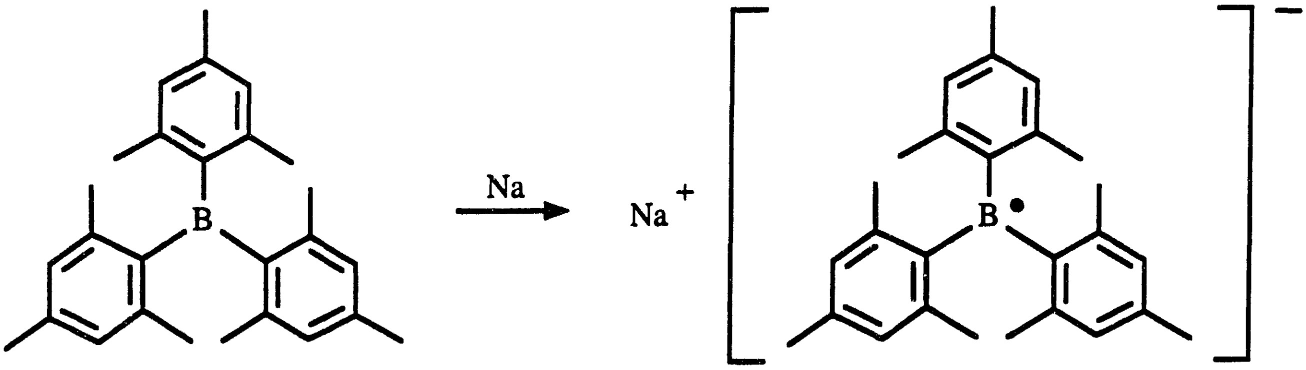


In comparison with naphthalene, the easy recovery of 1-dimethylaminonaphthalene from the reaction mixture offers a significant advantage. However, as a reagent NaDMAN in THF is less stable than NaNAPH. It was necessary to prepare NaDMAN at lower temperature (-10 °C) and immediately prior to use. Storing NaDMAN solution at room temperature resulted in gradual loss of its reactivity over several days.

5. SYNTHESIS OF STERICALLY HINDERED TRIARYLBORANES AS POTENTIAL ELECTRON CARRIERS FOR SODIUM METAL

It has been known for sometime that triarylboranes are excellent electron carriers because of the presence of an empty p-orbital on the boron atom, allowing an electron from sodium metal to reside over it.[25] One such example is trimesitylborane (**20**), which reacts readily with sodium to form the corresponding radical anion **21** (Fig. 10).[25] Radical anion **21** is stable over an extended period of time at room temperature and dechlorinates 4,4'-dichlorobiphenyl almost instantaneously.[26] Because of severe steric hinderance surrounding the boron atom, the regenerated trimesitylborane is stable to water, making it possible to workup the reaction mixture with water.

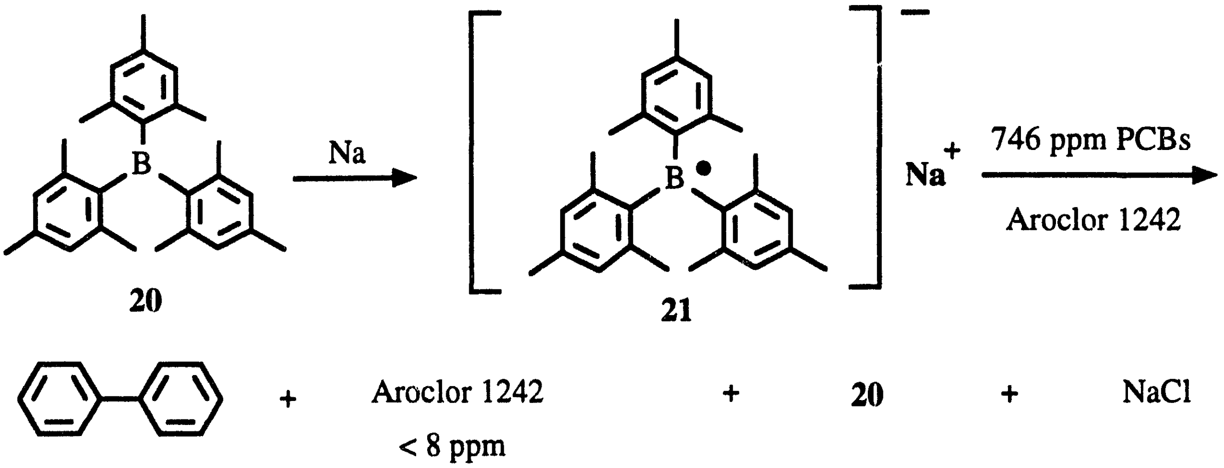
Figure 10. Reaction of Trimesitylborane (**20**) with Sodium Metal



20 **21**

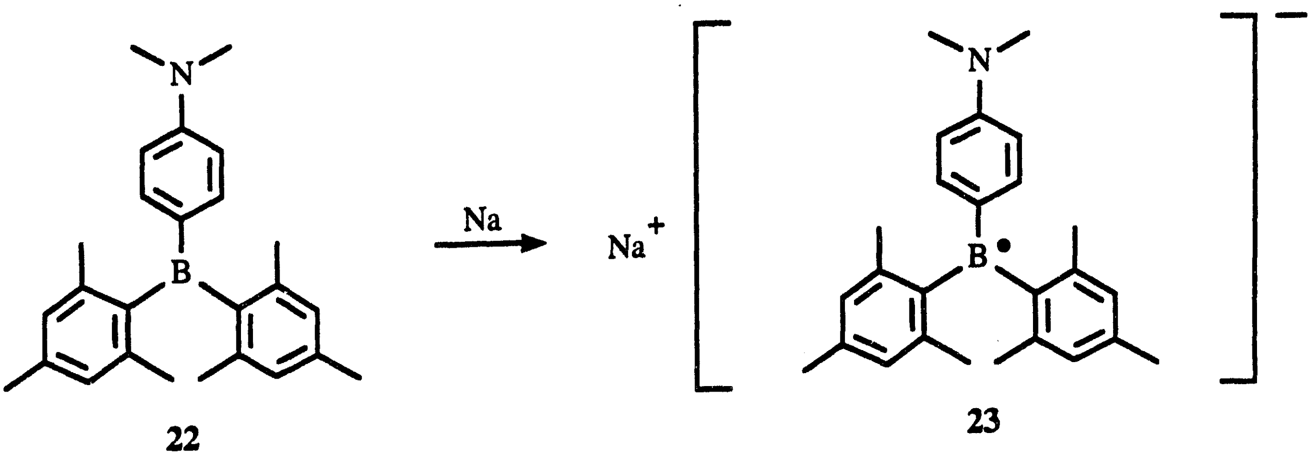
Indeed, we observed that **21** (5.5 mole equivalent) was very effective in dechlorinating Aroclor 1242 from 746 ppm to less than 8 ppm (Figure 11). There was no decomposition of trimesitylborane (**20**) as indicated by GC/MS. Interestingly, chlorobenzene was found to be much more resistent to dechlorination by **21**. A substantial amount of chlorobenzene remained unreacted even in the presence of a large excess of **21** (50 mole equivalent). Apparently, chlorobenzen has a much higher reductive potential, and the initial electron transfer from **21** to chlorobenzene is not an efficient process.

Figure 11. Dechlorination of Aroclor 1242 by the Radical Anion of Trimesitylborane **21**



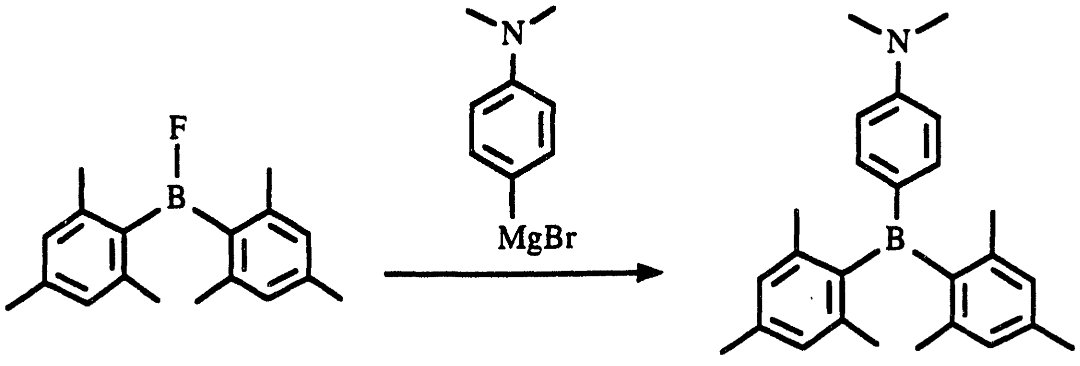
As in the case of using naphthalene as an electron carrier, it was also very difficult to separate trimesitylborane (**20**) from the reaction mixture. We envisioned that a sterically hindered triarylborane substituted with a dimethylamino group, such as 4-(dimethylamino)phenyldimesitylborane (**22**)[27] in Figure 12, could serve as an excellent electron carrier. The anticipated higher stability of the corresponding radical anion **23** over that of NaDMAN coupled with easy recovery by a simple acid extraction could make the dechlorination process operationally feasible.

Figure 12. 4-(Dimethylamino)phenyldimesitylborane (**22**) as an Electron Carrier



Recently, it came to our attention that 4-(dimethylamino)phenyldimesitylborane (**22**) was reported to be stable toward water and was easily prepared by using the protocol outlined in Figure 13.[27] We have prepared **22** by using a modified procedure in order to achieve higher yield (72%). The ability of **22** in serving as an electron carrier for sodium metal for dechlorination and the feasibility of recovering **22** from the reaction mixture for reuse were also investigated.

Figure 13. Synthetic Procedure for 4-(Dimethylamino)phenyldimesitylborane (**22**)



22, 58% yield

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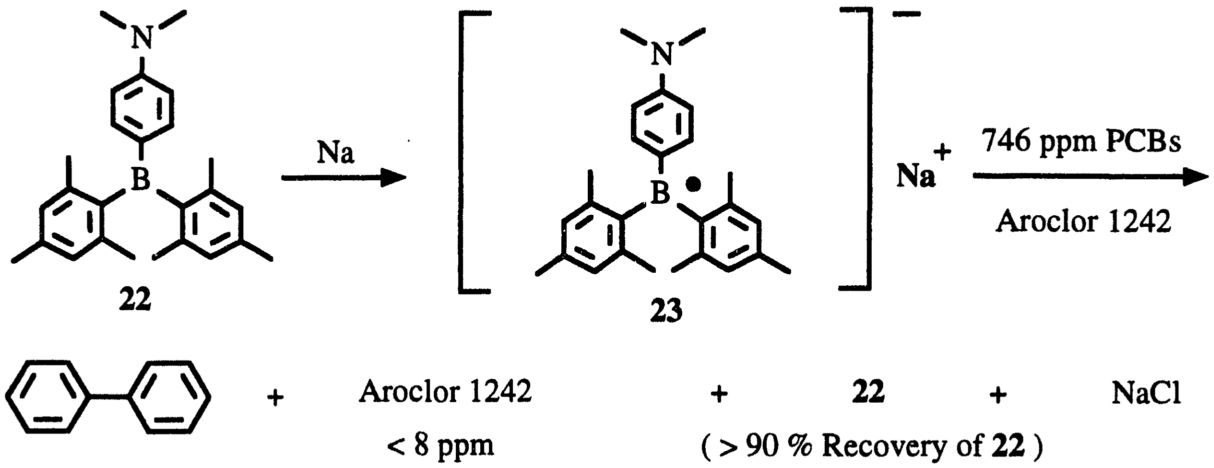
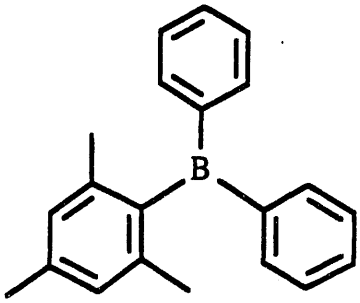
We discovered that **23** (6 mole equivalent) was enough to dechlorinate Aroclor 1242 from 746 ppm to less than 8 ppm (Figure 14). Similarly, 2-chlorobiphenyl was also effectively dechlorinated from 500 ppm to less than 1 ppm by **23** (6 mole equivalent). Recovery of 90% of **22** after the reaction was easily accomplished by simply washing the reaction mixture with 30% HCl. As in the case of trimesitylborane radical anion **21**, borane radical anion **23** failed to exhibit efficient dechlorination property toward chlorobenzene. It appeared that a large excess of **23** (approximately 10 mole equivalent) was required to achieve only about 30% dechlorination of chlorobenzene.

Figure 14. Dechlorination of Aroclor 1242 by Radical Anion **23**



We have also spent considerable efforts in trying to determine the extent of steric hinderance surrounding the boron atom that will be required in order to prevent hydrolysis of triarylborane by water. This information is of crucial importance because hydrolytic workup will be performed after the dechlorination process is complete. It is known in the literature that the sterically unhindered triphenylborane is readily hydrolyzed by water, whereas trimesitylborane is stable to water.[28] We also quickly learned in our laboratory that diphenylmesitylborane (**24**) in Figure 15 containing only one modestly congested aryl group is also very susceptible to water hydrolysis.

Figure 15. The Chemical Structure of Diphenylmesitylborane (**24**)



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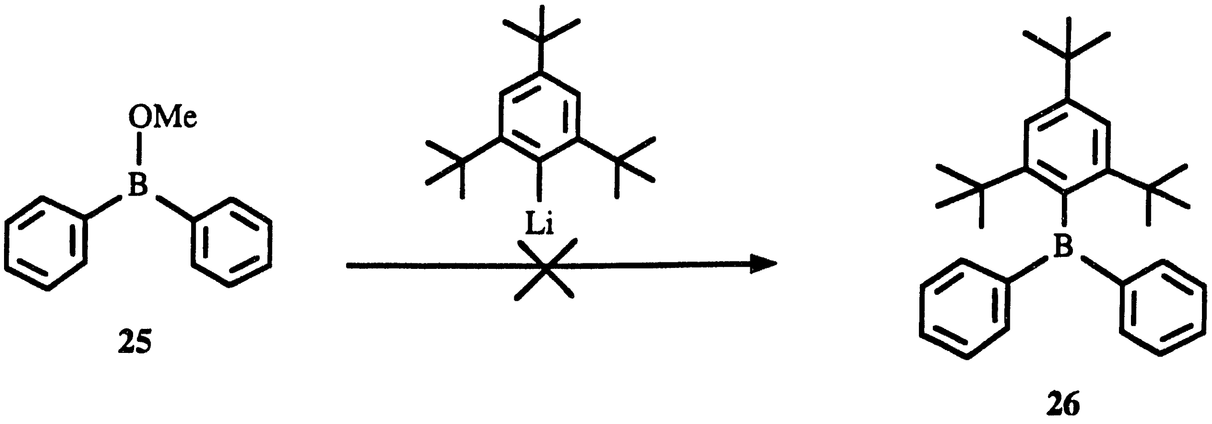
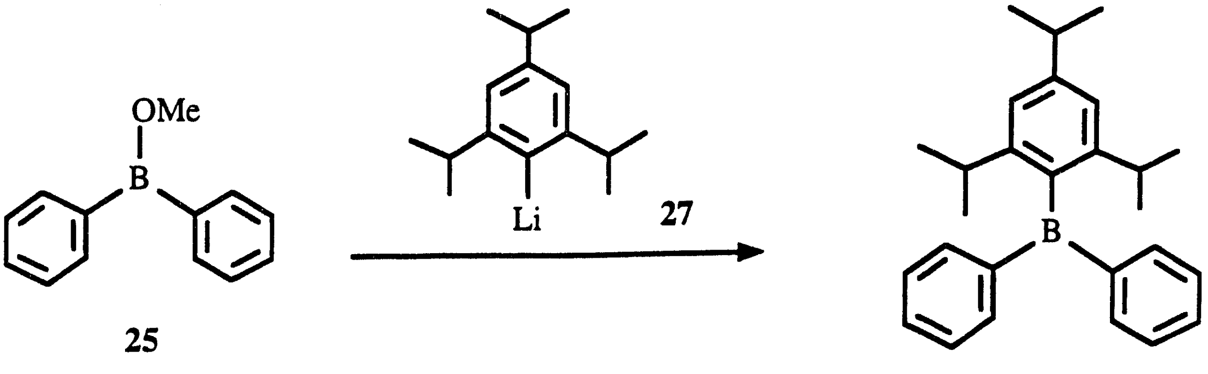
Repeated attempts to synthesize diphenyl(2,4,6-tri-*tert*-butylphenyl)borane (**26**) having an extremely congested aryl group by treating methyl diphenylborinate (**25**)[29] with 2,4,6-tri-*tert*-butylphenyllithium[30] as shown in Figure 16 were unsuccessful. Perhaps 2,4,6-tri-*tert*-butylphenyllithium with two very bulky *tert*-butyl groups at the *ortho* positions is too hindered for the reaction to take place.

Figure 16. Attempted Synthesis of Diphenyl(2,4,6-tri-*tert*-butylphenyl)borane (**26**)



Fortunately, by using a slightly less hindered 2,4,6-triisopropyllithium (**27**),[31] the resulting diphenyl(2,4,6-triisopropylphenyl)borane (**28**) can be easily synthesized as shown in Figure 17. Triarylborane **28**, a new triarylborane which had not been synthesized before, exhibited high stability toward water and air, making it possible to conduct hydrolytic workup after the dechlorination process.

Figure 17. Successful Synthesis of Diphenyl(2,4,6-triisopropylphenyl)borane (**28**)



28, 39% yield

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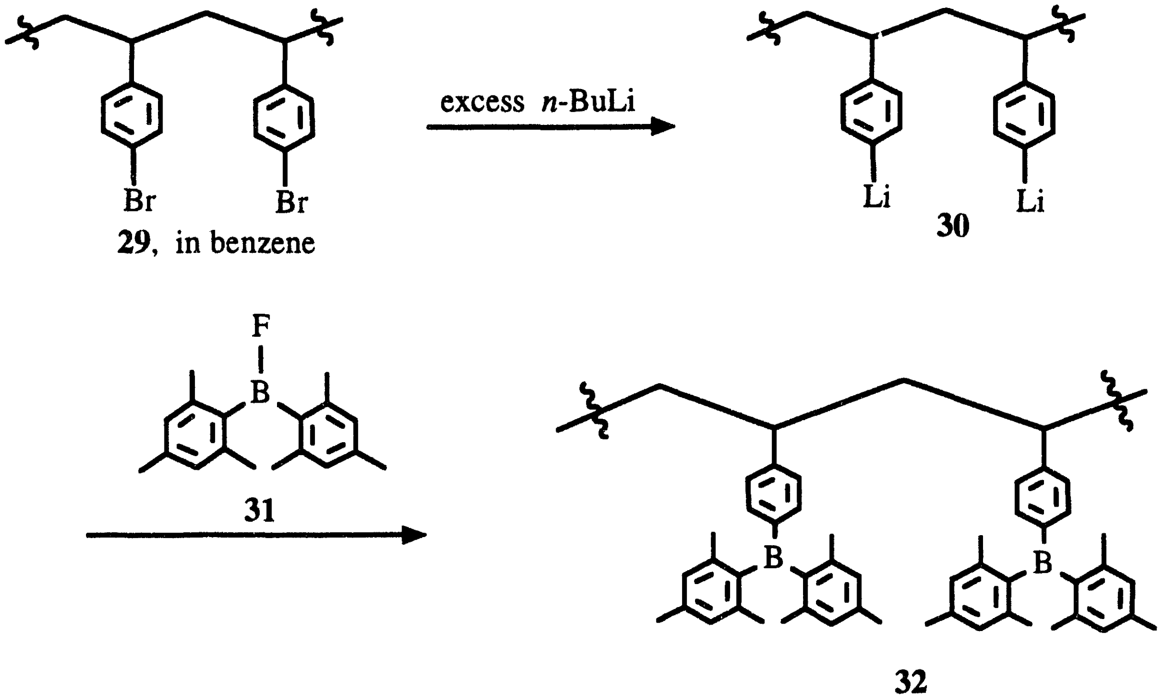
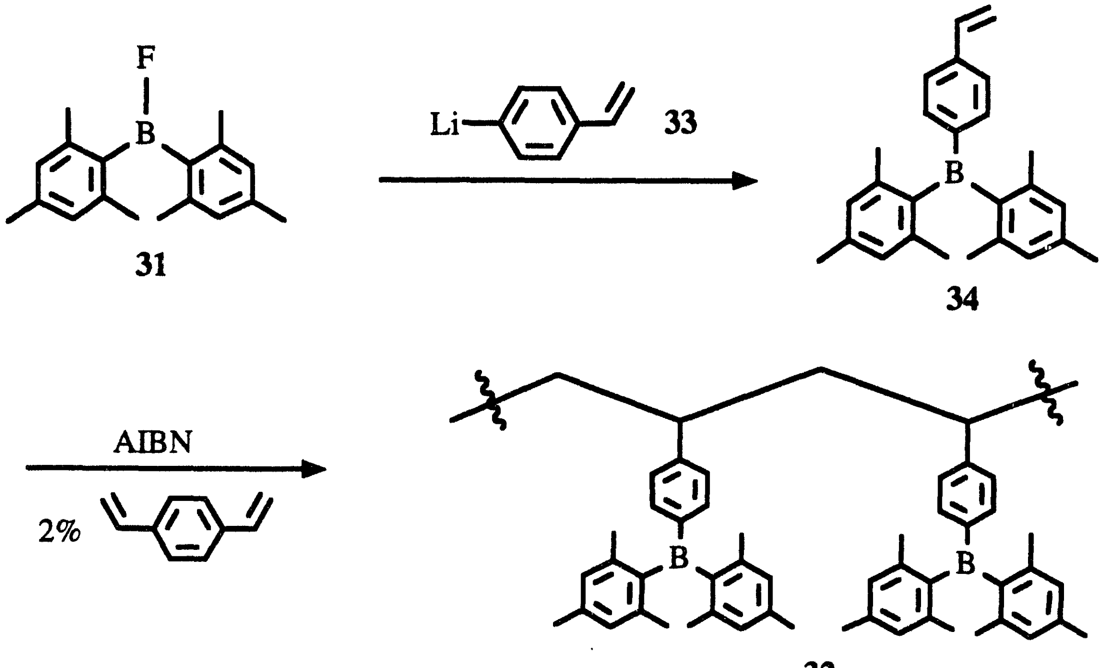
We also are developing new polymeric materials containing sterically hindered triarylborane centers as electron carrier for sodium metal. Immobilizing the boron centers on a polymer backbone would greatly facilitate the recovery process for recycle and reuse. Specifically, we are trying to attach the boron centers to the backbone of the readily available bromopolystyrene (**29**)[32] as shown in Figure 18. We have treated bromopolystyrene (**29**) with *n*-butyllithium to furnish **30** using benzene as the reaction solvent to fully swell the cross-linked resin. The lithiated polymer **30** was then treated with fluorodimesitylborane (**31**) in an attempt to produce **32** containing sterically hindered triarylborane substituents as an electron carrier for the dechlorination process. The reaction product is currently being analyzed.

Figure 18. Synthesis of Polystyrene **32** Containing Triarylborane Substituents



We are also developing alternative synthetic routes to polystyrene containing sterically hindered triarylborane substituents. We have successfully synthesized monomer **34** having a styrene moiety by simply treating 4-vinylphenyllithium (**33**), readily prepared from *n*-butyllithium and 1-bromo-4-vinylbenzene, with fluorodimesitylborane **31** (Figure 19). The analysis of the reaction mixture by GC/MS clearly indicated that monomer was produced. Isolation and purification by column chromatography (silica gel / hexanes) furnished pure **34** in ca. 30% yield and allowed further structural identification by ^{1}H NMR. The next phase of the experimental work will be to carry out polymerization of **34** with a radical initiator, such as azobisisobutyronitrile (AIBN), in the presence of 2% of 1,4-divinylbenzene in order to lead to crossed-linked polystyrene **32** containing the desired boron centers as the electron carrier for sodium metal. If the steric hinderance surrounding the boron atom is later proven to be too severe for a successful polymerization to occur, styrene will be added to produce sterically less demanding copolymers.

Figure 19. An Alternative Route for the Synthesis of Polystyrene Derivative **32**



31 **33** **34** **32**

6. EXPERIMENTAL SECTION

6.1 Establishment of an Analytical Procedure for Chlorinated Aromatics and PCBs

A GC/MS system comprised of an HP 5890A Gas Chromatograph and an HP 5970B Mass Selective Detector was employed as the analytical tool for identification of organic halides and quantitative determination of their concentrations. A flexible fused silica capillary column (HP-1, crosslinked methyl silicone gum, 25 m x 0.20 mm ID x 0.33 μm thickness) was installed in the GC oven. The GC conditions for analytical studies are summarized as follows:

Injection port temperature	250 °C
Detector temperature	280 °C
Initial and final oven temperatures	70 or 120 °C to 250 °C
Oven temperature programming rate	20 °C per minute

6.2 Determination of Detection Limits of Aromatic Halides

In order to determine the detection limits of the GC/MS system for various aromatic chlorides, a serious of standard solutions with varying concentrations were prepared. Four types of aromatic chlorides, such as chlorobenzene, 4-chlorobiphenyl, Aroclor 1242, and Aroclor 1254, were dissolved in freshly distilled dry tetrahydrofuran (THF) with concentrations ranging from 0.5 ppm to 10 ppm by weight. The detection limits of the GC/MS system for these chlorinated aromatics are summarized in Table 1.

Table 1. Detection Limits of Chlorinated Aromatics by the GC/MS System

chlorinated aromatics	detection limit ppm (w/w)[a]
chlorobenzene	< 1
4-chlorobiphenyl	< 1
Aroclor 1242	< 7
Aroclor 1254	< 8

[a] Part per million of chlorinated aromatics by weight in THF.

It is clear from Table 1 that for individual compounds, such as chlorobenzene and 4-chlorobiphenyl, a minimum concentration of 1 ppm can be detected by the GC/MS system using total ion current for monitoring. On the other hands, for mixtures, such as Aroclor 1242 and 1254 which contain many congeners, the detection limit of the instrument is reduced to 7-8 ppm due to the presence of lower concentrations of each individual congener in the mixture.

6.3 Preparation of Sodium Naphthalide (NaNAPH) Reagent.

The sodium naphthalide (NaNAPH) process patented by Goodyear was repeated in order to establish a baseline for comparison with new processes developed in our laboratory. The

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following experimental procedure is representative.

A 50-mL flask equipped with a nitrogen gas purge system and a magnetic stirring bar coated with glass was charged with 10 mL of freshly distilled dry THF and 0.23 g (10 mmol) of sodium metal cut into small pieces. To this sodium metal suspension in THF was added 0.64 g (5 mmol) of naphthalene with gentle stirring. The formation of a green radical anion solution started in a few minutes and was complete within two hours at room temperature. The concentration of the reagent is ca. 0.5 M. Sodium naphthalide prepared by this procedure is relatively stable and can be stored under a nitrogen atmosphere for future use. However, the freshly prepared reagent appears to exhibit higher reactivity for dechlorination of aromatic chlorides.

6.4 Preparation of Standard Solution of Chlorobenzene in Tetrahydrofuran

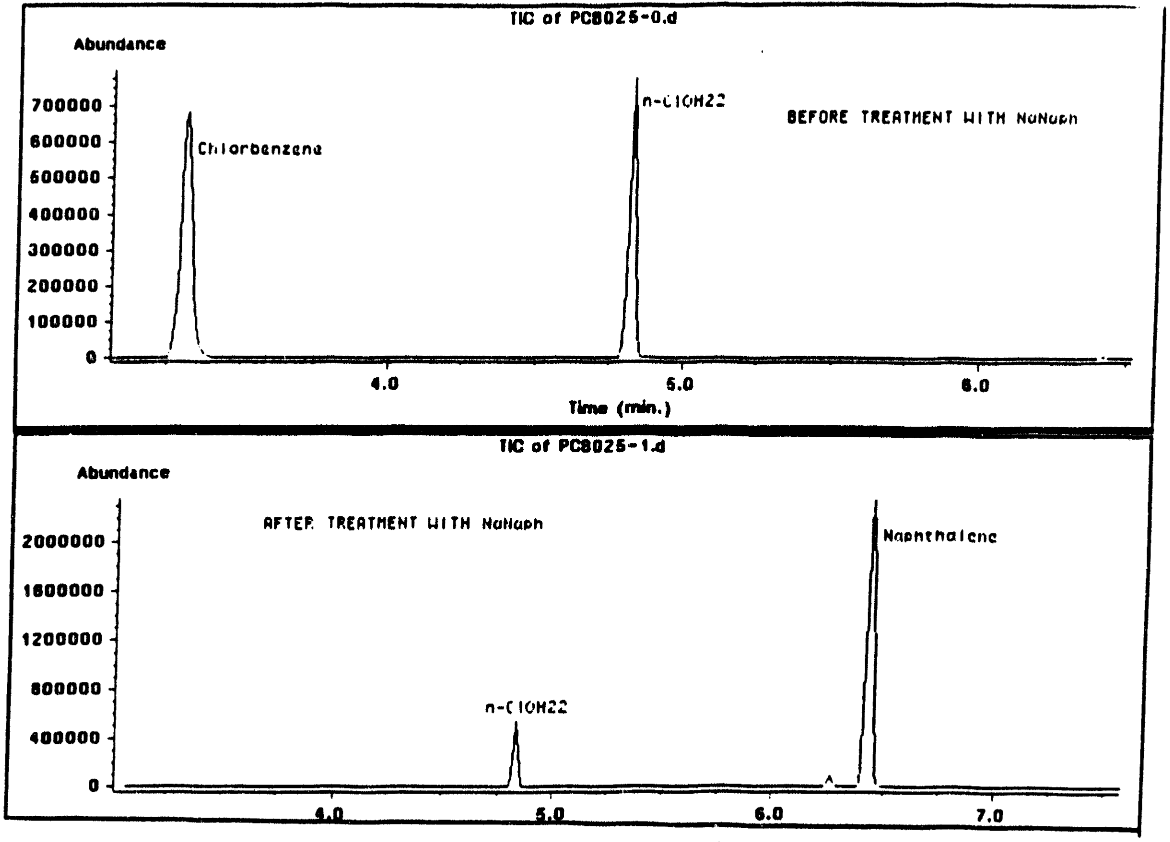
To a 100-mL volumetric flask were charged 51.5 mg of chlorobenzene and 53.0 mg of *n*-decane as an internal standard. The freshly distilled dry THF then was added to the flask until the total volume reached 100 mL. The concentration of the chlorobenzene solution is 515 ppm by volume or 595 ppm by weight. The concentration in terms of the weigh of the chlorinated aromatics relative to the total weight of the sample was utilized throughout this study.

6.5 Dechlorination of Chlorobenzene by NaNAPH Reagent

To a 100-mL flask fitted with a nitrogen gas purge system and a magnetic stirring bar coated with glass was added by a syringe 50 mL of the 595 ppm chlorobenzene solution containing 25.8 mg (0.23 mmol) of chlorobenzene. To this solution was added the freshly prepared NaNAPH solution (0.5 M) until the dark green color of the solution persisted. A total volume of 2.0 mL of the NaNAPH reagent was introduced. A small aliquot of the reaction mixture was immediately withdrawn by using a syringe and quenched with water. Analysis by the GC/MS system indicated the dechlorination process was already complete, and chlorobenzene could no longer be detected (< 1 ppm). The efficiency of the process is therefore greater than 99.8%. The NaNAPH to chlorobenzene molar ratio is 4 (a minimum ratio of 2 is required), far lower than those reported in the Goodyear patent. The GC/MS ion chromatograms before and after chlorobenzene was treated with the NaNAPH reagent are shown in Figure 20.

Dechlorination of chlorobenzene by using a NaNAPH solution stored under a nitrogen atmosphere at room temperature for 3 days was also studied. It was discovered that a molar ratio of 10 between the NaNAPH reagent and chlorobenzene became necessary. It appeared that decomposition of NaNAPH reagent occurred slowly at room temperature even under the protection of a nitrogen atmosphere.

Figure 20. GC/MS Ion Chromatograms of Dechlorination of Chlorobenzene by NaNAPH



6.6 Preparation of Sodium 1-Dimethylaminonaphthalide (NaDMAN)

Preparation of NaDMAN solution in THF is as straightforward as that of NaNAPH. A 50-mL flask equipped with a nitrogen gas purge system and a magnetic stirring bar coated with glass was charged with 10 mL of freshly distilled THF and 0.23 g (10 mmol) of sodium metal cut into small pieces. To this sodium metal suspension in THF was added via a syringe 0.86 g (5.0 mmol) of 1-dimethylaminonaphthalene at -10 °C with gentle stirring. The formation of a green radical anion solution occurred within minutes and the reaction was complete in about three hours at -10 °C. The concentration of the reagent was ca. 0.5 M. It was observed that this reagent is less stable than NaNAPH at ambient temperature even under the protection of a nitrogen atmosphere. After storing NaDMAN at room temperature for only two to three days, it essentially had lost all its reactivity for the dechlorination reaction.

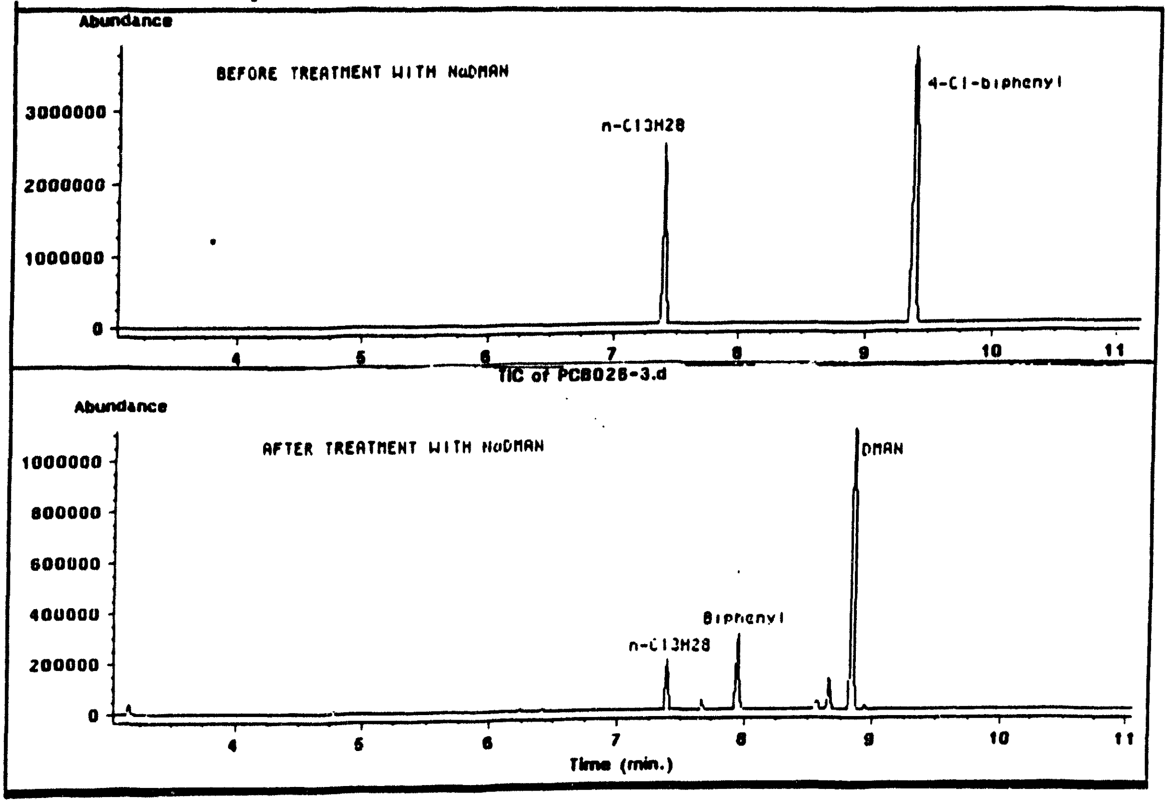
6.7 Dechlorination of Chlorobenzene by the NaDMAN Reagent

The following procedure is representative for dechlorination of chlorinated compounds by the NaDMAN reagent. A 100-mL flask fitted with a nitrogen gas purge system and a magnetic stirring bar coated with glass was charged with 30 mL of a 635 ppm chlorobenzene solution in THF containing 17 mg (0.15 mmol) of chlorobenzene. To this solution at room temperature was added a freshly prepared NaDMAN (0.5 M) until the dark green color of the solution persisted. The total volume of the reagent added was 1.5 mL (reagent to chlorobenzene molar ratio = 5 to 1). At this point, the dechlorination process was already complete and chlorobenzene could no longer be detected by the GC/MS system, indicating the concentration of chlorobenzene in the treated solution was less than 1 ppm and the efficiency of the process was better than 99.8%.

6.8 Dechlorination of 4-Chlorobiphenyl by the NaDMAN Reagent.

Dechlorination of 4-chlorobiphenyl by the NaDMAN reagent was investigated. Similar result was also obtained with 4-chlorobiphenyl being rapidly dechlorinated from an initial concentration of 585 ppm to less than 1 ppm, producing biphenyl as the reaction product. The GC/MS ion chromatograms before and after treatment are shown in Figure 21.

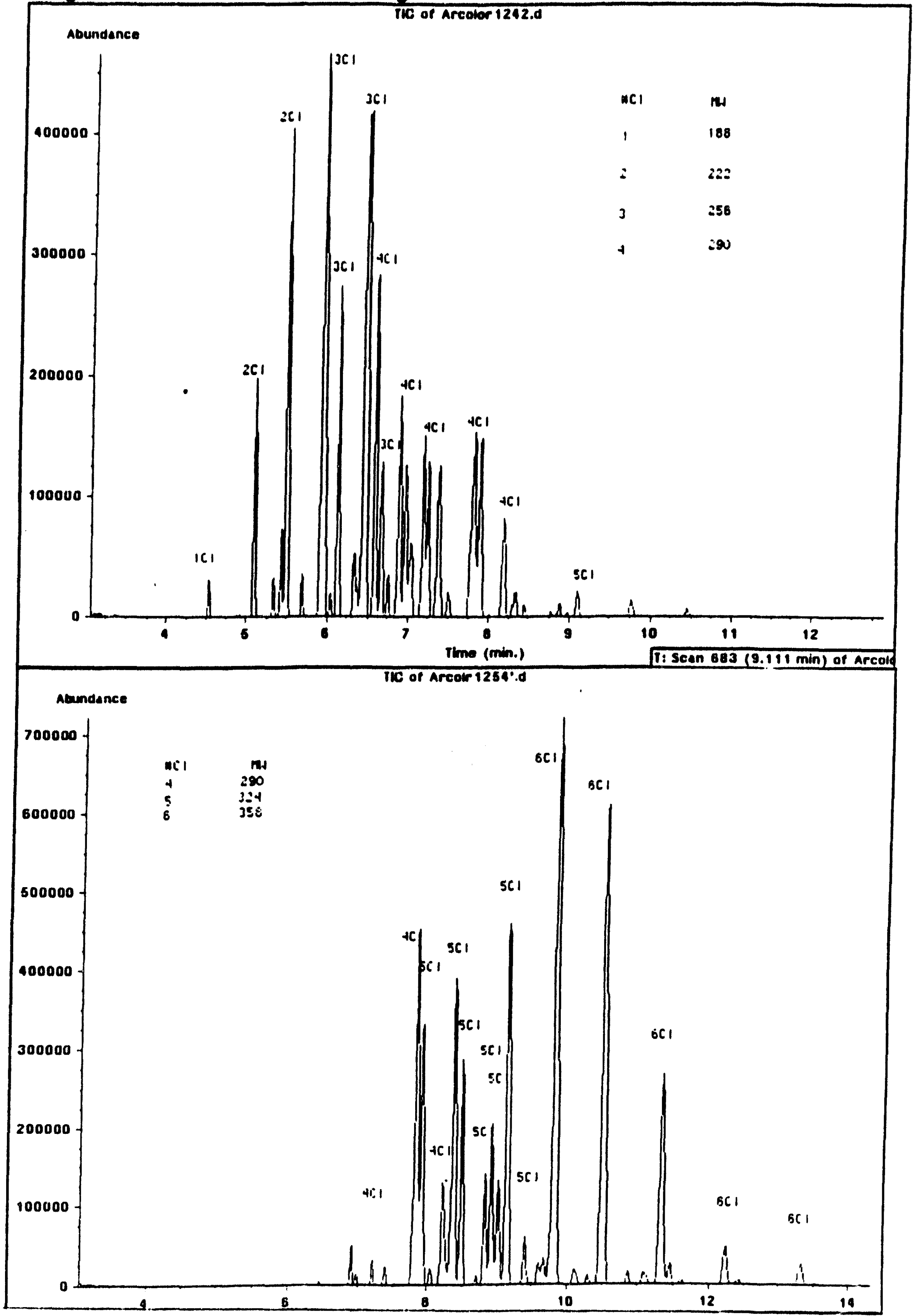
Figure 21. GC/MS Ion Chromatograms of Dechlorination of 4-Chlorobiphenyl by NaDMAN



6.9 Dechlorination of Aroclor 1242 and Aroclor 1254 by the NaDMAN reagent.

Aroclor 1242 and Aroclor 1254 were purchased from AccuStandard Co. of New Haven, CT. As indicated by the last two digits of the four-digit number, Aroclor 1242 contains approximately 42% chlorine by weight and Aroclor 1254 has 54% chlorine by weight. The GC/MS ion chromatograms of these two PCB mixtures are shown in Figure 22 in which the number of chlorine atoms in the congeners are indicated on the top of the peak. The tallest peak was selected to determine the limit of detection.

Figure 22. GC/MS Ion Chromatograms of Aroclors 1242 and 1254



The dechlorination procedure described for dechlorination of chlorobenzene by NaDMAN was also utilized. To 30 mL of a 614 ppm solution of Aroclor 1242 containing 16 mg of the PCB mixture having 0.19 mmol of chlorine was treated with a 0.5 M NaDMAN solution until the dark green color persisted. A total volume of 1.5 mL of NaDMAN was introduced, indicating a molar ratio of ca. 4 to 1 of reagent vs. chlorine content was needed to dechlorinate Aroclor 1242 to less than 8 ppm. Similar result was also obtained when 30 mL of a 583 ppm solution of Aroclor 1254 containing 15.5 mg of the PCB mixture having 0.24 mmol of chlorine was treated with 2 mL of a 0.5 M solution of NaDMAN (molar ratio between NaDMAN and chlorine content = ca. 4 to 1), reducing Aroclor 1254 to less than 7 ppm. The GC/MS ion chromatograms of these two experiments are shown in Figures 23 and 24.

Figure 23. GC/MS Ion Chromatograms of Dechlorination of Aroclor 1242 by NaDMAN

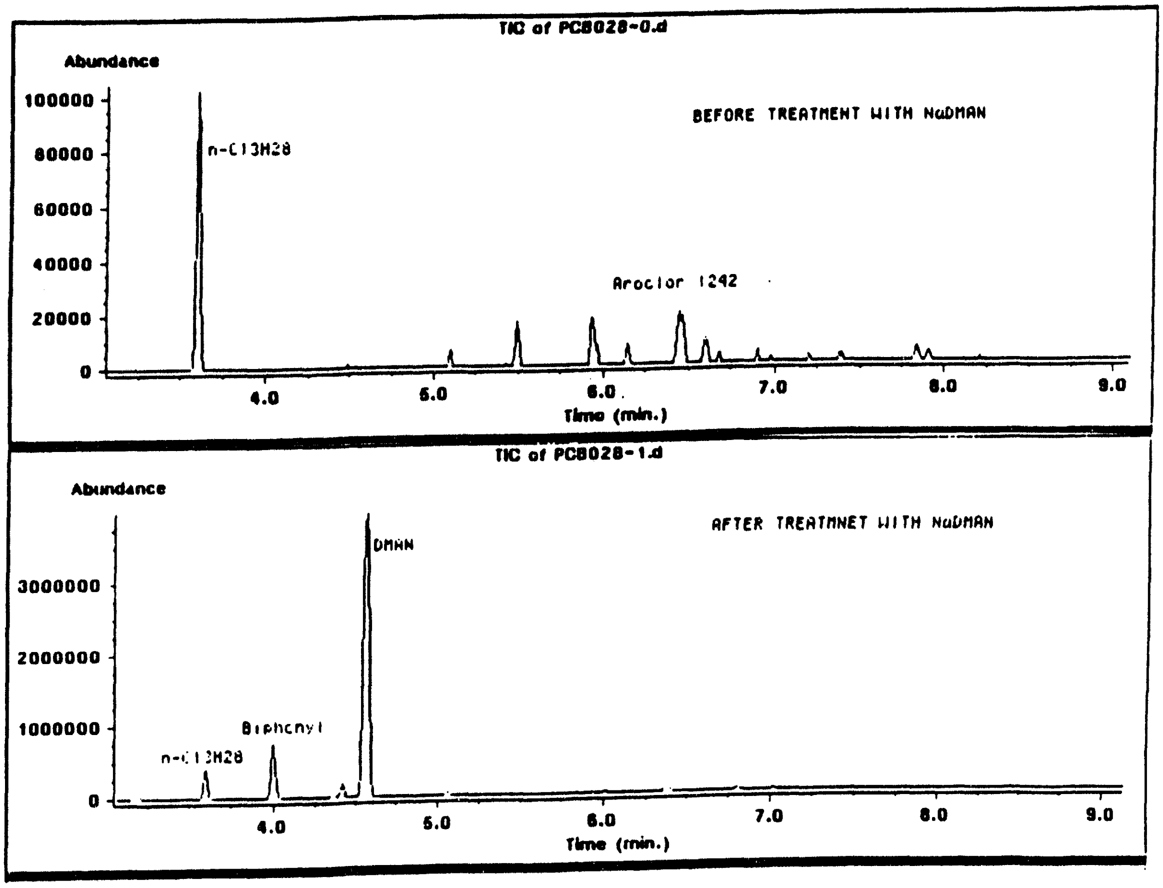
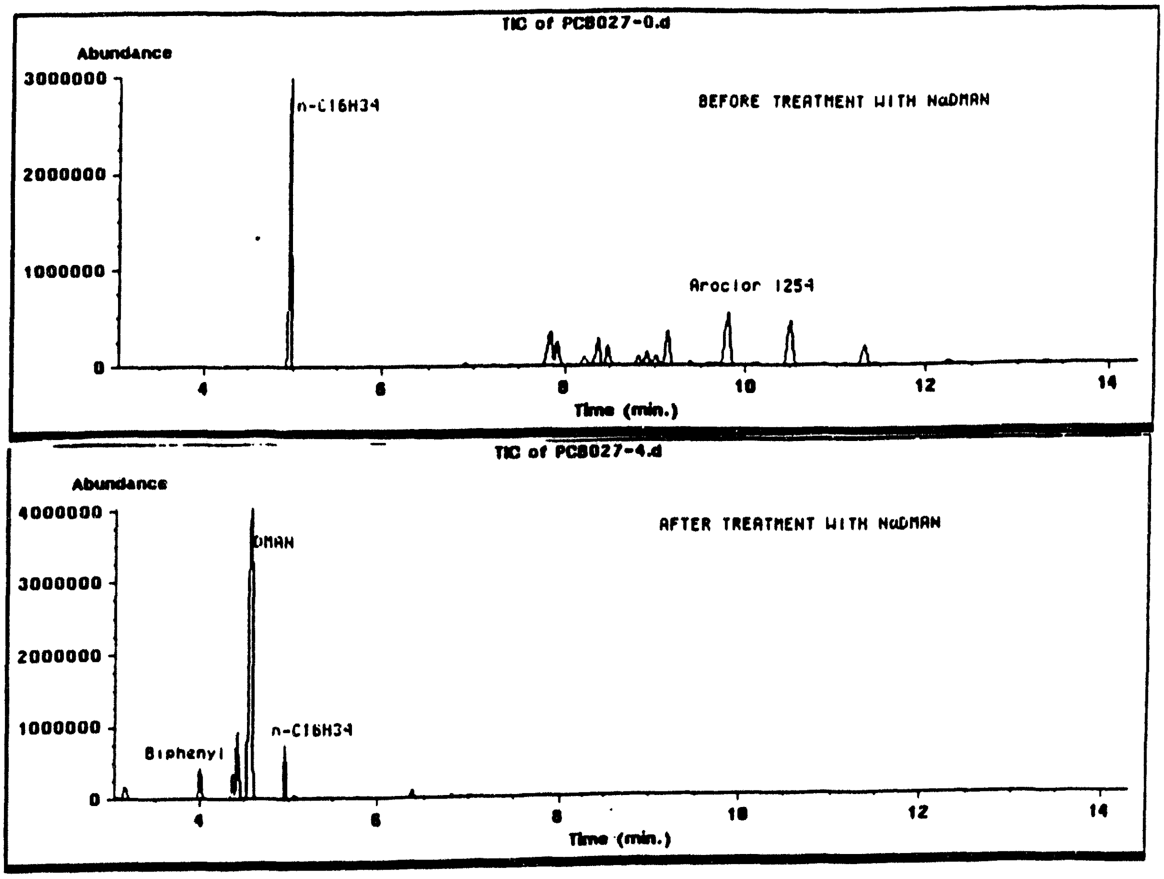


Figure 24. GC/MS Ion Chromatograms of Dechlorination of Aroclor 1254 by NaDMAN



6.10 Recovery of 1-Dimethylaminonaphthalene

Recovery of 1-dimethylaminonaphthalene from the reaction mixture was carried out by bubbling a stream of air through the solution until the dark green color disappeared. The mixture was then washed twice with 30 mL of a 10% HCl solution. The combined aqueous layers were treated with a 20% NaOH solution until the pH value became 14 followed by extraction three times with 50 mL of diethyl ether. The combined ether layers were dried over $MgSO_4$ and the ether solvent was evaporated under vacuum, providing essentially a quantitative recovery of 1-dimethylaminonaphthalene with a purity of 90%.

6.11 Synthesis of 4-(Dimethylamino)phenyldimesitylborane (**22**)

In a 50-mL flask equipped with a nitrogen purge system and a magnetic stirring bar were placed 0.50 g (2.5 mmol) of 4-bromo-*N,N*-dimethylaniline and 10 mL of freshly distilled dry THF. The reaction mixture was cooled to -78 °C in a dry ice-acetone bath. To this solution was added dropwise via a syringe 1.05 mL of a 2.5 M solution of *n*-butyllithium in hexanes. After 10 min, the mixture was transferred via cannula to a separate flask containing 0.75 g (2.8 mmol) of dimesitylboron fluoride (**31**) dissolved in 5 mL of dry THF at -78 °C. The reaction mixture was allowed to warm to room temperature and then was poured into a beaker containing 50 mL of water and 50 mL of diethyl ether. The organic layer was separated, and the aqueous layer was extracted with diethyl ether (3 x 30 mL). The combined organic layers were washed with water and brine, dried over anhydrous Na_2SO_4, and concentrated. The residue was purified by column chromatography (silica gel / hexane) to furnish 0.66 g (72%) of **22**. Further purification by recrystallization from acetonitrile afforded 0.42 g of a very pure product: mp 164-166 °C (lit.[27] mp 161-163 °C), ^{1}H NMR ($CDCl_3$, 270 MHz) δ 7.44 (2 H, d, J = 8.8 Hz), 6.81 (4 H, s), 6.60 (2 H, d, J = 8.8 Hz), 3.03 (6H, s), 2.30 (6 H, s), 2.07 (12 H, s). The ^{1}H NMR spectrum (270 MHz) of **22** is shown in Figure 25.

6.12 Synthesis of Diphenyl(2,4,6-triisopropylphenyl)borane (**28**)

Diphenyl(2,4,6-triisopropylphenyl)borane (**28**) was successfully synthesized by treating methyl diphenylborinate[29] with 2,4,6-triisopropyllithium.[31] To a 100-mL flask fitted with a magnetic stirring bar and purged with nitrogen were added 20 mL of dry tetrahydrofuran (THF) as the solvent of the reaction and 1.42 g (5.0 mmol) of 1-bromo-2,4,6-triisopropylbenzene purchased from Lancaster Synthesis Inc. and the reaction mixture was cooled to -78 °C. A solution of *n*-butyllithium (2.5 mL, 2.5 M in hexanes, 5.5 mmol) was then introduced dropwise over 10 minutes by using a syringe. After 15 minutes of stirring at -78 °C, the reaction mixture was transferred via cannula to a separate 100-mL flask containing 1.08 g (5.5 mmol) of methyl diphenylborinate in 15 mL of dry THF kept at -78 °C. The reaction mixture was then allowed to warm to room temperature and stirred overnight. After 50 mL each of pentane and water were introduced, the organic layer was separated and the aqueous layer was extracted with pentane (2 x 25 mL). The combined organic layers were concentrated, and the residue was purified by column chromatography (silica gel / hexanes) to afford 0.708 g (39% yield) of diphenyl(2,4,6-triisopropylphenyl)borane (**28**) as a white solid: IR 2960, 2866, 1591, 1434, 1237, 1184, 876, 747, 700 cm^{-1}; ^{1}H NMR ($CDCl_3$, 270 MHz) δ 7.67 (4 H, dd, J = 8.0 and 1.6 Hz), 7.52-7.40 (6 H, m), 7.00 (2 H, s), 2.94 (1 H, septet, J = 7.0 Hz), 2.37 (1 H, septet, J = 6.8 Hz), 1.32 (6 H, d, J = 7.0 Hz), 0.96 (12 H, d, J = 6.8 Hz); MS m/e 368 (M$^+$), 353, 325, 290, 247, 233, 191, 169. The ^{1}H NMR spectrum (270 MHz) and the GC/MS of diphenyl(2,4,6-triisopropylphenyl)borane (**28**) are shown in Figures 26 and 27, respectively.

Figure 25. The ^{1}H NMR Spectrum (CDCl$_3$, 270 MHz) of **22**

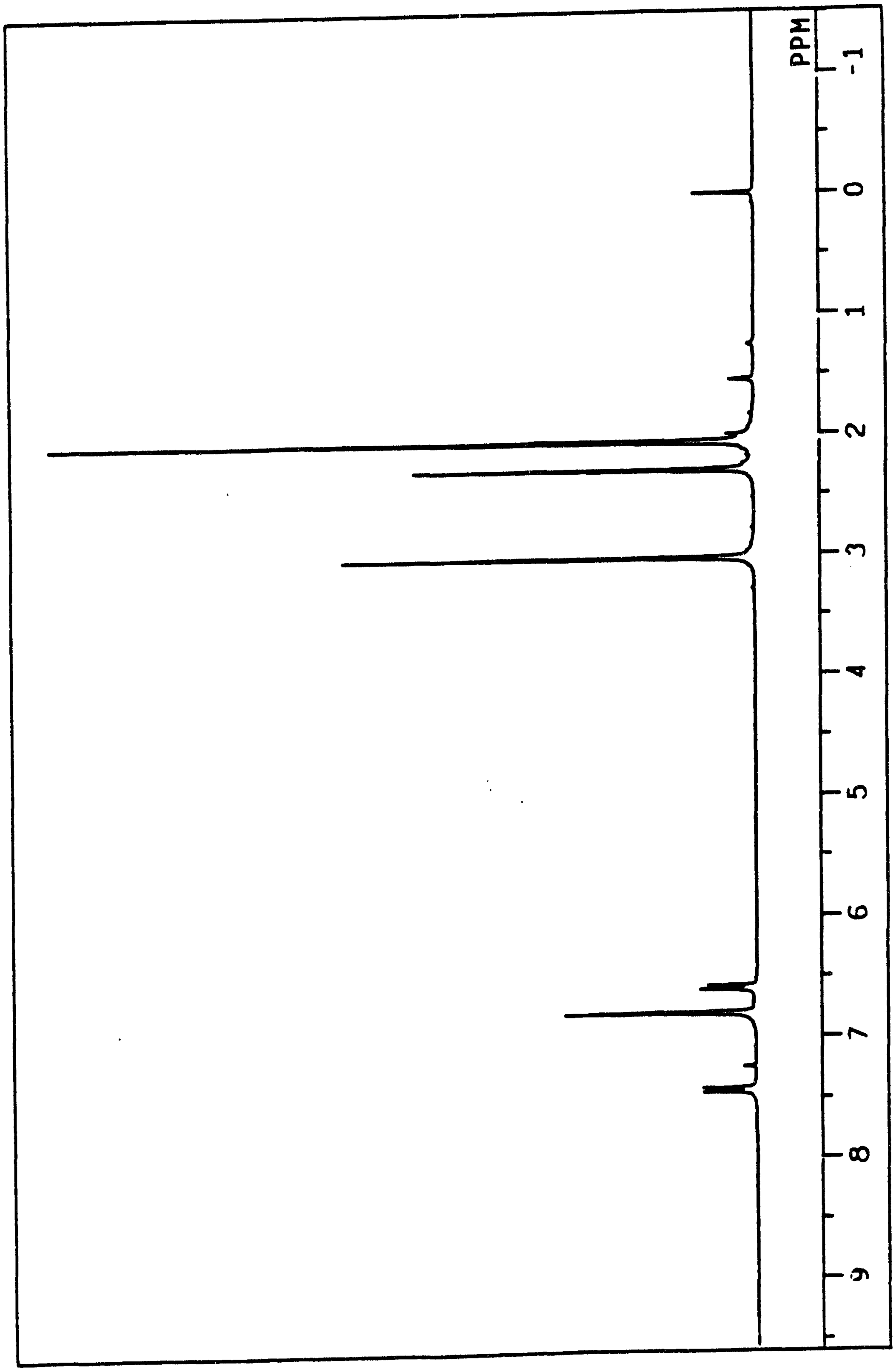
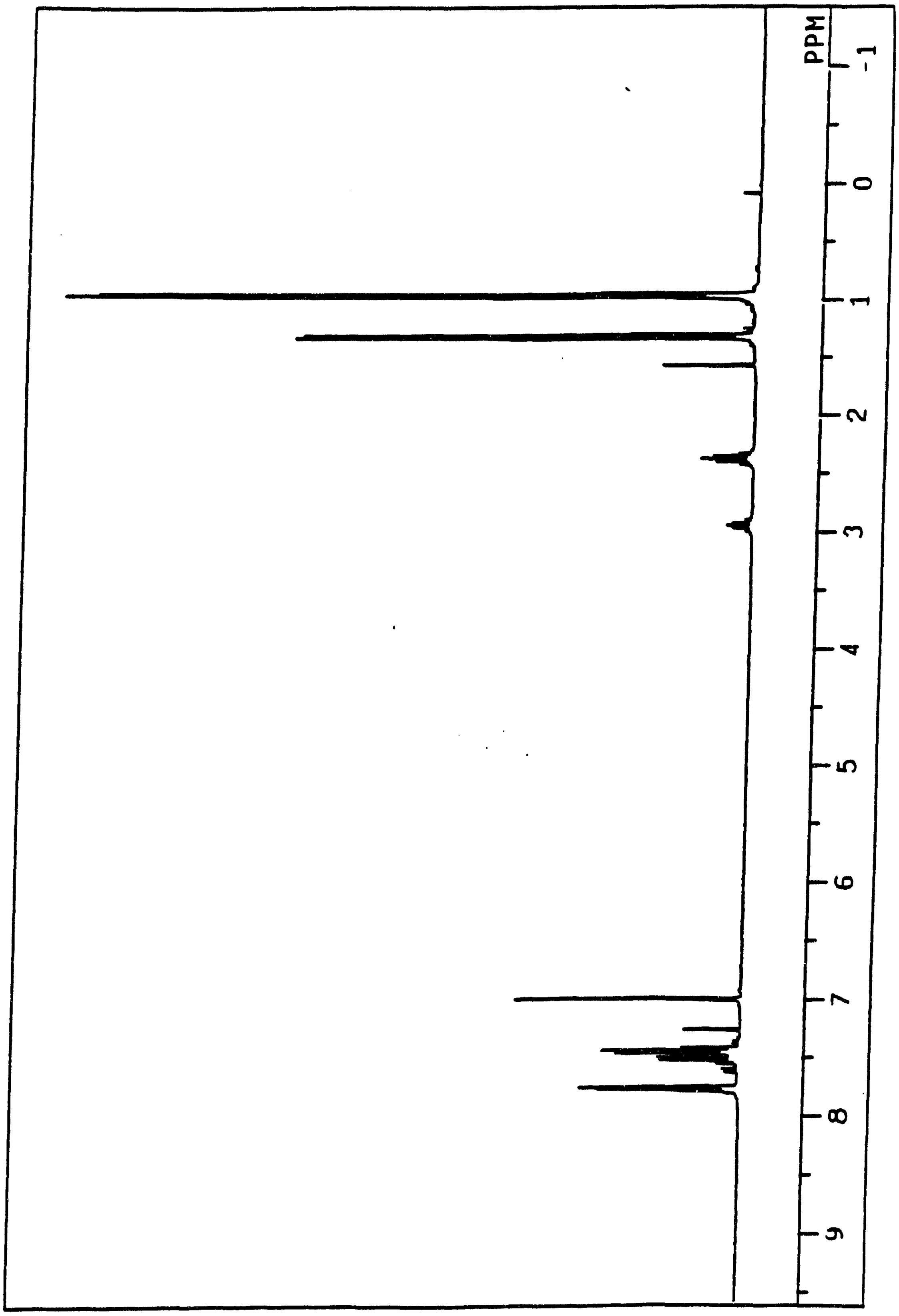


Figure 26. The ^1H NMR Spectrum ($CDCl_3$, 270 MHz) of Diphenyl(2,4,6-triisopropylphenyl)borane (**28**)



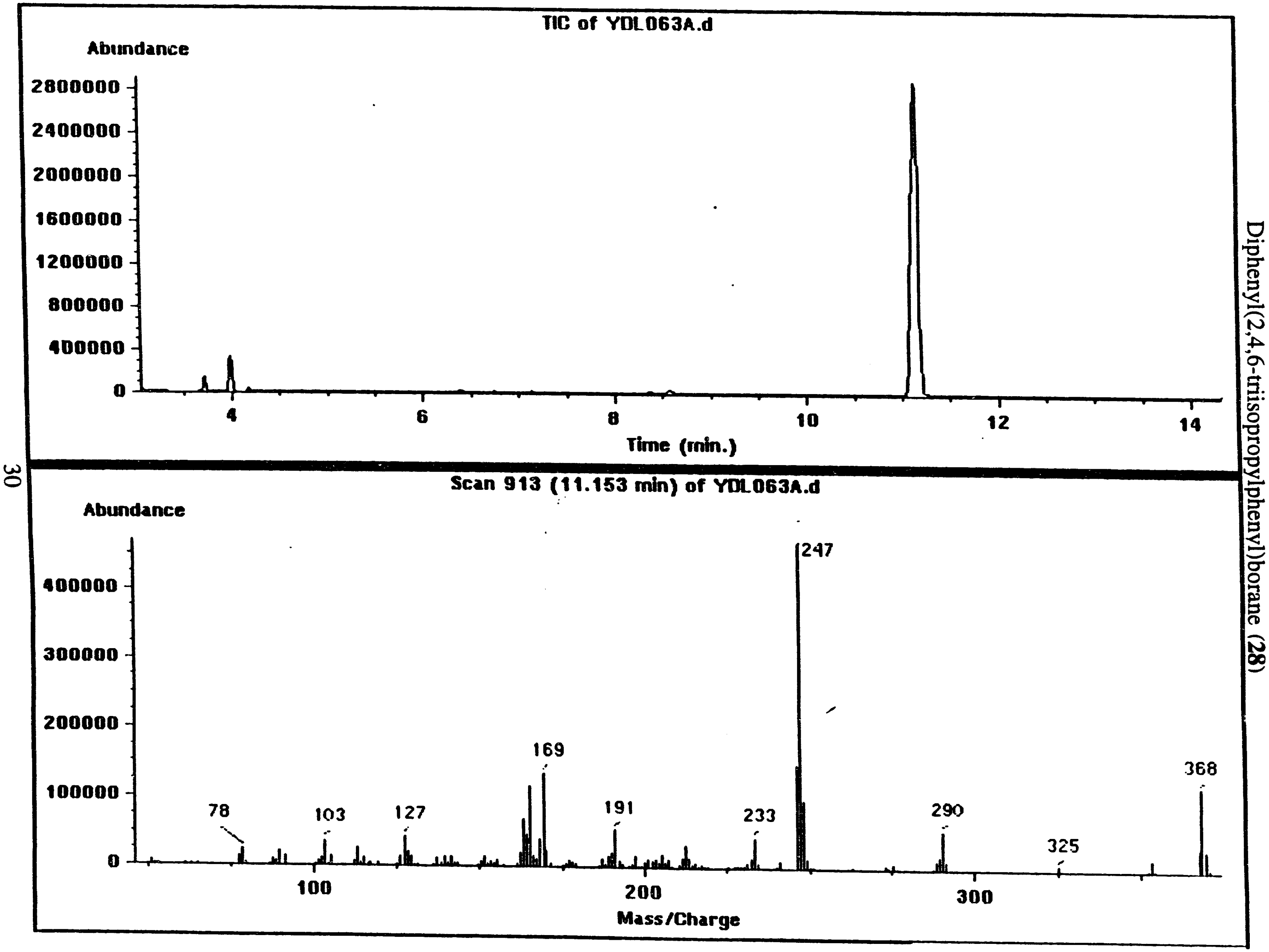
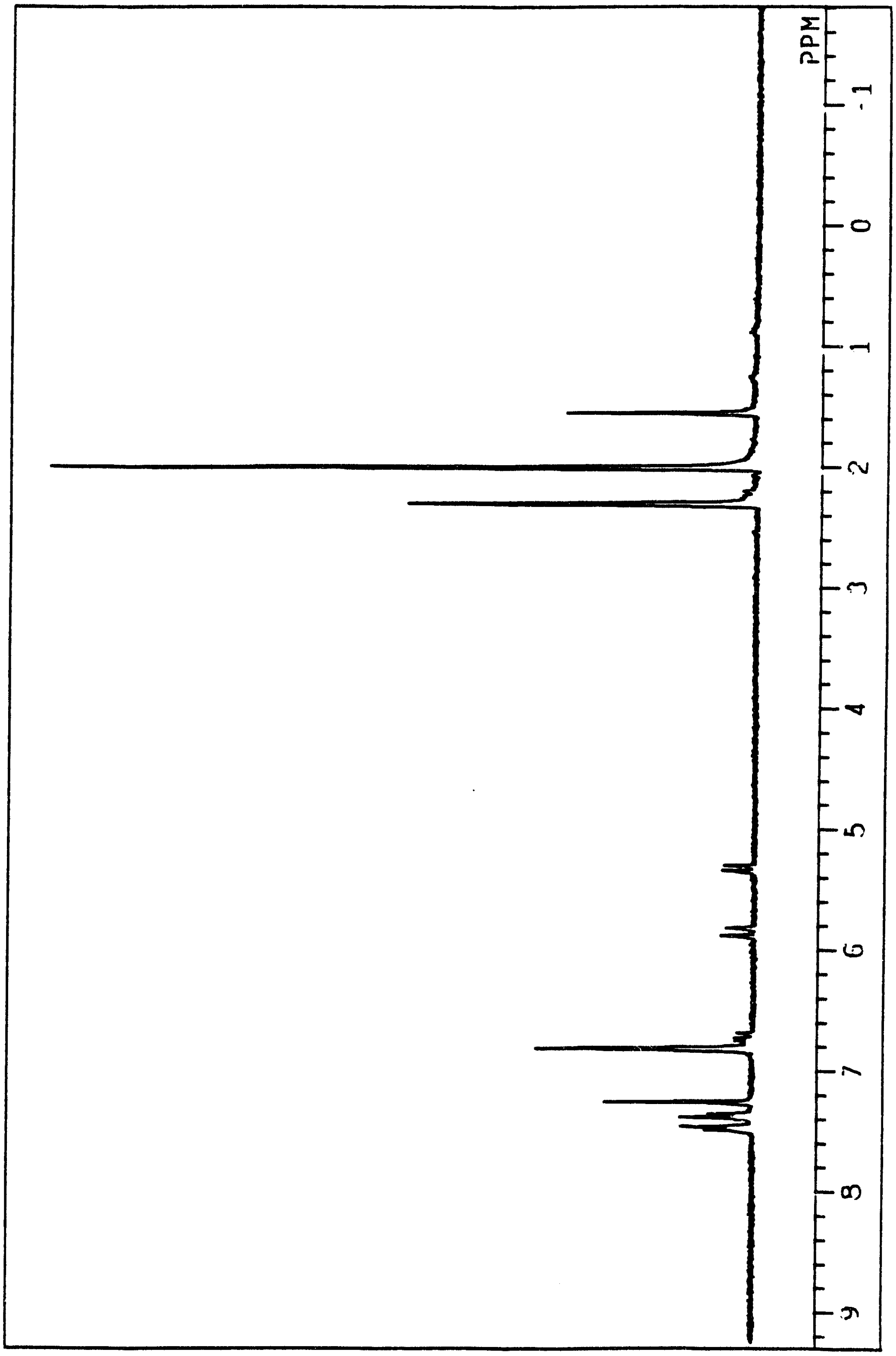


Figure 27. The GC/MS Ion Chromatograms of Diphenyl(2,4,6-triisopropylphenyl)borane (**28**)

6.13 Synthesis of Dimesityl(4-vinylphenyl)borane (**34**)

The reaction procedure described for the synthesis of **22** was also employed except that 4-bromostyrene was used in place of 4-bromo-*N,N*-dimethylaniline to afford **34** in ca. 30% yield as a white solid: ^{1}H NMR ($CDCl_3$, 270 MHz) δ 7.48 (2 H, d), 7.37 (2 H, d), 6.82 (4 H, s), 6.74 (1 H, dd), 5.85 (1 H, d), 5.32 (1 H, d), 2.31 (6 H, s), 2.00 (12 H, s); MS m/e 352 (M^+), 233, 232, 231. The ^{1}H NMR spectrum (270 MHz) and the GC/MS of Dimesityl(4-vinylphenyl)borane (**34**) are shown in Figures 28 and 29, respectively.

Figure 28. The ^{1}H NMR Spectrum ($CDCl_3$, 270 MHz) of Dimesityl(4-vinylphenyl)borane (**34**)



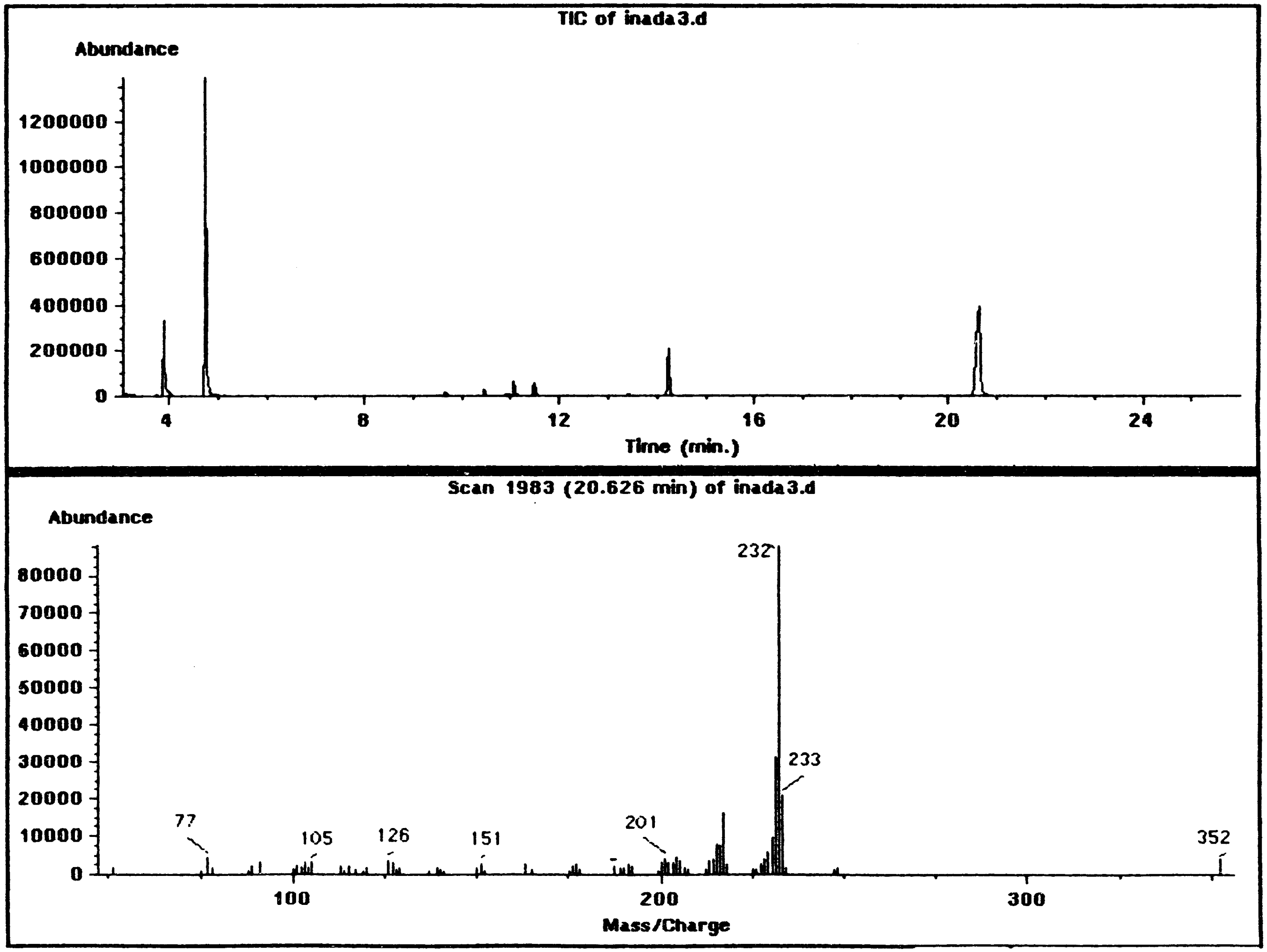


Figure 29. The GC/MS Ion Chromatograms of Dimesityl(4-vinylphenyl)borane (**34**)

7. CONCLUSIONS

In this report, four general methods for chemical destruction of PCBs have been reviewed. These technologies have achieved limited success in some commercial-scale operations. The laboratory scale studies suggest that these remediation processes have good potential for effective dechlorination of PCBs. In our laboratory at West Virginia University, we have successfully utilized 1-dimethylaminonaphthalene as an electron carrier for sodium metal for dechlorination of aromatic halides. The easy recovery of 1-dimethylaminonaphthalene from the reaction mixture for recycle offers a significant advantage over other electron carriers, such as naphthalene. Currently, efforts are being made to synthesize sterically hindered and chemically more stable triarylboranes as potential electron carriers for sodium metal. Attachment of the electron carrier to a polymer backbone to allow easy separation after the dechlorination reaction is also being investigated. Continued research in the area of chemical remediation is still needed to adapt these chemical processes to an extremely complex problem of PCB pollution in the environment. The PCB pollutant in the environment may exist in the soil matrices, in aqueous solution and in transformer oil with varying concentrations, and may coexist with other pollutants. It is unlikely that one single chemical remedial procedure will be able to address all these problems. A variety of procedures need to be developed for effective removal of PCBs from the environment.

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REMEDIATION OF HAZARDOUS SITES WITH STEAM REFORMING
(MC-11)

Quarterly Technical Progress Report
for Period January 1 through March 31, 1994

Work Performed Under
Contract Number: 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
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May 1994

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ABSTRACT

The fabrication and installation of the pressurized system continues. A cold flow model was designed and fabricated to verify the fluidization distribution calculations under pressurized conditions. The tube bundle has also been simulated to visually evaluate changes in distribution with velocity.

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LIST OF FIGURES

1. TECHNICAL BACKGROUND

A complete discussion of the technical background was presented in this quarterly report for the period July 1 through September 30, 1993. For continuity of the discussion in this part, the following 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 N_2) 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., PCB's, 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 remains the same as previously reported with the exception that NRCCE will arrange for the independent sampling and analysis of waste streams from the system during testing.

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

As described in the previous quarterly report, the fabrication of top and bottom shells were 100 percent completed and the reactor was made ready for refractory pouring.

Based on MTCI's previous experience with the fluid-bed steam reformer, one area of concern was the behavior of the fluidized bed and the performance of the fluidized bed with the current configuration of the pulse heater tube bundle (see Quarterly Report, October - December 1993, Figure 5). As shown in Figure 1, one area of concern (marked by X) is the U-bend of the heat transfer tubes. It is anticipated that poor fluidization in these areas might cause poor heat transfer in that region resulting in localized tube over heating which will eventually cause tube failure.

Thus, it was decided to design and fabricate a cold flow model and test this theory.

Figure 2 shows the schematic drawing of the cold flow model test rig.

Compressed air is used to fluidize the reactor model. The fluidization velocity will be kept between 1 - 1.2 ft/second and will be measured using a flow-measuring device. The fluidization air will be introduced to the reactor via nine sparge tubes. Sand or clear silica will be used as the bed media and performance of the fluid bed will be observed visually.

Figures 3 and 4 shows the drawing of the reactor model. The reactor model is fabricated from clear acrylic sheets with metal strips for reinforcements. The bottom section is fabricated from carbon steel. Also, the sparge tube is fabricated from carbon steel.

The reactor is approximately 14" wide x 26" length. The height of the first section is 5 feet and the second section another 5 feet. In the first section, up to three tube bundles can be inserted to simulate realistic situations. The second section will be used as a splash zone.

The tube bundle also is fabricated from acrylic with acrylic tube sheets. Metal 180 degrees close radius bends are used instead of plastic bends; bending acrylic or plastic might create problems.

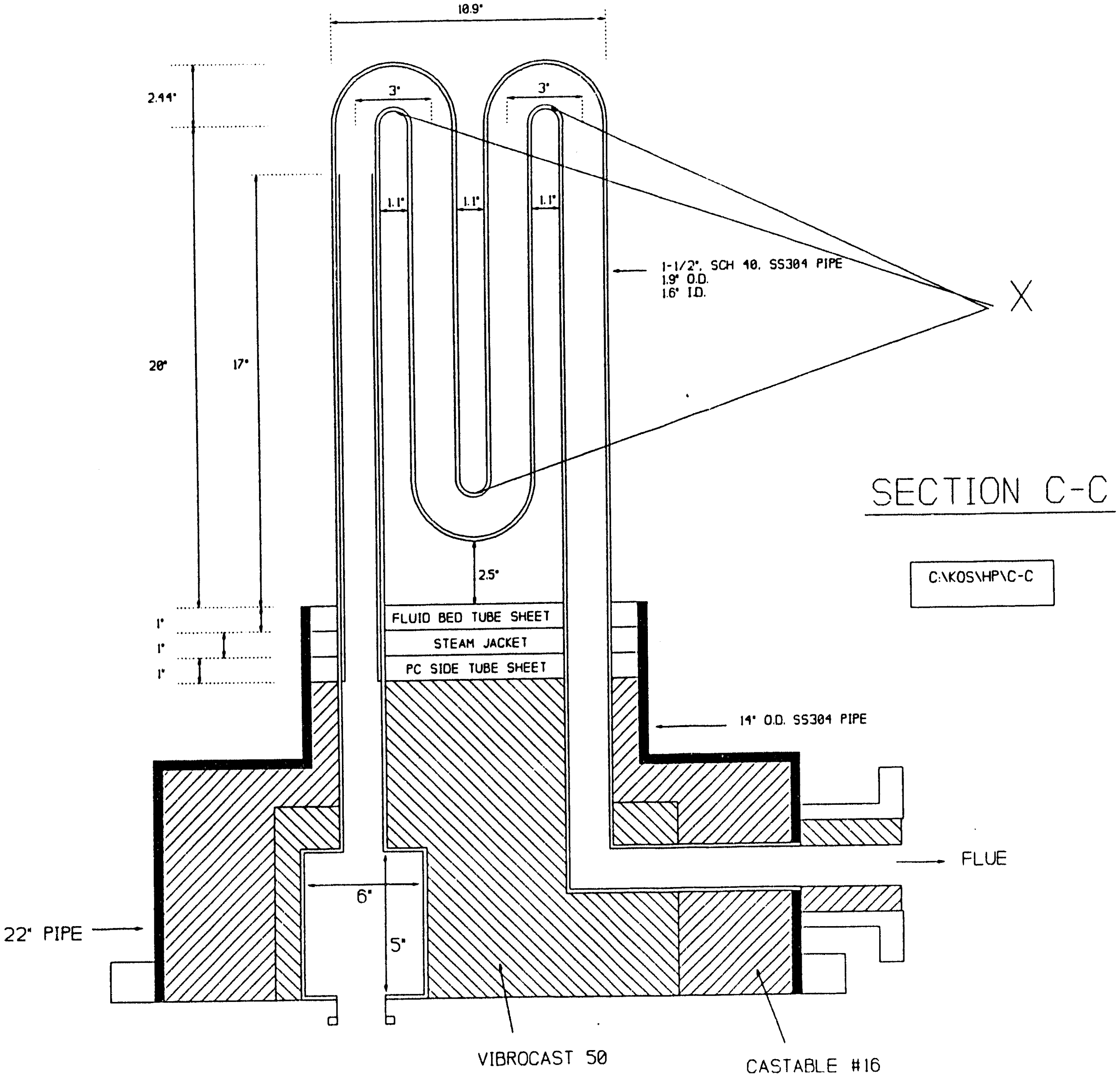

FIGURE 1: SCHEMATIC OF PULSE HEATER BUNDLE

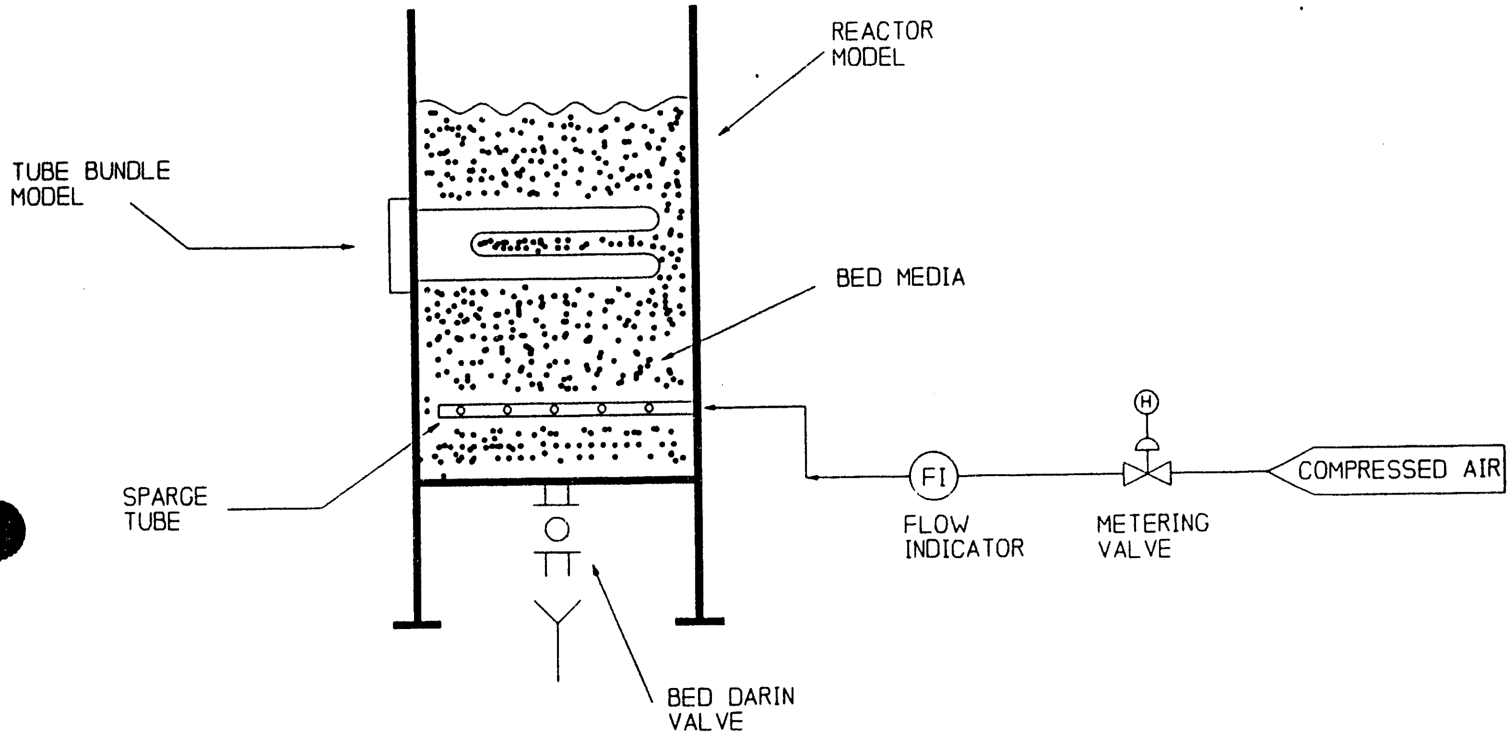

FIGURE 2: SCHEMATIC OF COLD FLOW MODEL TEST RIG

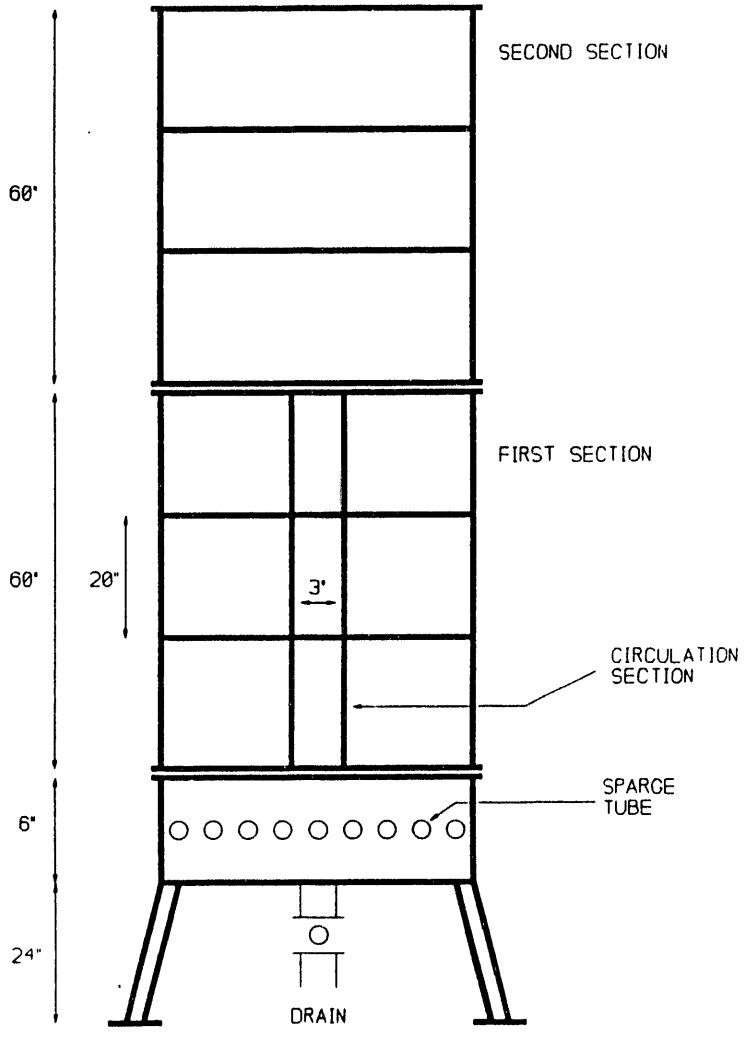

FIGURE 3: COLD FLOW MODEL OF REACTOR - SIDE VIEW

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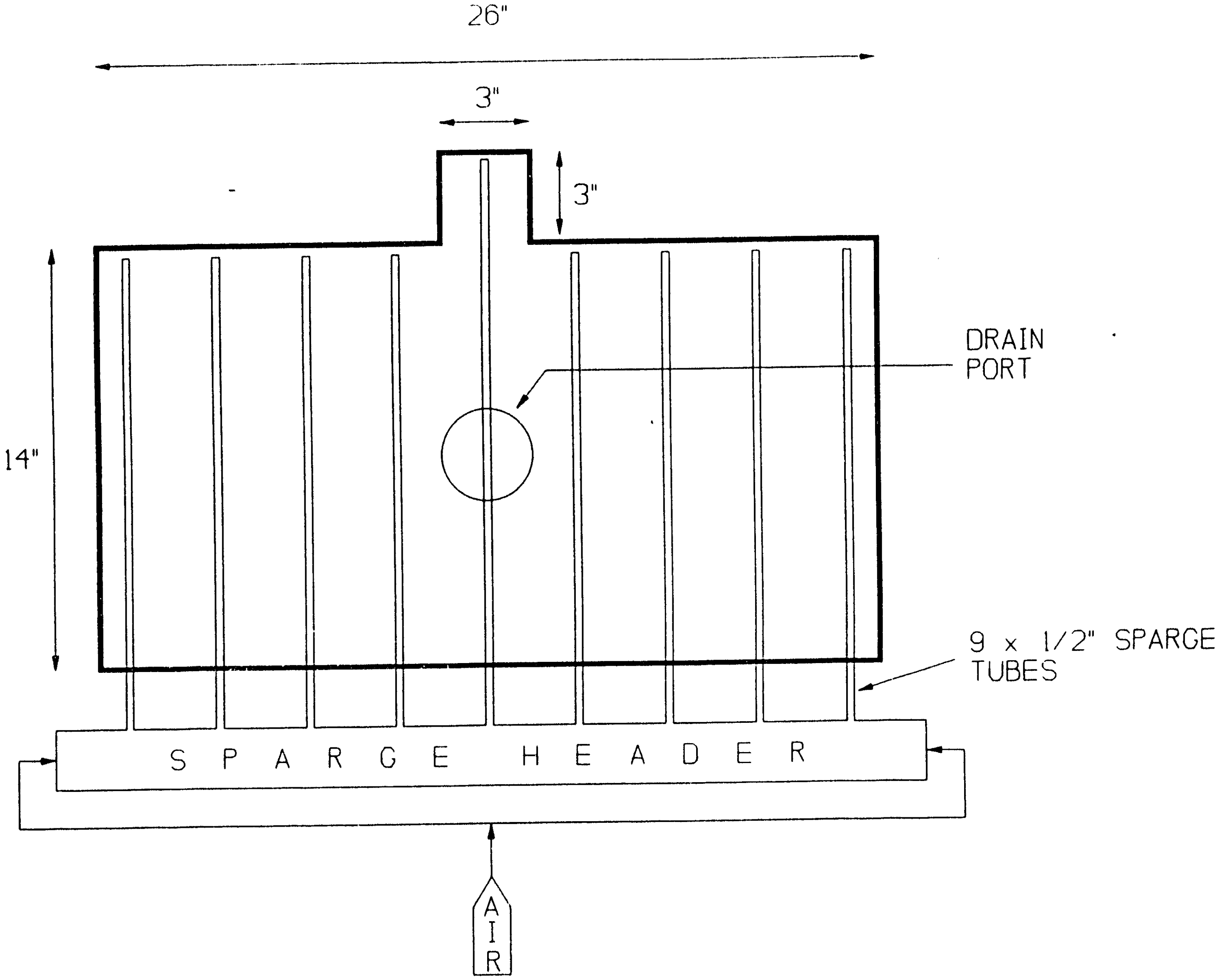

FIGURE 4: COLD FLOW MODEL OF REACTOR - PLAN VIEW

4. CONCLUSIONS

The cold flow model should provide sufficient data, visual and otherwise, to determine fluidization characteristics and/or changes to sparge design or configuration.

PLANS FOR NEXT REPORTING PERIOD

- Finish fabricating the cold flow model.
- Perform fluidization test.
- Finalize tube bundle design.
- Pour reactor refractory.

SOIL DECONTAMINATION WITH A PACKED FLOTATION COLUMN
(MC-19)

Quarterly Technical Progress Report
for Period January 1 through March 31, 1994

Work Performed Under
Contract Number: 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

By

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ABSTRACT

The general objective of this research is to evaluate a new technology for remediation of plutonium contaminated soil at the Nevada Test Site. The major effort of the research will be to optimize a flotation process in which a packed column is used to float fine particles of cerium oxide that will be selected as a surrogate because of their similarities in flotation chemistry.

In this quarter, (January 1 - March 31, 1994), work has been conducted to search for a method to increase the agglomeration strength of cerium dioxide which has a hardness of 1 or 2, as received from a chemical supplier. This work was needed because the cerium dioxide, as received, was too soft to be used in our flotation experiments. Also, a series of flotation experiments was conducted to float cerium dioxide with oleic acid at various pH's with a Hallimond cell. The results show that the flotation of cerium dioxide is possible only around a pH of 4, but not around a pH of 8 as observed with many other oxide minerals.

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1.0 Executive Summary

As mentioned in the Abstract, the cerium dioxide sample which was received from a chemical supplier was too soft to be used in the flotation experiments. Thus, various methods were tried to increase the strength of agglomerates so that they could withstand the abrasion during flotation. One method has been found to be effective and is summarized as follows:

1. Dissolution of 50 g of as-received cerium dioxide with 45 ml of concentrated sulfuric acid in a 1000 ml beaker on a hot plate.
2. Digestion of the solid with 1000 ml deionized water in the same beaker and plate.
3. Filtration of the slurry on a Whatman No. 42 filter paper.
4. Addition of approximately 200 ml of a 4 molar sodium hydroxide solution to the filtrate to precipitate cerium hydroxide or cerium dioxide.
5. Addition of approximately 50 ml of a polyacrylamide stock solution to flocculate the fine particles of the precipitate.
6. Filtration of the flocs on a Whatman No. 42 filter paper.
7. Roasting of the flocs at 1000°C for 3 hours in a furnace.

In this quarter, a series of flotation experiments was conducted using oleic acid as a collector with a Hallimond cell. A 10^{-2} molar stock solution of oleic acid was prepared by emulsifying an appropriate amount of oleic acid in a solution of pH 10. A one-half gram of 65-200 mesh cerium dioxide and 80 ml of water were added to a 150 ml beaker. The pH was adjusted to a desired level, 10 ml of the oleic acid stock solution was added, the pH was readjusted, and conditioned for 5 minutes. Water was added so that the final solution volume, combined with other reagents, was 100 ml. This whole content of slurry was transferred to the Hallimond cell. Air was passed through the cell at an average flow rate of 1 ml/sec for 1 minute, and the floated and unfloated particles were collected to determine the flotation recovery. Table 1 presents the results of the tests.

Table 1. Flotation Recovery of Cerium Dioxide
with 10^{-3} Molar Oleic Acid in a Hallimond Cell

pH	1.85	3.0	4.03	5.75	7.7
Recovery(%)	53.0	62.6	75	44.8	42.5

The flotation peak at pH 4.03 as shown in Table 1 is considered to be due to physisorption of oleic acid on the surface of cerium dioxide.

USE OF GRANULAR ACTIVATED CARBON COLUMNS FOR THE SIMULTANEOUS REMOVAL OF ORGANICS, HEAVY METALS, AND RADIONUCLIDES
(MC-21)

Quarterly Technical Progress Report
for Period January 1 through March 31, 1994

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For
U. S. Department of Energy
Office of Fossil Energy
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1. EXECUTIVE SUMMARY

The goal of this research is to investigate the feasibility (technical and economic) of using granular activated carbon (GAC) columns to treat an aqueous waste stream containing organic contaminants, heavy metals, and radionuclides. If the GAC column process is demonstrated to be technically feasible and cost effective, it will represent a significant tool in the plan to remediate the nation's hazardous waste sites. As of the writing of this report, laboratory works has been completed to determined the following:

1. Effect of column pretreatment on Pb removal.
2. Effect of the empty bed contact time (EBCT) on column performance.
3. Effect of phenol on Pb removal.
4. Effect of the influent Pb concentration on column performance.
5. Efficacy of taking the lead GAC column off-line following exhaustion.

Column pretreatment increased the bed volumes (BVs) of wastewater treated at breakthrough and exhaustion by 31 and 7 percent, respectively and increased the total Pb removed (X/M, mg Pb/g carbon) by 17 percent over the virgin column. Based on these results, column pretreatment should be employed and regeneration should not adversely affect column performance.

The BVs treated at breakthrough increased with increasing EBCT while the BVs treated at exhaustion decreased with EBCT. More BVs were treated at exhaustion for the lower EBCTs because there was significant Pb removal capacity remaining from the pre-breakthrough period. The Pb surface loading (X/M) remained fairly constant for EBCTs between 1.85 and 6.75 minutes and increased by about 15 percent when the EBCT was increased to 12.75 minutes. Compared with organic contaminants, for which adsorption is heavily dependent on the EBCT, Pb adsorption is relatively insensitive to the length of time the contaminant spends in the column.

The presence of phenol decreased Pb surface loading (X/M) by about 15 percent for an EBCT of 0.93 minutes and by about 23 percent for an EBCT of 12.75 minutes. The X/M at 12.75 minutes EBCT was greater than at 0.93 minutes in the presence of phenol. Possible reasons for this include: 1) phenol adsorption decreased the number of surface sites available for Pb desorption and 2) a lower column pH resulted when phenol was present. The effect of Pb on phenol removal was being studied at the time this report was being prepared.

Breakthrough and exhaustion of the columns occurred at lower BVs as the Pb concentration increased (*i.e.*, a larger volume of wastewater was treated at lower influent Pb concentration). However, the amount of lead removed (X/M) increased dramatically as the influent lead concentration increased. The increase in removal with increasing contaminant concentration is not uncommon and is caused by an increase in the sorption driving force. In addition, at higher lead concentrations, Pb is more easily precipitated on the carbon surface or in the carbon pore. The overall result is that as the Pb concentration increases, there is more opportunity for the Pb to be removed by the carbon.

For the experiments where the exhausted column was either taken off -line and or left on-line, both the Pb breakthrough and effluent pH curves were identical. Thus, leaving the exhausted columns on-line did not adversely affect system performance.

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2. INTRODUCTION

The Department of Energy (DOE) is currently responsible for 110 locations in 33 states and Puerto Rico under its Remedial Action and Decontamination and Decommissioning Programs (USDOE 1991). Many DOE locations contain more than one area of contamination and each "site" usually requires different remedial action activities. DOE estimates that about 4,000 sites require some sort of remediation. Twenty-three sites at 16 DOE locations are on the Superfund National Priority List (NPL). Recently the US Environmental Protection Agency (EPA) released a publication summarizing market and technology trends for cleaning up the nation's waste sites (USEPA 1993). Of the 62 DOE sites having assessment and characterization activities in progress, 29 of these sites reported groundwater as a matrix of concern. Almost all of the sites reported soil as being a matrix of concern. The type of contaminants present at these sites are extremely diverse and include organic solvent products, heavy metals, diesel fuels, VOCs, PCBs, PAHs, radionuclides (low and high level), and nitrates. For the majority of the contaminated sites there exists the need to treat contaminated groundwater either because it was part of the chosen remediation or confinement plan ("pump and treat") or because a liquid residual exist from *in-situ* or *ex-situ* treatment schemes. The groundwater or liquid residuals are usually contaminated with more than one contaminant class (*i.e.*, organics, heavy metals, or radionuclides). Often the levels of contamination are low enough that treatment by biological processes (*e.g.* activated sludge), or physical-chemical processes (*e.g.*, metal precipitation- settling) are ineffective. Tertiary treatment processes are required to lower the contaminant concentration to very low levels. Examples of tertiary processes include the use of granular activated carbon (GAC) columns for the removal of organic contaminants and the use of ion exchange columns for the removal of heavy metals and radionuclides.

3. PURPOSE

The purpose of this research is to investigate the feasibility (technical and economic) of using granular activated carbon (GAC) columns to treat an aqueous waste stream containing organic contaminants, heavy metals, and radionuclides. If the GAC column process is demonstrated to be technically feasible and cost effective, it will represent a significant tool in the plan to remediate the nation's hazardous waste sites. Specific objectives of the research, signified as Tasks 1 through 3, are to investigate the following topics:

Task 1: The use of GAC columns to treat a waste containing organic compounds and/or heavy metals.

Task 2: The efficacy of using activated carbon to remove radionuclides.

Task 3: The use of GAC columns to treat a mixed-waste.

Norit Americas, Inc. (formerly American Norit Co., Inc.), an activated carbon manufacturer, is the private sector partner on this research. Norit Americas, Inc. have provided pilot-scale columns and will assist in developing design and costing procedures.

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4. BACKGROUND

The use of granular activated carbon (GAC) columns to remove trace amounts of organic compounds from aqueous waste streams is widely used. If heavy metals or radionuclides were present, other processes such as precipitation, reverse osmosis, or ion exchange would be added to the treatment flow sheet. Significant savings could result if an organic-heavy metal wastes and mixed-wastes could be successfully treated using a **single** process. The PIs in conjunction with Norit Americas, Inc. have developed a GAC column process that removes inorganic contaminants from the aqueous phase using GAC columns. Because the feasibility of using GAC columns to remove organic contaminants is well known, the next logical step is to demonstrate the ability of the GAC process to simultaneously remove organic and inorganic contaminants.

In this section, background information on use of sorption processes for the removal of contaminants is presented. The majority of background section will be devoted to the use activated carbon for the removal of heavy metals and radionuclides. Information on the use of the ion exchange process for the removal of radionuclides will also be presented. Since the use of GAC columns for organic contaminant removal is an accepted treatment process only a general overview on this topic is presented.

4.1 Metal Removal by Activated Carbon

4.1.1 Equilibrium Studies

Numerous investigators have reported on the ability of activated carbon to remove heavy metals from solution. The majority of the work has been in the batch mode. Solution pH has been identified as the variable governing metal adsorption onto hydrous solids (Stumm and Morgan 1981). For most heavy metals, adsorption increases with increasing pH. The opposite is observed when the metal exists as an anion (*e.g.*, $Cr_2O_7^{-2}$). The fraction of metal ions removed increases from zero to one over a narrow pH range. This pH range is referred to as the "pH-adsorption edge." An example of a pH-adsorption edge is provided in Figure 1 for 10 mg/L cadmium and Hydrodarco B (HDB) a Norit Americans, Inc. carbon. Also included in Figure 1 is the amount of cadmium that was removed via solution precipitation (0 g/L carbon). Complete cadmium removal is achieved at pH values far less than the pH at which precipitation occurs. The sorption-pH relationship is important because it represents a method for regenerating spent carbon The pH affects the status of the outer hydration sheaths of the metal ion, metal solution speciation, and the surface charge of the activated carbon. At lower pHs, chemisorption and ion exchange are the dominant removal mechanisms. As the pH approaches the pH at which solution precipitation occurs, surface precipitation becomes more important.

Other parameters that affect metal removal include the adsorbate/adsorbent ratio, the surface charge and type of sites on the carbon surface, and the presence of secondary contaminants. As the adsorbate/adsorbent ratio increases, the pH-adsorption edge shifts to higher pH values (*i.e.*, removal is decreased, see Figure 1). Electrostatic and chemical characteristics of carbon surface sites directly affect the adsorption capability of carbons. Examples of surface groups on activated carbon include phenolic, carboxyl, n- and f-lactones, and quinone groups (Snoeyink and Weber 1967). Presently, there is insufficient research to correlate metal removal to specific sites. The presence of secondary contaminants can increase, decrease or have no effect on metal removal. Reed and Nonavinakere (1992) studied the removal of nickel and cadmium by three activated carbons in the presence of EDTA, succinic acid, PO_4^{2-}, and competing metals. EDTA adversely

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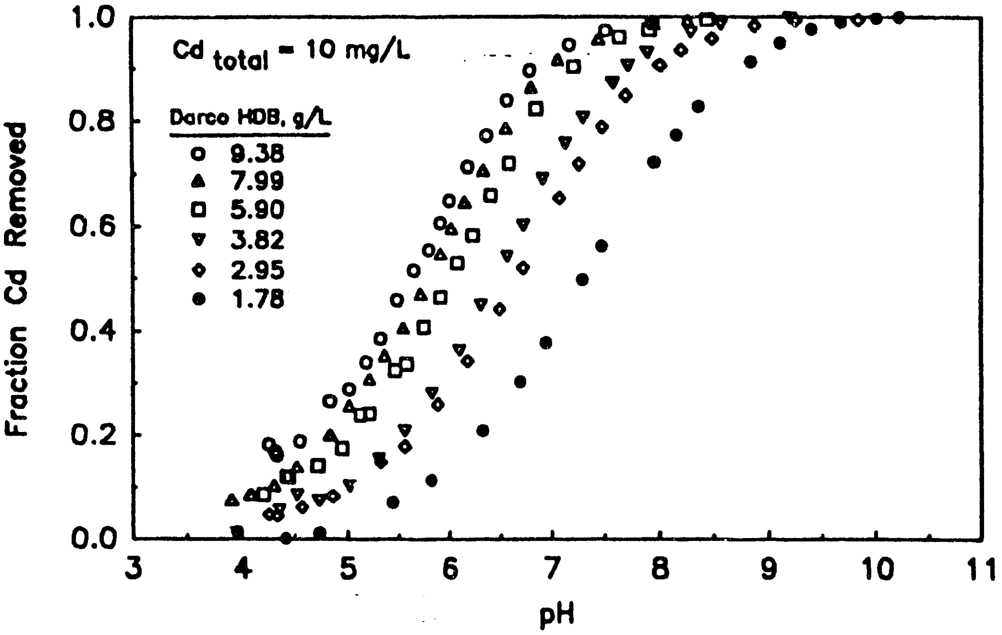

Figure 1. Example of pH-Adsorption Edge (Reed and Matsumoto 1993)

affected metal removal while, succinic acid and PO_4^{3-} did not. The presence of two metals (Cd and Ni) did not decrease the removal of either metal compared to single metal experiments.

4.1.2 Adsorption Kinetics

The rate of metal adsorption on PAC and ground GAC has been reported to be rapid. Reed and Matsumoto (1993) reported that cadmium removal by two commercial PACs was rapid at low adsorbate/adsorbent ratios but slowed considerably when the adsorbate/adsorbent ratio was high. The slower kinetics were attributed to the predominance of surface precipitation as the removal mechanism Huang and Smith (1981) conducted extensive research on the cadmium adsorption kinetics of Nuchar SN and Nuchar SA at several pH values and adsorbate/adsorbent ratios, and in the presence of cyanide (CN^-) and fluoroborate (BF_4). Maximum adsorption was reached within the first two minutes of reaction. Metal removal kinetics for GAC are slower compared to PAC. Pore diffusion has been identified by Huang and Smith (1981) as the rate limiting step. Huang and Wirth (1982) aggregated a powdered carbon, Nuchar SA, into various sized beads and found that as the size of the aggregated carbon increased, interparticle diffusion became more important in the adsorption process.

4.1.3 Column Studies

In 1991, the Principal Investigator and American Norit Co. began a series of experiments to test the effectiveness of GAC columns in removing heavy metals from solution. In summary, synthetic waste streams containing cadmium, lead, and acetic acid were treated to trace levels of metals using a GAC column (Reed and Arunachalam 1993, Reed *at al.* 1993). Acetic acid was included to simulate the presence of small chain organic acids usually found in landfill leachates. Examples of typical results are presented in Figures 2 through 4. In Figure 2, the normalized lead effluent concentration versus the number of bed volumes (BVs) of waste treated are presented. In a single run, over 300 BVs were treated prior to breakthrough (defined as $0.03C_0$). Over 900 BVs were treated during the three column runs. The carbon column was regenerated using a simple procedure consisting of an acid rinse (0.1 HNO_3) followed by a base rinse (0.1 N NaOH). Note that the regeneration process did not adversely affect the performance of subsequent column runs. The acid rinse provided the low pHs required to desorb the metal from the carbon while the base rinse raised the pH of the carbon surface to an acceptable level for the next column run (see Figure 1 for effect of pH on metal retention by carbons). If organics are present, the base rinse can also function as an organic desorption step. The vast majority of the carbon-bound metal was desorbed from the carbon and concentrated into a smaller volume of liquid.

In Figure 3, breakthrough curves are presented for two wastewaters, one containing Cd and acetic acid, and the other Cd, Pb, and acetic acid. The breakthrough curve for the binary metal systems (Pb and Cd) was identical to the cadmium only curve. Similar results were observed for the removal of lead in the absence and presence of Cd. Thus, at least for Cd and Pb, multiple metals did not adversely affect column performance. However, the amount of wastewater treated at breakthrough decreased when acetic acid was present. It is hypothesized that the acetic acid lowered the pH of the carbon at a faster rate causing a decrease in metal removal. In addition, desorption of the metal ($C_e/C_0 > 1.0$) occurred at the point where the effluent and influent pH were equal (pH = 4.7). Thus, if GAC columns are to be used in a treatment setting, care must be taken to remove the column from operation just prior to the point of exhaustion.

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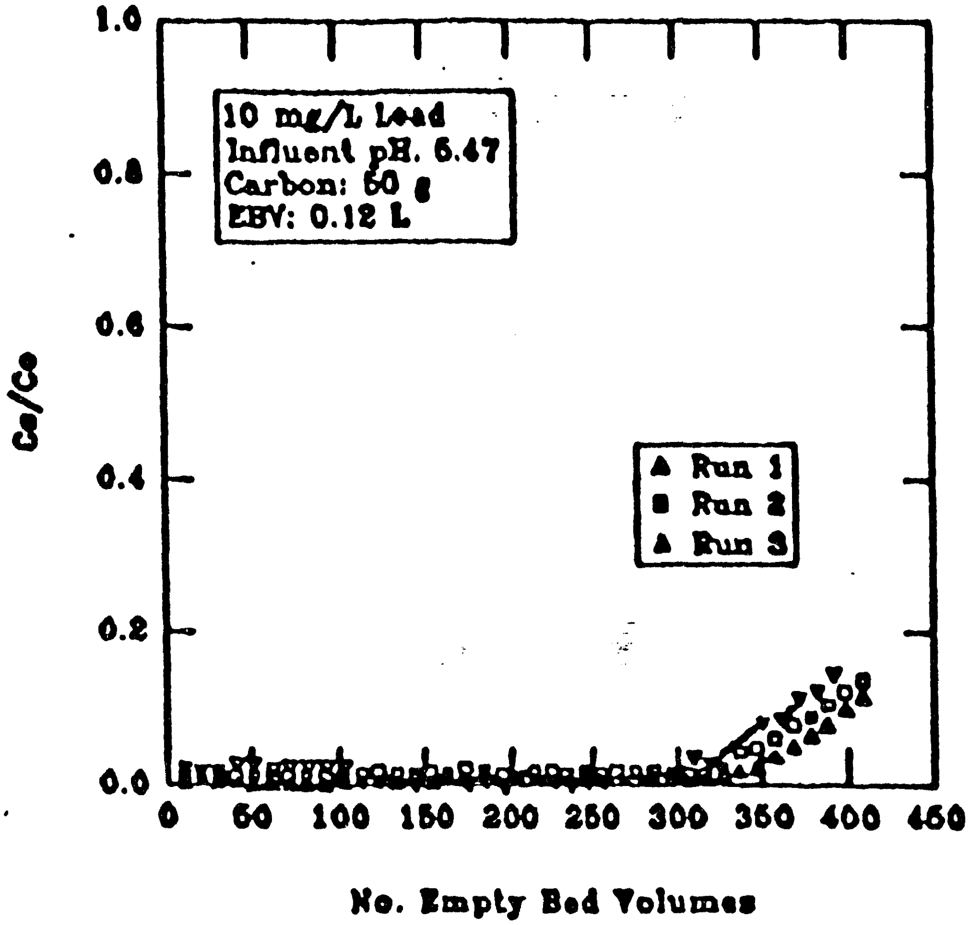

Figure 2. Pb Breakthrough Curve for 10 mg/L Pb (Reed and Matsumoto 1993)

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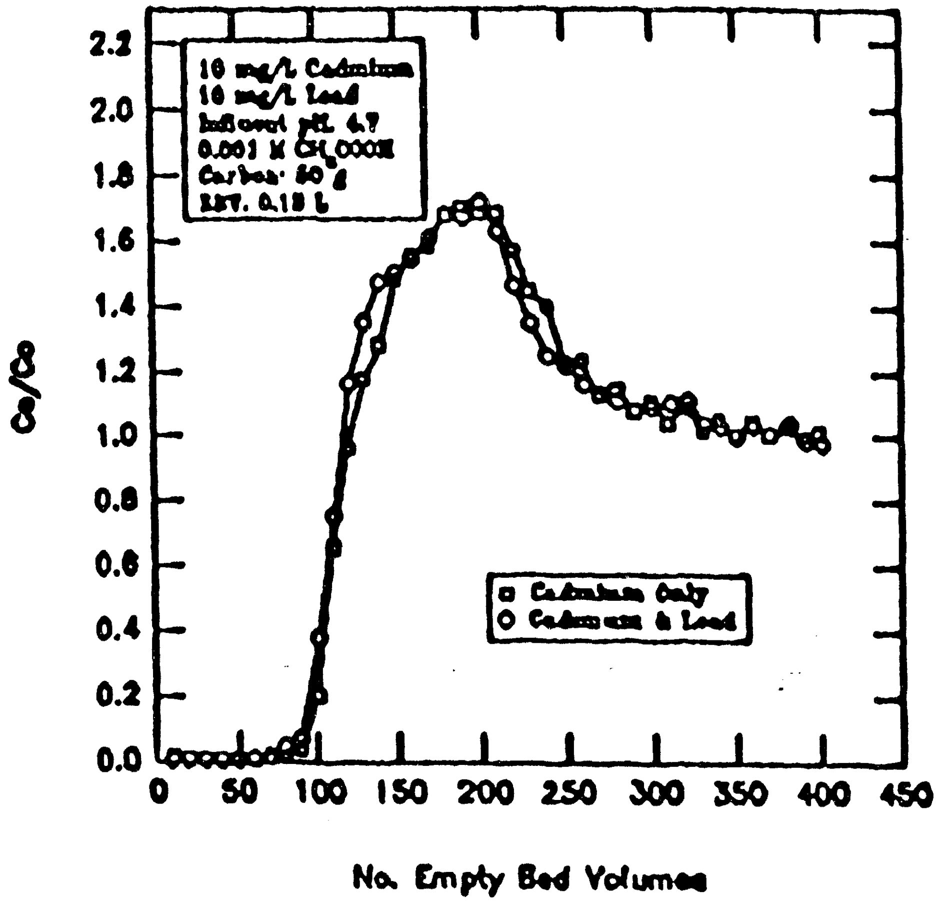

Figure 3. Cadmium Breakthrough Curves for Cd, Pb, and Acetic Acid (Reed *et al 1994)*

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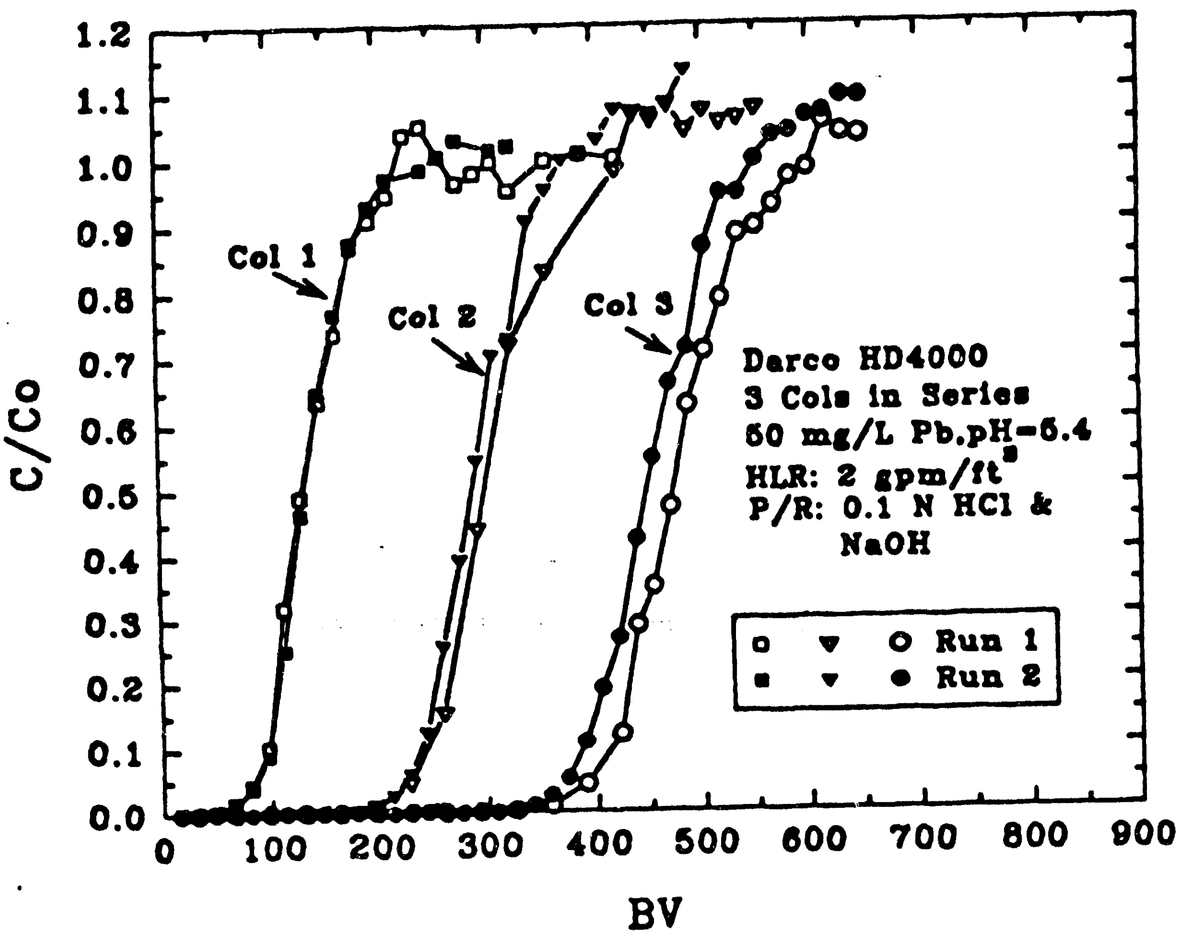

Figure 4. Serial Column Pb Breakthrough Curves for 50 mg/L

Breakthrough curves for three GAC columns, operating in series are presented in Figure 4. The use of the columns in series allows up-line columns to be operated to exhaustion. For the conditions indicated in Figure 4, the BVs treated at breakthrough increased by over 60 percent compared to three parallel column operation. GAC columns were also effective in removing low concentrations of Pb.

In summary, it is apparent that the use of GAC columns to remove heavy metals from aqueous waste streams is technically feasible. Additional information on the effectiveness of the process when other classes of contaminants are present (*i.e.*, organics and radionuclidies) and the cost effectiveness of the process are required before the process can be employed at an actual waste site.

4.2 Removal of Radionuclides from Aqueous Waste Streams

The use of activated carbon for the removal of radionuclides has not been reported in the literature. However, ion exchange has been used extensively in the nuclear industry to both treat and recover radioactive waste. Both synthetic resins and natural zeolites (*e.g.*, clinoptilolite, montmorillonite) have been used. Radioactive ions are exchanged for the stable ions of the exchanger and regeneration of the exchange media is not usually practiced. Because exchange reactions are one mechanism by which activated carbon removes ions from solution it is expected that carbon will also be able to remove radionuclides. Several studies on the removal of radionuclides from aqueous solutions using ion exchange have been recently published. Todorovic *et al.* (1992) reported on the use of magnetite and hematite for the removal of Cs, Sr, and Co. Removal increased with increasing pH and kinetics were relatively fast. Ahmad *et al* (1992) investigated the removal of cobalt from aqueous waste streams using lateritic mineral mixtures. Removal was a strong function of pH (removal increased with increased pH) and the exchange reaction was rapid. Park and Meyer (1992) studied the removal of Cs, Sr, and Tn from a high level nuclear waste using a multistage countercurrent batch contactor. Recovery efficiencies of 77, 64, and 99 percent for Cs, Sr, and Th were reported.

4.3 Removal of Organic Contaminants by Activated Carbon

Activated Carbon treatment has long been recognized as an effective means for removal of a broad range of organic chemicals from water. Powdered activated carbon (PAC) adsorption is generally used for the removal of dissolved organics, color, and taste-and-odor-causing organic compounds, and synthetic organic compounds from municipal water treatment. Generally, high molecular weight, non-polar compounds are adsorbed more effectively than molecular-weight, polar compounds. Direct addition of powdered activated carbon (PAC) to the aeration basin of an activated sludge plant has sometimes been employed in the United States. Ying (1987) found that the addition of powdered activated carbon (PAC) to an sequencing batch reactor (SBR) resulted in an effluent with extremely with low contaminant concentrations. Models have been also developed to predict organic priority pollutant removals by the powdered activated carbon treatment process (PACT process). Kinetic coefficients that characterize removal by biodegradation, powdered activated carbon adsorption, and air-stripping obtained from pilot-plant data were used in the models. These models can be also used to estimate the relative importance of the three removal mechanisms in order to adjust wastewater treatment plant to enhance the removal of specific organic compounds (O'Brien, 1992).

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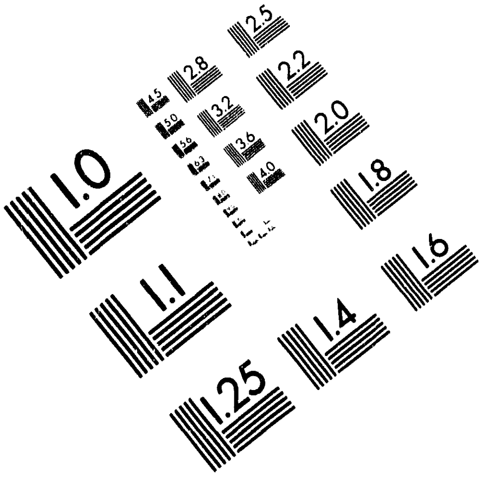
Although GAC treatment is more expensive than PAC treatment, GAC is more effective than PAC for removing a wide range of organics including taste-and odor-causing compounds, total organic carbon, THM formation potential, VOCs, and synthetic organic contaminants. Carbon adsorption also can be included in a wastewater treatment scheme for water reuse, where it can be employed as point source treatment or as a final polish operation for removal of trace organic contaminants. Studies showed that treatment for wastewaters, containing low concentrations of hazardous organics often involves adsorption on granular activated carbon(GAC) as final step after biological treatment (Irvine, 1988). Also, the Granular Activated Carbon-Sequencing Batch Biofilm Reactor (GAC-SBBR) was used to determine the efficiency of removal of toluene. It was found that biodegradation and adsorption were responsible for 92% and 8%, respectively of the toluene removal (Chosick, 1991). In practice, however, the design and implementation of granular activated carbon (GAC) systems complicated by the variable nature of source-water composition, specifically the presence of background dissolved organic matter and the corresponding effects that the substances comprising the dissolved organic matter exert on the removal of specifically target organic compounds. The effects of dissolved organic matter, reactor configuration, and granular activated carbon were examined under simultaneous loading and early preloading conditions. Differences in isotherms capacities obtained using batch-reactor and column-reactor estimation methods were observed when natural background organic matter and TCE were adsorbed onto preloaded GAC. Significant increases in isotherm slope were observed with increasing preloading time for GAC of two different particle sizes (Carter, 1992). VOCs fed to a GAC anaerobic reactor can theoretical be removed by one or both of the following mechanisms: adsorption onto the GAC surface and biological degradation. The potential of the expanded-bed granular activated carbon anaerobic reactor in treating a high strength waste containing volatile organic compounds was studied. A total of six VOCs were fed to the reactor in a high strength matrix of background solvents. The reactor was found to effect excellent removal of VOCs (97 percent). Biological degradation was the dominant mechanism of removal. (Narayanan, 1993). The empty bed contact time (EBCT) is one of the more important design parameters for GAC columns and organic contaminants. The EBCT is related to the size of the column and the efficiency of contaminant removal. Love and Elders reported that the BVs treated at breakthrough for *cis*-1,2-dichloroethylene doubled when the EBCT was increased from 6 to 12 minutes but increased by only an additional 10 percent when the EBCT was raised to 18 minutes. One objective of this research is to determine if the removal of heavy metals and radionuclide by GAC columns follow this trend.

5. METHODOLOGY

5.1 Materials and Methods

The effects of column pretreatment, empty bed contact time (EBCT), phenol, influent Pb concentration, and taking the lead GAC column off-line following exhaustion on Pb removal were investigated. GAC columns were operated in the up-flow mode. Several column arrangements, dependent on the empty bed contact time (EBCT), were used. In Table 1, a summary of the column setup is presented.



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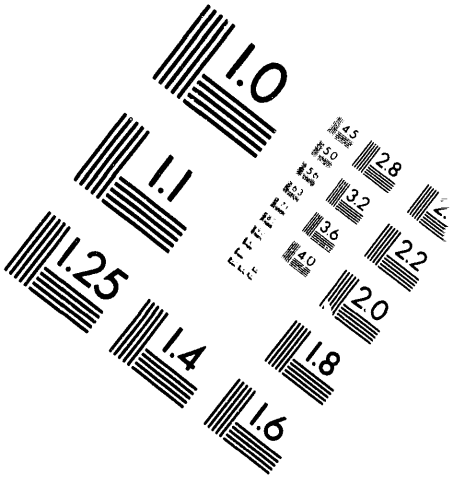

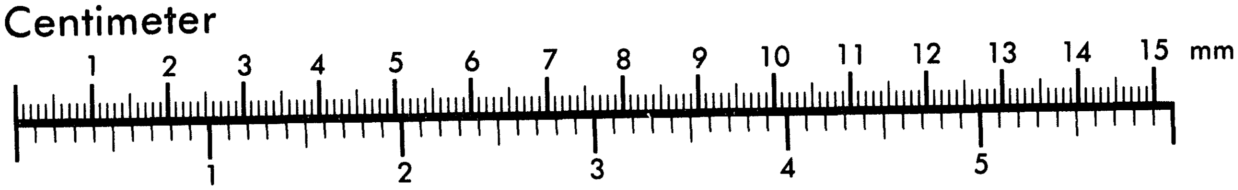

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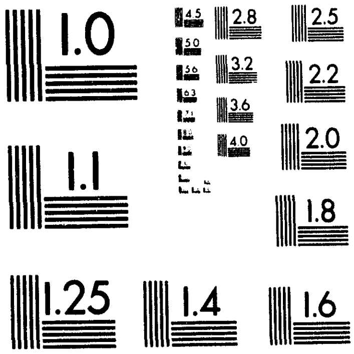

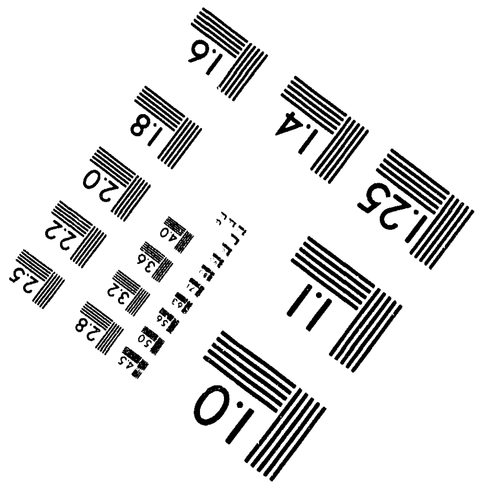

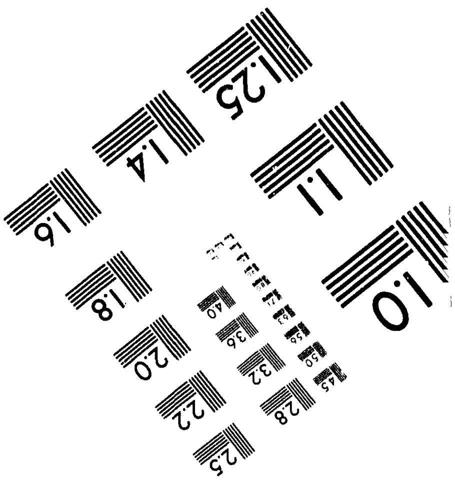

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Table 1 Summary of Column Set-Up

Column Dimensions	Number of Columns	EBCT (min)	Flow Rate (mL/min)	Mass Carbon (g)
2.5 cm I.D. x 15 cm length	1	1.85	40	33
2.5 cm I.D. x 15 cm length	2	3.70	40	66
2.5 cm I.D. x 15 cm length	3	5.55	40	99
2.5 cm I.D. x 61 cm length	1	6.75	43	127
2.5 cm I.D. x 122 cm length	1	12.75	93	500

Before being placed in the column the carbon (Hydrodarco 4000) was degassed, washed with distilled water, and sieved through a US No. 50 mesh sieve. Carbon was placed in the column without the introduction of air bubbles (air bubbles can cause short circuiting and carbon separation within the column). Except for the experiments where the effect of pretreatment was investigated, the columns were pretreated by pumping 10 bed volumes (BVs) of 0.1 N HCl followed by 10 BVs of 0.1 N NaOH at a rate of 3.3 BV/hr).

Several influent lead concentrations (1, 10, and 50 mg/L) were investigated. Lead was added as $Pb(NO_3)_2$. The pH of the influent was adjusted to 5.4 and the ionic strength to 0.01 using $NaNO_3$. The hydraulic loading rate to the column was maintained at 2 gpm/ft^2 for all experiments using Cole-Parmer variable speed pumps. During operation, the effluent was sampled on a regular basis and analyzed for Pb content and pH. For high lead levels (> 1 mg/L) Pb was measured using a Perkin-Elmer atomic absorption (AA) spectrophotometer according to USEPA Method 7420. At lower Pb concentration (< 1 mg/L) a Perkin-Elmer graphite furnace. After column exhaustion (effluent Pb $\approx$ influent Pb), the column was regenerated using the "pretreatment" process.

5.2 Experimental Protocol and Statement of Quality Assurance

Samples and analyses conducted during the course of this proposed study were conducted at the Environmental Engineering laboratories at West Virginia University. Chemical analyses that were conducted included Pb concentration, phenol, pH, and conductivity. For these tests, well-established protocols will be followed such as ***Standard Methods for the Examination of Water and Wastewater, Testing Methods for Evaluating Solid Waste: Physical/Chemical Methods*** (USEPA 1986), and the ***Annual Book of ASTM Standards*** (ASTM 1991). Recovery measurements were determined for all analyses. Experiments will be conducted under controlled temperature conditions, 20± 3°C.

Quality assurance (QA) is an important factor in the success of a research project. The purpose of implementing QA procedures is to insure that the methods used in collecting and processing data are valid and reliable. Elements of a QA plan include using accepted analytical methods, following standard operating procedures, and instituting quality control (QC) testing procedures. All experimental data and observations were recorded in permanent ink in laboratory notebook with carbon copies. Results were continuously monitored and processed to detect improper procedures or inconsistent results. Data were entered on a computerized data management package to facilitate data manipulation and analyses.

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6. RESULTS AND DISCUSSION

6.1 Effect of Column Pretreatment

Virgin and pretreated column experiments were conducted for 1 mg/L Pb. Pretreatment consisted of rinsing the virgin column with 10 BVs of 0.1 N HCl followed by 10 BVs of 0.1 N NaOH. In Figure 5, Pb breakthrough curves (normalized Pb concentration versus bed volumes (BV) of waste treated) and effluent pH curves are presented for virgin and pretreated columns. In Table 2, BVs treated at breakthrough ($C = 0.03C_0$) and exhaustion ($C = 0.95C_0$) and X/M at exhaustion are presented for the data in Figure 5. Column pretreatment increased the BVs treated at breakthrough and exhaustion by 31 and 7 percent, respectively and increased the total Pb removed (X/M) by 17 percent over the virgin column. Based on these results, column pretreatment should be practiced and regeneration should not adversely affect column performance (regeneration and pretreatment procedures are identical).

Table 2. Summary of the Effect of Pretreatment

Column Conditions	BV at Breakthrough	BV at Exhaustion	X/M at Exhaustion (mg/g)
Virgin	650	1050	1.93
Pretreated	950	1120	2.32
% Improvement	31	6	17

6.2 Effect of Empty Bed Contact Time (EBCT)

In Figure 6, Pb breakthrough curves and effluent pH curves are presented for 1 mg/L Pb and empty bed contact times (EBCT) of 1.85, 3.70, 5.55, 6.75, and 12.75 minutes. As the EBCT increased the shape of the Pb breakthrough curve became progressively steeper indicating that kinetics become less important at high EBCTs. In Table 3, BVs treated at breakthrough and exhaustion and X/M at exhaustion are presented for the data in Figure 6. BVs treated at breakthrough increased with increasing EBCT while the BVs treated at exhaustion decreased with EBCT. More BVs were treated at exhaustion for the lower EBCTs because there was significant Pb removal capacity remaining after breakthrough (*i.e.*, BVs treated at breakthrough decreased with decreasing EBCT). The Pb surface loading (X/M) remained fairly constant for EBCTs between 1.85 and 6.75 minutes and increased by about 15 percent when the EBCT was increased to 12.75 minutes. Compared with organic contaminants, for which adsorption is heavily dependent on the EBCT, Pb adsorption is relatively insensitive to the length of time the contaminant spends in the column. For example, Love and Elders reported that the BVs treated at breakthrough for *cis*-1,2-dichloroethylene doubled when the EBCT was increased from 6 to 12 minutes. Based on these results, the size of the column (*i.e.*, EBCT) would be dependent on the behavior of the organic contaminant(s), not Pb.

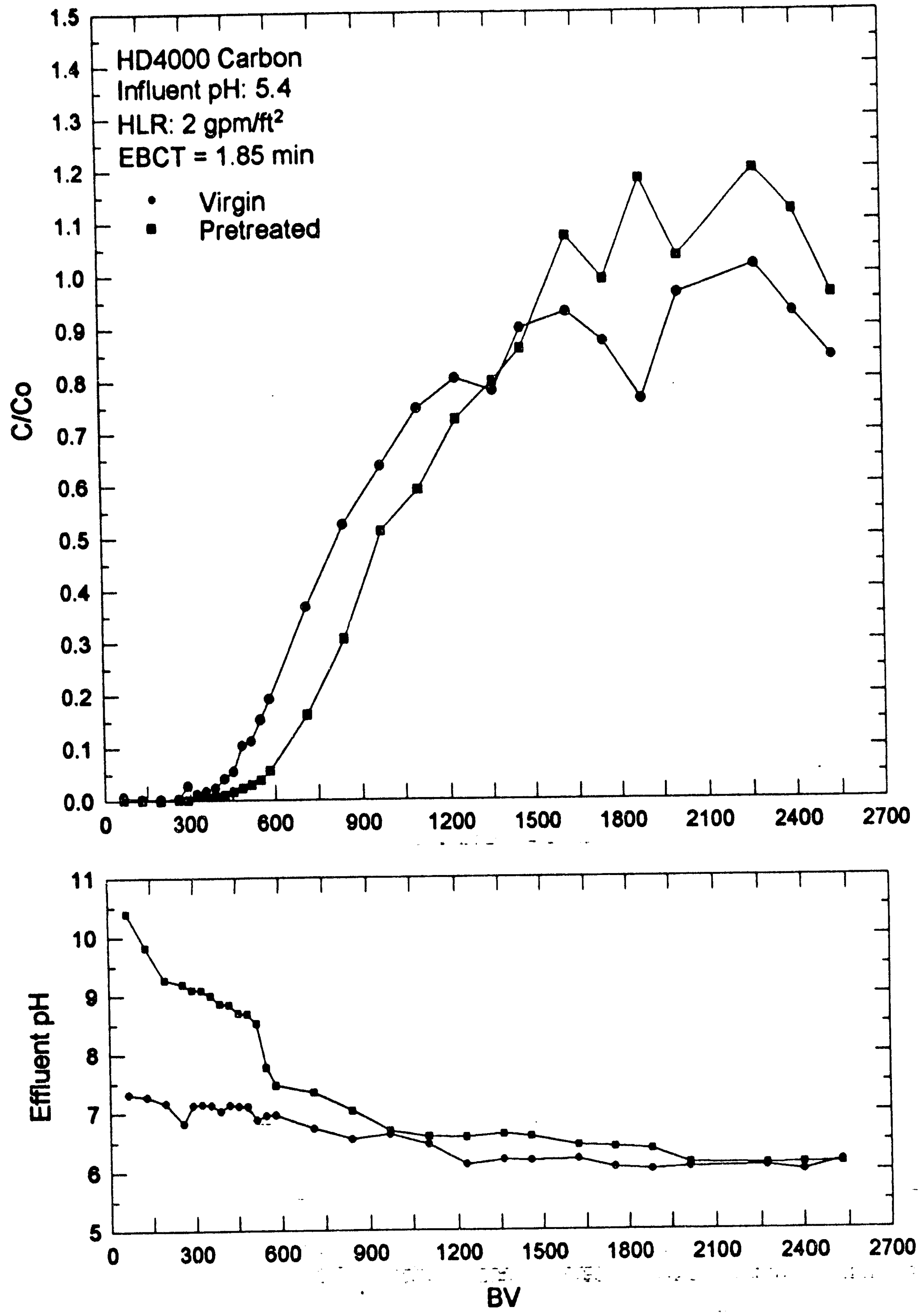

Figure 5. Pb Breakthrough and Effluent pH Curves for Virgin and Pretreated Columns

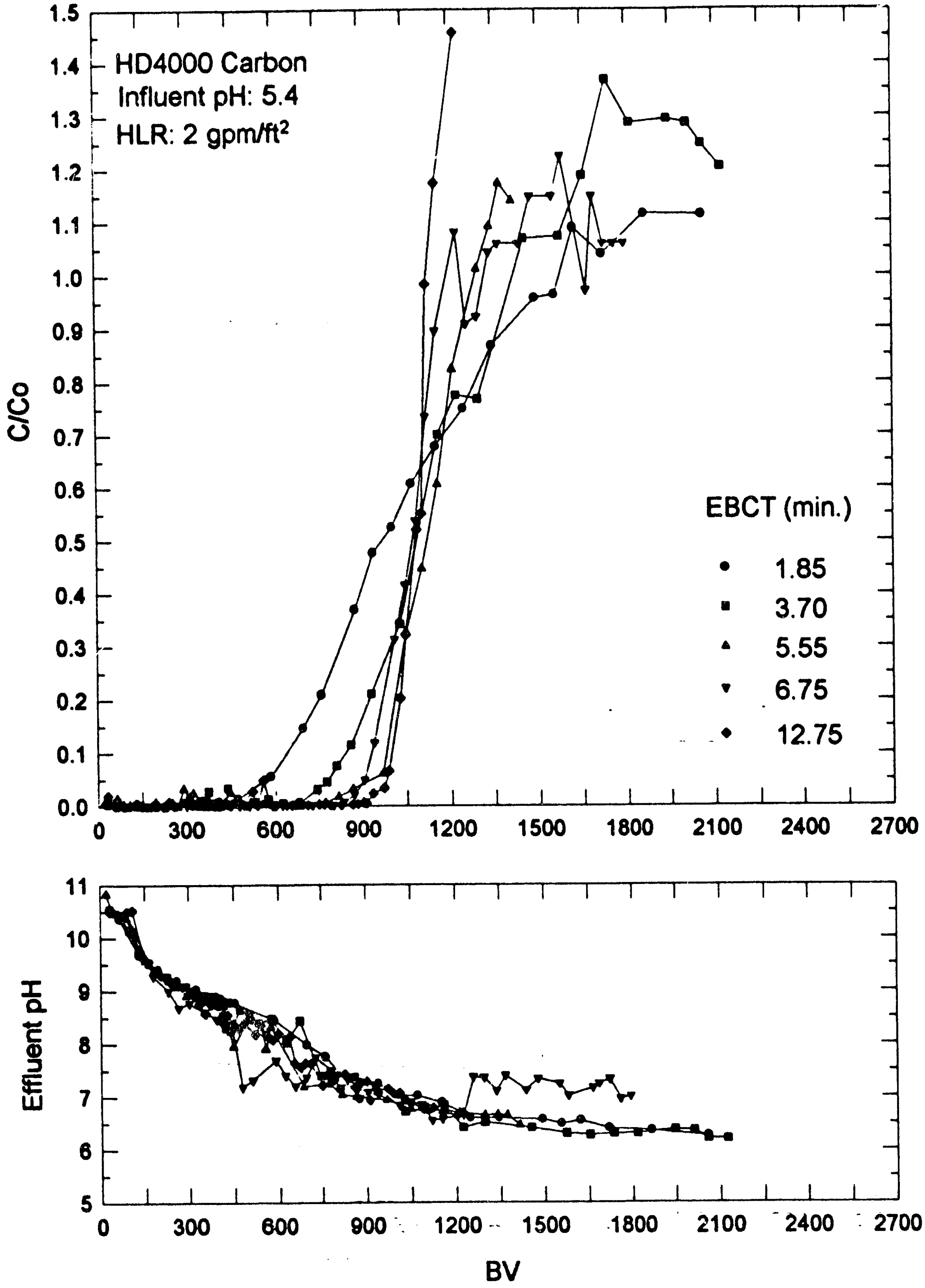

Figure 6. Pb Breakthrough and Effluent pH Curves for EBCTs of 1.85, 3.70, 5.55, 6.75, and 12.75 Minutes

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Table 3. Summary of EBCT Experiments at 1 mg/L Pb

EBCT (minute)	BV at Breakthrough	BV at Exhaustion	X/M at Exhaustion (mg/g)
1.85	520	1500	1.85
3.70	750	1350	2.02
5.55	850	1250	2.02
6.75	875	1160	1.96
12.75	950	1120	2.32

6.3 Effect of Phenol on Pb Removal

In Figure 7 and 8, Pb breakthrough and effluent pH curves in the absence and presence of phenol are presented for EBCTs of 0.93 and 12.75 minutes, respectively. Pb broke through earlier in the presence of phenol. In Table 4, BVs treated at breakthrough and exhaustion and X/M at exhaustion are presented for data in Figures 7 and 8. The presence of phenol decreased Pb surface loading (X/M) by about 15 percent for an EBCT of 0.93 minutes and by about 23 percent for an EBCT of 12.75 minutes. Possible reasons for this include: 1) phenol adsorption decreased the number of surface sites available for Pb desorption and 2) a lower column pH resulted when phenol was present. For the latter reason, the reader is referred to Figure 1 where the strong affect of pH on Pb removal is demonstrated (Pb removal decreased with decreasing pH). The effect of Pb on phenol removal was being studied at the time this report was being prepared.

Table 4. Summary of the Effect of Phenol on Pb Removal

EBCT (minute)	Influent Conditions	BV at Breakthrough	BV at Exhaustion	X/M at Exhaustion (mg/g)
0.93	1 mg/L Pb - 0 mg/l Phenol	275	1600	1.81
0.93	1 mg/L Pb - 10 mg/l Phenol	325	1600	1.54
12.75	1 mg/L Pb - 0 mg/l Phenol	950	1120	2.32
12.75	1 mg/L Pb - 10 mg/l Phenol	850	1070	1.77

6.4 Effect of Pb Concentration

The effect of Pb concentration was investigated using three influent lead concentrations (50, 10, and 1 mg/L) and three EBCTs (1.85, 3.70, and 5.55 minutes). Pb breakthrough curves for EBCTs of 1.85, 3.70, and 5.55 minutes are presented in Figures 9 through 11, respectively. In Table 5, a summary BVs treated at breakthrough and exhaustion and X/M at exhaustion are presented for data in Figures 9 through 11. As the Pb concentration increased, breakthrough and exhaustion of the columns occurred at lower BV's (*i.e.*, a larger volume of wastewater was treated at lower influent concentrations). However, the amount of lead removed (X/M) increased dramatically as the influent lead concentration increased. The increase in removal with increasing contaminant concentration is not uncommon and is caused by an increase in the sorption driving

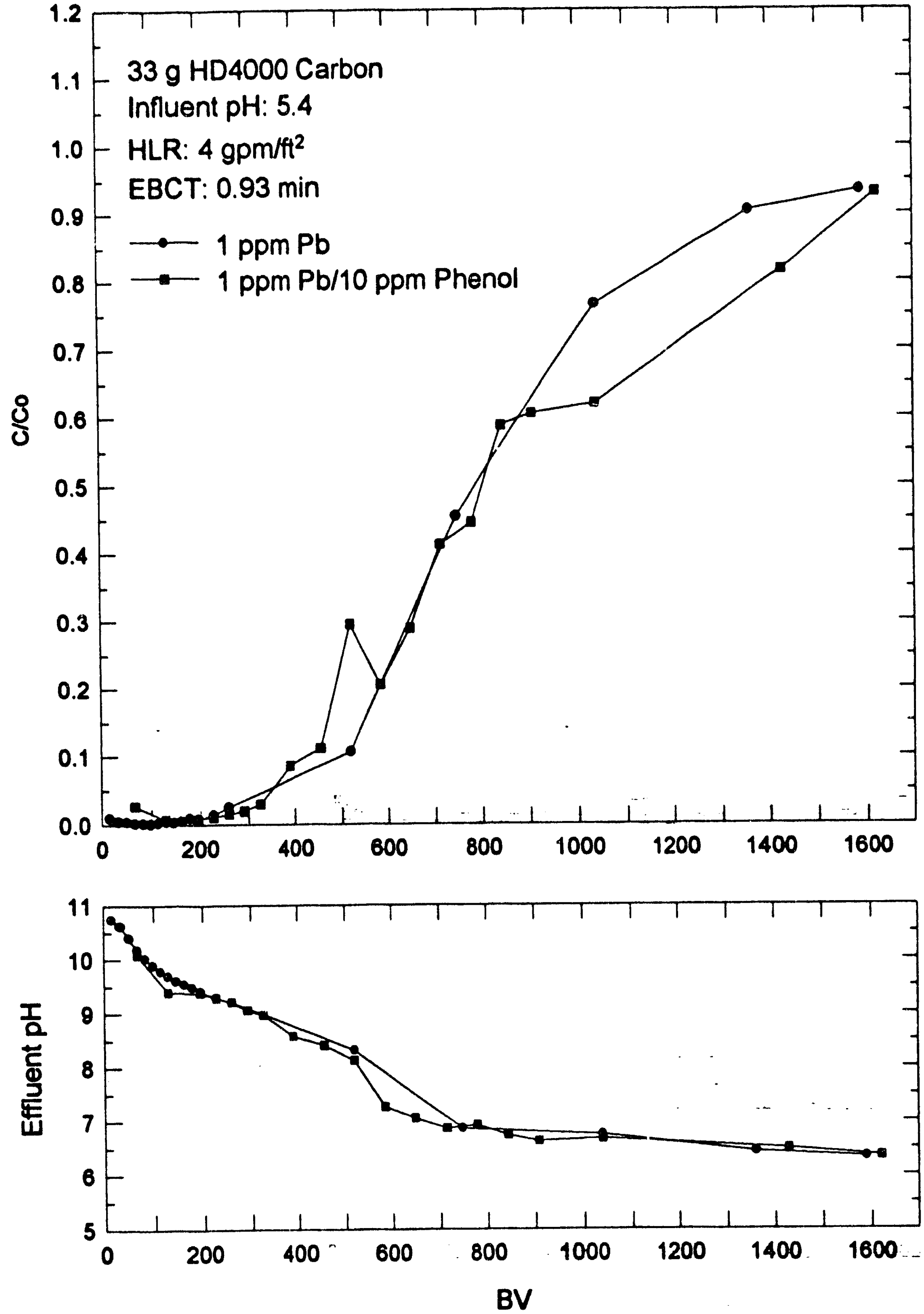

Figure 7. Pb breakthrough and Effluent pH Curves in the Absence and Presence of Phenol for an EBCT of 0.93 Minutes

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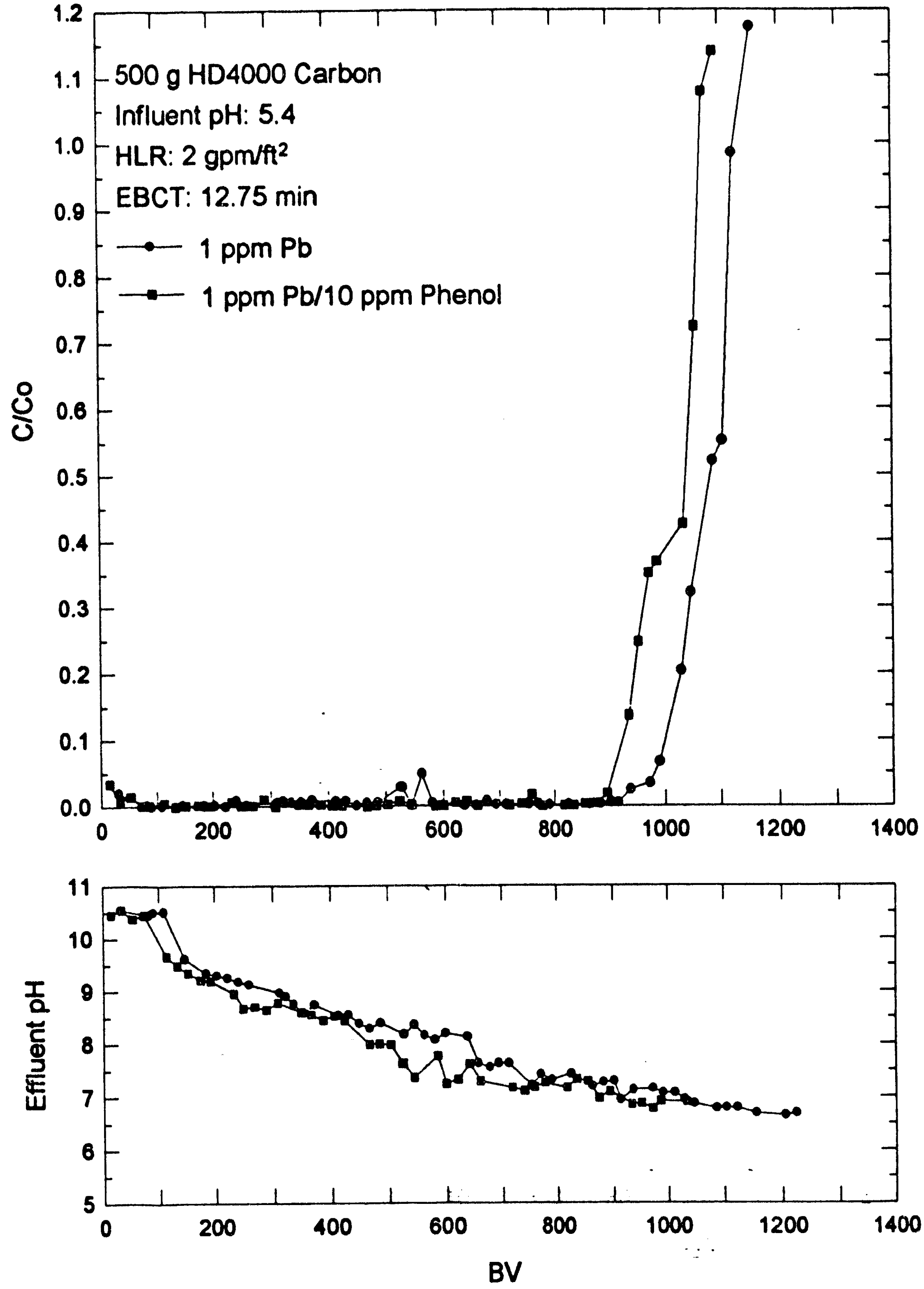

Figure 8. Pb Breakthrough and Effluent pH Curves in the Absence and Presence of Phenol for an EBCT of 12.75 Minutes

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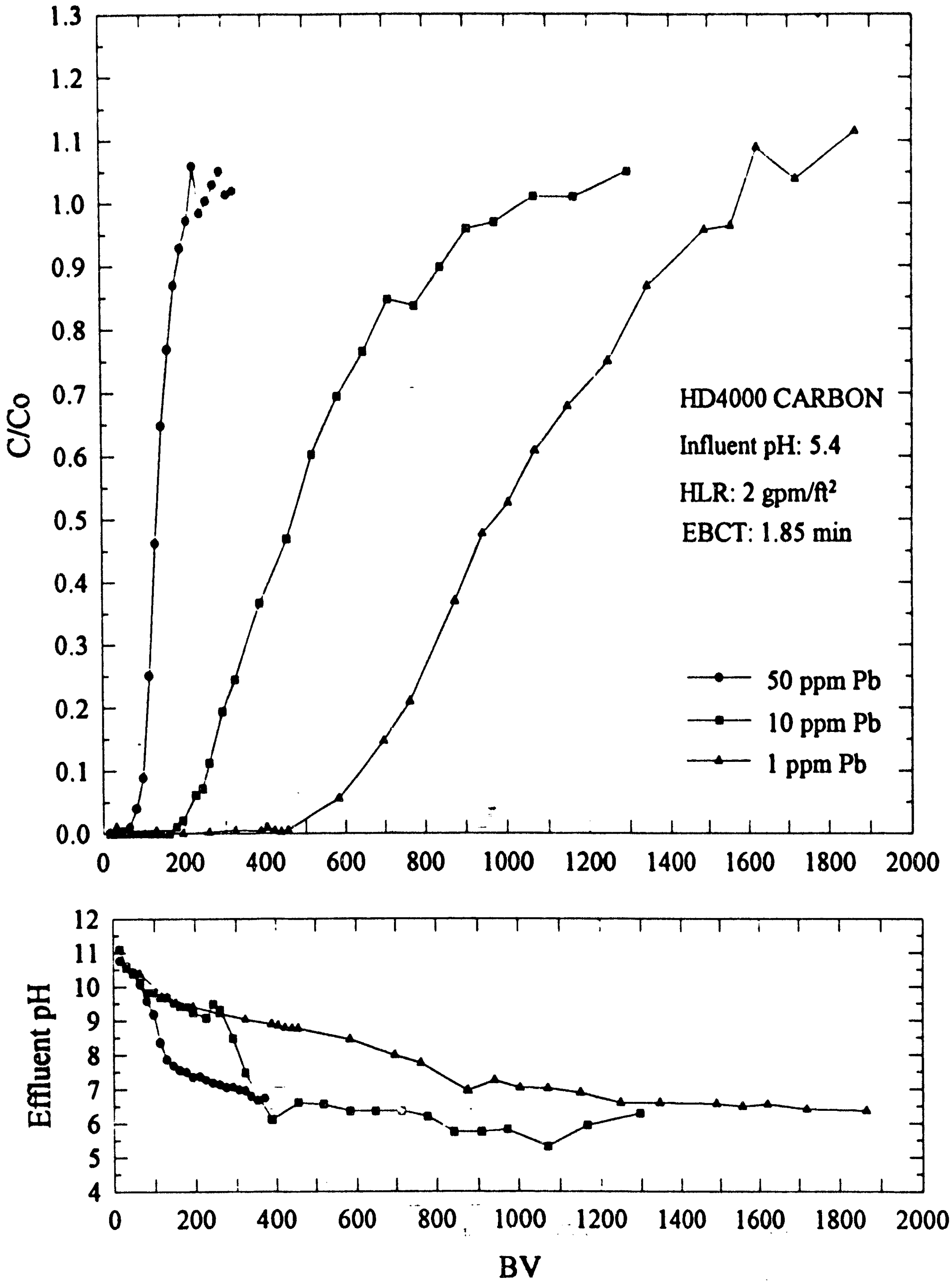

Figure 9. Pb Breakthrough Curves for Influent Pb Concentrations of 1, 10, and 50 mg/L for an EBCT of 1.85 Minutes

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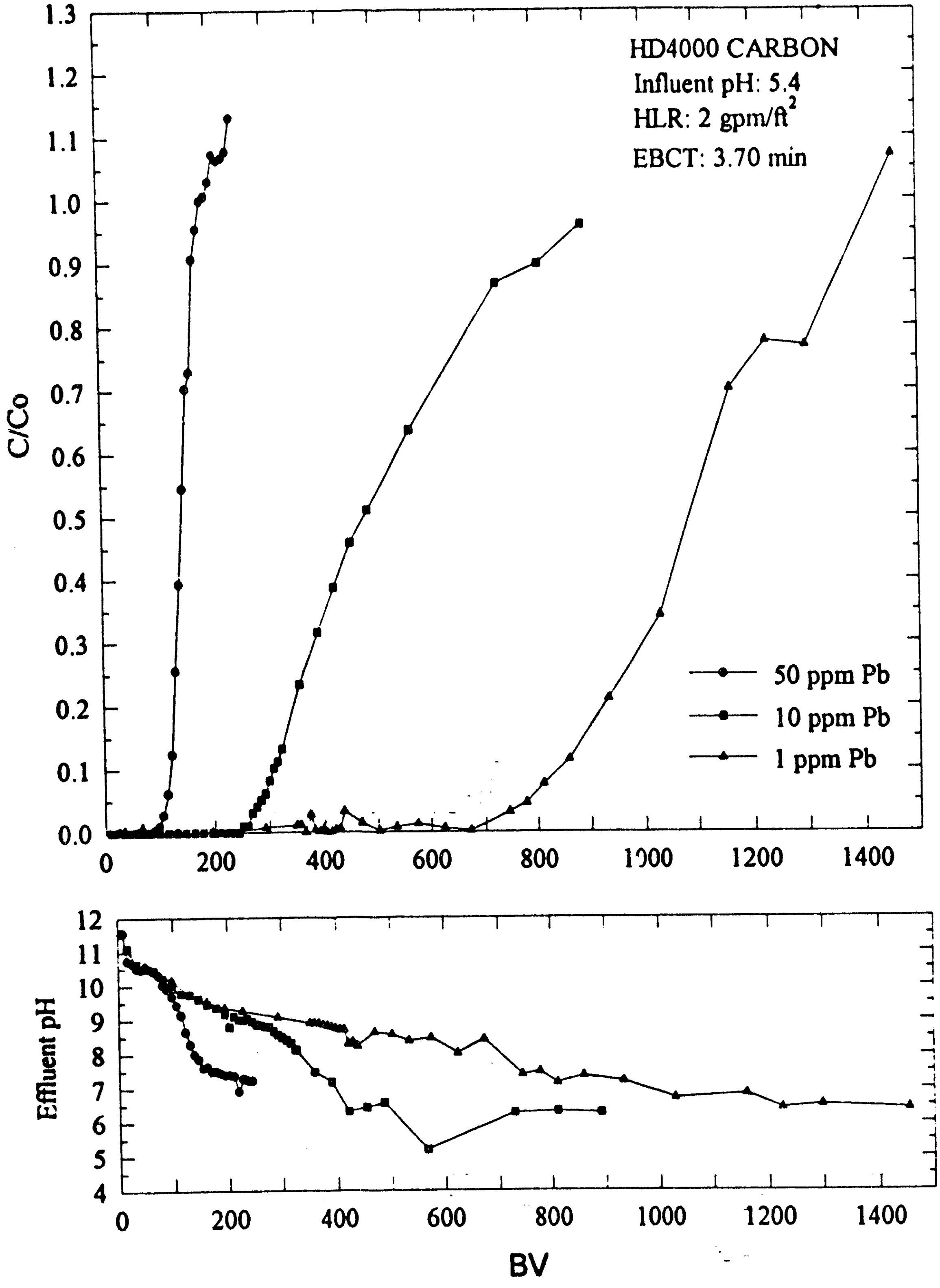

Figure 10. Pb Breakthrough Curves for Influent Pb Concentrations of 1, 10, and 50 mg/L for an EBCT of 3.70 Minutes

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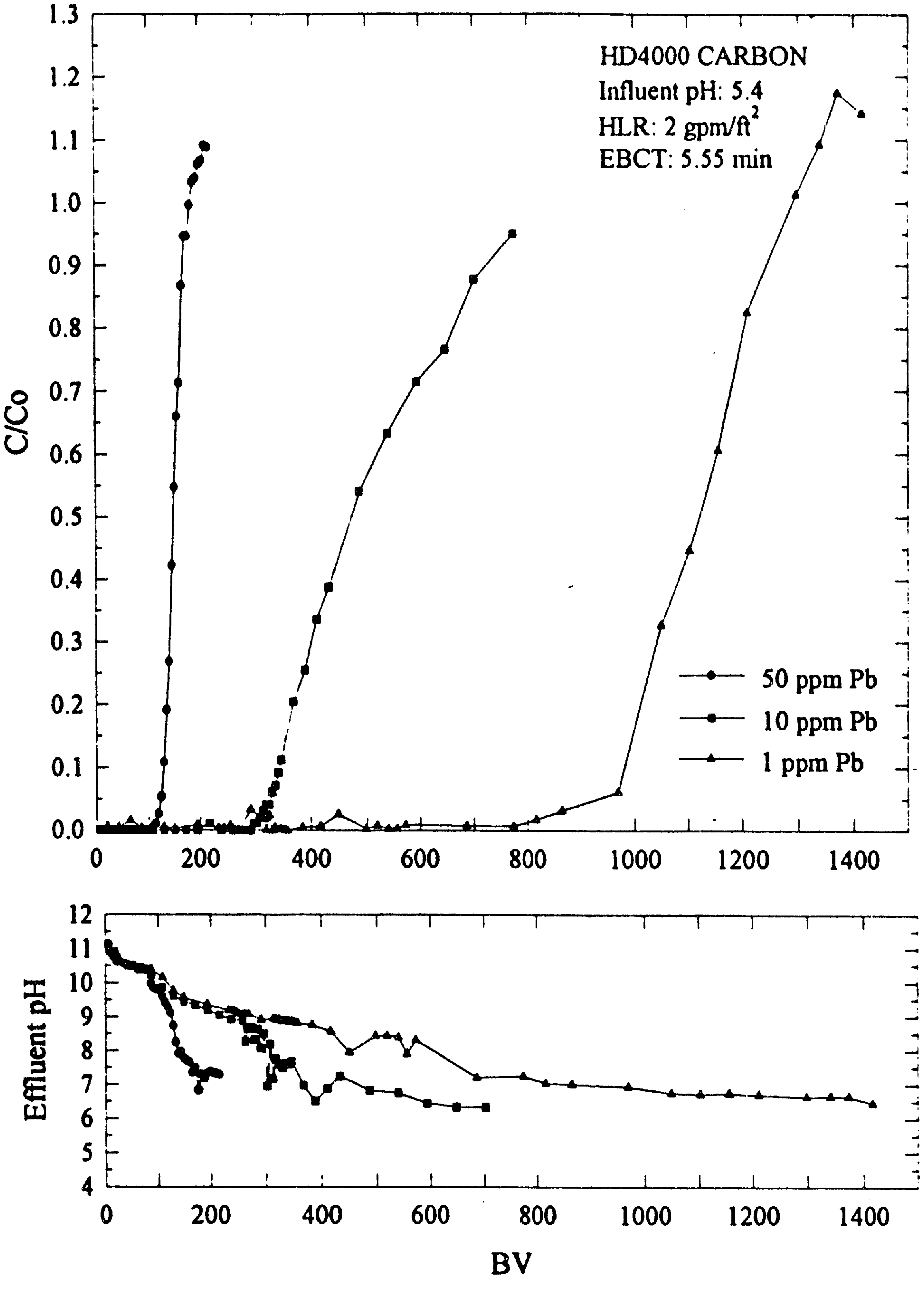

Figure 11. Pb Breakthrough Curves for Influent Pb Concentrations of 1, 10, and 50 mg/L for an EBCT of 5.55 Minutes

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force. The sorption driving force is related to the difference in concentration between the solution and surface (the concentration gradient is larger at higher influent concentrations). In addition, at higher lead concentrations, Pb is more easily precipitated on the carbon surface or in the carbon pore. The overall result is that as the Pb concentration increases, there is more opportunity for the Pb to be removed by the carbon. In summary, more waste was treated at low Pb influent concentrations but the mass of lead removed at higher influent Pb concentrations.

Table 5. Summary of the Effect of Influent Pb Concentration

EBCT (minute)	Influent Pb (mg/L)	BV at Breakthrough	BV at Exhaustion	X/M at Exhaustion (mg/g)
1.85	1	520	1500	1.85
	10	190	925	10.0
	50	80	240	15.2
3.70	1	750	1350	2.02
	10	265	885	10.1
	50	108	195	16.1
5.55	1	850	1250	2.02
	10	320	700	10.2
	50	125	190	2.02

6.5 Effect of Taking Lead Column Off-Line Following Exhaustion.

For the experiments where three columns were used in series it was observed that following exhaustion, Pb from the lead (first) column desorbed and entered the second column where it was removed. A similar phenomenon occurred when the second column reached exhaustion (Pb desorbed lead from column 2 and was removed in column 3). The lowering of the column pH as the column reached exhaustion caused this phenomenon (recall that adsorption decreases as pH decreases). The desorption of Pb from the upstream columns could conceivable decrease the effectiveness of the GAC column system because the Pb removal capacities of upstream columns (columns 1 and 2) are not fully utilized. To determine if process performanceing was suffering, a set of experiments were conducted in which the upstream column was removed from operation at the point of exhaustion. In Figure 12, Pb breakthrough and effluent pH curves are presented for serial columns 1, 2 and 3 (EBCTs of 1.85, 3.70, and 5.55 minutes). The solid symbols represent the experiment where the exhausted column was taken off -line and the open symbols represent the experiments where the exhausted column was left on-line. Pb breakthrough and effluent pH curves were identical for the two scenarios. In Table 6, a summary BVs treated at breakthrough and exhaustion and X/M at exhaustion is presented for the data in Figure 12. Leaving the exhausted columns on-line did not adversely affect performance.

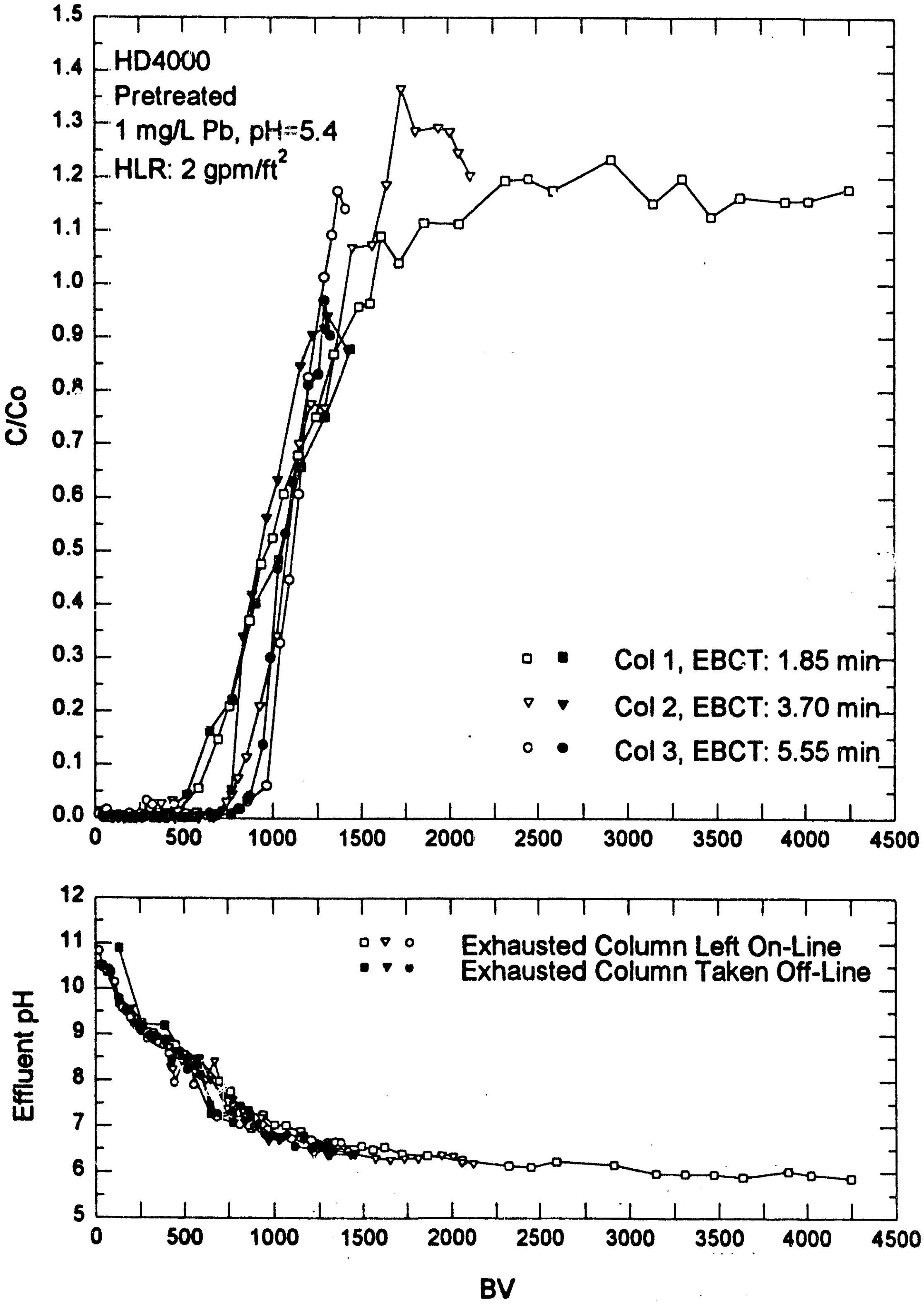

Figure 12. Pb Breakthrough and Effleunt pH Curves for Serial Columns 1, 2 and 3 (EBCTs of 1.85, 3.70, and 5.55 minutes)

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Table 6. Summary of the Effect of Taking Exhausted Columns Off-Line

Column No. (EBCT, min)	BV at Breakthrough	BV at Exhaustion	X/M at Exhaustion (mg/g)
Exhausted Column Left On-Line			
1 (1.85)	530	1500	1.85
2 (3.70)	750	1350	2.02
3 (5.55)	850	1250	2.02
Exhausted Column Taken Off-Line			
1 (1.85)	510	1450	1.95
2 (3.70)	760	1300	1.88
3 (5.55)	850	1300	2.11

7. CONCLUSIONS

The goal of this research is to investigate the feasibility (technical and economic) of using granular activated carbon (GAC) columns to treat an aqueous waste stream containing organic contaminants, heavy metals, and radionuclides. If the GAC column process is demonstrated to be technically feasible and cost effective, it will represent a significant tool in the plan to remediate the nation's hazardous waste sites. As of the writing of this report, laboratory works has been completed to determined the following:

1. Effect of column pretreatment on Pb removal.
2. Effect of the empty bed contact time (EBCT) on column performance.
3. Effect of phenol on Pb removal.
4. Effect the influent Pb concentration on column performance.
5. Efficacy of taking the lead GAC column off-line following exhaustion.

Column pretreatment increased the bed volumes (BVs) of wastewater treated at breakthrough and exhaustion by 31 and 7 percent, respectively and increased the total Pb removed (X/M, mg Pb/g carbon) by 17 percent over the virgin column. Based on these results, regeneration should not adversely affect column performance.

The BVs treated at breakthrough increased with increasing EBCT while the BVs treated at exhaustion decreased with EBCT. More BVs were treated at exhaustion for the lower EBCTs because there was significant Pb removal capacity remaining the pre-breakthrough period (*i.e.*, BVs treated at breakthrough decreased with decreasing EBCT). The Pb surface loading (X/M) remained fairly constant for EBCTs between 1.85 and 6.75 minutes and increased by about 15 percent when the EBCT was increased to 12.75 minutes. Compared with organic contaminants, for which adsorption is heavily dependent on the EBCT, Pb adsorption is relatively insensitive to the length of time the contaminant spends in the column.

The presence of phenol decreased Pb surface loading (X/M) by about 15 percent for an EBCT of 0.93 minutes and by about 23 percent for an EBCT of 12.75 minutes. Possible reasons for this

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include: 1) phenol adsorption decreased the number of surface sites available for Pb desorption and 2) a lower column pH resulted when phenol was present. The effect of Pb on phenol removal was being studied at the time this report was being prepared.

Breakthrough and exhaustion of the columns occurred at lower BVs as the Pb concentration increased (*i.e.*, a large volume of wastewater was treated at lower influent concentrations). However, the amount of lead removed (X/M) increased dramatically as the influent lead concentration increased. The increase in removal with increasing contaminant concentration is not uncommon and is caused by an increase in the sorption driving force. In addition, at higher lead concentrations, Pb is more easily precipitated on the carbon surface or in the carbon pore. The overall result is that as the Pb concentration increases, there is more opportunity for the Pb to be removed by the carbon.

For the experiments where the exhausted column was either taken off-line and or left on-line, both the Pb breakthrough and effluent pH curves were identical. Thus, leaving the exhausted columns on-line did not adversely affect performance.

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INSTRUMENTATION

MONOLAYER AND MULTILAYER SELF-ASSEMBLED POLYION FILMS FOR GAS-PHASE CHEMICAL SENSORS

(MC-7)

Quarterly Technical Progress Report
for Period January 1 through March 31, 1994

Work Performed Under
Contract Number: 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

By

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Chemistry Department
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May 1994

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1.0 EXECUTIVE SUMMARY

The calibration of the Kintek vapor generator was checked and found to be accurate. The survey of combinations of polyions for Multilayer deposition was continued, and the ellipsometry response of these layers to benzene and chloroform was mapped. Purification and ion exchange reactions of polyions was performed by dialysis. A series of thick Polyion coatings was deposited on SAW crystals by spray methods and the response of the coated crystals was determined for air streams with fixed concentrations of benzene, trichloroethylene and water vapor. None of the coated SAW crystals exhibited any enhanced response to the organic vapors above the level observed on an uncoated SAW crystal.

2.0 Results

A. Calibration of the Kintek Vapor Generator.

The air stream used to test the response of the SAW sensors has the organic components introduced by permeation tubes in the Kintek vapor generator. The organic liquid in the permeation tube diffuses through the tube walls and into the contiguous air stream at a rate which depends on temperature. The Kintek vapor generator allows control of both the permeation tube temperature and the gas flow rate; these two parameters combined with the leak rate of the permeation tube determines the concentration of the organic vapor in the air stream. Calibration data for each tube are provided by the vendor, but the calibration needs to be checked.

The simplest and most direct method for checking the calibration is to weigh the permeation tube before and after it has stayed in the oven at a fixed period of time at a fixed temperature. A sample calculation is given to show how both the concentration and the calibration of the permeation tube is obtained. At 30°C, the vendor's stated emission rate for a benzene permeation tube is 7,415 nL of benzene (normalized to standard temperature and pressure) per minute. For a flow rate of 260 mL of air per minute, the concentration of benzene should be:

$$\text{Conc.} = (7415/260)(303\text{K}/273\text{K}) = 32 \text{ nL benzene per mL air} = 32 \text{ ppmv}$$

The theoretical weight change for the tube after 3,930 minutes (almost 3 days) is:

$$\text{Wt.} = (7415 \text{ nL/min})(3930 \text{ min})(1 \text{ atm}/((0.08206 \text{ L.atm/mol.K})(273\text{K})))(78 \text{ g/mol})$$

$$= 0.10 \text{ g}$$

The actual weight change was 552.63 g - 552.53 g = 0.10 g. Figures 1 and 2 show the theoretical and actual weight changes observed for both the benzene and the trichloroethylene permeation tubes as a function of temperature. Not shown are the times of the experiment, which were adjusted to keep the weight change above 0.1 g and below 1 g. The figures demonstrate that the observed

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weight changes (and hence permeation rates) were within 20% of the expected values based on the manufacturer's data. Consequently, the manufacturer's emission rates were judged to be sufficiently accurate for our purposes.

B. Survey of Polyion Multilayer Deposition on Model Substrates.

A systematic investigation of polycation and polyanion combinations was investigated for the purpose of defining the best conditions for forming multilayers. The experimental protocol and some preliminary results were given in the previous report. The experiments were carried out using ellipsometry and silicon wafer substrates. After deposition of a multilayer, the sensitivity of the multilayer to benzene and chloroform was assessed by exposing the film to air saturated with the respective vapor for hours and measuring the change in ellipsometric thickness. An increase in apparent thickness can be caused by swelling of the film and/or an increase in the film index of refraction; the latter might arise because of the high indices of refraction for the organic liquids. Table 1 summarizes the results of the investigation.

Table 1. Summary of Polyion Multilayer Deposition.

Silane	Polycation	Polyanion	pH	# of layers	Thickness	Swelling? C_6H_6	$CHCl_3$	Notes
en	PAA	PAC	2	10	65 Å	yes	no	(1)
en	PAA	PVS	7	10	47 Å	yes	no	(2)
en	PAA	PSS	2	10	65 Å	yes	no	(3)
en	PVP	PAC	4	10	102 Å	yes	no	(4)
en	PVP	PVS	3	10	26 Å	no		(5)
en	PVP	PVS	3	10	13 Å	no		(6)
en	PVP	PSS	3	10	122 Å	yes	no	(7)

Abbreviations: en = $(MeO)_3Si(CH_2)_3NH(CH_2)_2NH_2$, PAC = poly(acrylic acid, sodium salt), PAA = poly(allylamine hydrochloride), PVS = poly(vinylsulfonate, sodium salt), PSS = poly(styrenesulfonate, sodium salt), PVP = poly(4-vinylpyridine, hydrochloride salt).

Notes on Table 1:

(1) PAA layers were only 1 - 3 Å thick while PAC layers were ca. 9 Å thick.
(2) PAA deposition was very irregular; PVS layers were thin (3 Å).
(3) The thickness of the individual polyion layers was not monitored.
(4) PAC layers were ca. 14 Å thick while the PVP layers were ca. 4 Å thick.
(5) The thickness of the individual polyion layers was not monitored.
(6) The thickness of the individual polyion layers was not monitored.
(7) PSS layers were ca. 14 Å thick while the PVP layers were ca. 8 Å thick.

The total thickness in Table 1 included the thickness of the silane layer, which typically was 12 Å thick. The # of layers refers to the number of polyion layers; in each case the polyanion was adsorbed first because of the presumed cationic charge of the bound en-silane layer at neutral or acidic pHs. Swelling indicates an increase in apparent thickness of at least 5 Å.

Clearly the PVP/PVS combination did not successfully form multilayers. In all cases where the individual layer thicknesses were monitored, the polycation layer was thinner on the average than the polyanion layer. The most consistent deposition occurred when PVP was combined with PSS or PAC. In all of the thicker films, air saturated with benzene produced a significant increase in the multilayer thickness; the most dramatic case was the PAA/PAC multilayer, which increased from 65 Å to 81 Å after exposure to benzene vapor.

An attempt to isolate the swelling response of the benzene to a single polyion layer failed because the deposited layer was too thin to reliably measure changes in thickness.

C. Purification and Ion-Exchange of Polyions by Dialysis.

A dialysis membrane contains pores which pass low molecular weight molecules and ions but not high molecular weight compounds. A standard method for purifying water-soluble polymers is to place them in a dialysis bag and soak them in pure water. Low molecular weight impurities move out of the bag into the pure water (which is replaced regularly). The dialysis procedure is slow (1 - 3 days), but can be speeded up by stirring both the contents of the dialysis bag and the water bath.

This procedure was applied to three polymers: PSS, PAC and PVPMe (poly(4-vinyl-N-methylpyridine, methanesulfonate salt). The bags (Spectrapor) were composed of cellophane and had nominal molecular weight cutoffs of either 6,000 or 12,000 depending on the membrane. For the first two polyions, UV-VIS spectroscopy was used to follow both the transfer of low molecular weight impurities to the water bath and to determine the final concentration of the polyion at the end of the dialysis period. The concentration of the polyion remaining in the bag was reduced somewhat, and the pH of the dialyzed solution was 5 to 6. The dialyzed polyion solutions were used in the SAW crystal experiments (see below).

In order to replace the existing counter ion with another counter ion, the dialysis bag is filled with a solution of the polyion and an excess of the second counter ion as a salt. If ion exchange in the polyion is rapid, then removal of excess counter ions by dialysis should leave a polyion solution containing predominantly the new counter ion. PSS solutions containing Cu^{2+} or Ni^{2+} were prepared by this means starting with a 3-fold molar excess of the cations to the anionic sites. UV-VIS spectroscopy was used to estimate the final mole ratio of cations to anionic sites in the PSS. For Cu^{2+}, the ratio was 2.5 while for Ni^{2+}, it was 1.6; obviously not all of the excess cations had been removed during the 3-day dialysis period. A PVPMe solution was dialyzed with excess iodide in a similar manner. These polyion solutions were also used on SAW crystal experiments (see below).

Certain combinations of counter ions and polyions proved to be insoluble. Ferroin (iron(II) tris(*o*-phenanthroline) complex), a 2+ cation, and methylene blue (a +1 cation) both formed precipitates with PSS. The insolubility of polyions with large counter ions indicates that future work with large counter ions, particularly those with size- and shape-selective cavities, may require a modification of the self-assembly procedure. Surprisingly, solutions of Ag^+ with PSS or PAA also proved to be unstable; an off-color precipitate slowly formed. This may have been caused by the presence of chloride or other anions which react with Ag^+. Since Ag^+ is one of the cations which tends to form complexes with aromatics, another method for incorporating Ag^+ into polyion films was sought (see below).

D. Response of Polyion Coatings on SAW Crystals to Organic Vapors.

Since a preliminary experiment with a polyion multilayer on a SAW crystal showed no apparent sensitivity to a low concentration of benzene (see the previous report), a screening protocol was developed to more rapidly assess the response of the polyion/counter ion combinations to benzene and trichloroethylene (TCE). The polyions were deposited as relatively thick (and presumably non-uniform) films on the SAW crystal by aspirating a dilute (ca. 1 mM) polyion solution in a water/methanol mixture into a nebulizer (procured from an unused Atomic Absorption Spectrometer) and passing the SAW crystal rapidly and repeatedly through the spray. Tests on clean silicon wafers showed that this procedure produced more uniform films and gave better thickness control than simply placing a few microliters of polyion solution on the surface and allowing it to evaporate. An estimation of the amount of polyion film was obtained by measuring the frequency of the SAW crystal before and after deposition; in each case the crystal was allowed to equilibrate with a stream of dry air before measuring the frequency. Each step in the protocol lasted at least 30 minutes,

(a) Equilibrate the SAW crystal with flowing dry air overnight.
(b) Collect frequency data for at least 30 minutes in dry air.
(c) Challenge the SAW crystal with 3600 ppmv benzene, 0% R.H.
(d) Pass dry air over the crystal.
(e) Challenge the SAW crystal with 3400 ppmv TCE, 0% R.H.
(f) Pass dry air over the crystal.

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(g) Adjust the relative humidity to ca. 50% and allow the SAW crystal to stabilize (large beat frequency increases are observed).
(h) Challenge the SAW crystal with 3600 ppmv benzene, 50% R.H.
(i) Pass 50% R.H. air over the crystal.
(j) Challenge the SAW crystal with 3400 ppmv TCE, 50% R.H.
(k) Pass 50% R.H. air over the crystal.
(l) Pass 0% R.H. air over the crystal.

The protocol included responses of the crystal to the analytes in dry and humid air since the adsorption of water may affect the affinity of binding sites for the analytes. All experiments were performed at room temperature (ca. 23°C).

The behavior of a blank crystal (no coating) is illustrated in Figure 3; the order of the protocol is changed so that TCE is passed first over the crystal. The spikes observed at the beginning of the TCE challenge appear to be switching transients unrelated to the effect of TCE on the crystal oscillation frequency. Typically the organic vapors cause about a 1 ppm (200 Hz) increase in the beat frequency, indicating a slight adsorption of the organic vapor onto the SAW crystal surface. Raising the relative humidity from 0% to 55% changes the beat frequency by 12 ppm. The response of the blank crystal to organic vapors in the humid air is about the same as in dry air. A periodic ripple appears in the SAW frequency when wet air is passing over the crystal; this ripple is believed to be caused by back pressure oscillations in the humidifier section of the air generator. Its presence reduces the limit of detection for the SAw sensor. The final passage of dry air over the crystal does not result in the crystal returning to the original oscillation frequency; we hypothesize that the humid air has caused irreversible changes in the structure of the SiO_x protecting layer that covers the electrodes on the crystal.

Figures 4 and 5 show the response of a SAW crystal coated with PSS/Ni^{2+}. The main feature of Figure 4 is the enormous response of the coated crystal to the step in relative humidity. An enlargement of the frequency response to benzene and TCE in dry air is shown in Figure 5. Here the crystal exhibits rapid response in the sub-ppm range, indicating that the coated crystal is <u>less</u> sensitive to the organic vapors than the blank crystal.

Frequency changes for both the organics and for water vapor for six coated crystals and one blank crystal are summarized in Table 2. The approximate thickness of the coating is listed as the change in beat frequency caused by deposition of the coating. The sixth entry is a PAC coating which was subsequently dipped in a 5 mM $AgNO_3$ solution with the expectation that some of the Ag^+ would migrate into the PAC layer; this step resulted in the formation of silver deposits on the wires connected to the aluminum pads. The seventh entry is a repeat of the pure PAC layer experiment using a thicker coating. The main conclusion obtained from Table 2 is that the polyion coatings, with and without cations designed to enhance binding of aromatics, exhibit smaller or equal frequency changes to benzene and TCE as the blank crystal. <u>These coatings function well as humidity sensors but not as nonpolar organic vapor sensors</u>. A possible cause for the reduced response to organic vapors is that the hydrophilic polymers actually inhibit the adsorption of the

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hydrophobic vapors onto the crystal.

TABLE 2: Response of Polyion Coatings to Benzene, TCE and Water Vapor

			0% R.H.		50% R.H.		Water
	Layer	Thickness	Benzene	TCE	Benzene	TCE	Vapor
1.	Blank	0	1.5	1.0	1.5	1.0	12
2.	PSS/Na	84	0.2	2.0	0.0	0.0	80
3.	PSS/Cu	56	0.5	1.2	0.0	0.0	55
4.	PSS/Ni	213	0.4	1.4	0.0	0.0	250
5.	PAC/Na	5.5	0.5	0.8			70
6.	PAC/Ag	75	0.8	1.1			
7.	PAC/Na	113	0.1	0.2			

All data are frequency changes in ppm; 1 ppm = 200 Hz. An estimate of average coating mass can be obtained from the approximate relation 1 ppm = 4 ng/cm^2. The organic vapor concentrations were 3600 ppmv for benzene and 3400 ppmv for TCE.

E. Future Directions.

Because the ellipsometry experiments suggest that some response of multilayers to benzene vapor is anticipated, work will continue with the polycation coatings and with the polyion multilayer coatings. It is also judicious to test some typical gas chromatography stationary phases (e.g. Carbowax 20M) in order to confirm the ability of the SAW system to respond to benzene and TCE. A more diverse and non-traditional selection of coatings will be examined in the future. These will include (a) CuCl and CuBr crystals, deposited by spray-coating from an acetonitrile solution, (b) Stoddard's ion, a cyclophane with a high affinity for benzene (to be donated by Prof. Diane Smith at San Diego State University), and (c) polyions precipitated with long chain counter ions. The first coating is based on the known affinity of Cu(I) for aromatics, alkenes and alkynes [1]. Cu(I) salts would be difficult to incorporate into polyions because of their insolubility in water and their tendency to disproportionate to Cu(0) and Cu(II). The last coating is motivated by the observation that the largest response of various polymer coatings to benzene was found for poly(vinyl stearate), a polymer with long alkane side chains [2].

3.0 References

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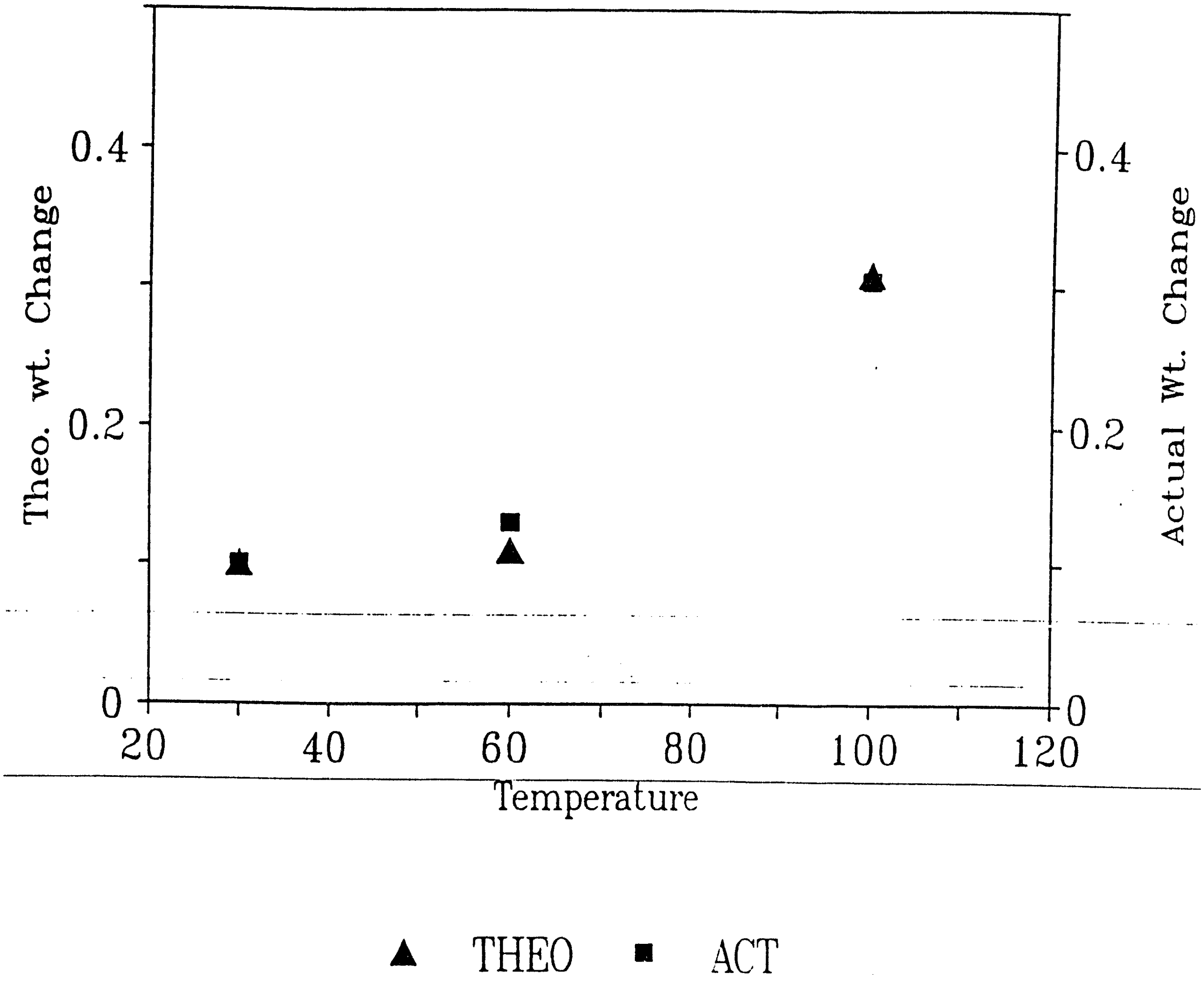
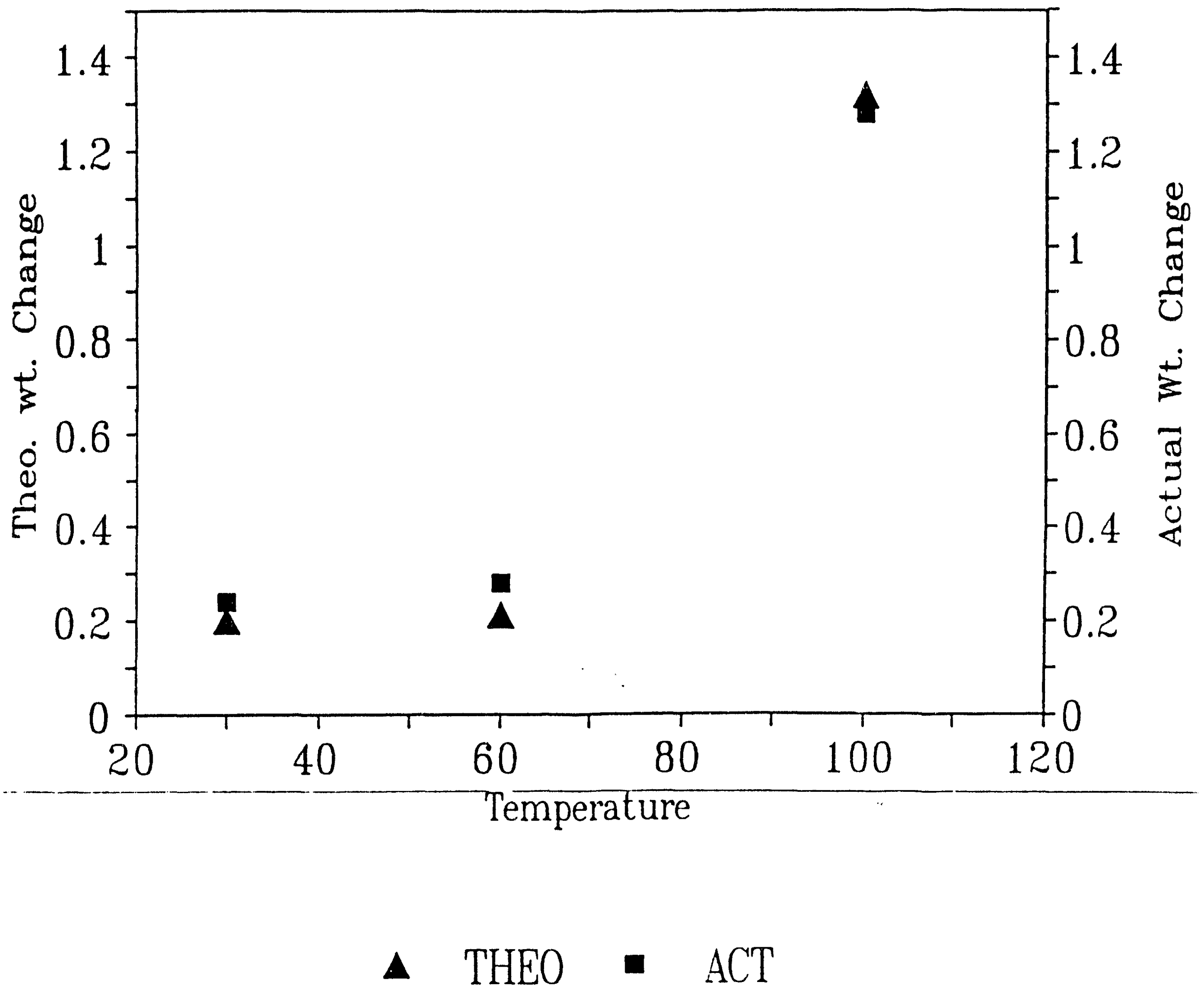
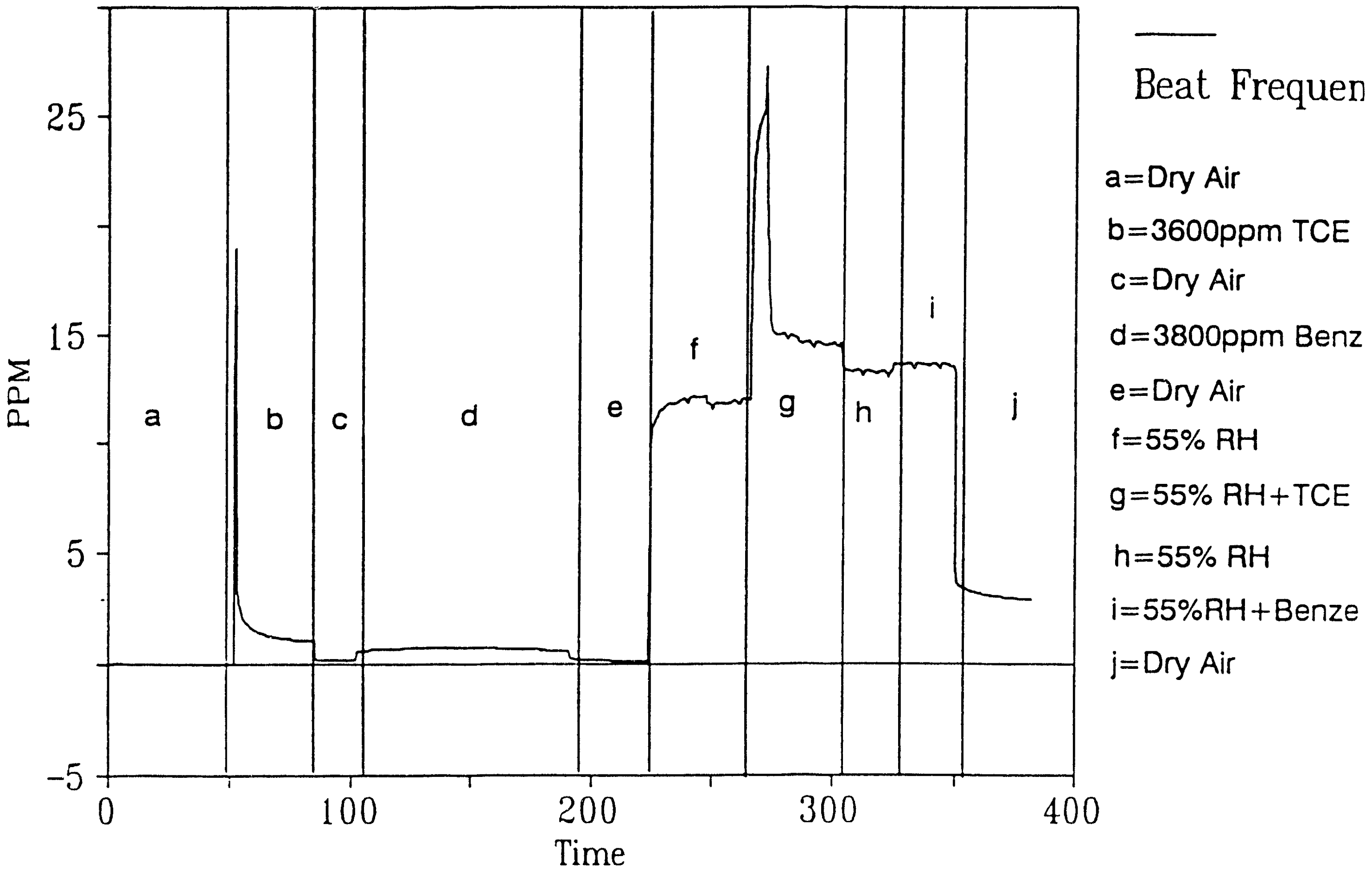
Benzene Permeation Source Calibration Verification



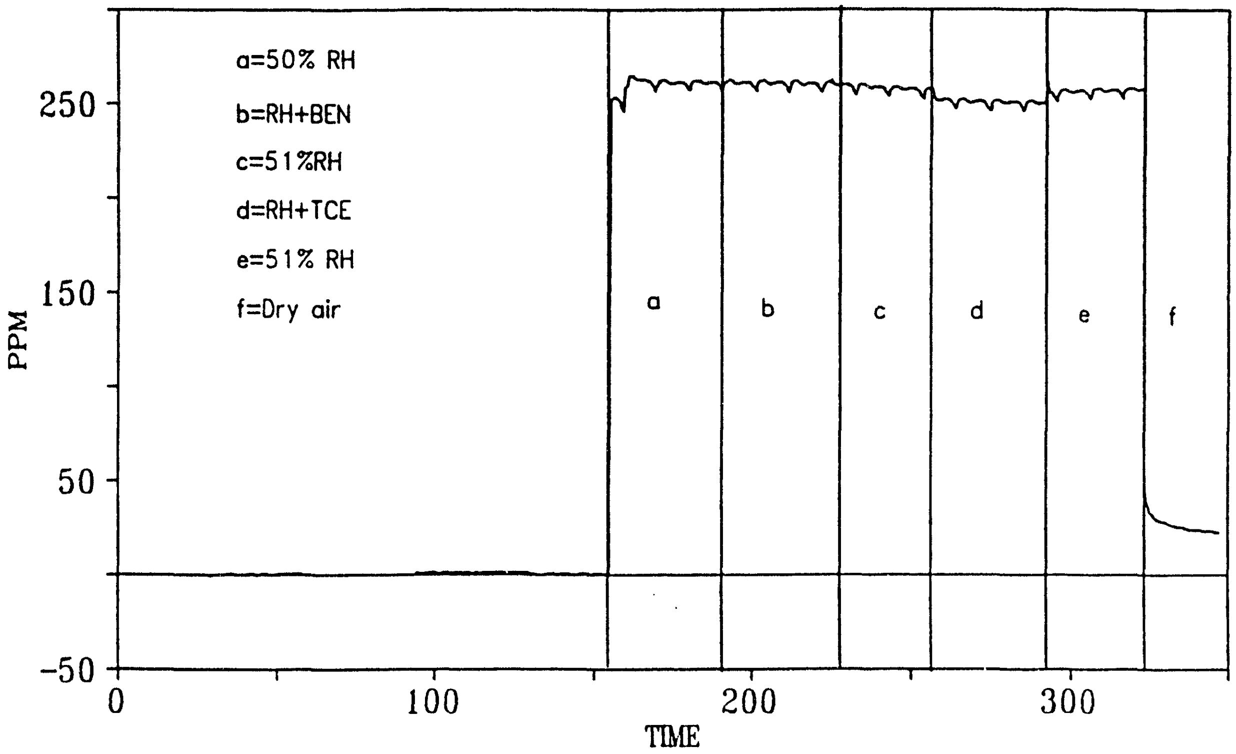
Trichloroethylene Permeation Source Calibration Verification



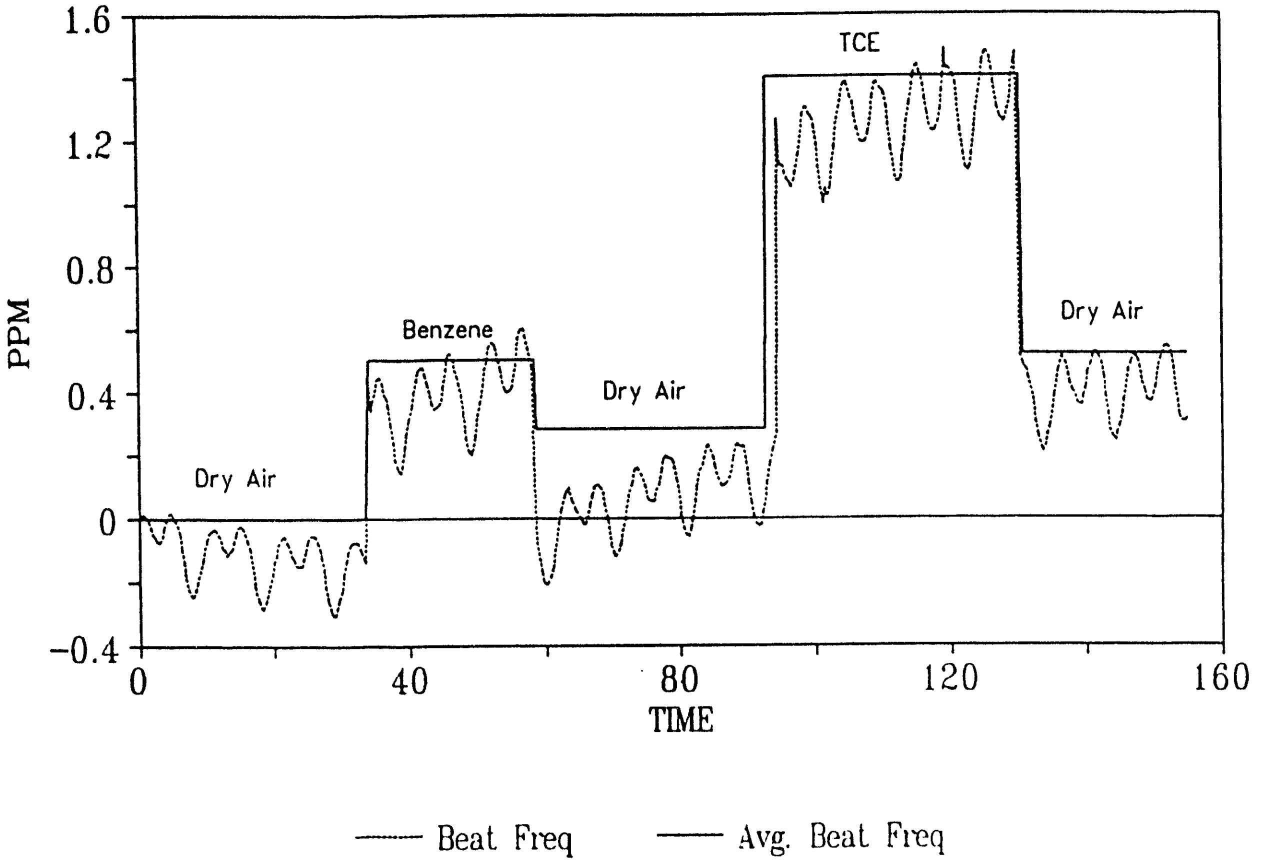
BLANK--Exposure to Dry Air/Benzene/TCE and RH--p0224-01



Exposure of PSS/Ni Coated SAW Crystal to Benzene, TCE, and RH--p0317-01.wq1



Enlargement of first 155 min--p03170-01



COMPACT MERCURIC IODIDE DETECTOR TECHNOLOGY DEVELOPMENT
(MC-22)

Quarterly Technical Progress Report
for Period January 1 through March 31, 1994

Work Performed Under
Contract Number: 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
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By

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May 1994

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1.Executive Summary

The objective of this research is to develop a mercuric iodide based detector technology for detecting radiation in low level mixed waste processing. It is a well established fact that application of an autonomous robotic device is the most appropriate for such task. Current radiation detectors need cryogenically cooling system and are awkward for use on autonomous robots. In this respect, mercuric iodide detectors are supposed to be very effective sensors for mobile robotic applications since they can detect radiation at room temperature without cryogenically cooling. It has high atomic mass (Z) for efficient radiation interactions i.e. high absorption capacity, large enough band gap for high resistivity and low leakage current, small enough band gap so that electron/hole ionization energy is small (less than 5 eV). Although the research work in the area of mercuric iodide semiconductors started in US., Europe, and other countries in early seventies , unfortunately some device related issues are not yet completely solved to realize the full potential of this semiconductor as radiation detector. Even it is extremely difficult to obtain a single crystal of mercuric iodide, since it is not commercially available. Therefore, one step of this research is to grow mercuric iodide crystals. The second and third steps will be dedicated to address some issues related to mercuric iodide detector processing and modeling . The final step will deal with issues related to the detector fabrication. In this report we will present our accomplishment towards step one.

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2.Technical Background

2.1 Why Mercuric Iodide:

Mercuric Iodide is a semiconductor detector having high atomic mass (Z) for efficient radiation interactions i.e. it has high absorption capacity, large enough band gap for high resistivity and low leakage current, small enough band gap so that electron / hole ionization energy is small (less than 5 eV). the feature that distinguishes Mercuric Iodide from many other compound semiconductors is the relatively better collection of electron hole pairs produced by the ionizing radiation.

2.2 Potentiality of Mercuric - Iodide as gamma ray detector.

It has very high potentiality to be used as gamma ray detector in radioactive decontamination process, since 1) it can be operated at room temperature without cryogenic cooling , 2) it has high resolution and 3) low polarization rate.

2.3 Survey of Previous Literature on crystal growing

The crystals of HgI_2 has been reported to be grown by solution as well as from vapor phase. The solution techniques reported in literature so far are:

i) By solvent evaporation [1].

ii) By slow cooling

iii) By shifting of equilibrium of Dimethyl Sulfoxide (DMSO) complexes [2]

iv) By gel technique [3]

The commonly reported vapor technique for HgI_2 crystal growth includes:

i) De sublimation [4]

ii) Pulling from vapor phase[4,5,6]

iii) Temperature oscillation method[7,8]

For the detector fabrication purpose very high quality crystal of HgI_2 is needed. Also the crystal should have high resolution and high collection efficiency.

In general growing of crystals from solution is comparatively an easy technique though the crystals grown from solvent evaporation and slow cooling are comparatively smaller in size than the one grown from vapor technique. Crystals of volume in the range of 0.1 - 0.5 cm^3 are reported from Dimethyl sulfoxide (DMSO) solution growth. Also the crystals from DMSO technique are reported to be quite pure and perfect but the growth rate is very slow (0.1 mm to 0.05 mm per day). Vapor phase crystals in same volume range are reported but of poor perfection and demands very high purity starting material. Also preventing or suppressing parasite nucleation is very difficult if not impossible (because of supersaturation). The set up for vapor technique is also pretty tedious as the vapors of HgI_2 are poisonous and cannot be disposed of in atmosphere; these all leads to designing, fabricating and testing the set up for vapor technique and taking all the precautionary measures to avoid the exposure to HgI_2 vapors which in itself needs 6-8 months.

On the other hand the method of growing single crystal of mercuric iodide from solution presents many advantages over other methods. The main advantage is that it works at temperatures near room temperature under atmospheric pressure. The growth process often takes place isothermally under suitable hydrodynamic conditions which are easy to handle. The crystal growth proceeds frequently layer by layer and crystal show often the vapor growth habit. As a result, one obtains usually high purity single crystals free of stresses and strains[9].

Also solution growth can be seeded and under proper conditions of growth may yield low dislocation density single crystal. If the cycle of growing crystal is followed 2-3 times using for every successive cycle the crystal of previous growth in place of HgI_2 powder, sufficiently big (still volume in 0.1-0.2 mm^3), pure and perfect crystal for preliminary studies (for the purpose of experimentation) could be grown. So it was planned to grow crystal from solution.

Solubility and temperature are two very important factors determining the crystal growth from solution. Greater the solubility, better are the chances of growth of crystal from that solvent. The other important factor is temperature at which crystal could be grown because higher the temperature, higher is the driving force. The highest temperature that could be attained for growing the crystal from a particular solvent is governed by the boiling point of that solvent. So these two factors will be considered along with the other factors reported in literature for crystal growth.

The Solvents that has already been reported in literature[3] so far for HgI_2 crystal growth are:

i) HI

ii) KI- water solution

iii) Sodium metasilicate gels

iv) Acetone

However, carefully studying solubility data(see table 1[10]) we tried to grow crystals using the following solvents:

i) Acetone

ii) Methanol (MeOH)

iii) Castor Oil

iv) Dimethyl sulfoxide(DMSO)

In the following section we will present our experimentation, results and observations regarding crystal growth.

3. Experimental Methodology for developing crystals

The growth of HgI_2 crystal from solution was carried out in two ways:

i) Evaporation Technique

ii) Cooling the solution

The general outline of experimentation was:

a) First the temperature of solution in the beaker was calibrated with the temperature of outer wall of beaker. This was needed because during crystal growth the temperature could be monitored only through a thermocouple attached (kept in touch) with outer wall of beaker as the beaker in which crystal is grown is covered with glass plate or cork. For the calibration purpose water was used as the solvent in the beaker. The arrangement is shown in fig.1

b) In second step a saturated solution of HgI_2 powder with the solvent from which the crystal has to be grown is prepared at temperature close to the boiling point of solvent.

c) A seed crystal is added to the saturated solution for preferential growth.

d) Either the solution is evaporated at constant temperature or brought down by couple of degrees and crystal grown at constant temperature. The arrangement for crystal growth is shown in fig 2.

4.Observations and discussion

4.1 Crystal Grown from Acetone:

From the solubility data 5.72 % by weight (HgI_2) shall be dissolved in acetone at 58^oC to get the saturated solution[44].

Calculations for making saturated solutions:

Specific gravity of acetone = 0.787

Weight of 100 ml of acetone = 100 X 0.787 = 78.7 gms

5.72% of 78.7 = (5.72 X 78.7)/100 = 4.5 gms

Therefore, 4.5 gms of HgI_2 powder needs to be dissolved in 100 ml of acetone at 58^oC to get a saturated solution at that temperature.

To confirm the solubility data, HgI_2 powder was added in increments of 0.5 gms with constant stirring and it was observed that powder did not get dissolve in acetone easily even when the concentration of powder was only 1.00 gms in 100ml and it needed continuous stirring for sufficient time. The same was observed to hold when the solution was raised up to 60^oC to add maximum possible amount of HgI_2 powder to get a saturated solution.

Another important observation was only 3.5 gms of HgI_2 could be added to 100 ml of acetone as against 4.5 gms given in literature.

Therefore, the solubility of HgI_2 in acetone at 60^o C was found to be :

(3.5/78.7) X 100 = 4.45 % by weight in place of 5.72% reported in literature

Therefore % difference in solubility = [(4.5 - 3.5)/4.5] X 100 = 22.3 %

The reason in difference in solubility that could be thought at this moment is that the powder used for experiment was 99% pure(and not 100% pure).

The solution was maintained at 60^oC for 3-4 hrs to ensure that the solution has reached saturation and no more powder could be dissolved.

The solution was filtered in to another beaker leaving behind the undissolved powder/ particles in previous beaker so that no undissolved particle act as a nucleation center. The solution was clear and transparent (if the solution is slightly red then it means that it has HgI_2 suspension). The check for saturation is that add a tinge of powder in solution and if it does not get dissolve in solution even after 1/2 hr at elevated temperature (60°C in this case) then solution is saturated.

The furnace was brought down to 40°C and maintained at that temperature with acetone-HgI_2 solution in it to let the crystal grow at that temperature. The solution was let undisturbed for overnight (10-12 hrs) . Crystals of size 0.4375 X 0.4375 mms were collected at the base of beaker. (Shown in photograph 1).

4.2 Crystal Grown from Methanol (MeOH):

From solubility data 6.11 % by weight (HgI_2) shall be dissolved in methanol at 60°C to get saturated solution.

Calculations for making saturated solution:

Specific gravity of MeOH = 0.79

Therefore, weight of 100 ml of MeOH = 100 X 0.79 = 79 gms

6.11 % of 79 gms = 0.0611 X 79 = 4.8 gms

Therefore 4.8 gms of HgI_2 shall be added to 100 ml of MeOH at 60°C to get a saturated solution. It was observed that rate of solubility in MeOH is much less than in acetone; it took much longer stirring to dissolve HgI_2 in MeOH.

Also again the solubility of HgI_2 in MeOh was found to be much less than the one quoted in literature. Only 3.8 gms of HgI_2 could be dissolved in 100 ml of MeOH as opposed to 4.8 gms quoted in literature.

Therefore %age solubility of HgI_2 in MeOH was found to be:

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(3.8/7.9) X 100 = 4.8 % as against 6.11% reported in literature.

Therefore % age difference in solubility data = [(4.8-3.8)/4.8] X 100 = 20.84%

Solution was maintained at 60°C for 7-8 hrs to ensure that no more HgI_2 could be dissolved in the solution. As for acetone, the solution was filtered to another beaker to get rid of undissolved powder and particles to avoid the sites of nucleation. An attempt was made to have preferential growth by introducing a seed crystal on copper wire from melt.

The furnace was brought down to 40°C and maintained at that temperature. The solution was left undisturbed in the furnace at 40°C for 7-8 hrs to let the crystal grow.(Though it was planned to leave the solution undisturbed for 12 hours but whole methanol got evaporated in 7-8 hrs).

Sharp , pointed (needle like) bright red crystals of dimensions 1.7 X 0.7 mm. (Shown in photograph 2) were grown.

Since the results were encouraging so it was decided that the crystal obtained from above process will be dissolved back in MeOH to get still better crystals (i.e. bigger).

Few crystals were removed from the bottom of beaker and remaining were dissolved in 100 ml of MeOH and further 2.8 gms (note that only 2.8 gms and not 3.8 gms as required in the previous case to get the saturated solution was added because the solution had the crystal dissolved in it) was added to get saturated solution. The saturated solution was kept at 55°C for an hour to make sure that no more powder could be added to it (i.e. the solution is saturated solution). The temperature of furnace was brought down to 45°C and saturated solution was kept in it for 7-8 hours to evaporate the MeOH from solution.Crystal obtained is shown in photograph 3.

An interesting observation was made that the beaker was covered with Al foil and the vapors of MeOH - HgI_2 solution reacted with the foil as tiny (visible) pieces of Al foil were found at the base of beaker along with the crystal. In future extreme care should be taken not to use any aluminium made tool or equipment for growing crystals by this process, because aluminum is highly reactive with MeOH-HgI_2 solution.

4.3 Crystal Grown from Castor Oil:

Since the solubility of HgI_2 in castor oil is reported to be 16.7 % by weight at 100°C and B.P of castor oil is above 100°C; so it was decided to try the crystal growth from castor oil. In literature only Quinoline is reported to have solubility more than castor oil (23.1% by weight) at 138°C (Table 1). Due to high solubility of HgI_2 in castor oil and high temperature at which crystal growth could be attempted, it was expected to obtain real big crystal from castor oil- HgI_2 solution.

The first observation was that the solubility rate of HgI_2 powder in castor oil was too slow. It took almost 2 hours to dissolve even 4 % by weight of HgI_2 in castor oil.

Calculations for making saturated solution:

Specific gravity of castor oil = 0.96

Therefore weight of 15 ml of castor oil = 0.96 X 15 = 14.4 gms

16.7 % of 14.4 gms = 0.167 X 14.4 = 2.4 gms

Therefore 2.4 gms of HgI_2 shall be dissolved in 15 ml of castor oil at 100°C to get a saturated solution of castor oil- HgI_2

Once again it was observed that solubility rate was too low in castor oil, it took more than 2 hrs to dissolve 0.6 gms HgI_2 in 15 ml of castor oil at elevated temperature of 100°C.

Another important observation was, although as per literature 2.4 gms of HgI_2 shall be dissolved in castor oil at 100°C to get saturated solution, but even 0.7 gms of HgI_2 did not get dissolved in 15 ml of castor oil (as the suspension was observed at this value).

The furnace was brought down to 88°C and the castor oil - HgI_2 left in it undisturbed. Even after 5 hours , no change was observed (no signs of crystal growth) so two things were decided:

i) To bring the temperature of the furnace further down to 60°C.

ii) To try preferential growth

For preferential growth, a part of solution was taken in another mold. It was a square glass tube surrounded by a round glass tube mounted on a glass plate. Cold water was filled between square and round tube and solution was poured in inner square tube so that crystal grow preferentially at the bottom right corner as the mold was tilted so as to have water only towards the right corner between the two tubes. The observation was that, nucleation did occur preferentially towards the right corner but crystal obtained were too small, smaller than the one obtained from acetone. It took 10 hrs to grow these crystals.

For the remaining part of solution which was maintained at 60°C, after 12 - 14 hours tiny crystals were seen at the bottom of solution. It was not possible to pick out those crystals from the solution. Also since castor oil is too viscous so even the attempt to pour it out in another beaker, leaving behind the crystal did not work out as it carried the crystals along with it. So the beaker was kept upside down on another beaker with filter paper in between, and finally crystals were collected on filter paper.

4.4 Crystal Grown From DMSO:

I.F. Nocolau and J.P. Jolly attempted to grow high perfection and purity HgI_2 crystal from non ionic complexing agent for the first time. Out of the various organic as well as inorganic complexing agent, Dimethylsulfoxide (DMSO), Tributhylphosphate (TBP), Trimethylphosphinoxide (TMPO) and N-Dimethylacetamide (DMA) were the one studied by these two.

Encouraged by the crystal grown from Methanol and studying the information from [43], it was planned to attempt to grow HgI_2 crystal from DMSO- MeOH mixture.

Calculations for making saturated solution:

Referring to solubility diagram of HgI_2 in DMSO- MeOH mixture versus temperature, it was decided to first prepare a DMSO-MeOH solution of mole fraction = 0.8 and it was decided to attempt the crystal grown at 40^oC.

Since the solubility of HgI_2 in DMSO-MeOH mixture of mole fraction = 0.8 is nearly 250%, it was decided to attempt firstly with 5 ml of DMSO.

Calculation for DMSO- MeOH(of mole fraction = 0.8)

Density of DMSO = 1.095

5 ml of DMSO = 5 X 1.095 = 5.475 gms

Molecular weight of DMSO i.e. $(CH_3)_2SO$ = 78

Molecular weight of MeOH i.e. CH_3OH = 32

Now for Mole fraction of mixture , $X_{DMSO} = 0.8$

$X_{DMSO} = n_{DMSO} / (n_{DMSO} + n_{MeOH})$

where n_{DMSO} = number of moles of DMSO

n_{MeOH} = number of moles of MeOH

Now n_{DMSO} = gms of DMSO/ Molecular weight of DMSO

n_{MeOH} = gms of MeOH/ Molecular weight of MeOH

therefore $0.8= (5.475/78.0) / [(5.475/78) + (x/32)]$

$x= 0.5356$ gms

i.e. 0.5356 gms of MeOH is required for 5 ml of DMSO to make DMSO-MeOH mixture of mole fraction = 0.8

Now density of MeOH = 0.79

therefore, 0.535 gms of MeOH = 0.678 ml of MeOH

Referring to the graph (fig.3), mole fraction of HgI_2 i.e. R_{HgI2} for $X_{DMSO} = 0.8$ at $40^oC = 0.37$

$R_{HgI2} = (n_{HgI2}) / (n_{DMSO} + n_{MeOH})$

Molecular weight of $HgI_2 = 450$

$0.37 = (x/\text{molecular weight of } HgI_2) / [(5.475/78) + (0.535/32)]$

$x = 14.4$ gms

So 14.4 gms of HgI_2 powder needs to be added to 5.678 ml mixture of DMSO-MeOH of mole fraction 0.8.

HgI_2 crystal can be grown by two methods using DMSO-MeOH solution with HgI_2:

i) By diluting solution with MeOH

ii) By slow cooling of solution

First it was decided to grow the crystal by dilution technique:

A saturated solution of DMSO-MeOH and HgI_2 was prepared by adding 14.4 gms of HgI_2 to 5.678 ml of DMSO- MeOH (mole fraction= 0.8)

Few drops of MeOH were added to the solution, instantaneously the dilution of solution caused the precipitation of small crystal at the bottom of the beaker. The crystal were too small to be of any use for either detector fabrication or further experimentation..

In second attempt to grow crystal from DMSO-MeOH solution, it was decided to cool the solution at room temperature and let the crystal grow at room temperature.

Following the above calculations and graph, 0.14 ml of MeOH needs to be added to 1 ml of DMSO to get DMSO-MeOH mixture of mole fraction= 0.8. Further 2.9 gms of HgI_2 needs to be added in the above prepared 1.14 ml of DMSO-MeOH solution at 40^oC to get the saturated solution.

The solution prepared following the above data was brought down to room temperature, but while filtering the solution to another beaker (to be left for crystal growth at room temperature), it was observed that fine crystal started growing on the filter paper itself. Surprisingly no growth / signs of growth of crystal were observed in DMSO-MeOH-HgI_2 filtered solution even after 20 days (at room temperature). The probable reason that could be thought was that due to crystal growth on filter paper the filtered solution became diluted.

4.5 Poly Crystal from Melt:

Since it has been reported in literature that phase transformation of HgI_2 is reversible so it was decided to heat the powder of HgI_2 to 270^{o}C (melting point of HgI_2 is 259^{o}C and B.P is 354^{o}C) and then cool it to get the polycrystal. In first attempt the cooling was done at room temperature, the polycrystal obtained was dark red in color with black boundaries. In second attempt the cooling was done in furnace and a better polycrystal (lighter in color and with less black boundaries was obtained.). This was similar as reported in literature.

5. Conclusions

Some very important conclusions can be drawn from the above experimentation. There are two possible methods of growing crystals from mercuric iodide namely solution technique and vapor technique. It is much easier to produce better quality crystals using vapor technique, where as it produce mercuric iodide vapor which is hazardous for the environment. On the other hand solution technique does not produce any environmental pollution if the experiments are performed carefully. We recommend thorough study should me made on exploring the possibilities of preparing good quality crystals (good enough to be used in detector fabrication purposes) by solution technique.

We observed using methanol as solvent big, better quality crystals can be grown. Crystal growth rate is also high. But the problem is to control the evaporation rate of methanol. MeOH- HgI_2 solution is highly reactive with aluminum , so care should be taken not to use any equipment/tools made of aluminum for growing crystals using this solvent. With acetone as solvent it was observed that the growth rate of crystal is much slower than in methanol. Also crystals were of much smaller size. We also tried to grow crystals from castor oil for the first time. Crystals were too small size to have any significant application. Growth rate was also slow. From DMSO, initiation of crystal growth was very quick but the growth rate was very very slow. Sixty to seventy days are required to get a usable crystal, because the growth rate is 0.1 mm to 0.05mm/day. At this stage we can conclude that we will consider only methanol as potential solvent for growing crystals for our specific purpose, without polluting the environment with mercuric iodide vapor.

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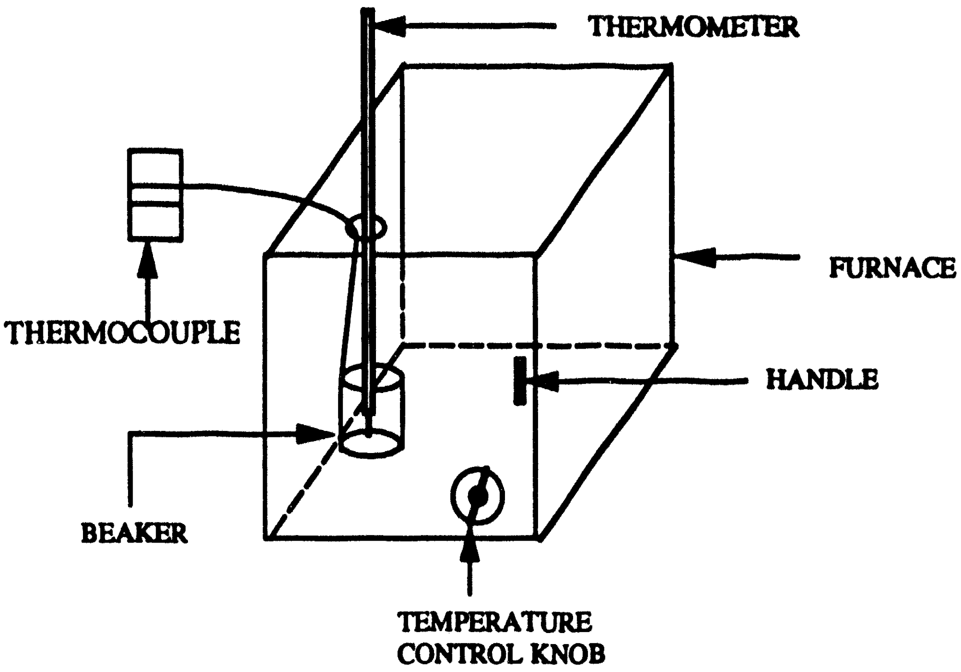


Fig. 1 Schematic Diagram of the Calibration Set Up

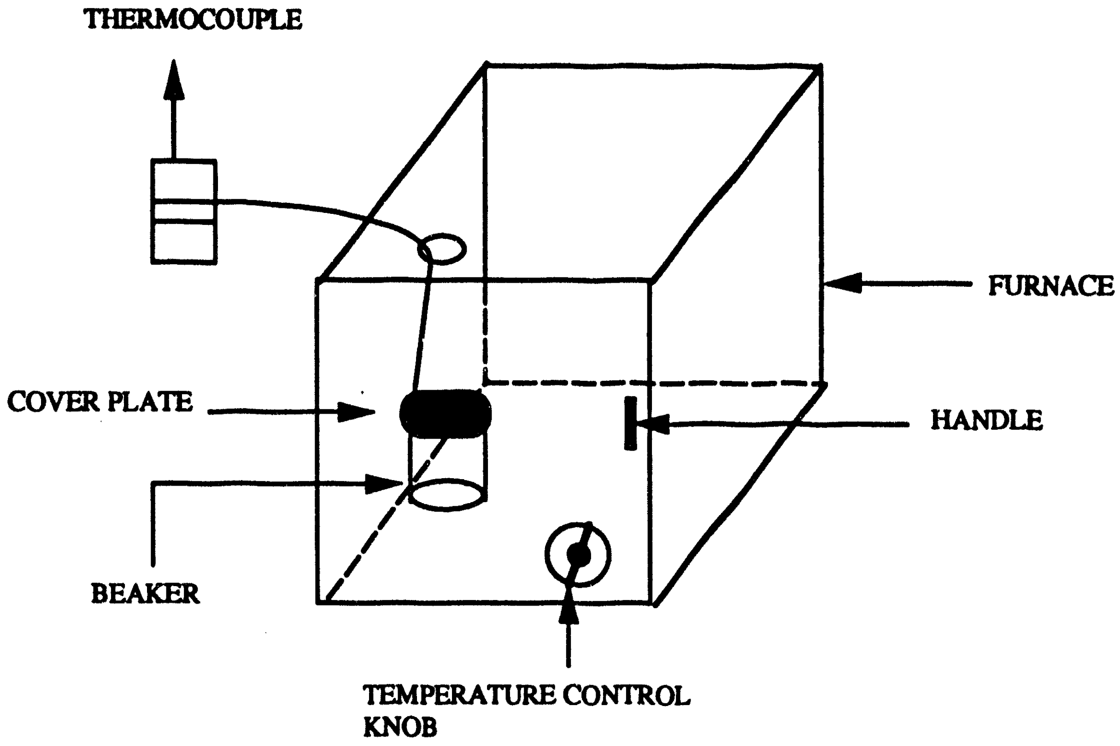


Fig. 2 Schematic Diagram of the Experimental Set-up

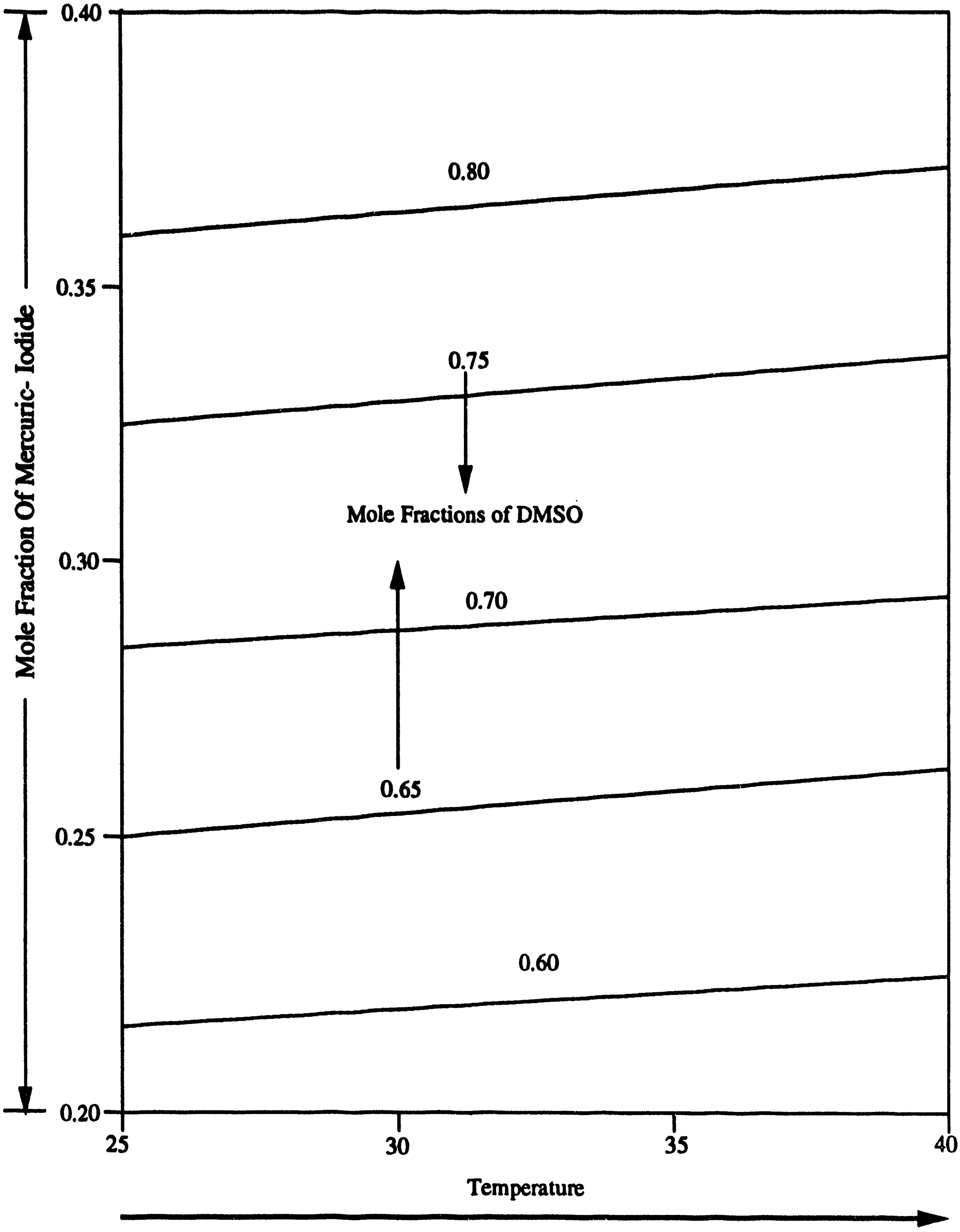
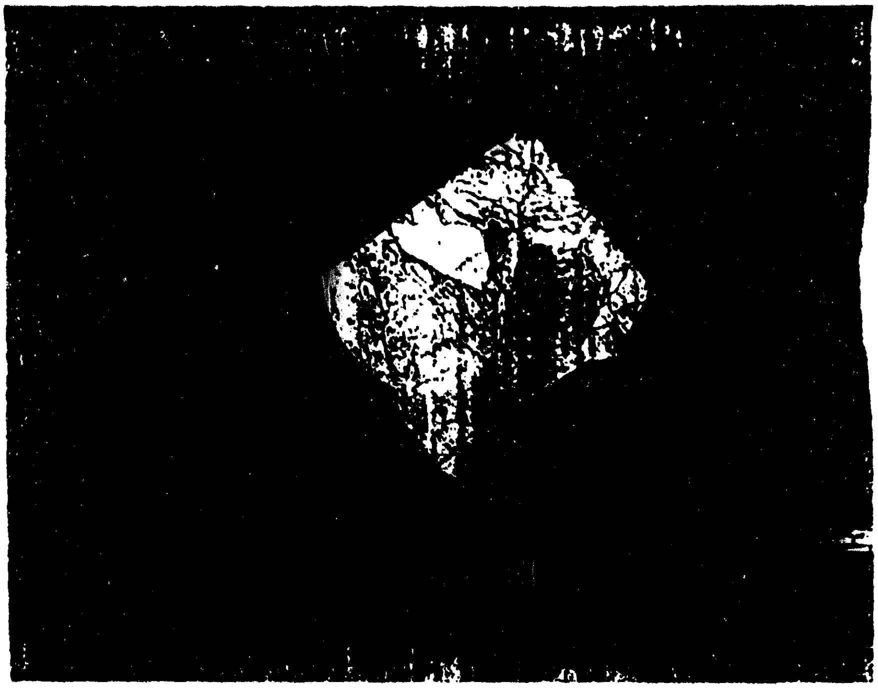


Fig 3 **Solubility Diagram**

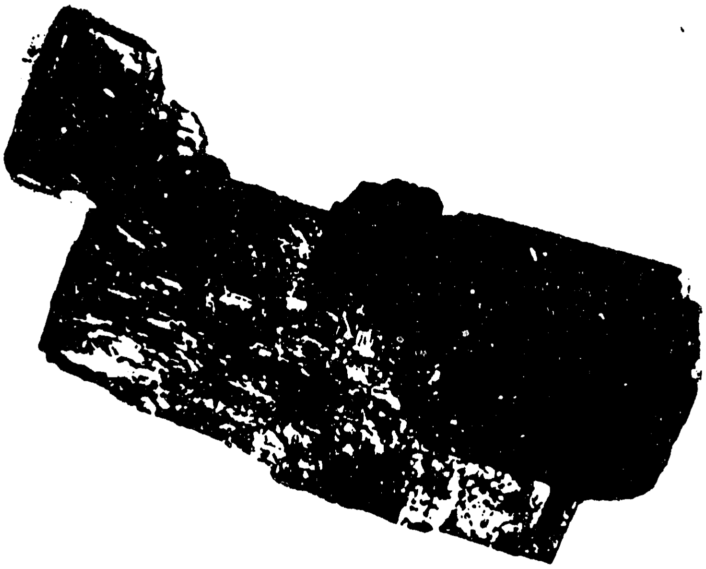
SOLVENT	SOLUBILITY WT. %	TEMP(in centigrades)
1. Acetone	2.00	23
"	3.00	25
"	4.51	40
"	5.72	58
2. Methanol	3.13	15 - 20
"	3.59	19
"	3.83	23
"	6.11	60
3. Castor Oil	3.80	25
"	16.70	100
4. Quinoline	4.70	100
"	26.70	145
"	48.80	170
"	54.40	166.5

Table 1. SOLUBILITY DATA FOR MERCURIC IODIDE [10]



Photograph 1

Photograph 2



Photograph 3

EVALUATION OF IR AND MASS SPECTROMETRIC TECHNIQUES FOR ON-SITE MONITORING OF VOLATILE ORGANIC COMPOUNDS
(MC-23)

Quarterly Technical Progress Report
for Period January 1 through March 31, 1994

Work Performed Under
Contract Number: 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
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May 1994

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1. Executive Summary

The objective of this project is the identification of optimal instrumental approaches to the field determination of Volatile Organic Compounds, such as chlorinated hydrocarbons and aromatics. IR and Mass Spectrometries were selected for evaluation because they are currently the strongest techniques available for this purpose. Professor Seehra is performing a critical evaluation of the IR techniques based upon literature research, telephone conferences, and when necessary, site visits. Professor King is developing tandem mass spectrometry methods to be implemented with an ion trap mass spectrometry system for the characterization of a series of selected target compounds.

During the past quarter, we have conducted a detailed survey of the literature regarding field IR spectrometry methods. Basic questions regarding the relative merits of point vs. open path FT-IR sampling, various baseline correction methods, compound spectral fingerprints for unambiguous identification, and portability are under investigation. During the coming months, Professor Seehra will carry out a critical evaluation of the literature. This will include telephone conferences with the principal researchers in the subject area and, site visits, if needed.

In the mass spectrometry project, the effort to date has focussed on the acquisition of a suitable ion trap mass spectrometry system and a preliminary search of literature methods for the characterization of target compounds. Based upon our evaluation of commercially available ion trap mass spectrometry systems, the NRCCE at West Virginia University placed an order for the acquisition of a Varian Saturn III Ion Trap System modified to permit tandem mass spectrometry and chemical ionization operation. It is expected that this system will be in place by the end of the next quarter. Our evaluation of existing literature methods for the characterization of BTEX (a mixture of volatile organics principally composed of Benzene, Toluene, Ethylbenzene, and Xylene) components will be completed during the next quarter. The design of the atmospheric sampling interface, based upon information from the literature, is beginning at the present time. Upon arrival of the instrument a research assistant will be hired to develop methods for the characterization of BTEX components. The sensitivity, accuracy, and precision of the newly developed methods will be compared with existing literature methods in the final two quarters of the project.

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2. Evaluation of IR Methods:

As given in the original proposal, our primary objective during the first quarter was to complete the literature survey on the use of infrared spectroscopic techniques for on-site detection of volatile organic compounds. This task has been completed using the Chemical Abstracts Service database of STN International and the regular literature survey. Copies of the relevant papers have been collected and they are now under active evaluation. A preliminary survey of these papers shows that several IR spectroscopic systems are currently under active use at plant sites and research groups in the United States for the on-site detection of volatile organic compounds. A critical evaluation of each of theses systems will now be carried out using telephone conversations with the researchers, plant managers, and manufacturers of this equipment. This evaluation may involve a site visit for the most promising technique.

3. Development of Mass Spectrometry Methods

During the first 1.5 months of the project, information was gathered from vendors regarding the capabilities, size, and cost of ion trap mass spectrometry systems capable of utilizing chemical ionization and performing tandem mass spectrometry. Based upon this evaluation and consideration of size and cost, the WVU NRCCE placed an order for a Varian Saturn III system to be used in this work. At the same time, Prof. King has been awarded the use of a Finnigan MAT research Grade ITMS system for use in his research. Both systems are expected to be available by the end of the next quarter. Two approaches to atmospheric monitoring mass spectrometry that can be incorporated into this project were found in the literature. The first method involves the use of molecular beam sampling followed by electron impact ionization in the source region of a triple quadrupole mass spectrometer. The second method involves atmospheric pressure ionization followed by extraction sampling into an ion trap mass spectrometer. Because both approaches are amenable to the system to be used in this work, part of the performance evaluation will involve their comparison in terms of sensitivity and accuracy.

As a preliminary step to developing our own analysis procedures for use with the atmospheric monitoring mass spectrometry system, a literature search is underway at the present time to identify existing procedures for the determination of BTEX components by tandem mass spectrometry. On the basis of a critical evaluation of the sensitivity, accuracy, and precision of these procedures to be conducted during the next quarter, a set of benchmark procedures will be identified for comparison with new methods developed in this project.

4. Future Plans

For the IR spectroscopic techniques, the major task during the coming months will be the careful reading and evaluation of the several dozen papers recently collected on the subject. This will be followed by telephone conversations with the various researchers in the field and may involve some site visits, as needed. Results of these investigations will be reported in the next quarter. The project is on schedule.

The MS work is limited to the evaluation of information available in the literature for the next quarter. Once technical drawings of the ion trap MS systems are available, construction of the atmospheric sampling sources will begin. The goal is to have these sources ready to install on the instrumentation upon its arrival. Once the instrumentation is in place, identified literature methods will be employed to characterize the analytical performance and to establish operator expertise with the mass spectrometer. During the third quarter the development of new procedures based on tandem mass spectrometry and selected ion chemical ionization will begin. During the final quarter a comparison between the newly developed methods and the literature methods will be conducted.

During the final quarter of the project the task of comparing IR and MS methods for VOC identification will be undertaken. This comparison will involve all of the IR information gathered by Prof. Seehra, the MS information gathered by Prof. King, and the results from the new MS system developed under this project.

TECHNOLOGY ASSESSMENTS

A SYSTEMATIC DATABASE OF THE STATE OF HAZARDOUS WASTE CLEAN-UP TECHNOLOGIES (MC-1)

Quarterly Technical Progress Report
for Period January 1 through March 31, 1994

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

For
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May 1994

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1.0 EXECUTIVE SUMMARY

It is estimated that over 3700 hazardous waste sites are under the jurisdiction of the Department of Energy (DOE). Over the next 30 years, the Department of Energy (DOE) is committed to bringing all its facilities into compliance with applicable Federal, State, and local environmental laws and regulations. To perform this clean-up effort in the most efficient manner at each site will require that DOE managers have access to all available information on pertinent technologies; i.e., to aid in maximum technology transfer. The purpose of this effort is to systematically develop a database of those currently available and emerging clean-up technologies.

The development of a database of those currently available and emerging clean-up technologies is to be done in several phases: 1) A systems approach, 2) data collection, and 3) software development. Although the project officially started October 1, 1992, our award did not arrive until December, 1992. Thus, our main effort in the first quarter was 1) the recruitment of graduate research assistants, 2) the organization of project responsibilities, and 3) the procurement of software. In the second quarter we have 1) began an initial screening of DOE hazardous waste sites, 2) developed a conceptual model to classify DOE hazardous waste problems, and 3) developed an initial formulation of the structure (or fields) of the database. In the third quarter a user interface was developed to input and retrieve data from the database. This user interface was coded in FOXPRO 2.5 for DOS. Using the conceptual model and the structure of the database developed in quarter II, the user interface allows a user to input, search, retrieve and print records from the database via a menu driven system.

2.0 BACKGROUND

It is estimated that over 3700 hazardous waste sites are under the jurisdiction of the Department of Energy (DOE). These sites were primarily generated from 45 years worth of environmental pollution from the design and manufacture of nuclear materials and weapons, and contain numerous types of wastes including: 1) volatile, low-volatile and nonvolatile organics, 2) radionuclides (e.g., uranium, plutonium and cesium), 3) nonradioactive heavy metals (e.g., chromium, nickel, and lead), and 4) toxic chemicals. These contaminants affect several media including soils (saturated and unsaturated), groundwater, vegetation, and air. Numerous and diverse DOE hazardous waste sites can be enumerated from soils contaminated by organics such as trichloroethylene (TCE) and perchloroethylene (PCE) at the Savannah River site to biota and vegetation contaminated by radionuclides such as radiocesium and radiostrontium at the Oak Ridge site.

Over the next 30 years, the Department of Energy (DOE) is committed to bringing all its facilities into compliance with applicable Federal, State, and local environmental laws and regulations. This clean-up task is quite complex involving numerous sites containing various radioactive, organic and inorganic contaminants. To perform this clean-up effort in the most efficient manner at each site will require that DOE managers have access to all available information on pertinent technologies; i.e., to aid in maximum technology transfer. The purpose of this effort is to systematically develop a database of those currently available and emerging clean-up technologies.

The construction of a database of clean-up technologies requires a systematic development of those steps necessary to achieve clean-up objectives. These steps and associated technology groupings are given in Figure 1.

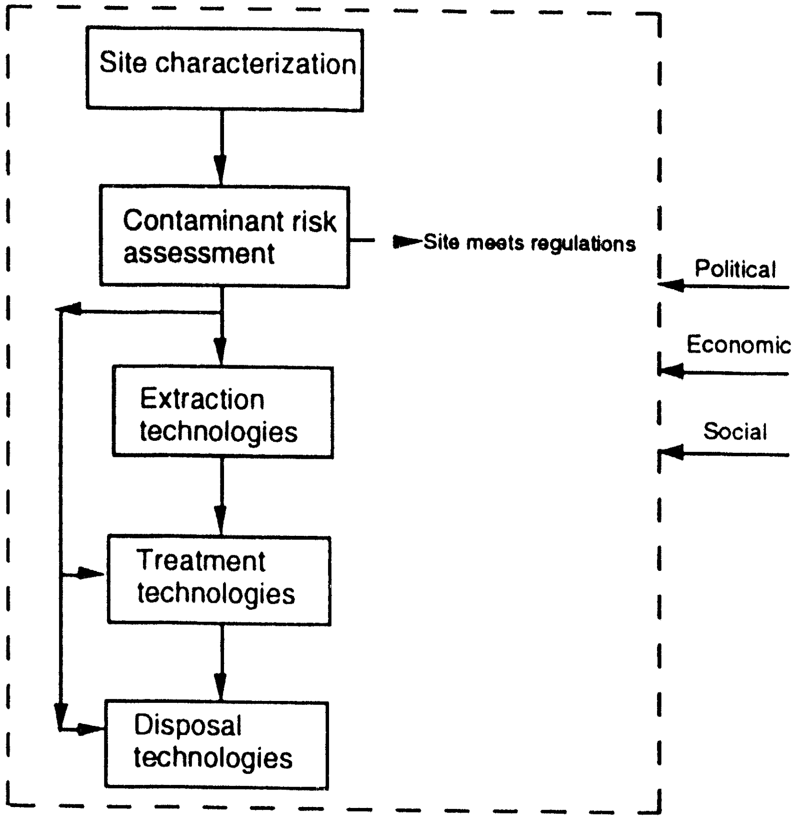

Figure 1: Division of technologies based on primary steps necessary for clean-up

The initial step in assessing a potential hazardous waste site is the characterization and identification of the type and extent of the contamination. In this characterization step technologies are required both for in-situ and ex-situ assessment of contamination levels. Once site characterization is performed, the risks posed by the contamination must be assessed. This step necessitates the use of mathematical models to predict contaminant fate and subsequent impact on local populations. Assuming that a risk exists, technologies must then be examined (or developed) to either extract the contaminant from the fostering media for treatment and/or disposal, treat the contaminant in-situ, or directly dispose of the contaminant. Furthermore, at each step in the clean-up process decisions regarding technology choices must be made within the existing political, economic, and social climate.

Using the conceptual approach given in Figure 1, a systematic assessment of available and emerging technologies in each area will be developed. This will be accomplished for each area by the development of a database of both current and emerging technologies. An example to illustrate the concept of such a database is given in Figure 2. In this simple example, the user of the database may be interested in investigating the available technologies for cleaning up a soil contaminated by dioxin (TCDD). In this case, information regarding soil extraction and treatment procedures is organized such that the user can extract pertinent clean-up information.

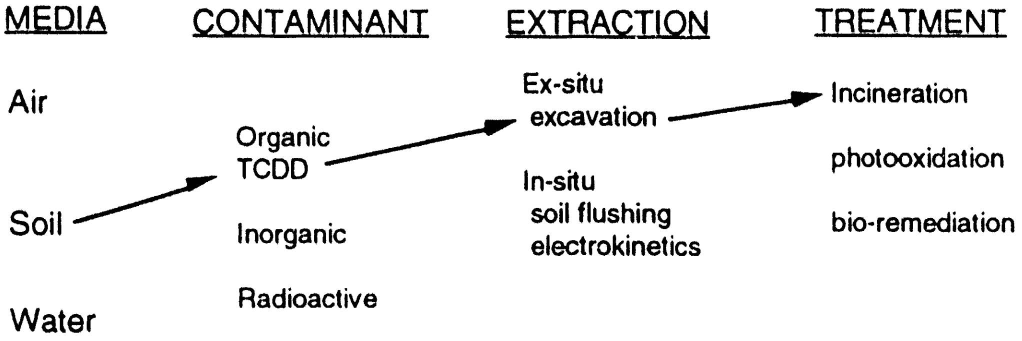

Figure 2: Conceptual view of database construction in which the arrows indicate one path explored for the clean-up of 2,3,7,8-Tetrachlorodibenzo-p-dioxin (TCDD)

It is envisioned in the initial phase of development that a DOE manager via a computer terminal will have access to information in the database via a query system. This system will allow the user to access the different available technologies for each step in the clean-up process, and extract pertinent information on how to proceed and obtain more detailed information. A natural result of such a systematic assessment is the discovery of where clean-up capabilities are lacking. Thus, as the process proceeds, a database will be compiled of those clean-up processes that are in need of further research.

3.0 METHODOLOGY

The development of a database of hazardous waste technologies will be carried out in several phases:

Phase I: A systems approach. This phase involves a systematic development of the components to be included in the database. The approach will drive the development of the computer database. The following sub-tasks are to be performed:

1. An initial screening of DOE hazardous waste sites;
2. The development of a conceptual model to classify DOE hazardous waste problems;
3. An initial formulation of the structure (or fields) of the database.

Phase II: Data collection. In this phase a complete review of the current clean-up technologies will be done. This review will be driven by the database structure developed in phase I (sub-task 3), and will be accomplished through a comprehensive literature review, discussions with clean-up experts, and possible hazardous waste site visitations. Phase III: Software development. In parallel with the data collection phase of this work, a computer based database is to be developed. This includes a data storage/retrieval system along with user friendly access software. Several main sub-tasks are to be performed including:

1. Development of a user friendly front end (i.e., user interface);
2. Development of the structure of the database;
3. Input of the technologies collected in the data collection phase;
4. Software verification and testing.

4.0 RESULTS AND DISCUSSION

Although the project officially started October 1, 1992, our award did not arrive until December, 1992. Thus, our main effort in the first quarter was 1) the recruitment of graduate research assistants, 2) the organization of project responsibilities, and 3) the procurement of software. As of January, 1992 we have recruited several graduate students who will function both to aid in the collection of data (phase II) and to work on software development. We have also organized project responsibilities toward the collection of data. All faculty will be responsible for the collection of data on characterization, extraction, treatment and disposal technologies in their field of expertise. Such data will be reported to the P.I. for integration into the database. We have also selected and ordered database software for the project. We have selected the relational database software FOX PRO 2.5 as our development package. This software will be run on an Intel 486 based computer.

In quarter II we have 1) began an initial screening of DOE hazardous waste sites, 2) developed a conceptual model to classify DOE hazardous waste problems, and 3) developed an initial formulation of the structure (or fields) of the database. An initial screening of DOE hazardous waste sites was initiated using the DOE Environmental Restoration and Waste Management Five Year Plan+. This report, however, gives only very general information on contaminated DOE sites. For example, information is given on the clean-up of volatile organics in saturated soils at the DOE's Savannah River site. The levels and extent of contamination are not given. We are in the process of searching for site specific data on the extent and level of contamination at specific sites.

In order to identify remediation technologies applicable to specific DOE sites, we have developed a conceptual model to classify DOE hazardous waste problems. This entails first the development of a general classification of hazardous waste problems. This general classification is simply a

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[+] USDOE, 1991. Environmental Restoration and Waste Management Five Year Plan. DOE/S-0090P.

division of contamination problems based on 1) the media in which the pollutant resides, and 2) the chemical characteristics of the pollutants. This division is illustrated by the matrix given in Figure 3 in which the bold boxes indicate a class of technologies used to remediate sites with the given pollutant/media characteristics. Thus, for each step in the remediation process (i.e., characterization, extraction, and treatment) there exists sets of potential technologies that can address the specific problems. The choice of this division was based on the behavior of pollutants in the environment. Pollutant behavior is driven by both its physical/chemical characteristics and the media in which it resides (i.e., pollutant fate and transport are driven by media pollutant interactions along with pollutant characteristics). These fate and transport characteristics will drive the potential technologies that will be applicable for remediation. For example, pollutants which reside in soils and are tightly bound, hydrophobic, and not susceptible to bioremediation (e.g., dioxins) can be remediated using similar approaches. In this case, this class of pollutants is typically excavated and treated ex-situ via thermal or chemical technologies for organics or possible immobilization for inorganics.

	POLLUTANT CLASS		
MEDIA	ORGANICS	INORGANICS	RADIONUCLIDES
SOIL			
GROUND WATER			
AIR			

Figure 3: Classification of technologies into groups used to address combinations of different pollutants with different media.

Within each pollutant class we have further grouped chemicals with similar physical and/or chemical characteristics; i.e., groups of chemicals which tend to have similar behavior in the environment. These groups are given in Table 1[+++]. In a similar fashion the media in which the pollutant resides can be subdivided based on its affect on pollutant behavior. In Table 2 we list several factors affecting pollutant behavior in soil, groundwater, and air (Note: this is not intented to be a complete list of factors). Thus, by developing classifications for both the pollutant and the respective media it resides in, we are reducing the subset of remediation technologies that need be explored for a particular circumstance.

[+++] EPA, 1989. Superfund Treatability Clearinghouse Abstracts. EPA/540/2-89/001.

For specific hazardous waste problems (i.e., pollutants in specific media) we envision candidate alternative remediation strategies. These alternative remediation technologies themselves can be categorized based on the processes used in remediation. We have categorized remediation technologies into four general classes[1]:

1) physical/chemical
2) thermal
3) biological, and
4) immobilization. Within each technology class there exists several specific remediation technologies which can be applied at each stage of the remediation process (i.e., characterization, extraction, treatment and disposal). Physical/chemical technologies include such processes as dehalogenation, air stripping, and chemical sorption; thermal technologies include such processes as vitrification, incineration and fluidized bed combustion; biological technologies include aerobic and anaerobic decomposition; immobilization includes such processes as cement solidification and carbonate immobilization.

Table 1

Grouping of Pollutants based on behavior in the environment.

Pollutant Class	Example
Halogenated non-polar aromatics	Chlorobenzene
PCB's, halogenated dioxins and furans	Tetrachlorodibenzo-p-dioxin
Halogenated phenols, cresols, amines, and other polar aromatics	Tetrachlorophenol
Halogenated aliphatic compounds	Vinyl chloride
Halogenated cyclic aliphatics, ethers, esters, and keytones	Toxaphene
Nitrated aromatic and aliphatic compounds	Trinitrotoluene
Heterocyclics and simple non-halogenated aromatics Benzene	
Polynuclear aromatics	Naphthalene
Other polar non-halogenated organic compounds	Methanol
Non-volatile metals	Iron
Volatile metals	Mercury
Other inorganics	Sulfate
Other organics	Methyl Propane
Radionuclides	Cs-137

Table 2

Division of media with several factors affecting pollutant behavior in the environment.

Media	Factor Affecting Transport
SOIL	Texture (%sand,%silt,%clay)
	Grain size distribution
	pH
	Hydraulic conductivity
	Organic content
	Moisture content
	Temperature
	Biota
	Bulk density
Cation exchange capacity	
GROUND WATER	Dissolved organic content
	Colloidal particals
	Dissolved oxygen content
	Temperature
	Biota
	pH
AIR	Pressure
	Temperature
	Humidity

Based on the classification schemes for pollutants, media, and remediation technologies described above, we have developed an initial structure for the database. This structure is illustrated in Figure 4. To date we have created the structure for five relational databases. These databases will contain specific information regarding pollutants and the alternative technologies available for remediation. In conjunction to these databases, a User interface, search routines and a report generator will be developed. The User interface will be used both in the data gathering phase in which the data is input in each database (i.e., the development of input screens) along with User interface during execution of search routines. The search routines will entail programs that generate a "best" match of site specific data on the pollutant and the media it resides in to potential remediation technologies.

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Finally, report generation routines will be developed to extract information from the database. We are currently in the data gathering phase of the project with only minimal development of screens for User input of information.

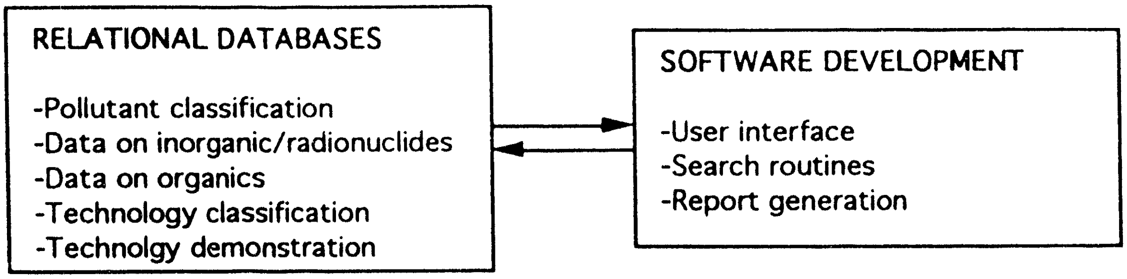


Figure 4: Components of database

Tables 3-7 show the initial structure (or fields) of the relational databases given in Figure 4. Tables 3-5 represent the structure used to collect data on specific inorganic, organic and radioactive pollutants. First, a classification of all pollutants is accomplished by the database represented by Table 3. The groups (i.e., field 2) are assigned based on the classification scheme developed previous (see Table 1). Tables 4-5 then tabulate specific data regarding each pollutant. This data gives information regarding the physical and chemical characteristics of each pollutant that are important for assessing pollutant behavior in different media. Such data includes a pollutants volatility, solubility, molecular weight, etc. Tables 6-7 give the organization for database construction of remediation technologies. Two databases of remediation technologies are to be constructed: 1) a general classification of technologies used to address contaminated sies (Table 6), and 2) a database of technologies already demonstrated at the laboratory, bench or field scale.

Table 3
Division of Pollutants into Classes

Field	Field Name	Description
1	NUM	Pollutant class number (e.g., P01,P02, etc.)
2	GROUP	Name of Pollutant Class identified by NUM
3	CLASS	General class: organic/inorganic/radionuclide
4	POLLUTANT	Specific pollutant

Table 4

Physical and chemical data for specific inorganic and radioactive pollutants

Field	Field Name	Description
1	POLLUTANT	Specific pollutant
2	NUM	Pollutant class number (e.g., P01,P02, etc.)
3	REDOX_NUM	Oxidation number
4	BOIL_PT	Boiling point (C^0)
5	MELT_PT	Melting point (C^0)
6	DENSITY	Density of pollutant (g/ml)
7	SOLUBILITY	Solubility of pollutant (g/100 ml)
8	DIFFUSION	Diffusion coefficient (Cm^2/sec)
9	GIBBS	Standard state free energy (kcal/g-mole)
10	VAPOR_PRESS	Vapor pressure (atm)
11	HENRY_CON	Henry's law constant (atm-m^3/mole)
12	HALF_LIFE	Half life for radionuclide (year)
13	DAUGHTER	Daughter produced by decay of radionuclide
14	BIO_EFFECT	Description of biological effect of pollutant

Table 5
Physical and chemical data for specific organic pollutants

Field	Field Name	Description
1	POLLUTANT	Specific pollutant
2	NUM	Pollutant class number (e.g., P01,P02, etc.)
3	MOL_WT	Molecular weight (g/mole)
4	BOIL_PT	Boiling point (C^0)
5	MELT_PT	Melting point (C^0)
6	DENSITY	Density of pollutant (g/ml)
7	SOLUBILITY	Solubility of pollutant (g/100 ml)
8	DIFFUSION	Diffusion coefficient (Cm^2/sec)
9	GIBBS	Standard state free energy (kcal/g-mole)
10	VAPOR_PRESS	Vapor pressure (atm)
11	HENRY_CON	Henry's law constant (atm-m^3/mole)
12	LOG_OCT_H2	Log of octanol to water partition coefficient
13	PHOTODEG	Ability of organic to photo degrade (Yes/No)
14	BIODEGRAD	Ability of organic to biodegrade (Yes/No)
15	BIO_AGENTS	Specific biological agents found to degrade
16	POLAR	Is organic polar (Yes/No)
17	BIO_EFFECT	Description of biological effect of pollutant

Table 6
Classification of Technologies used to remediate contaminated sites

Field	Field Name	Description
1	REMED_PHAS	Phase of remediation: Characterization/Extraction/Treatment/Disposal
2	TECH_GROUP	Technology group: Physical-Chemical/Biological/Thermal/Immobilization
3	PROCESS	Specific process used under TECH_GROUP
4	MEDIA	Process Media: Soil/Ground water/ Air
5	CONTAM_GRP	Pollutant class number (e.g., P01,P02, etc.)
6	REF	References in which technology is described

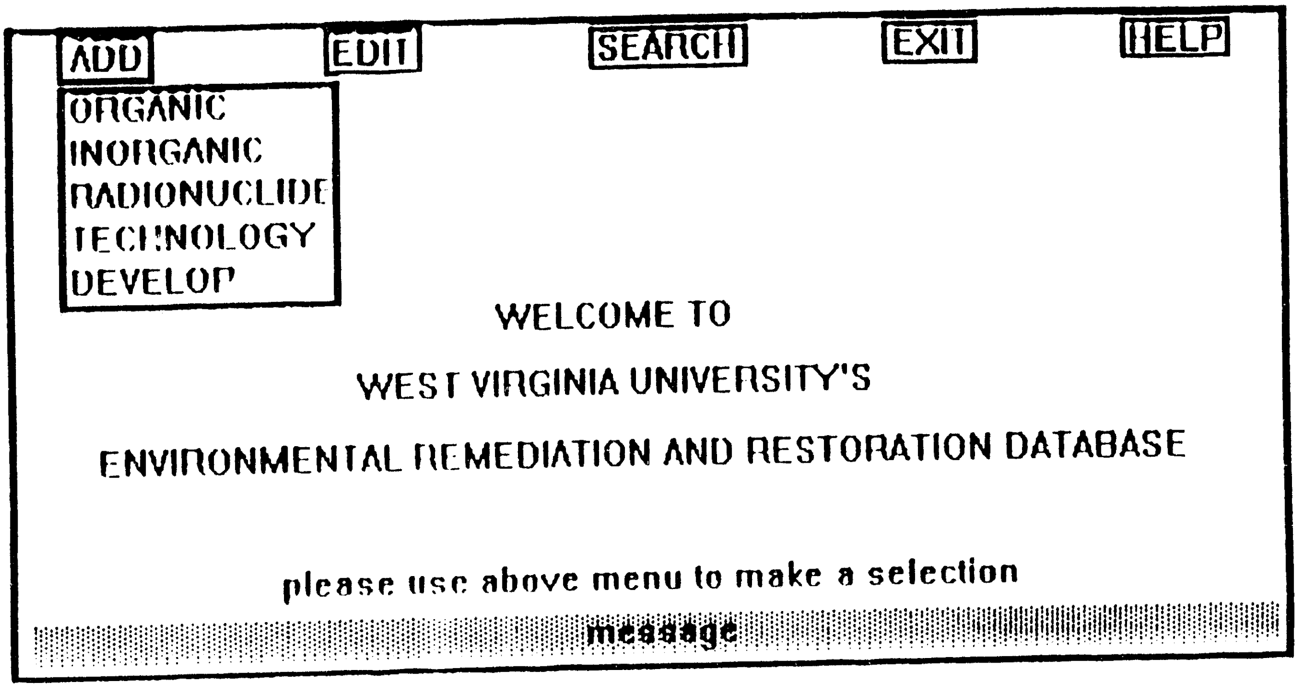
Table 7

Compilation of technologies that have been demonstarted at laboratory, bench or field scale

Field	Field Name	Description
1	TECHNOLOGY	Title of technology
2	DEVELOPER	Developer of technology
3	MEDIA	Process Media: Soil/Ground water/ Air
4	DOMAIN	Remediation domain: In-situ/Ex-situ
5	SCALE	Scale of application: Lab/Bench/Field
6	DESCRIPTION	Description of technology
7	APP_WASTE	General class of applicable waste
8	SPEC_WASTE	Specific waste in which technology is applied
9	WAST_CLASS	Pollutant class number (e.g., P01,P02, etc.)
10	TECH_GROUP	Technology group: Physical-Chemical/Biological/Thermal/Immobilization
11	PROCESS	Specific process used under TECH_GROUP
12	SITE	Site description (if any)
13	STATUS	Status of work
14	CONTACTS	Specific persons to contact
15	DOCUMENTS	Publications of work
16	COST	Cost data
17	REF	Reference in which information was obtained

In the third quarter, we used the conceptual model and database structure to develop a user interface. The user interface is a set of routines coded in FOXPRO 2.5 that allows a user to input, retrieve, search and print any record in the database via a menu driven system. The development of a user interface is essential for efficient use of the database along with the protection of data. The code developed to interface between the user and the database is given in the attached Appendix A. In conjunction with software development, we have continued gathering data to input into the database. We are currently gathering and inputing data on general descriptions of each technology (as given in Table 6). Furthermore, we are in the process of assessing the available information via external databases (e.g., ATTIC, PROTEC, etc.). We hope to reduce data collection tasks by downloading available information from existing databases.

In the fourth quarter, we have continued both the development of software, and the data collection phase. The first version of user interface software in FOXPRO 2.5 has been completed. The initial introductory screen is given in Figure 5. This screen welcomes the user and designates the five main menu options as ADD, EDIT, SEARCH, EXIT and HELP. If the user chooses the ADD option from the main menu, a list of databases appears. The five accessible databases include organic pollutants (ORGANIC), inorganic pollutants (INORGANIC), radionuclide pollutants (RADIONUCLIDE), remediation technologies (TECHNOLOGY), and developed/demonstrated technologies (DEVELOP). The first three contain relevant chemical data on organic and inorganic pollutants. The TECHNOLOGY database gives general information on remediation technologies, and the DEVELOP database provides demonstrations of the technologies and site-specific information. Once the user selects a database, the program immediately provides a blank record in which to enter data.



WELCOME TO

WEST VIRGINIA UNIVERSITY'S

ENVIRONMENTAL REMEDIATION AND RESTORATION DATABASE

please use above menu to make a selection

Figure 5. The Introductory Screen to the User Interface Software

The EDIT option from the main menu povides the same database choices. However, once a selection is made, a second screen appears which requests search criteria. The push button MAINMENU at the bottom of this screen will return to the main menu. If the SEARCH button is activated, the program will then use the specified criteria to locate the record and display it on a third screen.

The display screen allows the user to browse the record but not make any changes. It then provides four alternatives: EDIT, DELETE, CANCEL, and PRINT RECORD. CANCEL will return to the search criteria input screen. DELETE will request double confirmation and then erase the displayed record. PRINT RECORD will allow the user to print the record to the screen or to the printer. The program controlling this print option calls a specific report (an .RPT file exists for each of the five databases). The program then transfers the field information from the appropriate database into the report format and sends the report to the requested destination. Finally, EDIT will bring the displayed record up on data entry screens where it can be edited.

On every data entry screen (purple screens) in both the ADD and EDIT mode, there are three common features. First, there are regions for entering the information. We found that certain programming features are best suited for certain data types. For example, when only one choice is to be selected from a few options, push buttons are convenient. However, check boxes are more suitable if multiple selections are possible. We also used checkboxes to activate AT...EDIT regions in which to edit memo fields. The second feature available is the HELP menu in the upper right hand corner of the screens. When this menu is activated, a program is called which will define any field for the user. It also provides the width and type of the field. At the conclusion of the inquiry, the program returns to the previous screen. Finally, at the bottom of each data entry screen, there are SAVE and CANCEL push buttons. If the user chooses SAVE, the changes to the record will be saved in the appropriate database. If CANCEL is chosen, the changes will be disregarded. The CANCEL option is also helpful if the user inadvertently selects the wrong database.

The programs for ADD and EDIT were designed to create a user-friendly interface which would allow input into the appropriate database without exposing the database format or fields. This approach lends itself to good quality control of the entered data. Programming was also done in such a way that any user error can be easily corrected, and there is always a CANCEL option. Furthermore, a great deal of consideration was taken into the color, type, and organization of the screens. While there is still some programming to be done, we feel that the database is currently at a level in which data entry will be convenient and efficient.

Extensive programming has been done to complete the ADD and EDIT options allowing the user to input, retrieve and edit data. Currently, the SEARCH option is disabled. The first version of the user interface code was tested by several users (i.e., individuals not participating in the development of the code). Feedback from these tests was used to improve the user interface.

The data collection phase continued with the collection of data for the technology database (i.e., Table 6). We have completed general and technical descriptions of biological and thermal remediation technologies. The general description provides the reader with easily understood information about a technology's process and concepts. This section is written at a level so that a person who is not an environmental engineer can get a basic idea of where and how the environmental technology can be applied. The technical description gives more detailed information on the process and theory behind the technology. The theory includes any important chemical equations or formulas that indicate how the technology works. This section also discusses factors that influence technology performance and limitations. Examples of these descriptions are found in Appendix B. We have also begun collecting information on immobilization and chemical remediation technologies.

5.0 CONCLUSION

The resources necessary for the development of a computer database of hazardous waste technologies have been assembled. In the second quarter, we have systematically developed the structure of the database. This structure was driven by the necessity to relate the physical and chemical data of specific hazardous waste sites to specific remediation technologies. We have created the databases (i.e., developed the fields) using Microsoft FOXPRO. We are in the data collection phase of the project. To date, we have entered into the database 296 specific pollutants, and 58 classes of technologies. At this time we are in the process of obtaining specific data on the pollutants entered (i.e., filling out Tables 5 and 6), and obtaining more information regarding specific technology classes (i.e., filling out Table 7). We have also begun entering data on technology demonstrations on the laboratory, bench and field scale. In the third quarter, we expended a great deal of effort on the development of a user interface. The user interface will allow the access and storage of information via a menu driven system. Once tested this system shall allow any user (not necessarily familiar with FOXPRO) to interface with the database including inputing, searching and printing database records. In the fourth quarter, we continued the development of user interface software including refinements to the code based on feedback from external reviewers. We have completed an initial collection of data for the technology database on both biological and thermal remediation and treatment. In the fifth quarter, we have continued software and data collection efforts.

The work planned on the database system in the near future can be divided into two areas, those of database modification and survey activities. The database modifications will consist of changing some of the interface screens, and the continuation of data expansion. New technologies will be researched, and new methods of data presentation, involving the expanded opportunities of FoxPro for Windows, will be experimented with.

The survey procedure will continue until all possible sources of information have been exhausted. At that point, the survey emphasis will shift to the next phase. Overall, the survey process has been divided up into six phases, which somewhat overlap. The six phases are listed below.

1. Conduct research into all possible phone contacts which pertain to waste remediation and related databases.
2. Call all contacts, and immediately follow up on all secondary leads generated by the primary contacts.
3. Evaluate all databases found during the survey.
4. Acquire all databases that have been evaluated as possible database models.

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5. Conduct an in-depth evaluation of each database judged to be a possible model.
6. Determine the direction and extent of WVU's continued involvement in the development of a hazardous waste and remediation database.

APPENDIX A

User Interface Code in FOXPRO 2.5

```
*******************************************************************
*  MAIN menu program: Runs main menu and passes control to
*  selected function.
*
*  MEMORY VARIABLES:
*    done: logical var done = .T. stops executing of program
*
*******************************************************************
PUBLIC done
done = .F.
* Run main menu definition
DO c:\metc\database\prog\maindef.prg
DO WHILE (.NOT. done)
  SET TALK OFF
  * Turn off FOXPRO menu
  SET SYSMENU OFF
  * Display logo
  ACTIVATE WINDOW name
  @ 13,34 SAY "WELCOME TO" COLOR GR+/B
  @ 15,26 SAY "WEST VIRGINIA UNIVERSITY'S" COLOR GR+/B
  @ 17,14 SAY "ENVIRONMENTAL REMEDIATION AND RESTORATION DATABASE" COLOR GR+/B
  @ 9,14 SAY "(Please use the above menu to make a selection.)"
  * Run the main menu until done is set to true.
  ACTIVATE MENU main
ENDDO
*
*
* Function to control execution of main menu
PROCEDURE control
PARAMETER choice,bar

*Find the choice made: EDIT/DEL, ADD, SEARCH, QUIT
DO CASE
 * Stop execution of the program
  CASE choice = 'quit'
      done = .T.
      * reset FOXPRO environment
      CLEAR READ ALL
      CLEAR WINDOW ALL
      SET ESCAPE ON
      SET TALK ON
      CLOSE DATABASES
 * Add a record to the database
  CASE choice = 'add'
      DO editrec WITH bar, .T.;
        IN c:\metc\database\prog\editrec.prg
 * Edit existing data in the database
  CASE choice = 'edit'
      * Initialize memory variables used in editmenu
        srchstring = SPACE(30)
        DEACTIVATE WINDOW name
      * Pass control to editmenu
        DO editmenu WITH bar,srchstring;
          IN c:\metc\database\prog\editmenu.prg
        ACTIVATE WINDOW name
        @ 13,34 SAY "WELCOME TO" COLOR GR+/B
        @ 15,26 SAY "WEST VIRGINIA UNIVERSITY'S" COLOR GR+/B
        @ 17,14 SAY "ENVIRONMENTAL REMEDIATION AND RESTORATION DATABASE";
          STYLE 'BI' COLOR GR+/B
        @ 9,14 SAY "(Please use the above menu to make a selection.)"
  CASE choice = 'search'
        WAIT WINDOW 'MENU CHOICE CURRENTLY DISABLED'
  CASE choice = 'help'
        WAIT WINDOW 'MENU CHOICE CURRENTLY DISABLED'
ENDCASE
```

```
RETURN
*
```

```
* Define main menu for hazardous waste technology database
*
*  Define a window and display initial greeting
CLEAR
DEFINE WINDOW name FROM 0,0 TO 25,79 PANEL SHADOW;
COLOR SCHEME 1

*  Define the menu used to select action
DEFINE MENU main IN WINDOW name
*
DEFINE PAD addpad OF main PROMPT 'ADD' AT 0,3 COLOR SCHEME 6
DEFINE PAD editpad OF main PROMPT 'EDIT' AT 0,18 COLOR SCHEME 6
DEFINE PAD srchpad OF main PROMPT 'SEARCH' AT 0,33 COLOR SCHEME 6
DEFINE PAD endit OF main PROMPT 'EXIT' AT 0,48 COLOR SCHEME 6
DEFINE PAD helppad OF main PROMPT 'HELP' AT 0,63 COLOR SCHEME 6
*
ON PAD addpad OF main ACTIVATE POPUP add
ON PAD editpad OF main ACTIVATE POPUP edit
ON PAD srchpad OF main ACTIVATE POPUP search
ON PAD endit OF main ACTIVATE POPUP exit
ON PAD helppad OF main ACTIVATE POPUP help
*
* Define ADD popup/menu
*
DEFINE POPUP add FROM 1,3 IN WINDOW name COLOR SCHEME 6
DEFINE BAR 1 OF add PROMPT 'ORGANIC';
MESSAGE 'Add an organic pollutant to database' COLOR ,,,,GR+/BR+
DEFINE BAR 2 OF add PROMPT 'INORGANIC';
MESSAGE 'Add an inorganic pollutant to database' COLOR ,,,,GR+/BR+
DEFINE BAR 3 OF add PROMPT 'RADIONUCLIDE';
MESSAGE 'Add a radionuclide pollutant to database' COLOR ,,,,GR+/BR+
DEFINE BAR 4 OF add PROMPT 'TECHNOLOGY';
MESSAGE 'Add a general technology to database' COLOR ,,,,GR+/BR+
DEFINE BAR 5 OF add PROMPT 'DEVELOP';
MESSAGE 'Add a developed/demonstrated technology to database';
  COLOR ,,,,GR+/BR+
*
ON SELECTION POPUP add DO control WITH 'add', BAR()
*
* Define EDIT/DELETE popup/menu
*
DEFINE POPUP edit FROM 1,18 IN WINDOW name COLOR SCHEME 6
DEFINE BAR 1 OF edit PROMPT 'ORGANIC';
MESSAGE 'Delete/edit organic pollutant in database' COLOR ,,,,GR+/BR+
DEFINE BAR 2 OF edit PROMPT 'INORGANIC';
MESSAGE 'Delete/edit an inorganic pollutant to database' COLOR ,,,,GR+/BR+
DEFINE BAR 3 OF edit PROMPT 'RADIONUCLIDE';
MESSAGE 'Delete/edit a radionuclide pollutant to database' COLOR ,,,,GR+/BR+
DEFINE BAR 4 OF edit PROMPT 'TECHNOLOGY';
MESSAGE 'Delete/edit a general technology in database' COLOR ,,,,GR+/BR+
DEFINE BAR 5 OF edit PROMPT 'DEVELOP';
MESSAGE 'Delete/edit a developed/demonstrated technology in database';
  COLOR ,,,,GR+/BR+
*
ON SELECTION POPUP edit DO control WITH 'edit', BAR()
*
*
* Define SEARCH popup/menu
*
DEFINE POPUP search FROM 1,33 IN WINDOW name COLOR SCHEME 6
DEFINE BAR 1 OF search PROMPT 'SEARCH';
MESSAGE 'Search routines to be developed....' COLOR ,,,,GR+/BR+
*
ON SELECTION POPUP search DO control WITH 'search', BAR()
```

```
*
*
* Define EXIT selection
*
DEFINE POPUP exit FROM 1,48 IN WINDOW name COLOR SCHEME 6
DEFINE BAR 1 OF exit PROMPT 'EXIT';
MESSAGE 'End database session' COLOR ,,,,GR+/BR+
*
ON SELECTION POPUP exit DO control WITH 'quit',0
*
* Define HELP popup/menu
*
DEFINE POPUP help FROM 1,63 IN WINDOW name COLOR SCHEME 6
DEFINE BAR 1 OF help PROMPT 'HELP';
MESSAGE 'HELP routines to be developed....' COLOR ,,,,GR+/BR+
*
ON SELECTION POPUP help DO control WITH 'help', BAR()
*
RETURN
```

```
**********************************************************************
*PROGRAM TO EDIT/DELETE A RECORD
PROCEDURE editmenu
PARAMETERS mchoice,srchstring
**********************************************************************
* stopit = true stops editmenu
  stopit = .F.
* Mem var for search/mainmenu
runchoice = 1
DEFINE WINDOW editsearch FROM 0,0 TO 24,79 COLOR SCHEME 1

* Define POPUP for field choices for organic/inorganic database
DEFINE POPUP efield1 COLOR SCHEME 5
DEFINE BAR 1 OF efield1 PROMPT 'Pollutant       '
DEFINE BAR 2 OF efield1 PROMPT 'Chem. Abstract #'
*
* Define POPUP for field choices technology database
DEFINE POPUP efield2 COLOR SCHEME 5
DEFINE BAR 1 OF efield2 PROMPT 'Technology'
DEFINE BAR 2 OF efield2 PROMPT 'Subclass  '
*
* Define POPUP for field choices for develop database
DEFINE POPUP efield3 COLOR SCHEME 5
DEFINE BAR 1 OF efield3 PROMPT 'Tech. Name'
DEFINE BAR 2 OF efield3 PROMPT 'Technology'
DEFINE BAR 3 OF efield3 PROMPT 'Developer '
DEFINE BAR 4 OF efield3 PROMPT 'Site      '
*
*  Execute edit menu until user chooses to go back to main menu.
*
DO WHILE (.NOT. stopit)
* Test_in is a boolean variable that determines if user
    has indexed on a field
test_in = .F.
* Fchoice is the field that the user chooses
fchoice=space(15)
* hold = true means searchstring has been chosen
hold = .F.
  * Set up a screen to get info from user
  ACTIVATE WINDOW editsearch
  @ 3,22 SAY "Input search character string:"
  @ 7,8 SAY "Choose search criterion and press ENTER or double-click mouse:"
  @ 16,29 SAY "Selections made:"
  DO CASE
    * Set up search screen for organic database.
    CASE mchoice=1
      @ 1,14 SAY "SEARCH FOR RECORD IN ORGANIC POLLUTANT DATABASE" COLOR GR+/B
      @ 17,10 TO 20,65
      @ 18,11 SAY "SEARCH STRING:"
      @ 19,11 SAY "SEARCH CRITERION:"
      * If value is to be held, reprint value in box.
      IF hold = .T.
        @ 4,22 SAY srchstring
        @ 18,30 SAY srchstring
      * Otherwise, get the new value and print in box.
      ELSE
        @ 4,22 GET srchstring VALID dispitem(18,30,srchstring)
      ENDIF
      @ 8,25 GET fchoice PICTURE "@&N" POPUP efield1;
        SIZE 6,25 VALID tindex(@test_in)
      @ 22,29 GET runchoice FUNCTION '*H SEARCH;MAINMENU';
        COLOR ,,,,,GR+/R
      READ CYCLE
```

```
    * Set up search screen for inorganic/radionuclide database.
    CASE (mchoice=2.or.mchoice=3)
      @ 1,13 SAY "SEARCH FOR RECORD IN INORGANIC/RADIONUCLIDE DATABASE" COLOR
      GR+/B
      @ 17,10 TO 20,65
      @ 18,11 SAY "SEARCH STRING:"
      @ 19,11 SAY "SEARCH CRITERION:"
      * If value is to be held, reprint value in box.
      IF hold = .T.
        @ 4,22 SAY srchstring
        @ 18,30 SAY srchstring
      * Otherwise, get the new value and print in box.
      ELSE
        @ 4,22 GET srchstring VALID dispitem(18,30,srchstring)
      ENDIF
      @ 8,25 GET fchoice PICTURE "@&N" POPUP efield1;
        SIZE 6,25 VALID tindex(@test_in)
      @ 22,29 GET runchoice FUNCTION '*H SEARCH;MAINMENU'
      READ CYCLE

    * Set up search screen for technology database.
    CASE mchoice=4
      @ 1,17 SAY "SEARCH FOR RECORD IN TECHNOLOGY DATABASE" COLOR GR+/B
      * Define POPUP for field choices
      @ 17,10 TO 20,65
      @ 18,11 SAY "SEARCH STRING:"
      @ 19,11 SAY "SEARCH CRITERION:"
      * If value is to be held, reprint value in box.
      IF hold = .T.
        @ 4,22 SAY srchstring
        @ 18,30 SAY srchstring
      * Otherwise, get the new value and print in box.
      ELSE
        @ 4,22 GET srchstring VALID dispitem(18,30,srchstring)
      ENDIF
      @ 8,25 GET fchoice PICTURE "@&N" POPUP efield2;
        SIZE 6,25 VALID tindex(@test_in)
      @ 22,29 GET runchoice FUNCTION '*H SEARCH;MAINMENU'
      READ CYCLE

    * Set up search screen for develop database.
    CASE mchoice=5
      @ 1,19 SAY "SEARCH FOR RECORD IN DEVELOP DATABASE" COLOR GR+/B
      * Read runchoice=goto mainmenu or run search
      @ 17,10 TO 20,65
      @ 18,11 SAY "SEARCH STRING:"
      @ 19,11 SAY "SEARCH CRITERION:"
      * If value is to be held, reprint value in box.
      IF hold = .T.
        @ 4,22 SAY srchstring
        @ 18,30 SAY srchstring
      * Otherwise, get the new value and print in box.
      ELSE
        @ 4,22 GET srchstring VALID dispitem(18,30,srchstring)
      ENDIF
      @ 8,25 GET fchoice PICTURE "@&N" POPUP efield3;
        SIZE 6,25 VALID tindex(@test_in)
      @ 22,29 GET runchoice FUNCTION '*H SEARCH;MAINMENU'
      READ CYCLE
  ENDCASE

  Convert field choices in POPUP to match field choices in database files.
 O CASE
CASE fchoice='Chem. Abstract #'
  fchoice='CAS_NUM'
CASE fchoice='Tech. Name'
```

```
   fchoice='TECH_NAME'
 CASE fchoice='Subclass  '
   fchoice='SUB_CLASS'
ENDCASE

  * If the user chooses the search button, control is passed
  * to the search routine.
  IF (runchoice = 1)
    * If there is a search criterion selected do the search
    IF (test_in = .T.)
      DEACTIVATE WINDOW editsearch
      DO search WITH mchoice,fchoice,srchstring
    * Otherwise display a message and go back to editmenu.
    ELSE
      * If the user forgets to enter a field to search on, a screen
      *   appears to instruct the user to do so.
      WAIT WINDOW 'YOU MUST CHOOSE A SEARCH CRITERION.  Press ENTER to
      continue.'
      * Hold is first initialized as .F.
      * However, if the user does not enter a field on the first screen in
      *  editmenu, hold becomes .T. so that the value of the searchstring
      *  is not lost.
      hold = .T.
    ENDIF
* Otherwise, return to the mainmenu
  ELSE
    DEACTIVATE WINDOW editsearch
    *stopit= .T.
    EXIT
  ENDIF
ENDDO
RETURN
*------------------------------------------------------------------*
* Function testindex determines if a user has indexed on a field
* Prints fchoice in the "Selections Made" box and returns true
*   if a user has indexed on a field
FUNCTION tindex
PARAMETER test_in
test_in = .T.
@ 19,30 SAY fchoice
RETURN test_in
*------------------------------------------------------------------*
* Function dispitem prints the value of the srchstring in the
*  "Selections Made" box
FUNCTION dispitem
PARAMETER x,y,item
@ x,y SAY item
RETURN
*
*
*********************************************************************
* ROUTINE TO SEARCH
PROCEDURE search
PARAMETERS mchoice,fchoice,srchstring
*********************************************************************
* Make search string lower case
srchstring = ALLTRIM(LOWER(srchstring))
DEFINE WINDOW dispsrch FROM 0,0 TO 24,79 COLOR SCHEME 5
CLEAR
ACTIVATE WINDOW dispsrch
* Find nearest record
SET NEAR ON
* Open the specified database
DO CASE
  CASE mchoice=1
    USE C:\METC\DATABASE\DATA\ORGAN_CH.DBF
```

```
  CASE (mchoice=2 .OR. mchoice=3)
    USE C:\METC\DATABASE\DATA\INOR_RAD.DBF
  CASE mchoice=4
    USE C:\METC\DATABASE\DATA\TECHNOLO.DBF
  CASE mchoice=5
    USE C:\METC\DATABASE\DATA\DEVELOP.DBF
NDCASE
* Choice index to order database
SET ORDER TO TAG &fchoice
SEEK srchstring
* If the string is found, then display the record
IF (FOUND() .OR. (.NOT. EOF()))
  DEACTIVATE WINDOW dispsrch
  DO disprec WITH mchoice
* If the string is not found, message will appear, and control
*   is passed to editmenu
ELSE
    * If the search string is not found a screen appears and informs
    *   the user.
    WAIT WINDOW 'Search string not found!  Press ENTER to continue.'
    DEACTIVATE WINDOW dispsrch
    * Reassign search string as a character value before passing
    *  control back to editmenu.
    srchstring = SPACE(30)
    RETURN
ENDIF
SET EXACT ON
```

```
********************************************************************
* PROCEDURE TO EDIT RECORD
PROCEDURE editrec
PARAMETERS mchoice,addopt,recnum
********************************************************************
appblank = .F.
continue = .T.
whichelp = 0
whatmemo = 0
okcancel = 0
sacancel = 0
screen = 1
change1 = 0
change2 = 0
pushd = 0
pushtg = 0
pushsc = 0
bioopt = 0
check = 0
picks = 0
pickw = 0
picka = 0
pickc = 0
picke = 0
pickt = 0
pickd = 0
picalph = 0
picbeta = 0
picgamm = 0
checkba = 0
checkbe = 0
checkr = 0
ymedia = SPACE(6)
ypollut = SPACE(7)

DEFINE WINDOW record FROM 0,0 TO 24,79 COLOR SCHEME 5
ACTIVATE WINDOW record

* Define help popup
DEFINE MENU fhelp IN WINDOW record
DEFINE PAD helppad OF fhelp PROMPT 'HELP' AT 0,70
ON PAD helppad OF fhelp ACTIVATE POPUP help1
DEFINE POPUP help1 FROM 1,67 IN WINDOW record COLOR SCHEME 1
DEFINE BAR 1 OF help1 PROMPT 'Field Definitions' COLOR SCHEME 10
DEFINE BAR 2 OF help1 PROMPT 'Cancel' COLOR SCHEME 10
ON SELECTION POPUP help1 DO helpit WITH BAR(),1

* Open database which user wants if add was chosen in mainmenu
*    and scatter the data to empty memory variables.
IF addopt = .T.
  DO CASE
    CASE mchoice = 1
      USE C:\METC\DATABASE\DATA\ORGAN_CH.DBF
    CASE (mchoice = 2 .OR. mchoice = 3)
      USE C:\METC\DATABASE\DATA\INOR_RAD.DBF
    CASE mchoice = 4
      USE C:\METC\DATABASE\DATA\TECHNOLO.DBF
    CASE mchoice = 5
      USE C:\METC\DATABASE\DATA\DEVELOP.DBF
  ENDCASE
  GOTO BOTTOM
  SCATTER MEMO MEMVAR BLANK
  Otherwise, scatter the data to the existing memory variables
ELSE
  SCATTER MEMO MEMVAR
```

```
ENDIF
* This segment will print the current contents of the field
*  on the designated screen.
DO CASE
  * What to do with checkboxes in radionuclide database.
  CASE mchoice = 3
    * Write the current contents of the specified field on the
    *   screen beside the checkboxes.
    IF m.emission_1 = 'alpha'
      m.picalph = 1
      @ 18,32 SAY m.emission_1
    ENDIF
    IF m.emission_2 = 'beta'
      m.picbeta = 1
      @ 19,32 SAY m.emission_2
    ENDIF
    IF m.emission_3 = 'gamma'
      m.picgamm = 1
      @ 20,32 SAY m.emission_3
    ENDIF

  * What to do with push buttons and checkboxes in
  *   technology database.
  CASE mchoice = 4
    * Write the current contents of the specified field on the
    *   screen above the push buttons.
    @ 7,12 SAY m.domain
    @ 5,30 SAY m.tech_group
    * Write the current contents of the specified field on the
    *   screen beside the checkboxes.
    IF m.media1 = 'soil'
      m.picks = 1
      @ 10,34 SAY m.media1
    ENDIF
    IF m.media2 = 'water'
      m.pickw = 1
      @ 11,34 SAY m.media2
    ENDIF
    IF m.media3 = 'air'
      m.picka = 1
      @ 12,34 SAY m.media3
    ENDIF
    IF m.rem_phase1 = 'characterization'
      m.pickc = 1
      @ 14,50 SAY m.rem_phase1
    ENDIF
    IF m.rem_phase2 = 'extraction'
      m.picke = 1
      @ 15,50 SAY m.rem_phase2
    ENDIF
    IF m.rem_phase3 = 'treatment'
      m.pickt = 1
      @ 16,50 SAY m.rem_phase3
    ENDIF
    IF m.rem_phase4 = 'disposal'
      m.pickd = 1
      @ 17,50 SAY m.rem_phase4
    ENDIF
ENDCASE

ACTIVATE MENU fhelp NOWAIT

[illegible] Display record to edit or add
DO CASE
  * Setup screen to edit/add a record in the organic database.
  CASE mchoice = 1
```

```
*       DO testmemo WITH mchoice,checkba,checkbe,checkr,0,0,0
    DO testmem2 WITH mchoice
    * Display appropriate heading to add/edit organic database
    IF addopt = .T.
       @ 1,24 SAY "ADD A RECORD TO ORGANIC DATABASE" COLOR GR+/B
    ELSE
       @ 1,24 SAY "EDIT A RECORD IN ORGANIC DATABASE" COLOR GR+/B
    ENDIF
    @ 3,4 SAY "POLLUTANT:" GET m.pollutant VALID lcase(@m.pollutant)
    @ 4,4 SAY "CAS #:" GET m.cas_num VALID lcase(@m.cas_num)
    @ 5,4 SAY "CLASS #:" GET m.poll_num VALID lcase(@m.poll_num)
    @ 6,4 SAY "MOLECULAR WEIGHT (amu):" GET m.mol_wt FUNCTION "@Z" PICTURE
    "########.###"
    @ 7,4 SAY "BOILING POINT (C):" GET m.boil_pt FUNCTION "@Z" PICTURE
    "######.###"
    @ 8,4 SAY "MELTING POINT (C):" GET m.melt_pt FUNCTION "@Z" PICTURE
    "######.###"
    @ 9,4 SAY "VAPOR PRESSURE (Pa):" GET m.vapor_pres FUNCTION "@Z" PICTURE
    "########.##"
    @ 10,4 SAY "HENRY'S CONSTANT (Pa-m^3/mol):" GET m.henry_con FUNCTION "@Z"
    PICTURE "###.#######"
    @ 11,4 SAY "SOLUBILITY (mg/L):" GET m.solubility FUNCTION "@Z" PICTURE
    "####.###############"
    @ 12,4 SAY "SOLUBILITY PH:" GET m.sol_ph FUNCTION "@Z" PICTURE "##.##"
    @ 13,4 SAY "LOG OCTONOL TO WATER PARTITION COEFF:" GET m.log_oct_h2 FUNCTIC:
    "@Z" PICTURE "######.#####"
    @ 14,4 SAY "IT CAN PHOTODEGRADE (T/F):" GET m.photodeg
    @ 15,4 SAY "IT CAN BIODEGRADE (T/F):" GET m.biodegrad
    @ 16,4 SAY "IT IS POLAR (T/F):" GET m.polar
*    @ 18,17 SAY "(Check desired box for further information.)" COLOR GR+/B
    * Draw a box around check box choices.
*    @ 19,4 TO 21,72
    * Create check boxes for memo fields.
 *   @ 20,6 GET m.checkba PICTURE '@*C BIOLOGICAL AGENTS';
 *     VALID dispmemo('bio_agents',addopt)
 *   @ 20,32 GET m.checkbe PICTURE '@*C BIOLOGICAL EFFECT';
 *     VALID dispmemo('bio_effect',addopt)
 *   @ 20,58 GET m.checkr PICTURE '@*C REFERENCE';
 *     VALID dispmemo('reference',addopt)
 *   @ 22,31 GET okcancel FUNCTION '*H SAVE;CANCEL' COLOR SCHEME 1
    @ 17,4 SAY "(Check desired button for further information.)" COLOR GR+/B
    @ 18,4 TO 22,35
    @ 19,6 GET whatmemo FUNCTION;
      '*VN BIOLOGICAL AGENTS;BIOLOGICAL EFFECT;REFERENCE';
      VALID dismemo(1,whatmemo,addopt)
    * Create push buttons to save the record or exit the screen.
    @ 22,55 GET okcancel FUNCTION '*H SAVE;CANCEL' COLOR SCHEME 1
    READ CYCLE

  * Setup screen to edit/add a record in the inorganic database.
  CASE mchoice = 2
    * Display appropriate heading to add/edit inorganic database
    IF addopt = .T.
       @ 1,21 SAY "ADD A RECORD TO INORGANIC DATABASE" COLOR GR+/B
    ELSE
       @ 1,21 SAY "EDIT A RECORD IN INORGANIC DATABASE" COLOR GR+/B
    ENDIF
    @ 3,4 SAY "POLLUTANT:" GET m.pollutant VALID lcase(@m.pollutant)
    @ 4,4 SAY "CAS #:" GET m.cas_num VALID lcase(@m.cas_num)
    @ 5,4 SAY "CLASS #:" GET m.poll_num VALID lcase(@m.poll_num)
    @ 6,4 SAY "VALENCE OF POLLUTANT:" GET m.redox_num;
      VALID lcase(@m.redox_num)
    @ 7,4 SAY "MOLECULAR WEIGHT (amu):" GET m.mol_wt FUNCTION "@Z" PICTURE
    "########.###"
    @ 8,4 SAY "BOILING POINT (C):" GET m.boil_pt FUNCTION "@Z" PICTURE
    "######.###"
```

```
  @ 9,4 SAY "MELTING POINT (C):" GET m.melt_pt FUNCTION "@Z" PICTURE
  "######.###"
  @ 10,4 SAY "DENSITY (g/L):" GET m.density FUNCTION "@Z" PICTURE "######.###
  @ 11,4 SAY "SOLUBILITY (mg/L):" GET m.solubility FUNCTION "@Z" PICTURE
  "####.###############"
  @ 12,4 SAY "SOLUBILITY PH:" GET m.sol_ph FUNCTION "@Z" PICTURE "##.##"
  @ 13,4 SAY "DIFFUSION (cm^2/sec):" GET m.diffusion FUNCTION "@Z" PICTURE
  "######.###"
  @ 14,4 SAY "VAPOR PRESSURE (Pa):" GET m.vapor_pres FUNCTION "@Z" PICTURE
  "########.##"
  @ 15,4 SAY "HENRY'S CONSTANT (Pa-m^3/mol):" GET m.henry_con FUNCTION "@Z"
  PICTURE "##.########"
  @ 18,16 SAY "(Check desired box for further information.)" COLOR GR+/B
  * Draw a box around check box choices.
  @ 19,16 TO 21,59
  * Create check boxes for memo fields.
  @ 20,18 GET m.check PICTURE '@*C BIOLOGICAL EFFECT';
    VALID dispmemo('bio_effect',addopt)
  @ 20,45 GET m.check PICTURE '@*C REFERENCE';
    VALID dispmemo('reference',addopt)
  * Create push buttons to save the record or exit the screen.
  @ 22,30 GET okcancel FUNCTION '*H SAVE;CANCEL' COLOR SCHEME 1
  READ CYCLE

* Setup screen to edit/add a record in the inor_rad database.
CASE mchoice = 3
  * Display appropriate heading to add/edit radionuclide database
  IF addopt = .T.
     @ 0,19 SAY "ADD A RECORD TO RADIONUCLIDE DATABASE" COLOR GR+/B
  ELSE
     @ 0,19 SAY "EDIT A RECORD IN RADIONUCLIDE DATABASE" COLOR GR+/B
  ENDIF
  @ 2,2 SAY "POLLUTANT:" GET m.pollutant VALID lcase(@m.pollutant)
  @ 3,2 SAY "CAS #:" GET m.cas_num VALID lcase(@m.cas_num)
  @ 4,2 SAY "CLASS #:" GET m.poll_num VALID lcase(@m.poll_num)
  @ 4,42 SAY "VALENCE OF POLLUTANT:" GET m.redox_num;
    VALID lcase(@m.redox_num)
  @ 5,2 SAY "MOLECULAR WEIGHT (amu):" GET m.mol_wt FUNCTION "@Z" PICTURE
  "########.###"
  @ 5,42 SAY "DENSITY (g/L):" GET m.density FUNCTION "@Z" PICTURE "######.###'
  @ 6,2 SAY "BOILING POINT (C):" GET m.boil_pt FUNCTION "@Z" PICTURE
  "######.###"
  @ 6,42 SAY "MELTING POINT (C):" GET m.melt_pt FUNCTION "@Z" PICTURE
  "######.###"
  @ 7,2 SAY "DIFFUSION (cm^2/sec):" GET m.diffusion FUNCTION "@Z" PICTURE
  "######.###"
  @ 7,42 SAY "VAPOR PRESSURE (Pa):" GET m.vapor_pres FUNCTION "@Z" PICTURE
  "########.##"
  @ 8,2 SAY "HALF LIFE (yrs):" GET m.half_life FUNCTION "@Z" PICTURE
  "##########.########"
  @ 8,42 SAY "DAUGHTER:" GET m.daughter VALID lcase(@m.daughter)
  @ 9,2 SAY "SOLUBILITY (mg/L):" GET m.solubility FUNCTION "@Z" PICTURE
  "####.###############"
  @ 9,42 SAY "SOLUBILITY PH:" GET m.sol_ph FUNCTION "@Z" PICTURE "##.##"
  @ 10,2 SAY "HENRY'S CONSTANT (Pa-m^3/mol):" GET m.henry_con FUNCTION "@Z"
  PICTURE "##.########"
  @ 12,2 SAY "(Check all types of emission.)" COLOR GR+/B
  * Draw a box and create emission checkboxes.
  @ 13,3 TO 17,14
  @ 14,18 SAY "EMISSION 1:"
  @ 14,4 GET m.picalph PICTURE '@*C ALPHA';
    VALID place(14,30,picalph,'emission_1')
  @ 15,18 SAY "EMISSION 2:"
  @ 15,4 GET m.picbeta PICTURE '@*C BETA';
    VALID place(15,30,picbeta,'emission_2')
  @ 16,18 SAY "EMISSION 3:"
```

```
  @ 16,4 GET m.picgamm PICTURE '@*C GAMMA';
    VALID place(16,30,picgamm,'emission_3')
  @ 14,42 SAY "ENERGY 1 (mev):" GET m.energy_1 FUNCTION "@Z" PICTURE
  "#####.##"
  @ 15,42 SAY "ENERGY 2 (mev):" GET m.energy_2 FUNCTION "@Z" PICTURE
  "#####.##"
  @ 16,42 SAY "ENERGY 3 (mev):" GET m.energy_3 FUNCTION "@Z" PICTURE
  "#####.##"
  * Draw a box around check box choices.
  @ 18,16 SAY "(Check desired box for further information.)" COLOR GR+/B
  @ 19,16 TO 21,60
  * Create check boxes for memo fields.
  @ 20,18 GET m.check PICTURE '@*C BIOLOGICAL EFFECT';
    VALID dispmemo('bio_effect',addopt)
  @ 20,46 GET m.check PICTURE '@*C REFERENCE';
    VALID dispmemo('reference',addopt)
  * Create push buttons to save the record or exit the screen.
  @ 22,31 GET okcancel FUNCTION '*H SAVE;CANCEL' COLOR SCHEME 1
  READ CYCLE

* Setup screen to edit/add a record in the technology database.
CASE mchoice = 4
  * Display appropriate heading to add/edit technology database
  IF addopt = .T.
     @ 0,20 SAY "ADD A RECORD TO TECHNOLOGY DATABASE" COLOR GR+/B
  ELSE
     @ 0,20 SAY "EDIT A RECORD IN TECHNOLOGY DATABASE" COLOR GR+/B
  ENDIF
 @ 2,4 SAY "TECHNOLOGY:" GET m.technology VALID lcase(@m.technology)
  @ 3,4 SAY "SUB-CLASS:" GET m.sub_class VALID lcase(@m.sub_class)
  @ 4,12 SAY "(Choose the correct technology group and domain.)" COLOR GR+/B
  @ 5,4 SAY "GENERAL TECHNOLOGY GROUP:"
  @ 5,50 SAY "BIOLOGICAL TYPE:" COLOR B/BG
  @ 5,67 SAY m.tech_oxi
  @ 6,6 GET m.pushtg FUNCTION;
    '*HN BIOLOGICAL;THERMAL;IMMOBILIZATION;PHYSICAL/CHEMICAL;UNKNOWN';
    VALID push (5,30,pushtg,'tech_group')
  @ 7,4 SAY "DOMAIN:"
  @ 8,12 GET m.pushd FUNCTION '*HN IN-SITU;EX-SITU;UNKNOWN';
    VALID push(7,12,pushd,'domain')
  @ 9,4 SAY "MEDIA:"
  @ 9,11 SAY "(Check all applicable media.)" COLOR GR+/B
  @ 10,25 SAY 'MEDIA 1:'
  @ 11,25 SAY 'MEDIA 2:'
  @ 12,25 SAY 'MEDIA 3:'
  @ 10,12 GET m.picks PICTURE '@*C SOIL';
    VALID place(10,34,picks,'media1')
  @ 11,12 GET m.pickw PICTURE '@*C WATER';
    VALID place(11,34,pickw,'media2')
  @ 12,12 GET m.picka PICTURE '@*C AIR';
    VALID place(12,34,picka,'media3')
  @ 13,4 SAY "REMEDIATION PHASE:"
  @ 13,23 SAY "(Check all appropriate remediation phases.)"  COLOR GR+/B
  @ 14,36 SAY "REM. PHASE 1:"
  @ 15,36 SAY "REM. PHASE 2:"
  @ 16,36 SAY "REM. PHASE 3:"
  @ 17,36 SAY "REM. PHASE 4:"
  @ 14,12 GET m.pickc PICTURE '@*C CHARACTERIZATION';
    VALID place(14,50,pickc,'rem_phase1')
  @ 15,12 GET m.picke PICTURE '@*C EXTRACTION';
    VALID place(15,50,picke,'rem_phase2')
  @ 16,12 GET m.pickt PICTURE '@*C TREATMENT';
    VALID place(16,50,pickt,'rem_phase3')
  @ 17,12 GET m.pickd PICTURE '@*C DISPOSAL';
    VALID place(17,50,pickd,'rem_phase4')
  * Draw a box around check box choices.
```

```
  @ 18,16 SAY "(Check desired box for further information.)" COLOR GR+/B
  @ 19,4 TO 21,74
  * Create check boxes for memo fields.
  @ 20,6 GET m.check PICTURE '@*C DESCRIPTION';
    VALID dispmemo('descript',addopt)
  @ 20,31 GET m.check PICTURE '@*C REFERENCE';
    VALID dispmemo('reference',addopt)
  @ 20,55 GET m.check PICTURE '@*C POLLUTANT INFO';
    VALID addextra('ypollut',m.poll_key)
  * Create push buttons to save the record or exit the screen.
  @ 22,31 GET okcancel FUNCTION '*H SAVE;CANCEL' COLOR SCHEME 1
  READ CYCLE

* Setup screen to edit/add a record in the develop database.
CASE mchoice = 5
  * This DO WHILE loop allows the user to go back and forth between
  *  two screens when in the develop database.
  DO WHILE continue

    DO CASE
      CASE screen = 1
        * Define and activate the first screen of the develop record.
        DEFINE WINDOW record FROM 0,0 TO 24,79 COLOR SCHEME 5
        ACTIVATE WINDOW record

        * Define help popup
        DEFINE MENU fhelp2 IN WINDOW record
        DEFINE PAD helppad OF fhelp2 PROMPT 'HELP' AT 0,70
        ON PAD helppad OF fhelp2 ACTIVATE POPUP help2
        DEFINE POPUP help2 FROM 1,67 IN WINDOW record COLOR SCHEME 1
        DEFINE BAR 1 OF help2 PROMPT 'Field Definitions' COLOR SCHEME 10
        DEFINE BAR 2 OF help2 PROMPT 'Cancel' COLOR SCHEME 10
        ON SELECTION POPUP help2 DO helpit WITH BAR(),2
        ACTIVATE MENU fhelp2 NOWAIT

        * Write the current contents of the specified field on the
        *   screen above the push buttons.
        @ 9,39 SAY m.tech_group
        @ 17,12 SAY m.domain
        @ 9,11 SAY m.scale

        * Display appropriate heading to add/edit develop database
        IF addopt = .T.
          @ 0,16 SAY "ADD A RECORD TO DEVELOP DATABASE (Screen 1)" COLOR GR+/B
        ELSE
          @ 0,15 SAY "EDIT A RECORD IN DEVELOP DATABASE (Screen 1)" COLOR
          GR+/B
        ENDIF
        @ 2,4 SAY "COMPANY'S NAME FOR TECHNOLOGY:"
        @ 3,16 GET m.tech_name VALID lcase(@m.tech_name)
        @ 4,4 SAY "TECHNOLOGY:" GET m.technology;
          VALID lcase(@m.technology)
        @ 5,4 SAY "DEVELOPER:" GET m.developer VALID lcase(@m.developer)
        @ 6,4 SAY "SITE:" GET m.site VALID lcase(@m.site)
        @ 7,10 SAY;
          "(Choose the correct scale, domain, and technology group.)" COLOR
          GR+/B
        @ 9,4 SAY "SCALE:"
        * Draw a box around scale push buttons and define choices.
        @ 10,6 TO 16,16
        @ 11,7 GET m.pushsc FUNCTION '*VN BENCH;LAB;PILOT;FIELD;UNKNOWN';
          VALID push(9,11,pushsc,'scale')
        @ 17,4 SAY "DOMAIN:"
        * Draw a box around domain push buttons and define choices.
        @ 18,6 TO 22,16
        @ 19,7 GET m.pushd FUNCTION '*VN IN-SITU;EX-SITU;UNKNOWN';
```

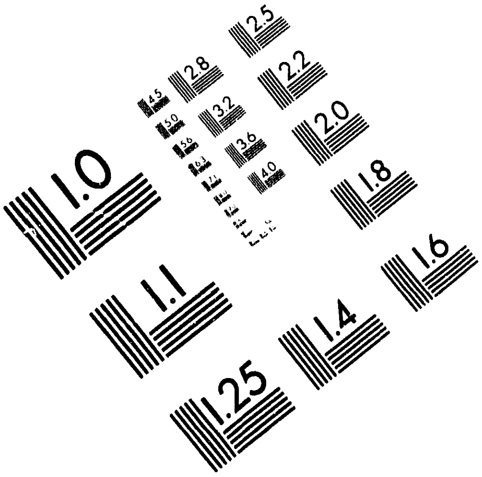
```
    VALID push(17,12,pushd,'domain')
  @ 9,21 SAY "TECHNOLOGY GROUP:"
  * Draw a box around tech group push buttons and define choices.
  @ 10,23 TO 16,46
  @ 11,24 GET m.pushtg FUNCTION;
    '*VN BIOLOGICAL;THERMAL;IMMOBILIZATION;PHYSICAL/CHEMICAL;UNKNCWN';
    VALID push (9,39,pushtg,'tech_group')
  @ 11,50 SAY "BIOLOGICAL TYPE:" COLOR B/BG
  @ 11,67 SAY m.tech_oxi

  * Enable user to continue to the next screen.
  @ 22,60 GET change1 PICTURE '@*CT NEXT SCREEN' COLOR ,,,,,,,,B/BG
  * Create push buttons to save the record or exit the screen.
  @ 22,30 GET okcancel PICTURE '@*H SAVE;CANCEL' COLOR SCHEME 1
  READ CYCLE
  * If the "NEXT SCREEN" checkbox is chosen, change the
  *  value of the screen to 2(second screen), and
  *  reinitialize the value of the checkbox to 0.
  IF change1 = 1
    screen = 2
    change1 = 0
  ENDIF

CASE screen = 2
  check = 0
  * Define and activate the second screen of the develop record.
  DEFINE WINDOW devscreen FROM 0,0 TO 24,79 COLOR SCHEME 5
  ACTIVATE WINDOW devscreen

  * Define help popup for second develop screen
  DEFINE MENU fhelp3 IN WINDOW devscreen
  DEFINE PAD helppad OF fhelp3 PROMPT 'HELP' AT 0,70
  ON PAD helppad OF fhelp3 ACTIVATE POPUP help3
  DEFINE POPUP help3 FROM 1,67 IN WINDOW devscreen COLOR SCHEME 1
  DEFINE BAR 1 OF help3 PROMPT 'Fields Definitions' COLOR SCHEME 10
  DEFINE BAR 2 OF help3 PROMPT 'Cancel' COLOR SCHEME 10
  ON SELECTION POPUP help3 DO helpit WITH BAR(),3
  ACTIVATE MENU fhelp3 NOWAIT

  * Write the current contents of the specified field on the
  *   screen beside the checkboxes.
  IF m.media1 = 'soil'
    m.picks = 1
    @ 5,34 SAY m.media1
  ENDIF
  IF m.media2 = 'water'
    m.pickw = 1
    @ 6,34 SAY m.media2
  ENDIF
  IF m.media3 = 'air'
    m.picka = 1
    @ 7,34 SAY m.media3
  ENDIF
  IF m.rem_phase1 = 'characterization'
    m.pickc = 1
    @ 11,50 SAY m.rem_phase1
  ENDIF
  IF m.rem_phase2 = 'extraction'
    m.picke = 1
    @ 12,50 SAY m.rem_phase2
  ENDIF
  IF m.rem_phase3 = 'treatment'
    m.pickt = 1
    @ 13,50 SAY m.rem_phase3
  ENDIF
  IF m.rem_phase4 = 'disposal'
```



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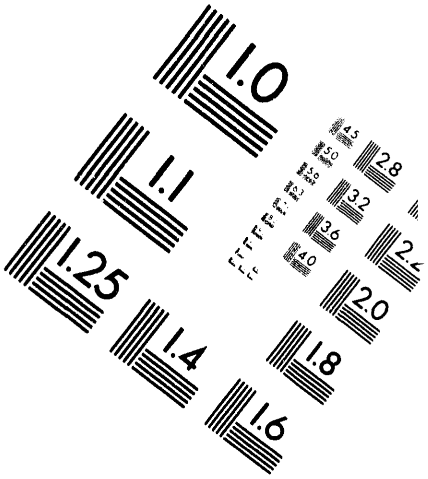
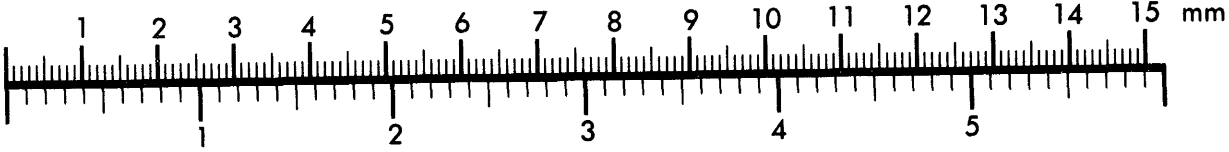
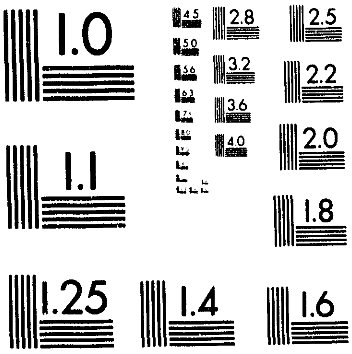
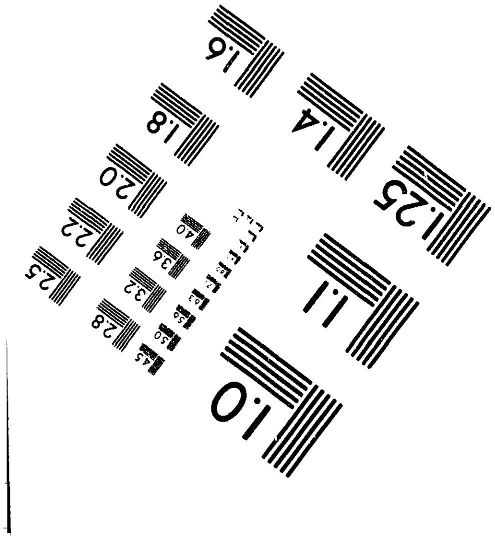


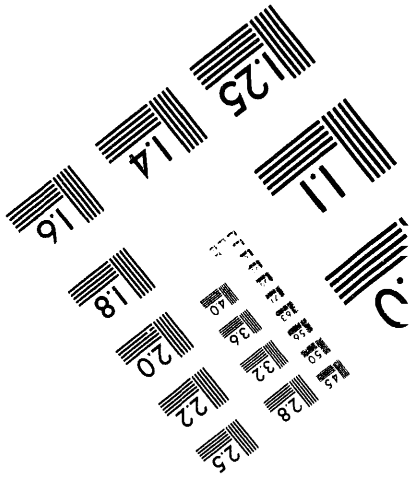
Centimeter



Inches







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```
  m.pickd = 1
  @ 14,50 SAY m.rem_phase4
ENDIF


* Display appropriate heading to add/edit develop database
IF addopt = .T.
  @ 0,16 SAY "ADD A RECORD TO DEVELOP DATABASE (Screen 2)" COLOR GR+
ELSE
  @ 0,15 SAY "EDIT A RECORD IN DEVELOP DATABASE (Screen 2)" COLOR
  GR+/B
ENDIF
@ 3,4 SAY "MEDIA:"
@ 3,11 SAY "(Check all applicable media.)" COLOR GR+/B
@ 5,25 SAY 'MEDIA 1:'
@ 6,25 SAY 'MEDIA 2:'
@ 7,25 SAY 'MEDIA 3:'
@ 5,12 GET m.picks PICTURE '@*C SOIL';
  VALID place(5,34,picks,'media1')
@ 6,12 GET m.pickw PICTURE '@*C WATER';
  VALID place(6,34,pickw,'media2')
@ 7,12 GET m.picka PICTURE '@*C AIR';
  VALID place(7,34,picka,'media3')
@ 9,4 SAY "REMEDIATION PHASE:"
@ 9,23 SAY "(Check all appropriate remediation phases.)" COLOR GR+/B
@ 11,36 SAY "REM. PHASE 1:"
@ 12,36 SAY "REM. PHASE 2:"
@ 13,36 SAY "REM. PHASE 3:"
@ 14,36 SAY "REM. PHASE 4:"
@ 11,12 GET m.pickc PICTURE '@*C CHARACTERIZATION';
  VALID place(11,50,pickc,'rem_phase1')
@ 12,12 GET m.picke PICTURE '@*C EXTRACTION';
  VALID place(12,50,picke,'rem_phase2')
@ 13,12 GET m.pickt PICTURE '@*C TREATMENT';
  VALID place(13,50,pickt,'rem_phase3')
@ 14,12 GET m.pickd PICTURE '@*C DISPOSAL';
  VALID place(14,50,pickd,'rem_phase4')
* Draw a box around check box choices.
@ 17,17 SAY "(Check desired box for further information.)" COLOR GR+/B
@ 18,4 TO 21,73
* Create check boxes for memo fields.
@ 19,5 GET m.check PICTURE '@*C DESCRIPTION';
  VALID dispmemo('descript',addopt)
@ 20,5 GET m.check PICTURE '@*C DOCUMENTS';
  VALID dispmemo('documents',addopt)
@ 19,24 GET m.check PICTURE '@*C STATUS';
  VALID dispmemo('status',addopt)
@ 20,24 GET m.check PICTURE '@*C COST';
  VALID dispmemo('cost',addopt)
@ 19,38 GET m.check PICTURE '@*C CONTACTS';
  VALID dispmemo('contacts',addopt)
@ 20,38 GET m.check PICTURE '@*C REFERENCE';
  VALID dispmemo('reference',addopt)
@ 19,55 GET m.check PICTURE '@*C MEDIA INFO';
  VALID addextra('ymedia',m.media_key)
@ 20,55 GET m.check PICTURE '@*C POLLUTANT INFO';
  VALID addextra('ypollut',m.poll_key)
@ 22,54 GET change2 PICTURE '@*CT PREVIOUS SCREEN' COLOR ,,,,,,,,B/BG
* Create push buttons to save or exit the screen.
@ 22,30 GET okcancel FUNCTION '*H SAVE;CANCEL' COLOR SCHEME 1
READ CYCLE
* If the "PREVIOUS SCREEN" checkbox is chosen, change the
*  value of the screen to 1(first screen), and
*  reinitialize the value of the checkbox to 0.
IF change2 = 1
  screen = 1
```

```
            change2 = 0
          ENDIF
      ENDCASE

      * If at any time in either screen SAVE or CANCEL are chosen,
      *  exit the DO WHILE loop and continue the program.
      IF (okcancel = 1).OR.(okcancel = 2)
        EXIT
      ENDIF

  ENDDO
ENDCASE

* Pass control depending on which push button is chosen
* If SAVE is chosen, transfer the memory variables to the database
IF okcancel = 1
  IF (appblank = .F.).AND.(addopt = .T.)
    APPEND BLANK
  ENDIF
  GATHER MEMVAR
ELSE
   * If SAVE is chosen and then CANCEL, only save the values given
   *   to media_key and poll_key.
   IF sacancel = 1
     DO CASE
       CASE mchoice = 4
         GATHER MEMVAR FIELDS poll_key
       CASE mchoice = 5
         GATHER MEMVAR FIELDS media_key,poll_key
     ENDCASE
   ENDIF
ENDIF
* If CANCEL is chosen or after SAVE choice is executed,
    deactivate window and pass control
DEACTIVATE WINDOW record
DEACTIVATE WINDOW devscreen
  * If in add mode, pass control to mainmenu
      IF addopt = .T.
        CLOSE DATABASES
        RETURN
  * If in edit mode, pass control to editmenu
      ELSE
        * When returning control to editmenu clear the searchstring.
        srchstring = SPACE(30)
        RETURN
      ENDIF

*-----------------------------------------------------------------*
* This function can be used with any of the fields where there are
*   specific choices given in push buttons.
* This function will display the choice made on the screen.

FUNCTION push
PARAMETERS x,y,push,fldname
* x and y are the coordinates where the choice will be written.
* Push determines which button was pushed.
* Fldname is the name of the field which is being edited.

* When a button is pushed, determine which field is being used.
DO CASE
  * Assign a value to the field domain depending on which
  *   button was chosen.
  CASE fldname = 'domain'
    DO CASE
      CASE push = 1
        m.domain = 'in-situ'
```

```
    CASE push = 2
      m.domain = 'ex-situ'
    CASE push = 3
      m.domain = '       '
  ENDCASE

* Assign a value to the field tech_group depending on which
*   button was chosen.
CASE fldname = 'tech_group'
  DO CASE
     CASE push = 1
       m.tech_group = 'biological        '
       * If biological is chosen, display a window to ask which
       *   type of technology it is.
          DO CASE
            * Place the window at certain coordinates depending on
            *   whether you are in technology or develop database.
            CASE mchoice = 4
              DEFINE WINDOW try FROM 8,42 TO 13,79 COLOR SCHEME 8
            CASE mchoice = 5
              DEFINE WINDOW try FROM 14,42 TO 19,79 COLOR SCHEME 8
          ENDCASE
          ACTIVATE WINDOW try
          @ 0,1 SAY "Choose biological technology type:" COLOR B/BG
          @ 1,13 GET m.bioopt FUNCTION '*VT AEROBIC;ANAEROBIC;COMBINED'
          READ
          * Write the choice into the database under field tech_oxi.
          DO CASE
            CASE bioopt = 1
              m.tech_oxi = 'aerobic   '
            CASE bioopt = 2
              m.tech_oxi = 'anaerobic'
            CASE bioopt = 3
              m.tech_oxi = 'combined '
          ENDCASE
          DEACTIVATE WINDOW try

     * If any other tech group is chosen, clear the tech_oxi field.
     CASE push = 2
       m.tech_group = 'thermal           '
       m.tech_oxi = '         '
     CASE push = 3
       m.tech_group = 'immobilization    '
       m.tech_oxi = '         '
     CASE push = 4
       m.tech_group = 'physical/chemical'
       m.tech_oxi = '         '
     CASE push = 5
       m.tech_group = '                 '
       m.tech_oxi = '         '
   ENDCASE
     * Regardless of the tech group, print the contents of
     *  tech_oxi on the screen beside the BIOLOGICAL TYPE heading.
     * The location is different for the technology and develop database.
     DO CASE
       CASE mchoice = 4
         @ 5,67 SAY m.tech_oxi
       CASE mchoice = 5
         @ 11,67 SAY m.tech_oxi
     ENDCASE

  * Assign a value to the field scale depending on which
  *   button was chosen.
  CASE fldname = 'scale'
     DO CASE
       CASE push = 1
```

```
          m.scale = 'bench'
        CASE push = 2
          m.scale = 'lab  '
        CASE push = 3
          m.scale = 'pilot'
        CASE push = 4
          m.scale = 'field'
        CASE push = 5
          m.scale = '     '
      ENDCASE
ENDCASE

* Display the choice made at the specified coordinates.
@ x,y SAY m.&fldname
* Reassign push to 0.
push = 0
RETURN
*-----------------------------------------------------------------*
* This function can be used with any of the fields where there are
*   specific choices given in check boxes.
* This function will confirm that the user has chosen a check box
*   by placing the contents of the field on the screen.

FUNCTION place
PARAMETER x,y,pick,fieldnm
* x and y are the coordinates where the choice will be written.
* Pick determines whether the checkbox was clicked or unclicked.
* Fieldnm is the name of the field which is being edited.

* If a checkbox is unclicked pick = 0. Assign blanks to the field.
IF pick = 0
  DO CASE
    CASE mchoice = 3
      m.&fieldnm = '     '
    CASE mchoice = 4
      m.&fieldnm = '                '
    CASE mchoice = 5
      m.&fieldnm = '                '
  ENDCASE
* If a checkbox is clicked, pick = 1. Assign the choice to the field.
ELSE
  DO CASE
    CASE fieldnm = 'emission_1'
      m.emission_1 = 'alpha'
    CASE fieldnm = 'emission_2'
      m.emission_2 = 'beta'
    CASE fieldnm = 'emission_3'
      m.emission_3 = 'gamma'
    CASE fieldnm = 'media1'
      m.media1 = 'soil'
    CASE fieldnm = 'media2'
      m.media2 = 'water'
    CASE fieldnm = 'media3'
      m.media3 = 'air'
    CASE fieldnm = 'rem_phase1'
      m.rem_phase1 = 'characterization'
    CASE fieldnm = 'rem_phase2'
      m.rem_phase2 = 'extraction'
    CASE fieldnm = 'rem_phase3'
      m.rem_phase3 = 'treatment'
    CASE fieldnm = 'rem_phase4'
      m.rem_phase4 = 'disposal'
  ENDCASE
ENDIF

* Write the new field contents at the designated coordinates.
```

```
@ x,y SAY m.&fieldnm
* Reassign pick to 0.
pick = 0
RETURN
*-----------------------------------------------------------------*
* This function converts all data entry to lower case.
FUNCTION lcase
PARAMETER string
string = LOWER(string)
RETURN
*-----------------------------------------------------------------*
* This procedure calls another program which defines fields
*   for the user.
PROCEDURE helpit
PARAMETERS mchoice,whichelp
DO CASE
   CASE mchoice = 1
     DO fieldhel IN c:\metc\database\prog\fieldhel.prg WITH mchoice,whichelp
   CASE mchoice = 2
     DO CASE
        CASE whichelp = 1
          DEACTIVATE POPUP help1
        CASE whichelp = 2
          DEACTIVATE POPUP help2
        CASE whichelp = 3
          DEACTIVATE POPUP help3
        CASE whichelp = 4
          DEACTIVATE POPUP help4
        CASE whichelp = 5
          DEACTIVATE POPUP help5
        CASE whichelp = 6
          DEACTIVATE POPUP help6
     ENDCASE
ENDCASE
RETURN
*
*-----------------------------------------------------------------*
* This function creates a region to add/edit memo fields.
FUNCTION dispmemo
PARAMETERS memname,addopt,check
savecan = 0

IF addopt = .T.
   appblank = .T.
   APPEND BLANK
ENDIF
*m.check=0
GATHER MEMVAR

DEFINE WINDOW dispmemo FROM 0,0 TO 25,79 COLOR SCHEME 7
ACTIVATE WINDOW dispmemo
@ 1,31 SAY 'MEMO REQUESTED'

* This variable will hold the original contents of the memo field
*   so that the changes will be erased from the screen if CANCEL
*   is chosen.
mvar = m.&memname

* Create a text editing region and push buttons.
@ 3,2 EDIT m.&memname SIZE 18,75 SCROLL COLOR SCHEME 10
@ 22,32 GET savecan FUNCTION '*H SAVE;CANCEL'
READ CYCLE

* The SAVE/CANCEL buttons give the user the option to save
*   or disregard the changes to the memo.
DO CASE
```

```
 * If the user chooses SAVE, the memo data will be gathered.
 CASE savecan = 1
  GATHER MEMVAR FIELDS &memname MEMO
  DEACTIVATE WINDOW dispmemo
*     DO testmemo WITH mchoice,checkba,checkbe,checkr,0,0,0

 * Otherwise, the changes to the memo field will be disregarded.
 CASE savecan = 2
  * This will clear the changes which were disregarded from
  *   the screen.
  m.&memname = mvar
  DEACTIVATE WINDOW dispmemo
ENDCASE
RETURN

*-------------------------------------------------------------------*
* This function will allow the user to add/edit pollutant or
*   media information.
FUNCTION addextra
PARAMETER medpoll,key

IF addopt = .T.
 APPEND BLANK
ENDIF
GATHER MEMVAR

DO CASE
 CASE medpoll = 'ymedia'
  DO addmedia IN c:\metc\database\prog\addmedia.prg;
    WITH key,sacancel,addopt
 CASE medpoll = 'ypollut'
  DO addpollu IN c:\metc\database\prog\addpollu.prg;
    WITH key,sacancel,addopt
NDCASE
ETURN
*-------------------------------------------------------------------*
FUNCTION dismemo
PARAMETERS mchoice,whatmemo,addopt
savecan = 0

IF addopt = .T.
   appblank = .T.
   APPEND BLANK
ENDIF
GATHER MEMVAR

DEFINE WINDOW dispmemo FROM 0,0 TO 25,79 COLOR SCHEME 7
ACTIVATE WINDOW dispmemo
@ 1,31 SAY 'MEMO REQUESTED'

DO CASE
 CASE mchoice = 1
  DO CASE
   CASE whatmemo=1
    memname = 'bio_agents'
   CASE whatmemo=2
    memname = 'bio_effect'
   CASE whatmemo=3
    memname = 'reference'
  ENDCASE
ENDCASE
 Create a text editing region and push buttons.
3,2 EDIT m.&memname SIZE 18,75 SCROLL COLOR SCHEME 10
@ 22,32 GET savecan FUNCTION '*H SAVE;CANCEL'
READ CYCLE
```

```
* This variable will hold the original contents of the memo field
*   so that the changes will be erased from the screen if CANCEL
*   is chosen.
mvar = m.&memname

* The SAVE/CANCEL buttons give the user the option to save
*   or disregard the changes to the memo.
DO CASE
  * If the user chooses SAVE, the memo data will be gathered.
  CASE savecan = 1
    GATHER MEMVAR FIELDS &memname MEMO
    DEACTIVATE WINDOW dispmemo
    DO testmem2 WITH mchoice
  * Otherwise, the changes to the memo field will be disregarded.
  CASE savecan = 2
    * This will clear the changes which were disregarded from
    *   the screen.
    m.&memname = mvar
    DEACTIVATE WINDOW dispmemo
ENDCASE
RETURN
```

```
*************************************************************************
* PROCEDURE  TO DELETE A RECORD
PROCEDURE delrec
PARAMETERS mchoice
*************************************************************************
* Mem var for yes/no if you want to delete record
yesno = 1
delm = 0
delp = 0
delitp = .T.
delitm = .T.
DEFINE WINDOW delete FROM 7,31 TO 14,49 PANEL SHADOW;
COLOR SCHEME 8
DEFINE WINDOW really FROM 7,28 TO 14,53 PANEL SHADOW;
COLOR SCHEME 1
ACTIVATE WINDOW delete
* Get user input yes/no
@ 1,2 SAY "ARE YOU SURE?"
@ 3,3 GET yesno FUNCTION '*H YES;NO'
READ CYCLE
* If the YES button is chosen ...
IF yesno = 1
  * Check again to make sure user wants to delete record
  DEACTIVATE WINDOW delete
  ACTIVATE WINDOW really
  * Get user confirmation
  @ 1,2 SAY "ARE YOU REALLY SURE?"
  @ 3,7 GET yesno FUNCTION '*H YES;NO'
  READ CYCLE
  * If user chooses yes delete record; otherwise return
  *   to edit menu
  * If the YES button is chosen again, delete the record.
  IF yesno = 1
    DO CASE
      CASE mchoice = 4
          IF poll_key = 0
            delitp = .F.
          ELSE
            delp = poll_key
          ENDIF
      CASE mchoice = 5
          IF poll_key = 0
            delitp = .F.
          ELSE
            delp = poll_key
          ENDIF
          IF media_key = 0
            delitm = .F.
          ELSE
            delm = media_key
          ENDIF
    ENDCASE
    DELETE
    PACK
    IF delitp = .T.
         SELECT 8
         USE C:\METC\DATABASE\DATA\POLLUTANT.DBF
         SET ORDER TO TAG poll_key
         SEEK delp
         DELETE
         PACK
    ENDIF
    IF delitm = .T.
         SELECT 9
         USE C:\METC\DATABASE\DATA\MEDIA.DBF
```

```
          SET ORDER TO TAG media_key
          SEEK delm
          DELETE
          PACK
     ENDIF
   ENDIF
   * Close the window and the databases and return to editmenu.
   DEACTIVATE WINDOW really
   CLOSE DATABASES
   * When returning control to editmenu, clear the searchstring
   *  and reassign hold as .F.
   srchstring = SPACE(30)
   RETURN
 * If the NO button is chosen, close the window and the databases
 *   and return to editmenu.
 ELSE
   DEACTIVATE WINDOW delete
   CLOSE DATABASES
   * When returning control to editmenu, clear the searchstring
   *  and reassign hold as .F.
   srchstring = SPACE(30)
   RETURN
 ENDIF
```

```
*HELP PROGRAM TO DEFINE FIELDS
PARAMETERS mchoice,whichelp
*
cancel = 1
*
*Indicate which database to use
SELECT 2
USE C:\METC\DATABASE\DATA\DEFINE.DBF
*
*Define help window
DEFINE WINDOW help FROM 0,0 TO 24,79 PANEL COLOR SCHEME 8
ACTIVATE WINDOW help
@ 1,27 SAY "HELP FOR DATABASE FIELDS" COLOR SCHEME 5
*display message at top
@ 3,2 SAY "Double-click mouse on field name and the;
 definition will appear in the box." COLOR B/BG
*
*Create and title definition box
@ 5,5 SAY "DEFINITION:" COLOR GR+/BG
@ 6,5 TO 8,76
*
*Explain field abbreviations
@ 11,43 SAY "C - Character Field"
@ 12,43 SAY "N - Numeric Field"
@ 13,43 SAY "M - Memo Field"
@ 14,43 SAY "L - Logical Field"
*Create and title field name list and mainmenu button
@ 10,5 SAY "CHOOSE FIELD NAME:" COLOR GR+/BG
DEFINE POPUP lfields PROMPT STRUCTURE SCROLL MARGIN;
    MARK ">" COLOR SCHEME 5
@ 19,44 GET cancel FUNCTION '*H PREVIOUS SCREEN'
@ 11,10 GET test PICTURE "@&N" POPUP lfields SIZE 11,14 DEFAULT " ";
VALID dispitem(test)
READ CYCLE
*
*Clear window and exit to previous screen if cancel is pushed
IF cancel = 1
  DEACTIVATE WINDOW help
  DEACTIVATE POPUP
  DO CASE
    CASE whichelp = 1
      DEACTIVATE POPUP help1
    CASE whichelp = 2
      DEACTIVATE POPUP help2
    CASE whichelp = 3
      DEACTIVATE POPUP help3
    CASE whichelp = 4
      DEACTIVATE POPUP help4
    CASE whichelp = 5
      DEACTIVATE POPUP help5
    CASE whichelp = 6
      DEACTIVATE POPUP help6
  ENDCASE
  SELECT 1
  RETURN
ENDIF
*
*Write definition in box
FUNCTION dispitem
PARAMETER item
@ 7,6 SAY &item

*End
```

```
   RETURN
 ELSE
   DEACTIVATE WINDOW pollut
   SELECT 5
   USE
   SELECT 1
   RETURN
 ENDIF
```

```
*******************************************************************
PROCEDURE addpollu
PARAMETER key,sacancel,addopt
*******************************************************************
* Program to add/edit a record to POLLUTAN.DBF
* This program is called by editrec.prg when the user pushes
*   the Pollutant Info checkbox
first = .F.
* Specify the media selection window
DEFINE WINDOW pollut FROM 0,0 TO 24,79 PANEL SHADOW COLOR SCHEME 5
* Open the pollutant database.
SELECT 5
  USE C:\METC\DATABASE\DATA\POLLUTAN.DBF ALIAS pollutant
* If the value of key, which is passed from editrec, is 0 find the
*   largest value of poll_key and add 1 to create a new poll_key.
IF key = 0
   first = .T.
   SET ORDER TO TAG poll_key ASCENDING
   GOTO BOTTOM
   key=poll_key+1
   SCATTER MEMO MEMVAR BLANK
   m.poll_key=key
* Otherwise, find the value of poll_key that matches the value of
*   key, which is passed from editrec.
ELSE
   SET ORDER TO TAG poll_key
   SEEK key
   SCATTER MEMO MEMVAR
ENDIF
ACTIVATE WINDOW pollut
@ 1,6 SAY "APPLICABLE POLLUTANTS AND THEIR CHEMICAL ABSTRACT SERVICE NUMBERS"
COLOR GR+/B
@ 3,2 SAY "POLLUTANT:" GET m.pollut1
@ 3,55 SAY "CAS NUMBER:" GET m.cas_num1
@ 4,2 SAY "POLLUTANT:" GET m.pollut2
@ 4,55 SAY "CAS NUMBER:" GET m.cas_num2
@ 5,2 SAY "POLLUTANT:" GET m.pollut3
@ 5,55 SAY "CAS NUMBER:" GET m.cas_num3
@ 6,2 SAY "POLLUTANT:" GET m.pollut4
@ 6,55 SAY "CAS NUMBER:" GET m.cas_num4
@ 7,2 SAY "POLLUTANT:" GET m.pollut5
@ 7,55 SAY "CAS NUMBER:" GET m.cas_num5
@ 8,2 SAY "POLLUTANT:" GET m.pollut6
@ 8,55 SAY "CAS NUMBER:" GET m.cas_num6
@ 9,2 SAY "POLLUTANT:" GET m.pollut7
@ 9,55 SAY "CAS NUMBER:" GET m.cas_num7
@ 10,2 SAY "POLLUTANT:" GET m.pollut8
@ 10,55 SAY "CAS NUMBER:" GET m.cas_num8
@ 11,2 SAY "POLLUTANT:" GET m.pollut9
@ 11,55 SAY "CAS NUMBER:" GET m.cas_num9
@ 12,2 SAY "POLLUTANT:" GET m.pollut10
@ 12,55 SAY "CAS NUMBER:" GET m.cas_num10
@ 15,2 SAY "ADDITIONAL COMMENTS:"
@ 16,7 EDIT m.note SIZE 4,65 SCROLL COLOR SCHEME 9
@ 21,30 GET sacancel FUNCTION "*H SAVE;CANCEL" COLOR SCHEME 1
READ CYCLE
IF sacancel=1
  IF (addopt=.T.).OR.(first=.T.)
    APPEND BLANK
  ENDIF
  GATHER MEMVAR MEMO
  DEACTIVATE WINDOW pollut
  SELECT 5
  USE
  SELECT 1
```

```
    *   screen in addmedia.
    IF sacancel=1
      * Put "air" into media3.
      m.mediathree="air"
      IF (addopt=.T.).OR.(first=.T.)
        APPEND BLANK
      ENDIF
      GATHER MEMVAR
      DEACTIVATE WINDOW addair
      SELECT 4
      USE
      SELECT 1
      RETURN
    * Otherwise, return to the first screen in addmedia.
    ELSE
      * IF CANCEL is chosen, reassign the field contents to
      *   their original value which was held in the
      *   memory variables.
        m.a_pressure = mapress
        m.a_flow = maflow
        m.a_temp = matemp
        m.a_humidity = mahum

      DEACTIVATE WINDOW addair
      SELECT 4
      USE
      SELECT 1
      RETURN
    ENDIF
  ENDCASE
* If the PREVIOUS RECORD button has been chosen, return to the calling
*   program(addmedia), and then return to the last screen displayed
*   in editrec.
[illegible]LSE
  DEACTIVATE WINDOW mediasel
  SELECT 4
  USE
  SELECT 1
  RETURN
ENDIF
*------------------------------------------------------------------*
* Display new choice for popup selection on popup
FUNCTION schoice
SHOW GETS
RETURN
*------------------------------------------------------------------*
```

```
  * Otherwise, return to the first screen in addmedia.
  ELSE
    * IF CANCEL is chosen, reassign the field contents to
    *   their original value which was held in the
    *   memory variables.
      m.w_org_cont = mworg
      m.w_colloid = mwcoll
      m.w_oxy_cont = mwoxy
      m.w_depth = mwdepth
      m.w_flow = mwflow
      m.w_temp = mwtemp
      m.w_ph = mwph

    DEACTIVATE WINDOW addwater
    SELECT 4
    USE
    SELECT 1
    RETURN
  ENDIF
 * If media=air is selected
CASE mediabut=3
  DEACTIVATE WINDOW mediasel
  * Specify the air window
  DEFINE WINDOW addair FROM 0,0 TO 24,79 COLOR SCHEME 5
  ACTIVATE WINDOW addair

  * Store original field contents in memory variables so that the
  *   changes will be erased from the screen if CANCEL is chosen.
    mapress = m.a_pressure
    maflow = m.a_flow
    matemp = m.a_temp
    mahum = m.a_humidity

  * Define help popup
    DEFINE MENU fhelp6 IN WINDOW addair
    DEFINE PAD helppad OF fhelp6 PROMPT 'HELP' AT 0,70
    ON PAD helppad OF fhelp6 ACTIVATE POPUP help6
    DEFINE POPUP help6 FROM 1,67 IN WINDOW record COLOR SCHEME 1
    DEFINE BAR 1 OF help6 PROMPT 'Field Definitions' COLOR SCHEME 10
    DEFINE BAR 2 OF help6 PROMPT 'Cancel' COLOR SCHEME 10
    ON SELECTION POPUP help6 DO helpit WITH BAR(),6
    ACTIVATE MENU fhelp6 NOWAIT

  * Mem var for save/cancel
  sacancel=0
  * Store air data to variables
  IF addopt = .T.
      @ 1,26 SAY "ADD AIR MEDIA INFORMATION" COLOR GR+/B
  ELSE
      @ 1,26 SAY "EDIT AIR MEDIA INFORMATION" COLOR GR+/B
  ENDIF
  @ 3,4 SAY "MEDIA #3: AIR"
  @ 4,4 SAY "AIR ABSOLUTE PRESSURE(Pa):" GET m.a_pressure FUNCTION "@Z"
  PICTURE "######.###"
  @ 5,4 SAY "AIR VOLUMETRIC FLOW RATE(m^3/hr):" GET m.a_flow FUNCTION "@Z"
  PICTURE "######.###"
  @ 6,4 SAY "AIR TEMPERATURE(deg C):" GET m.a_temp FUNCTION "@Z" PICTURE
  "###.##"
  @ 7,4 SAY "AIR HUMIDITY(%):" GET m.a_humidity FUNCTION "@Z" PICTURE "###.##"
  @ 11,21 SAY "(Check box for further Information.)" COLOR GR+/B
  @ 12,23 TO 14,54
  @ 13,24 GET m.check PICTURE "@*C AIR ADDITIONAL INFORMATION";
    VALID dispmemo('a_comment',addopt)
  @ 19,31 GET sacancel FUNCTION '*H SAVE;CANCEL' COLOR SCHEME 1
  READ CYCLE
  * If save is chosen, save the record and return to the first
```

```
DEFINE WINDOW addwater FROM 0,0 TO 24,79 COLOR SCHEME 5
ACTIVATE WINDOW addwater

* Store original field contents in memory variables so that the
*   changes will be erased from the screen if CANCEL is chosen.
  mworg = m.w_org_cont
  mwcoll = m.w_colloid
  mwoxy = m.w_oxy_cont
  mwdepth = m.w_depth
  mwflow = m.w_flow
  mwtemp = m.w_temp
  mwph = m.w_ph

* Define help popup
  DEFINE MENU fhelp5 IN WINDOW addwater
  DEFINE PAD helppad OF fhelp5 PROMPT 'HELP' AT 0,70
  ON PAD helppad OF fhelp5 ACTIVATE POPUP help5
  DEFINE POPUP help5 FROM 1,67 IN WINDOW record COLOR SCHEME 1
  DEFINE BAR 1 OF help5 PROMPT 'Field Definitions' COLOR SCHEME 10
  DEFINE BAR 2 OF help5 PROMPT 'Cancel' COLOR SCHEME 10
  ON SELECTION POPUP help5 DO helpit WITH BAR(),5
  ACTIVATE MENU fhelp5 NOWAIT

* Mem var for save/cancel
sacancel=0
IF addopt = .T.
  @ 1,25 SAY "ADD WATER MEDIA INFORMATION" COLOR GR+/B
ELSE
  @ 1,25 SAY "EDIT WATER MEDIA INFORMATION" COLOR GR+/B
ENDIF
@ 3,4 SAY "MEDIA #2: WATER"
@ 4,4 SAY "WATER ORGANIC CONTENT(mg/L):" GET m.w_org_cont FUNCTION "@Z"
PICTURE "##.##"
@ 5,4 SAY "WATER COLLOIDAL CONTENT(mg/L):" GET m.w_colloid FUNCTION "@Z"
PICTURE "####.##########"
@ 6,4 SAY "DISSOLVED OXYGEN CONTENT(mg/L):" GET m.w_oxy_cont FUNCTION "@Z"
PICTURE "##.##"
@ 7,4 SAY "DEPTH TO WATER TABLE(m):" GET m.w_depth FUNCTION "@Z" PICTURE
"###.###"
@ 8,4 SAY "VOLUMETRIC FLOW RATE(m^3/hr):" GET m.w_flow FUNCTION "@Z" PICTURE
"######.###"
@ 9,4 SAY "WATER TEMPERATURE(deg C):" GET m.w_temp FUNCTION "@Z" PICTURE
"###.##"
@ 10,4 SAY "WATER pH:" GET m.w_ph FUNCTION "@Z" PICTURE "##.##"
@ 13,21 SAY "(Check box for further information.)" COLOR GR+/B
@ 14,22 TO 17,55
@ 15,23 GET m.check PICTURE "@*C WATER BIOTA DESCRIPTION";
  VALID dispmemo('w_biota',addopt)
@ 16,23 GET m.check PICTURE "@*C WATER ADDITIONAL INFORMATION";
  VALID dispmemo('w_comment',addopt)
@ 20,31 GET sacancel FUNCTION '*H SAVE;CANCEL' COLOR SCHEME 1
READ CYCLE
* If save is chosen, save the record and return to the first
*   screen in addmedia.
IF sacancel=1
  * Put "water" into media2.
  m.mediatwo="water"
  IF (addopt=.T.).OR.(first=.T.)
    APPEND BLANK
  ENDIF
  GATHER MEMVAR
  DEACTIVATE WINDOW addwater
  SELECT 4
  USE
  SELECT 1
  RETURN
```

```
      "##.##"
      @ 12,4 SAY "SOIL VOLUME TREATED(m^3):" GET m.s_volume FUNCTION "@Z"
      PICTURE "######.####"
      @ 13,4 SAY "SOIL TEMPERATURE(deg C):" GET m.s_temp FUNCTION "@Z" PICTURE
      "###.##"
      @ 14,4 SAY "BULK DENSITY(kg/m^3):" GET m.s_bulk_den FUNCTION "@Z" PICTURE
      "######.###"
      @ 15,4 SAY "CATION EXCHANGE CAPACITY(meq/g):" GET m.s_cat_exch FUNCTION
      "@Z" PICTURE "######.###"
      @ 17,21 SAY "(Check box for further information.)" COLOR GR+/B
      @ 18,22 TO 21,55
      @ 19,23 GET m.check PICTURE "@*C SOIL BIOTA DESCRIPTION";
        VALID dispmemo('s_biota',addopt)
      @ 20,23 GET m.check PICTURE "@*C SOIL ADDITIONAL INFORMATION";
        VALID dispmemo('s_comment',addopt)
      @ 5,55 GET soiltext PICTURE "@^ UNKNOWN        ;CLAY;SILTY CLAY;SANDY
      CLAY;;
CLAY LOAM;SILTY CLAY LOAM;SANDY CLAY LOAM;SANDY LOAM;SILT LOAM;LOAM;;
LOAMY SAND;SAND;SILT" WHEN schoice()
      * Create push buttons to save or exit the screen.
      @ 22,31 GET sacancel FUNCTION '*H SAVE;CANCEL' COLOR SCHEME 1
      READ CYCLE
      * Selection from POPUP is copied into s_texture
      m.s_texture=LOWER(soiltext)
      * If save is chosen, save the record and return to the first
      *   screen in addmedia.
      IF sacancel=1
        * Put "soil" into media1.
        m.mediaone="soil"
        IF (addopt=.T.).OR.(first=.T.)
          APPEND BLANK
        ENDIF
        GATHER MEMVAR
        DEACTIVATE WINDOW addsoil
        SELECT 4
        USE
        SELECT 1
        RETURN
      * Otherwise, return to the first screen in addmedia.
      ELSE
        * IF CANCEL is chosen, reassign the field contents to
        *   their original value which was held in the
        *   memory variables.
          m.s_texture = mstext
          m.s_sand_per = msand
          m.s_silt_per = msilt
          m.s_clay_per = mclay
          m.s_ph = msph
          m.s_hydr_con = mshydr
          m.s_org_cont = msorg
          m.s_h2o_cont = msh2o
          m.s_volume = msvol
          m.s_temp = mstemp
          m.s_bulk_den = msbulk
          m.s_cat_exch = mscat

       DEACTIVATE WINDOW addsoil
       SELECT 4
       USE
       SELECT 1
       RETURN
      ENDIF
  * If media=water is selected
  CASE mediabut=2
    DEACTIVATE WINDOW mediasel
    * Specify the water window
```

```
* If media=soil is selected
 CASE mediabut=1
   DEACTIVATE WINDOW mediasel
   * Specify the soil window
   ACTIVATE WINDOW addsoil

   * Store original field contents in memory variables so that the
   *   changes will be erased from the screen if CANCEL is chosen.
     mstext = m.s_texture
     msand = m.s_sand_per
     msilt = m.s_silt_per
     mclay = m.s_clay_per
     msph = m.s_ph
     mshydr = m.s_hydr_con
     msorg = m.s_org_cont
     msh2o = m.s_h2o_cont
     msvol = m.s_volume
     mstemp = m.s_temp
     msbulk = m.s_bulk_den
     mscat = m.s_cat_exch
   * Mem var for save/cancel
   sacancel=0
   * Initialize POPUP variable
   soiltext=SPACE(15)
   * If the value of s_texture is blank, have UNKNOWN appear in
   *   th popup.
   IF m.s_texture = '               '
     STORE "UNKNOWN        " TO soiltext
   * Otherwise, have the value it has been given appear in the popup.
   ELSE
     upcase = UPPER(m.s_texture)
     STORE upcase TO soiltext
   ENDIF

   * Define help popup
     DEFINE MENU fhelp4 IN WINDOW addsoil
     DEFINE PAD helppad OF fhelp4 PROMPT 'HELP' AT 0,70
     ON PAD helppad OF fhelp4 ACTIVATE POPUP help4
     DEFINE POPUP help4 FROM 1,67 IN WINDOW record COLOR SCHEME 1
     DEFINE BAR 1 OF help4 PROMPT 'Field Definitions' COLOR SCHEME 10
     DEFINE BAR 2 OF help4 PROMPT 'Cancel' COLOR SCHEME 10
     ON SELECTION POPUP help4 DO helpit WITH BAR(),4
     ACTIVATE MENU fhelp4 NOWAIT

   IF addopt = .T.
     @ 1,26 SAY "ADD SOIL MEDIA INFORMATION" COLOR GR+/B
   ELSE
     @ 1,26 SAY "EDIT SOIL MEDIA INFORMATION" COLOR GR+/B
   ENDIF
   @ 3,4 SAY "MEDIA #1· SOIL"
   * Caption over POPUP box
   @ 4,55 SAY "CHOOSE SOIL TEXTURE:" COLOR B/BG
   * Selection from POPUP is placed next to "SOIL TEXTURE:"
   @ 4,4 SAY "SOIL TEXTURE:" GET soiltext
   @ 5,4 SAY "PERCENT SAND(%):" GET m.s_sand_per FUNCTION "@Z" PICTURE
   "##.##"
   @ 6,4 SAY "PERCENT SILT(%):" GET m.s_silt_per FUNCTION "@Z" PICTURE
   "##.##"
   @ 7,4 SAY "PERCENT CLAY(%):" GET m.s_clay_per FUNCTION "@Z" PICTURE
   "##.##"
   @ 8,4 SAY "SOIL pH:" GET m.s_ph FUNCTION "@Z" PICTURE "##.##"
   @ 9,4 SAY "HYDRAULIC CONDUCTIVITY(cm/s):" GET m.s_hydr_con FUNCTION "@Z"
   PICTURE "######.##########"
   @ 10,4 SAY "ORGANIC CONTENT(%):" GET m.s_org_cont FUNCTION "@Z" PICTURE
   "##.##"
   @ 11,4 SAY "MOISTURE CONTENT(%):" GET m.s_h2o_cont FUNCTION "@Z" PICTURE
```

```
*******************************************************************
PROCEDURE addmedia
PARAMETER key,sacancel,addopt
*******************************************************************
* Program to add/edit a record to MEDIA.DBF
* This program is called by editrec.prg when the user pushes
*   the Media Info checkbox
medloop = .T.
first = .F.
* Mem var for continue/previous record and media selection buttons
contpr=0
mediabut=1
* Specify the media selection window
DEFINE WINDOW mediasel FROM 0,0 TO 24,79 COLOR SCHEME 5
* Open the media database.
SELECT 4
  USE C:\METC\DATABASE\DATA\MEDIA.DBF ALIAS media
* If the value of key, which is passed from editrec, is 0 find the
*   largest value of media_key and add 1 to create a new media_key.
IF key = 0
   first = .T.
   SET ORDER TO TAG media_key ASCENDING
   GOTO BOTTOM
   key=media_key+1
   SCATTER MEMO MEMVAR BLANK
   m.media_key=key
* Otherwise, find the value of media_key that matches the value of
*   key, which is passed from editrec.
ELSE
   SET ORDER TO TAG media_key
   SEEK key
   SCATTER MEMO MEMVAR
ENDIF
* This do while loop allows the user to move back and forth between
*   the two screens in addmedia.
DO WHILE medloop
SELECT 4
  USE C:\METC\DATABASE\DATA\MEDIA.DBF ALIAS media
ACTIVATE WINDOW mediasel
@ 5,5 SAY "SELECT A MEDIA TYPE IN ORDER TO SUPPLY DETAILED MEDIA INFORMATION"
COLOR GR+/B
@ 8,28 TO 12,46 COLOR SCHEME 1
@ 9,30 GET mediabut FUNCTION '*R SOIL MEDIA;WATER MEDIA;AIR MEDIA'
* Define set of pushbuttons to save/cancel
*@ 14,15 SAY "Push CONTINUE to add media data; push PREVIOUS RECORD to exit"
@ 15,23 GET contpr FUNCTION '*H CONTINUE;PREVIOUS RECORD';
  VALID edmedia(contpr,mediabut) COLOR SCHEME 1
READ CYCLE
* If the PREVIOUS RECORD button is chosen, exit the do while loop
*   and return to the last screen displayed in editrec.
IF contpr = 2
  EXIT
ENDIF
ENDDO
RETURN
*-----------------------------------------------------------------------*
* This function is the second screen in addmedia.
FUNCTION edmedia
PARAMETERS contpr,mediabut,changeback
DEFINE WINDOW addsoil FROM 0,0 TO 24,79 COLOR SCHEME 5
* If the CONTINUE button is chosen, display the second screen
*   in addmedia.
check = 0
IF contpr=1
  DO CASE
```

```
**********************************************************************
* PROCEDURE TO DISPLAY RECORDS
PROCEDURE disprec
PARAMETERS mchoice,recnum
**********************************************************************
contin = .T.
* Mem var for edit/delete/previous menu
editdel = 0
printit = 0
DEFINE WINDOW display FROM 0,0 TO 24,79 COLOR SCHEME 1
* This do while loop allows the user to go back and forth between
*   the displayed record and either the first screen in editrec or
*   the first screen in printrpt.
DO WHILE contin
ACTIVATE WINDOW display
DO CASE
  * Display organic pollutant record
  CASE mchoice = 1
    @ 0,23 SAY "RECORD FROM ORGANIC DATABASE"
    @ 3,4 SAY "POLLUTANT:" GET pollutant DISABLE
    @ 4,4 SAY "CAS #:" GET cas_num DISABLE
    @ 5,4 SAY "CLASS #:" GET poll_num DISABLE
    @ 6,4 SAY "MOLECULAR WEIGHT (amu):" GET mol_wt FUNCTION "@Z" DISABLE
    @ 7,4 SAY "BOILING POINT (C):" GET boil_pt FUNCTION "@Z" DISABLE
    @ 8,4 SAY "MELTING POINT (C):" GET melt_pt FUNCTION "@Z" DISABLE
    @ 9,4 SAY "VAPOR PRESSURE (Pa):" GET vapor_pres FUNCTION "@Z" DISABLE
    @ 10,4 SAY "HENRY'S CONSTANT (Pa-m^3/mol):" GET henry_con FUNCTION "@Z"
    DISABLE
    @ 11,4 SAY "SOLUBILITY (mg/L):" GET solubility FUNCTION "@Z" DISABLE
    @ 12,4 SAY "SOLUBILITY PH:" GET sol_ph FUNCTION "@Z" DISABLE
    @ 13,4 SAY "LOG OCTONOL TO WATER PARTITION COEFF:" GET log_oct_h2 FUNCTION
    "@Z" DISABLE
    @ 14,4 SAY "IT CAN PHOTODEGRADE (T/F):" GET photodeg DISABLE
    @ 15,4 SAY "IT CAN BIODEGRADE (T/F):" GET biodegrad DISABLE
    @ 16,4 SAY "IT IS POLAR (T/F):" GET polar DISABLE
    * Define set of push buttons to edit/delete/previous menu
    @ 20,22 GET editdel FUNCTION '*H EDIT;DELETE;PREVIOUS MENU'
    @ 22,30 GET printit FUNCTION '*H PRINT RECORD' COLOR SCHEME 7
    READ CYCLE
 * Display inorganic pollutant record
 CASE mchoice = 2
   @ 0,22 SAY "RECORD FROM INORGANIC DATABASE"
   @ 3,4 SAY "POLLUTANT:" GET pollutant DISABLE
   @ 4,4 SAY "CAS #:" GET cas_num DISABLE
   @ 5,4 SAY "CLASS #:" GET poll_num DISABLE
   @ 6,4 SAY "VALENCE OF POLLUTANT:" GET redox_num DISABLE
   @ 7,4 SAY "MOLECULAR WEIGHT (amu):" GET mol_wt FUNCTION "@Z" DISABLE
   @ 8,4 SAY "BOILING POINT (C):" GET boil_pt FUNCTION "@Z" DISABLE
   @ 9,4 SAY "MELTING POINT (C):" GET melt_pt FUNCTION "@Z" DISABLE
   @ 10,4 SAY "DENSITY (g/L):" GET density FUNCTION "@Z" DISABLE
   @ 11,4 SAY "SOLUBILITY (mg/L):" GET solubility FUNCTION "@Z" DISABLE
   @ 12,4 SAY "SOLUBILITY PH:" GET sol_ph FUNCTION "@Z" DISABLE
   @ 13,4 SAY "DIFFUSION (cm^2/sec):" GET diffusion FUNCTION "@Z" DISABLE
   @ 14,4 SAY "VAPOR PRESSURE (Pa):" GET vapor_pres FUNCTION "@Z" DISABLE
   @ 15,4 SAY "HENRY'S CONSTANT (Pa-m^3/mol):" GET henry_con FUNCTION "@Z"
   DISABLE
   * Define set of push buttons to edit/delete/previous menu
   @ 20,22 GET editdel FUNCTION '*H EDIT;DELETE;PREVIOUS MENU'
   @ 22,30 GET printit FUNCTION '*H PRINT RECORD' COLOR SCHEME 7
   READ CYCLE
 * Display radionuclide record
 CASE mchoice = 3
   @ 0,21 SAY "RECORD FROM RADIONUCLIDE DATABASE"
   @ 2,4 SAY "POLLUTANT:" GET pollutant DISABLE
   @ 3,4 SAY "CAS #:" GET cas_num DISABLE
```

```
  @ 4,4 SAY "CLASS #:" GET poll_num DISABLE
  @ 5,4 SAY "VALENCE OF POLLUTANT:" GET redox_num DISABLE
  @ 6,4 SAY "MOLECULAR WEIGHT (amu):" GET mol_wt FUNCTION "@Z" DISABLE
  @ 7,4 SAY "BOILING POINT (C):" GET boil_pt FUNCTION "@Z" DISABLE
  @ 8,4 SAY "MELTING POINT (C):" GET melt_pt FUNCTION "@Z" DISABLE
  @ 9,4 SAY "DENSITY (g/L):" GET density FUNCTION "@Z" DISABLE
  @ 10,4 SAY "SOLUBILITY (mg/L):" GET solubility FUNCTION "@Z" DISABLE
  @ 11,4 SAY "SOLUBILITY PH:" GET sol_ph FUNCTION "@Z" DISABLE
  @ 12,4 SAY "DIFFUSION (cm^2/sec):" GET diffusion FUNCTION "@Z" DISABLE
  @ 13,4 SAY "VAPOR PRESSURE (Pa):" GET vapor_pres FUNCTION "@Z" DISABLE
  @ 14,4 SAY "HENRY'S CONSTANT (Pa-m^3/mol):" GET henry_con FUNCTION "@Z"
  DISABLE
  @ 15,4 SAY "HALF LIFE (yrs):" GET half_life FUNCTION "@Z" DISABLE
  @ 16,4 SAY "DAUGHTER:" GET daughter DISABLE
  @ 17,4 SAY "EMISSION 1:" GET emission_1 DISABLE
  @ 18,4 SAY "EMISSION 2:" GET emission_2 DISABLE
  @ 19,4 SAY "EMISSION 3:" GET emission_3 DISABLE
  @ 17,30 SAY "ENERGY 1 (mev):" GET energy_1 FUNCTION "@Z" DISABLE
  @ 18,30 SAY "ENERGY 2 (mev):" GET energy_2 FUNCTION "@Z" DISABLE
  @ 19,30 SAY "ENERGY 3 (mev):" GET energy_3 FUNCTION "@Z" DISABLE
  * Define set of push buttons to edit/delete/previous menu
  @ 22,22 GET editdel FUNCTION '*H EDIT;DELETE;PREVIOUS MENU'
  @ 22,62 GET printit FUNCTION '*H PRINT RECORD' COLOR SCHEME 7
  READ CYCLE
* Display technology record
CASE mchoice = 4
  @ 0,21 SAY "RECORD FROM TECHNOLOGY DATABASE"
  @ 3,4 SAY "TECHNOLOGY:" GET technology DISABLE
  @ 4,4 SAY "SUB-CLASS:" GET sub_class DISABLE
  @ 5,4 SAY "TECHNOLOGY GROUP:" GET tech_group DISABLE
  @ 6,7 SAY "OXIDATION TYPE (for biological technologies only):" GET tech_oxi
  DISABLE
  @ 7,4 SAY "DOMAIN:" GET domain DISABLE
  @ 8,4 SAY "MEDIA 1:" GET media1 DISABLE
  @ 9,4 SAY "MEDIA 2:" GET media2 DISABLE
  @ 10,4 SAY "MEDIA 3:" GET media3 DISABLE
  @ 11,4 SAY "REMEDIATION PHASE 1:" GET rem_phase1 DISABLE
  @ 12,4 SAY "REMEDIATION PHASE 2:" GET rem_phase2 DISABLE
  @ 13,4 SAY "REMEDIATION PHASE 3:" GET rem_phase3 DISABLE
  @ 14,4 SAY "REMEDIATION PHASE 4:" GET rem_phase4 DISABLE
  * Define set of push buttons to edit/delete/previous menu
  @ 20,22 GET editdel FUNCTION '*H EDIT;DELETE;PREVIOUS MENU'
  @ 22,30 GET printit FUNCTION '*H PRINT RECORD' COLOR SCHEME 7
  READ CYCLE
* Display develop record
CASE mchoice = 5
  @ 0,22 SAY "RECORD FROM DEVELOP DATABASE"
  @ 3,4 SAY "COMPANY'S NAME FOR TECHNOLOGY:" GET tech_name DISABLE
  @ 4,4 SAY "TECHNOLOGY:" GET technology DISABLE
  @ 5,4 SAY "DEVELOPER:" GET developer DISABLE
  @ 6,4 SAY "GENERAL TECHNOLOGY GROUP:" GET tech_group DISABLE
  @ 7,7 SAY "OXIDATION TYPE (for biological technologies only):" GET tech_oxi
  DISABLE
  @ 8,4 SAY "SITE:" GET site DISABLE
  @ 9,4 SAY "DOMAIN:" GET domain DISABLE
  @ 10,4 SAY "SCALE:" GET scale DISABLE
  @ 11,4 SAY "MEDIA 1:" GET media1 DISABLE
  @ 12,4 SAY "MEDIA 2:" GET media2 DISABLE
  @ 13,4 SAY "MEDIA 3:" GET media3 DISABLE
  @ 14,4 SAY "REMEDIATION PHASE 1:" GET rem_phase1 DISABLE
  @ 15,4 SAY "REMEDIATION PHASE 2:" GET rem_phase2 DISABLE
  @ 16,4 SAY "REMEDIATION PHASE 3:" GET rem_phase3 DISABLE
  @ 17,4 SAY "REMEDIATION PHASE 4:" GET rem_phase4 DISABLE
  * Define set of push buttons to edit/delete/previous menu
  @ 20,22 GET editdel FUNCTION '*H EDIT;DELETE;PREVIOUS MENU'
  @ 22,30 GET printit FUNCTION '*H PRINT RECORD' COLOR SCHEME 7
```

```
   READ CYCLE
ENDCASE
* Control passes depending on which push button is chosen
DO CASE
  * If edit is chosen, control is passed to editrec.
  CASE editdel = 1
    DEACTIVATE WINDOW display
    DO editrec WITH mchoice,.F.,recnum IN C:\METC\DATABASE\PROG\EDITREC.PRG
    editdel = 0
  * If delete is chosen, control is passed to delrec
  CASE editdel = 2
    DEACTIVATE WINDOW display
    DO delrec WITH mchoice IN C:\METC\DATABASE\PROG\DELREC.PRG
  * If previous menu is chosen, control is passed to editmenu.
  CASE editdel = 3
    DEACTIVATE WINDOW display
    CLOSE DATABASES
    * When returning control to editmenu clear the searchstring.
    srchstring = SPACE(30)
ENDCASE
* If the PRINT RECORD button is chosen, pass control to the
*   printrpt program.
IF printit = 1
  DO C:\METC\DATABASE\PROG\PRINTRPT.PRG WITH mchoice,recnum
  printit = 0
ENDIF
* If the DELETE or PREVIOUS MENU buttons are chosen, exit the
*   do while loop and return to editmenu.
IF (editdel = 2).OR.(editdel = 3)
  EXIT
ENDIF
ENDDO
RETURN
```

```
PROCEDURE printrpt
PARAMETERS mchoice,recnum
DEFINE WINDOW choices FROM 0,0 TO 24,79 PANEL SHADOW COLOR SCHEME 1
ACTIVATE WINDOW choices
SET TALK OFF
prnchoice=1
@ 5,13 SAY"This option allows you to print the record as a report!"
@ 10,20 SAY"Please select a printing option."
@ 12,32 GET prnchoice FUNCTION '*V PRINTER;SCREEN;CANCEL'
READ CYCLE
DO CASE
    CASE prnchoice=1
      DO printer WITH mchoice,recnum
    CASE prnchoice=2
      DO screen WITH mchoice,recnum
    CASE prnchoice=3
      DEACTIVATE WINDOW choices
      RETURN
ENDCASE
*
***********************************************************************
*
PROCEDURE printer
PARAMETERS mchoice,recnum
STORE RECNO() TO recnum
* This memory variable remains true unless media_key = 0.
getm = .T.
* This memory variable remains true unless poll_key = 0.
getp = .T.
DO CASE
    CASE mchoice=1
      REPORT FORM C:\METC\DATABASE\RPT\ORGANIC.FRX TO PRINT RECORD recnum
      NOEJECT
    CASE mchoice=2
      REPORT FORM C:\METC\DATABASE\RPT\INORGAN.FRX TO PRINT RECORD recnum
      NOEJECT
    CASE mchoice=3
      REPORT FORM C:\METC\DATABASE\RPT\RADIONUC.FRX TO PRINT RECORD recnum
      NOEJECT
    CASE mchoice=4
      REPORT FORM C:\METC\DATABASE\RPT\TECHRPT.FRX TO PRINT RECORD recnum
      NOEJECT

                   *** ALSO PRINT POLLUTANT INFORMATION ***
        * Reassign memory variable to .F. if there is no pollutant info.
          IF poll_key = 0
            getp = .F.
        * Otherwise, assign the poll_key number to a seek variable.
          ELSE
            whichp = poll_key
          ENDIF

        * If there is pollutant information, open pollutan.dbf and
        *   seek the corresponding record.
          IF getp = .T.
             SELECT 8
             USE C:\METC\DATABASE\DATA\POLLUTAN.DBF
             SET ORDER TO TAG poll_key
             SEEK whichp
             STORE RECNO() TO pollute
             REPORT FORM C:\METC\DATABASE\RPT\POLLUTE.FRX TO PRINT RECORD
             pollute NOEJECT
            * Close the pollutant database.
             SELECT 8
             USE
```

```
    * Return to the initial work area.
     SELECT 1
   ENDIF

CASE mchoice=5
 REPORT FORM C:\METC\DATABASE\RPT\DEVLOPER.FRX TO PRINT RECORD recnum
 NOEJECT

           *** ALSO PRINT MEDIA INFORMATION ***
  * Reassign memory variable to .F. if there is no media info.
   IF media_key = 0
    getm = .F.
  * Otherwise, assign the media_key number to a seek variable.
   ELSE
    whichm = media_key
   ENDIF

  * If there is media information, open media.dbf and seek
  *   the corresponding record.
   IF getm = .T.
     SELECT 9
     USE C:\METC\DATABASE\DATA\MEDIA.DBF
     SET ORDER TO TAG media_key
     SEEK whichm
     STORE RECNO() TO media
    * If soil information is provided, print the soil report.
     IF mediaone = 'soil'
        REPORT FORM C:\METC\DATABASE\RPT\SMEDIA.FRX TO PRINT RECORD
                                                    media NOEJECT
     ENDIF
    * If water information is provided, print the water report.
     IF mediatwo = 'water'
        REPORT FORM C:\METC\DATABASE\RPT\WMEDIA.FRX TO PRINT RECORD
        media NOEJECT
     ENDIF
    * If air information is provided, print the air report.
     IF mediathree = 'air'
        REPORT FORM C:\METC\DATABASE\RPT\AMEDIA.FRX TO PRINT RECORD
        media NOEJECT
     ENDIF
    * Close the media database.
     SELECT 9
     USE
    * Return to the initial work area.
     SELECT 1
   ENDIF


           *** ALSO PRINT POLLUTANT INFORMATION ***
  * Reassign memory variable to .F. if there is no pollutant info.
   IF poll_key = 0
    getp = .F.
  * Otherwise, assign the poll_key number to a seek variable.
   ELSE
    whichp = poll_key
   ENDIF

  * If there is pollutant information, open pollutan.dbf and
  *   seek the corresponding record.
   IF getp = .T.
     SELECT 8
     USE C:\METC\DATABASE\DATA\POLLUTAN.DBF
     SET ORDER TO TAG poll_key
     SEEK whichp
     STORE RECNO() TO pollute
     REPORT FORM C:\METC\DATABASE\RPT\POLLUTE.FRX TO PRINT RECORD
```

```
             pollute NOEJECT
            * Close the pollutant database.
             SELECT 8
             USE
            * Return to the initial work area.
             SELECT 1
          ENDIF

ENDCASE
DEACTIVATE WINDOW choices
DO disprec IN C:\METC\DATABASE\PROG\DISPREC.PRG WITH mchoice,recnum
*
******************************************************************************
*
PROCEDURE screen
PARAMETERS mchoice,recnum
STORE RECNO() TO recnum
SET TALK OFF
* This memory variable remains true unless media_key = 0.
getm = .T.
* This memory variable remains true unless poll_key = 0.
getp = .T.
DO CASE
    CASE mchoice=1
      REPORT FORM C:\METC\DATABASE\RPT\ORGANIC.FRX RECORD recnum PREVIEW
    CASE mchoice=2
      REPORT FORM C:\METC\DATABASE\RPT\INORGAN.FRX RECORD recnum PREVIEW
    CASE mchoice=3
      REPORT FORM C:\METC\DATABASE\RPT\RADIONUC.FRX RECORD recnum PREVIEW
    CASE mchoice=4
      REPORT FORM C:\METC\DATABASE\RPT\TECHRPT.FRX RECORD recnum PREVIEW

                  *** ALSO PRINT POLLUTANT INFORMATION ***
        * Reassign memory variable to .F. if there is no pollutant info.
          IF poll_key = 0
            getp = .F.
        * Otherwise, assign the poll_key number to a seek variable.
          ELSE
            whichp = poll_key
          ENDIF

        * If there is pollutant information, open pollutan.dbf and
        *   seek the corresponding record.
          IF getp = .T.
             SELECT 8
             USE C:\METC\DATABASE\DATA\POLLUTAN.DBF
             SET ORDER TO TAG poll_key
             SEEK whichp
             STORE RECNO() TO pollute
             REPORT FORM C:\METC\DATABASE\RPT\POLLUTE.FRX RECORD pollute PREVIEW
            * Close the pollutant database.
             SELECT 8
             USE
            * Return to the initial work area.
             SELECT 1
          ENDIF

    CASE mchoice=5
      REPORT FORM C:\METC\DATABASE\RPT\DEVLOPER.FRX RECORD recnum PREVIEW

                    *** ALSO PRINT MEDIA INFORMATION ***
         * Reassign memory variable to .F. if there is no media info.
          IF media_key = 0
            getm = .F.
         * Otherwise, assign the media_key number to a seek variable.
          ELSE
```

```
           whichm = media_key
         ENDIF

        * If there is media information, open media.dbf and seek
        *   the corresponding record.
         IF getm = .T.
            SELECT 9
            USE C:\METC\DATABASE\DATA\MEDIA.DBF
            SET ORDER TO TAG media_key
            SEEK whichm
            STORE RECNO() TO media
           * If soil information is provided, print the soil report.
            IF mediaone = 'soil'
               REPORT FORM C:\METC\DATABASE\RPT\SMEDIA.FRX RECORD media PREVIE
            ENDIF
           * If water information is provided, print the water report.
            IF mediatwo = 'water'
               REPORT FORM C:\METC\DATABASE\RPT\WMEDIA.FRX RECORD media PREVIE
            ENDIF
           * If air information is provided, print the air report.
            IF mediathree = 'air'
               REPORT FORM C:\METC\DATABASE\RPT\AMEDIA.FRX RECORD media PREVIE
            ENDIF
           * Close the media database.
            SELECT 9
            USE
           * Return to the initial work area.
            SELECT 1
         ENDIF

                 *** ALSO PRINT POLLUTANT INFORMATION ***
        * Reassign memory variable to .F. if there is no pollutant info.
         IF poll_key = 0
           getp = .F.
        * Otherwise, assign the poll_key number to a seek variable.
         ELSE
           whichp = poll_key
         ENDIF

        * If there is pollutant information, open pollutan.dbf and
        *   seek the corresponding record.
         IF getp = .T.
            SELECT 8
            USE C:\METC\DATABASE\DATA\POLLUTAN.DBF
            SET ORDER TO TAG poll_key
            SEEK whichp
            STORE RECNO() TO pollute
            REPORT FORM C:\METC\DATABASE\RPT\POLLUTE.FRX RECORD pollute PREVIEW
           * Close the pollutant database.
            SELECT 8
            USE
           * Return to the initial work area.
            SELECT 1
         ENDIF

ENDCASE
DEACTIVATE WINDOW choices
DO disprec IN C:\METC\DATABASE\PROG\DISPREC.PRG WITH mchoice,recnum
```

```
CLOSE DATABASES
SET TALK OFF
CLEAR
SELECT 1
USE c:\metc\database\data\organ_ch.dbf
SELECT 2
USE c:\metc\database\data\chem_cla.dbf
SELECT 3
USE c:\metc\database\data\inor_rad.dbf
SELECT 4
USE c:\metc\database\data\develop.dbf
SELECT 5
USE c:\metc\database\data\technolo.dbf
SELECT 6
USE c:\metc\database\data\media.dbf
SELECT 7
USE c:\metc\database\data\pollutan.dbf
FOR  m.index = 1 TO 7
SELECT int(m.index)
GOTO TOP
DO WHILE .T.
   IF EOF()
     EXIT
   ENDIF
*  define memory variable
   SCATTER MEMVAR
   DO CASE
*go through organic record and make all characters lower case
   CASE (m.index = 1)
     m.pollutant = lower(m.pollutant)
     m.cas_num = lower(m.cas_num)
     m.poll_num = lower(m.poll_num)
*go through chemical class record and make all characters lower case
   CASE (m.index = 2)
     m.group = lower(m.group)
     m.poll_num = lower(m.poll_num)
     m.gen_class = lower(m.gen_class)
     m.pollutant = lower(m.pollutant)
     m.cas_num = lower(m.cas_num)
*go through inorganic/rad record and make all characters lower case
   CASE (m.index = 3)
     m.pollutant = lower(m.pollutant)
     m.cas_num = lower(m.cas_num)
     m.poll_num = lower(m.poll_num)
     m.daughter = lower(m.daughter)
     m.emission_1 = lower(m.emission_1)
     m.emission_2 = lower(m.emission_2)
*go through develop record and make all characters lower case
   CASE (m.index = 4)
     m.tech_name = lower(m.tech_name)
     m.technology = lower(m.technology)
     m.developer = lower(m.developer)
     m.tech_group = lower(m.tech_group)
     m.domain = lower(m.domain)
     m.scale = lower(m.scale)
     m.rem_phase1 = lower(m.rem_phase1)
     m.rem_phase2 = lower(m.rem_phase2)
     m.rem_phase3 = lower(m.rem_phase3)
     m.site = lower(m.site)
*go through technology record and make all characters lower case
   CASE (m.index = 5)
     m.tech_group = lower(m.tech_group)
     m.technology = lower(m.technology)
     m.sub_class = lower(m.sub_class)
     m.media1 = lower(m.media1)
```

```
     m.media2 = lower(m.media2)
     m.media3 = lower(m.media3)
     m.domain = lower(m.domain)
     m.rem_phase1 = lower(m.rem_phase1)
     m.rem_phase2 = lower(m.rem_phase2)
     m.rem_phase3 = lower(m.rem_phase3)
*go through media record and make all characters lower case
   CASE (m.index = 6)
     m.media1 = lower(m.media1)
     m.media2 = lower(m.media2)
     m.media3 = lower(m.media3)
*go through pollutan record and make all characters lower case
   CASE (m.index = 7)
     m.pollut1 = lower(m.pollut1)
     m.cas_num1 = lower(m.cas_num1)
     m.pollut2 = lower(m.pollut2)
     m.cas_num2 = lower(m.cas_num2)
     m.pollut3 = lower(m.pollut3)
     m.cas_num3 = lower(m.cas_num3)
     m.pollut4 = lower(m.pollut4)
     m.cas_num4 = lower(m.cas_num4)
     m.pollut5 = lower(m.pollut5)
     m.cas_num5 = lower(m.cas_num5)
     m.pollut6 = lower(m.pollut6)
     m.cas_num6 = lower(m.cas_num6)
     m.pollut7 = lower(m.pollut7)
     m.cas_num7 = lower(m.cas_num7)
     m.pollut8 = lower(m.pollut8)
     m.cas_num8 = lower(m.cas_num8)
     m.pollut9 = lower(m.pollut9)
     m.cas_num9 = lower(m.cas_num9)
     m.pollut10 = lower(m.pollut10)
     m.cas_num10 = lower(m.cas_num10)
   ENDCASE
 * copy into fields
  GATHER MEMVAR
 SKIP
ENDDO
ENDFOR
```

APPENDIX B

Examples From Technology Database

Technology Report

Technology: rotating biological contactor

Technology Group: biological

Oxidation Type: aerobic

Sub Class:

Media 1:

Media 2: water

Media 3:

Domain: ex-situ

Remediation Phase 1:

Remediation Phase 2:

Remediation Phase 3: treatment

Remediation Phase 4:

Description:

TECHNICAL DESCRIPTION

The major objective of a rotating biological contactor (RBC) is the removal of soluble organic matter by its conversion to insoluble microbial cells which can be removed by sedimentation, thereby providing an effluent of high quality. Consequently, RBC's can be used as the major means of treatment for both municipal and industrial wastewaters. Like trickling filters, RBC's can also be used to achieve partial removal of soluble organic matter, and thus they find application for the pretreatment of industrial wastewaters as well.

In its simplest form, an RBC consists of parallel circular discs attached perpendicularly to a horizontal shaft which passes through their centers. The entire assembly is placed into a tank with the shaft slightly above the surface of the liquid so that the discs are approximately half immersed. Microorganisms grow on the surface of the discs and rotation of the shaft brings all of them into contact with the liquid allowing them to remove the organic matter from it. Although microbial growth results from this substrate utilization, the rotation of the discs through the liquid provides a constant shear force which causes continual sloughing of the culture, thereby maintaining a more or less constant film thickness. The rotation of the discs also mixes the liquid which keeps the stripped biomass in suspension and allows it to be carried from the reactor by the effluent. Aeration of the culture is accomplished by two mechanisms. As a point on a disc rises above the liquid surface a thin film of liquid remains attached to it and oxygen is transferred to that film as it is passed through the air. Rerimmersion of that point returns this highly aerobic liquid to the reactor, thereby increasing its dissolved oxygen content. In addition, a certain amount of air is entrained by the bulk of the liquid due to th eturbulence caused by the rotation of the discs. The mixing within the reactor disperses this air, thereby maintaining a relatively uniform dissolved oxygen concentration.

Although the exact composition of the microbial population on a disc depends upon the type of wastewater being treated and the relative position of the disc in the reactor, in general, the population tends to consist of more filamentous and fewer slime-forming organisms than that found on a trickling filter. Consequently, the sloughed biosolids tend to be relatively dense with good settling characteristics, although like waste activated sludge they are not particularly amenable to vacuum filtration.

As a general rule, full-scale RBC's have a disc diameter of 12 ft and a maximum shaft length of 25 ft. Each shaft is driven by a seperate electric motot-gear reducer or by an air drive system. Although the usual rotational speed for 12 ft diameter discs is 1.6 rpm, variable speed drives can be used for flexibility. The tankage hosing the discs is generally shallow (5 ft) and may be of either steel or concrete.

REFERENCE

Lim, Henry C., Grady, C.P. Leslie, Jr. (1980). Biological Wastewater Treatment Theory and Applications. Marcel Dekker, Inc., New York, NY. pp. 755-759.

References:

Lim, Henry C., Grady, C.P. Leslie, Jr. (1980). Biological Wastewater Treatment Theory and Applications. Marcel Dekker, Inc., New York, NY. pp. 755-759.

Technology Report

Technology: denitrification

Technology Group: biological

Oxidation Type: anaerobic

Sub Class:

Media 1:

Media 2: water

Media 3:

Domain: ex-situ

Remediation Phase 1:

Remediation Phase 2:

Remediation Phase 3: treatment

Remediation Phase 4:

Description:

TECHNICAL DESCRIPTION

Denitrification is the reduction of nitrate nitrogen as it serves as the terminal hydrogen acceptor for microbial respiration in the absence of molecular oxygen. As such, it is an alternative to the reduction of oxygen, and thus is called anaerobic respiration. The bacteria responsible for denitrification are facultative and utilize the same biochemical pathways during both aerobic and anaerobic respiration. The only major differences are in the enzymes catalyzing the terminal electron transfer and their sites in the electron transport chain. Denitrification can be accomplished by a large number of microbial genera commonly found in wastewater treatment systems, including Achromobacter, Aerobacter, Alcaligenes, Bacillus, Flavobacterium, Micrococcus, Proteus, and Pseudomonas, thereby making the establishment of a denitrifying culture relatively easy.

There are two types of enzyme systems involved with the reduction of nitrate nitrogen: assimilatory and dissimilatory. Assimilatory nitrate reduction converts nitrate nitrogen to ammonia nitrogen for use by the cells in biosynthesis, and functions when nitrate nitrogen is the only form of nitrogen available. Dissimilatory nitrate reduction results in the formation of nitrogen gas from nitrate nitrogen, and is the one responsible for the denitrification of wastewater.

Because dissimilatory nitrate reduction serves as an alternative means of microbial respiration, there has been considerable interest in the influence of oxygen upon the responsible enzyme system. Denitrification probably can occur at diminished rates in the presence of oxygen, provided that anoxin conditions had previously exsisted during which enzyme synthesis could occur. One factor complicating the determination of the effects of oxygen upon denitrification in wastewater treatment systems is the flocculent nature of the cultures involved. Because of the large size of microbial floc particles there is likely to be a region in the interior which is devoid of oxygen. Thus denitrification could occur in the interior of the floc even when oxygen was present in the medium. Nevertheless, considering all of the factors known about the synthesis and activity of the enzymes responsible for denitrification, it is generally agreed that the level of dissolved oxygen should approach zero in order to achieve consistently good performance.

The perspective from which denitrification must be viewed is just the opposite of that from which most wastewater treatment systems are viewed. In most systems the wastewater contains organic matter which serves as an electron donor and the designer must provide for the addition of the proper quantity of oxygen (the electron acceptor) to allow complete conversion of that organic matter to cell material and carbon dioxide. The objective during the design of a denitrification system, however, is the removal of an electron acceptor (nitrate) and to do this, a sufficient amount of electron donar (organic matter) must be available.

In the denitrification system a single-carbon compound would be an ideal candidate for the electron donar. In addition, if the electron donar is highly reduced, the TbOD per unit mass will be high, thereby minimizing the quantity which must be purchased for addition. The most highly reduced single-carbon compound is methane, but the practicality of its use is questionable. Another highly reduced single-carbon is methonal, which is widely available, of consistent quality, and relatively inexpensive. Furthermore, its yield is low, thereby minimizing the amount required. For all of these reasons, methonal is the compound usually chosenwhen an external electron donar must be added.

Denitrification reactors fall into two broad categories: slurry reactors and fixed film reactors. The slurry reactors are quite similar to those used for activated sludge except that the mixing systems are designed to minimize oxygen transfer while maintaining the sludge in suspension. The most effective way of excluding oxygen is to used a closed reactor, but it is not uncommon to see open ones as well. There is a great deal more variety among packed tower reactors. This makes it difficult to establish a general approach to design, although one method looks promising. One aspect of the variation is in the type of media employed, which covers the range from corrugated plastic sheets to fine sand grains. Another is in the void spaces, which may be filled with either liuid or nitrogen gas. A third is in the fluid regime, which can range from downward in thin films to upward at a velocity sufficient to fluidize sand particles.

REFERENCE

Lim, Henry C., Grady, C.P. Leslie, Jr. (1980). Biological Wastewater Treatment Theory and Applications. Marcel Dekker, Inc., New York, NY. pp. 888-891.

References:

Lim, Henry C., Grady, C.P. Leslie, Jr. (1980). Biological Wastewater Treatment Theory and Applications. Marcel Dekker, Inc., New York, NY. pp. 888-891.

Technology Report

Technology: activated sludge

Technology Group: biological

Oxidation Type: aerobic

Sub Class: step aeration activated sludge

Media 1:

Media 2: water

Media 3:

Domain: ex-situ

Remediation Phase 1:

Remediation Phase 2:

Remediation Phase 3: treatment

Remediation Phase 4:

Description:

TECHNICAL DESCRIPTION

A major change in the activated sludge process came in 1942 when Gould, author of "Operating Experiences in New York City," proposed the step aeration process as a means whereby more efficient utilization could be made of the aeration capacity in plants with conventional aeration basins. The influent waste flow is split into several portions which are then fed into the aeration basin at different points, thereby giving a more even distribution of oxygen demand. Gould originally proposed a flow diagram with the initial portion of the aeration basin receiving only concentrated sludge from the final settler. The purpose of this was to regenerate the sludge prior to mixture with the incoming waste. Currently, most flow diagrams which are depicted as SAAS no longer have sludge reaeration, but instead mix the sludge and th einfluent immediately. SAAS was proposed as a way of acheiving high degrees of treatment with short space time although it utilizes MCRT's within the same range as CAS. It also provides considerable operational flexibility and consequently is still in wide use today.

REFERENCE

Lim, Henry C., Grady, C.P. Leslie, Jr. (1980). Biological Wastewater Treatment Theory and Applications. Marcel Dekker, Inc., New York, NY. pp. 623.

References:

Lim, Henry C., Grady, C.P. Leslie, Jr. (1980). Biological Wastewater Treatment Theory and Applications. Marcel Dekker, Inc., New York, NY. pp. 623.

Technology Report

Technology:	aerobic digestion
Technology Group:	biological
Oxidation Type:	aerobic
Sub Class:	
Media 1:	
Media 2:	water
Media 3:	
Domain:	ex-situ
Remediation Phase 1:	
Remediation Phase 2:	
Remediation Phase 3:	treatment
Remediation Phase 4:	

Description:

TECHNICAL DESCRIPTION

Although primary sludges may have appreciable soluble organic matter associated with them, the predominant organic matter in both primary and secondary sludges is insoluble. Consequently, the main objective of aerobic digestion is the destruction of insoluble organic matter in an aerobic environment--an activity which is normally performed in three types of reactors: a CSTR, a CSTR with recycle, and a batch reactor. Actually, batch reactors are seldom used in the field, their primary use being to provide design data. Furthermore, the performance of a CSTR with recycle is the same as that of a simple CSTR as long as the MCRT of the former is equal to the space time of the latter.

Because of the relatively long MCRT's associated with aerobic digestion, a complex microbial community will normally exsist, ranging from bacteria to higher organisms such as nematodes.

There are no special physical characteristics associated with aerobic digesters although many are concrete tanks around 15 feet deep, similar in design to acivated sludge aeration chambers. Many, in fact, are converted activated sludge basins. Since the design is usually based on the assumption of complete mixing the only requirement with respect to reactor configuration is the fulfillment of that assumption. Mixing and oxygen transfer are accomplished by both bubble and mechanical aeration using air as the oxygen source although pure oxygen has been utilized when it is used in the remainder of the plant. With the exception of pure oxygen systems the tanks are usually uncovered. In small plants it is common for the digesters to be operated on a fill-and-draw schedule so that the tanks are equipped with with decant pipes. In large plants, on the other hand, operation is continuous so that the settling basin is usually provided to thicken the treated sludge and separate it from the bulk of the liquid prior to discharge.

Aerobic digestion is generally most applicable to secondary sludges such as those generated by the activated sludge and trickling filter processes. Because these sludges are predominantly biological solids the most important reaction will be microbial decay. Aerobic digestion has also been used on primary sludge although for best results the amount of organic material in the sludge should exceed 60%. Generally, however, it has been found to be more economic to use anaerobic digestion on primary sludge even when aerobic digestion is used for the secondary sludge. This is because the large amount of nonmicrobial organic matter present will be convertd to biomass, thereby exerting a large oxygen requirement during aerobic digestion and forming much more residual sludge than would be formed by anaerobic decomposition.

REFERENCE

Lim, Henry C., Grady, C.P. Leslie, Jr. (1980). Biological Wastewater Treatment Theory and Applications. Marcel Dekker, Inc., New York, NY. pp. 690-691.

References:

Lim, Henry C., Grady, C.P. Leslie, Jr. (1980). Biological Wastewater Treatment Theory and Applications. Marcel Dekker, Inc., New York, NY. pp. 690-691.

Technology Report

Technology: composting

Technology Group: biological

Oxidation Type: aerobic

Sub Class: windrow operation

Media 1: soil

Media 2:

Media 3:

Domain: ex-situ

Remediation Phase 1:

Remediation Phase 2:

Remediation Phase 3: treatment

Remediation Phase 4:

Description:

GENERAL DESCRIPTION

Composting manure and sludge is a process that involves the "microbial conversion of biodegradable organic materials into a relatively stable humus by thermophilic organisms under controlled conditions." The organisms that are used are mainly bacteria, actinomycetes, and fungi.

Composting is usually performed under aerobic conditions, in which atmospheric oxygen is present. "Aerobic decomposition by microorganisms converts biodegradable organic matter in manure to oxidized end products, primarily carbon dioxide and water." Harmful characteristics that correspond to the aerobic composting processes are generally constrained to odors in the beginning stages. Aerobic composting usually gives off a product with an "inoffensive odor characterized as musty and sweet."

Many factors influence biological activities and affect the rate of composting. In order for the microbial activities that cause composting to occur moisture is required. Moisture content for "aerobic thermophilic composting should be 40 to 60 percent initially." Composting materials should have voids to allow passage of air, which enhances aeration. Most likely, bulking agents are necessary to increase the porosity of fine-textured materials. Also, aeration is necessary to "(a) support aerobic microbial activity, (b) remove released moisture, and (c) remove excess heat." Adequate aeration is usually provided by one of two methods: (1) with the use of mechanical equipment, the compost pile can be turned and (2) a force-air system, in which "air is either blown or drawn into the compost."

Furthermore, for the common types of organic wastes a C:N:P:K (Carbon: Nitrogen: Phosphorus: Potassium) ratio of approximately 25:1:0.2:0.8 is desirable. Also, for the ultimate composting results the pH should initially be 6.5 to 7.2. Finally, temperature is the main determinant of the rate of composting. "Thermophilic temperatures of 130 degrees to 160 degrees Fahrenheit are commonly achieved, providing pathogen kill and dessication of weed seeds."

TECHNICAL DESCRIPTION

The windrow process is the most typically used method of composting. In this process organic wastes are stacked into windrows and then periodically turned. "Windrows should be 3 to 5 feet tall and have a base of about 10 to 15 feet. Air movement through the porous composting material should resemble a chimney effect as internal heating occurs." In order to promote aeration mechanical equipment is used to rotate the windrow. "Windrows should be turned frequently at first and then decreased by the end of the first month. A recommended turning frequency is:

1st week - 3 turnings
2nd week - 1-3 turnings
3rd week - 2 turnings
4th and 5th week - 1 turning
5th and above - 0 turning

Temperature should be used to determine the need for turning to stimulate or control heat production."

One month of turning the windrows followed by two months in a curing pile is considered the minimum amount of composting time.

References:

Sweeten, John M. "Composting Manure and Sludge."

Technology Report

Technology: rotary kiln

Technology Group: thermal

Oxidation Type:

Sub Class:

Media 1: soil

Media 2: water

Media 3: air

Domain: ex-situ

Remediation Phase 1:

Remediation Phase 2:

Remediation Phase 3: treatment

Remediation Phase 4:

Description:

GENERAL DESCRIPTION

Rotary kiln incinerators are those in which the primary chamber is a rotating cylinder lined with refractory materials. An afterburner is employed downstream from the kiln to complete the destruction of wastes. Rotary kiln incinerators operate with a wide variety of liquid, semisolid(sludge), and solid wastes, which may be burned simultaneously.

A disadvantage of the rotary kiln that may be especially troublesome with hazardous wastes is the need to maintain gastight seals at both ends of the kiln. Leakage of these seals results in fugitive emissions that can cause air pollution problems and hazards to personnel working on the unit. To minimize these problems, rotary kilns are always operated under negative pressure. The rotary kiln is considered to be the most versatile of hazardous waste incinerators.

TECHNICAL DESCRIPTION

The rotary kiln is a cylindrical , horizontal, refractory-lined shell which is mounted at a slight incline. Rotation of the shell causes mixing of the waste with the combustion air, thus improving combustion efficiency. The length to diameter ratio of the combustion chamber normally varies between 2:1 and 10:1 and the peripheral speed of rotation is normally in the range of 0.3m to 1.5m per minute. Combustion temperatures vary according to the characteristics of the material being incinerated but normally range from 810-1,650 degrees Celsius. Residence times vary from several seconds to hours, depending on the waste; gaseous and liquid wastes having shorter dwell times.

Most rotary kiln installations, particularly those handling hazardous wastes, are equipped with wet scrubber emission controls. Heat recovery equipment is also common. The latter may take the form of heat exchangers to preheat combustion air or of waste heat boilers for steam generation (usually practical only in large installations).

References:

Manahan, S.E. Hazardous Waste Chemistry, Toxicology and Treatment. Lewis Publishers, Michigan. 1990

Scurlock, A. and Lindsey, A. and Fields, T. and Huber,D. Incineration in Hazardous Waste Management. United States Environmental Protection Agency.

Technology Report

Technology: liquid injection

Technology Group: thermal

Oxidation Type:

Sub Class:

Media 1:

Media 2: water

Media 3:

Domain: ex-situ

Remediation Phase 1:

Remediation Phase 2:

Remediation Phase 3: treatment

Remediation Phase 4:

Description:

GENERAL DESCRIPTION

With liquid injection, freely flowing wastes are atomized by passage through a carefully designed nozzle. It is important that the droplets are small enough to allow the waste to completely vaporize and go through all the subsequent stages of combustion while they reside in the high-temperature zones of the incinerator. Residence times in such incinerators are short, so nozzles especially, as well as other features must be designed for specified waste stream characteristics such as viscosity. Certain wastes must be preheated. Nonclogging nozzles are available, but all nozzles must be carefully maintained. One of the chief costs is maintenance of refractory walls. Incinerator design is a complex, but advanced field. Many distinguishing design features are currently proprietary; especially nozzle designs and refractory composition.

Injection incinerator designs, especially nozzle design, tend to be waste specific. However, individual designs exist for the destruction of many different liquid waste mixes: motor and industrial oils, emulsions, solvents, lacquers, and organic chemicals of all kinds including relatively hard to destroy pesticides and chemical warfare agents.

TECHNICAL DESCRIPTION

Liquid injection combustors can be used to dispose of almost all combustible liquid wastes. High viscosity , with the consequent feeding and cumbustion problems, is the important limiting factor. Liquid injection combustors are of two general types, vertical and horizontal. Normal temperatures maintained vary widely; from 650-1650 degrees Celsius. A typical temperature is 870 degrees Celsius. Residence times also vary, from less than 1/2 second to better than one second. Normal heat release rates approximate 225,000 kg. cal/hr-cubic meter, although for special types, heat release rates may be as high as 900,000 kg. cal/hr.-cubic meter.

To increase the rate of vaporization and thus of combustion, the liquid wastes are atomized to present a heat transfer surface area as large as possible. Normally this is done when entering the combustor by mechanical means, by internal mixing nozzles, by two phase nozzles, by two phase nozzles, or by pressure nozzles. Droplet size is less than 40 microns in diameter. If viscosity precludes atomization, heating and mixing or other means may be necessary to reduce apparent viscosity. A forced draft must also be supplied to the combustion chamber to provide for the necessary mixing and turbulence.

References:

Manahan, S.E. Hazardous Waste Chemistry, Toxicology and Treatment. Lewis Publishers, Michigan. 1990

Technologies and Management Strategies for Hazardous Waste Control. United States Government, Office of Technology Assessment. Washington, D.C.

Scurlock, A. and Lindsey, A. and Fields, T. and Huber,D. Incineration in Hazardous Waste. United States Environmental Protection Agency. 1975

Technology Report

Technology: fluidized bed combustion

Technology Group: thermal

Oxidation Type:

Sub Class:

Media 1: soil

Media 2: water

Media 3: air

Domain: ex-situ

Remediation Phase 1:

Remediation Phase 2:

Remediation Phase 3: treatment

Remediation Phase 4:

Description:

GENERAL DESCRIPTION

Fluidized-bed incinerators have a bed of granular solid(such as sand) maintained in a suspended state by injection of air. These devices can be used for liquid wastes or solid wastes of relatively uniform particle size. Advantages of fluidized-bed incinerators are excellent mixing, minimal requirement for excess air, and potential to retain waste gases in the bed material. Preheating the air injected into the bed reduces its cooling effect and enables incineration of wastes with lower heating values.

Circulating fluidized-bed combustion(CBC) is an advanced form of fluidized-bed incinerator that has been adapted to use with mobile units on-site. This system circulates waste and sorbent solids(limestone) through a combustion chamber that is in a loop configuration.

TECHNICAL DESCRIPTION

Air driven by a blower enters a plenum at the bottom of the combustor and rises vertically through a distibutor plate into a vessel containing a bed of inert granular particles. Sand is typically used as the bed material. The upward flow of of air through the sand bed results in a dense turbulent mass which behaves similarly to a liquid. Waste material to be incinerated is injected into the bed where combustion occurs within the fluidizing media. Air passage through the bed produces strong agitation of the bed particles. This promotes rapid and relatively uniform mixing of the injected waste material within the fluidized bed.

The mass of the fluidized bed is large in relation to the injected material. Bed temperatures are quite uniform and typically in the 1400-1600 degrees Farenheit range. At these temperatures, heat content of the fluidized bed is approximately 16,000 Btu/cubic foot thus providing a large heat reservoir. By comparison, the heat capacity of flue gases at similar temperatures is three orders of magnitude less than a fluidized sand bed.

Heat is transferred from the bed into the injected waste materials to be incinerated. Upon reaching ignition temperature (which takes place rapidly) the material combusts and transfers heat back into the bed. Continued bed agitation by the fluidizing air allows larger waste particles to remain suspended until combustion is completed. Residual fines (ash) are carried off the bed by the exhausting flue gases at the top of the combustor. These gases are subsequently processed and/or scrubbed beffore atmospheric discharge. In specifying or designing a fluidized bed combustor, primary factors to be considered are: gas velocity; bed diameter; bed temperature; and, the type and composition of waste to be incinerated.

References:

Manahan, S.E. Hazardous Waste Chemistry, Toxicology and Treatment. Lewis Publishers, Michigan. 1990

Sittig, M. Incineration of Indusdtrial Hazardous Wastes and Sludges. Noyes Data Corporation. New Jersey. 1979

Technology Report

Technology: plasma arc

Technology Group: thermal

Oxidation Type:

Sub Class:

Media 1: soil

Media 2: water

Media 3: air

Domain: ex-situ

Remediation Phase 1:

Remediation Phase 2:

Remediation Phase 3: treatment

Remediation Phase 4:

Description:

GENERAL DESCRIPTION

Plasma incinerator systems make use of a plasma of ionized air injected through an electrical arc into which liquid wastes are injected. The extremely high 5,000-15,000 degrees Celsius temperature of the plasma breaks the waste molecules down to their constituent atoms, which remain in the elemental form or recombine to form simple molecules, such as CO and HCl. The combustible gas product is burned in later stage.

TECHNICAL DESCRIPTION

The plasma torch is a device that utilizes an electrical discharge to change minute quantities of almost any gas into the hottest sustainable flame known-up to 100,000 degrees F.
Plasma arc pyrolysis is possible because the "plasma flame" can be generated in the total absence of oxygen. It is the oxygen(air) required to sustain safe combustion in conventional incinerator plants that makes pyrolysis in incinerators unattainable.

The plasma flame is generated by the following steps:

1.Gas (argon,helium,hydrogen,oxygen,etc.) is introduced in small quantity to create a swirling motion that keeps the plasma flame in the center of the torch, away from metal parts.

2.An electrical discharge is established(plasma arc flame) and maintained between the electrode inside the torch and any electrical conductor.

3.The plasma flame then converts electrical energy into heat energy in an extremely efficent manner.

In the plasma arc reactor, ther ultrahigh arc

425

temperature of 100,000 degrees F is sustained to species.A plasma can be produced in several ways, the most common of which is a gaseous electrical discharge.The resultant molecular excitation leads to the formation jof a variety of metastable, atomic, free radical and ionic species.

References:

Manahan, S.E. Hazardous Waste Chemistry, Toxicology and Treatment. Lewis Publishers, Michigan. 1990

Kiang, Y. and Metry, A. Hazardous Waste Processing Technology. Ann Arbor Science. 1982

Technology Report

Technology:	wet air oxidation
Technology Group:	thermal
Oxidation Type:	
Sub Class:	
Media 1:	soil
Media 2:	water
Media 3:	
Domain:	ex-situ
Remediation Phase 1:	
Remediation Phase 2:	
Remediation Phase 3:	treatment
Remediation Phase 4:	

Description:

GENERAL DESCRIPTION

Wet air oxidation is the aqueous phase oxidation of dissolved or suspended organic subsances at elevated temperatures and pressures. The oxygen required by wet air oxidation reactions is provided by an oxygen containing gas, usually air, bubbled through the liquid phase, generally between 300 and 3000 psig. A significant advantage of wet air oxidation is the minimal air pollution problems that it causes. Contaminents tend to stay in the aqueous phase. Wet air oxidation can be used to oxidize any material, including inorganics with a COD value. Wet air oxidation also has been used in conjuction with biotreatment plant. In this type of system, only 50% oxidation is required. At this degree of oxidation, the solid residue is approximately 90% inert. The unoxidized organic matter is recycled to the inlet of the treatment plant. A feature of this system is the recycling of nutrients, which can reduce of eliminate the need to add nitrogen to the waste stream. Wet air oxidation has been used to recover chromium in treatment of sludge from a glue manufacturer. A wet air oxidation system also has been used for recovery of reusable fillers from paper mill sludges.

TECHNICAL DESCRIPTION

Organic compounds and oxidizable inorganic species can be oxidized by oxygen in aqueous solution. The source of oxygen usually is air. Rather extreme conditions of temperature and pressure are required with a temperature range of 175-327 degrees Celsius and a pressure range of 2,070-27,700 kiloPascals. The high pressures allow high concentration of oxygen to be dissolved in the water and the high temperatures enable the reaction to occur. As a first step in the initial process, the wastewater and air are brought up to pressure. An initial heating starts the reaction, after which exothermic oxidation reactions in the reaction mixture help to generate heat to keep the reaction going. the length of time that wastes are exposed to oxidation is controlled by reactor residence time. After discharge from the reactor, the treated wastewater is cooled to 35-60 degrees Celsius with incoming air/water mixture(which is preheated in the process) or with with cooling water. Gases are removed in a separator vessel. Hydrocarbon contaminant may be present in these gases. It is removed in part by wet scrubbing used to cool the gases, as well as by adsorption columns and afterburning. The oxidized liquor product may require additonal treatment, such as addition of sulfide to precipitate metals. Wet air oxidation has been applied to the destruction of cyanides in electroplating wastewaters.

References:

Manahan, S.E. Hazardous Waste Chemistry, Toxicology and Treatment. Lewis Publishers, Michigan. 1990

Technology Report

Technology: activated sludge

Technology Group: biological

Oxidation Type: aerobic

Sub Class: conventional activated sludge

Media 1:

Media 2: water

Media 3:

Domain: ex-situ

Remediation Phase 1:

Remediation Phase 2:

Remediation Phase 3: treatment

Remediation Phase 4:

Description:

TECHNICAL DESCRIPTION

Originally the activated sludge process employed long rectangular aeration basins with the influent and recycle introduced at one end and effluent removed at the other. Consequently this is usually referred to as conventional activated sludge (CAS), although the reactor has also been called a flow-through aeration basin. However, another version makes better use of space in the plant lay-out. The usual practice with CAS was to use air diffusers spaced evenly along one wall of each basin with the same amount of air supplied to each diffuser. The rising bubbles imparted a spiral flow to the liquid thereby minimizing longitudinal mixing. Although it was felt that this would provide plug flow, tracer studies on full-scale installations have shown the mixing pattern to be equivalent to three to five CSTR's in series. Usually CAS is designed with a MCRT between 3 and 15 days, which with typical domestic sewage gives a reactor space time (V/F) between 4 and 8 hours if the MLSS (activated sludge) concentration is around 2000 mg/liter. The recycle is generally between 10 and 30% of the influent flow and sludge wastage is from either the settler underflow of the aeration basin. Because of the mixing pattern in the reactor, the reaction environment changes from point to point with the result that more oxygen is needed near the influent end where it is low. Early designs did not take this changing oxygen requirement into account with the result that portions of the basins were oxygen limited, therby hurting process efficiency.

REFERENCE

Lim, Henry C., Grady, C.P. Leslie, Jr. (1980). Biological Wastewater Treatment Theory and Applications. Marcel Dekker, Inc., New York, NY. pp. 621-622.

References:

Lim, Henry C., Grady, C.P. Leslie, Jr. (1980). Biological Wastewater Treatment Theory and Applications. Marcel Dekker, Inc., New York, NY. pp. 621-622.

APPENDIX C

Database Survey Information

GENERAL APPEAL:

- **Introduce myself** My name is Keith Rinkus. I am a research assistant at West Virginia University, and the team leader for a research project funded by the Department of Energy, and the Morgantown Energy Technologies Center.

- **Who referred us to you**

- **Our System / Project** Our program has begun development of a database that stores waste treatment and remediation technology. Along with this development, our team is trying to conduct a survey of existing databases around the country. With this information, we hope to adapt our system to combine with others in existence.

- **Our database** Our database is built on a DOS Windows platform using the software FoxPro, manufactrued by Microsoft. It contains data records of chemicals, both organic, and inorganic, along with radionuclides, remediation technologies and relevant technology tests, i.e. developmental testing. The remediation technologies cover all medias; soil, air and water, and contain health hazards and references. Our database has the ability to search for a specific pollutant, chemical, or technology, and in the future, we hope to enable our program to suggest applicable technologies based on entered criteria.

- **Ask for cooperation** If you have the time, I would greatly appreciate your cooperation by answering a group questions about your database. These questions have been compiled to allow us to gain an accurate picture of your system, and your future plans for it. If you are unavailable at the moment, may I please make an appointment to call or visit at a different time or date?

DATABASE PROGRAM INFORMATION:

PURPOSE: a.) present; provide an in-depth source of information on remediation and restoration of contaminated sites. Technology listed includes treatment options for all media types, including soil, air and water.
b.) future; survey of databases in existence, to evaluate the role of our database program, i.e., to integrate it with, or be integrated by, other databases.

WHO USES THE DATABASE?: presently, the only personnel using the database are the developers, but, in the future it will be open to the public.

WHO COLLECTED THE DATA PRESENT IN THE DATABASE? Two professors, Dr. Mitchell Berg, Phd, Assistant Professor of Industrial Engineering, and Dr. Patrick Carriere, Phd, Assistant Professor of Civil Engineering. both at West Virginia Univ.. Along with the two professors, there were five undergraduate and graduate research associates.

DATA COLLECTION IS AN ONGOING PROCESS

WE ARE VERY INTERESTED IN INTEGRATING OUR DATABASE WITH OTHERS AROUND THE COUNTRY.

DEVELOPMENT INFORMATION:

Developer: Dr, Mitchell Berg, Phd.
Program Platform: IBM personal computer, 486 processor, running at 66 MHZ.
Program Operating System: Microsoft DOS ver.5.0, and Windows ver. 3.1.
Database Software: Microsoft FoxPro for windows, ver. 2.5
Remote access capable? -no
Summary of Data in cumulative databases

Number of database (.dbf) files :	08
Number of records in each separate dbf:	
media records:	00
pollutant records:	00
database records:	10
inorganic chemicals or radionuclides :	30
Organic chemicals:	165
Technologies:	79
Development:	127
Chemical classifications:	316
TOTAL:	727

WHAT TYPES OF USER INTERFACES EXIST OR ARE PLANNED?

Presently there are add/search/edit capabilities which allow the developers to list, or retrieve any of the file records listed above. They can be listed by chemical, chemical class, existing technology group, (i.e. biological, physical, etc.), specific technology, (i.e., composting, nitrification, etc.). or subgroup (i.e. strong-base anion exchangers, windrow composting, etc.).

In the future, the system will be able to "suggest" a treatment technology particularly suited to any existing hazardous waste situation (i.e. phenol contaminated soil, etc.), and list numerous lab, bench, pilot and field scale tests that have been performed.

CALLER:

PHONE NUMBER: (   )

EXT.

DATE: / /

TIME: AM PM

CONTACT NAME AND TITLE:

REFERRED BY:

GENERAL QUESTIONS (7):

1. WHAT IS THE INTENDED PURPOSE OF THE DATABASE?

PRESENT:

FUTURE PLANS:

2.WHO USES THE DATABASE?

IN HOUSE USE ONLY: ☐

OPEN TO THE PUBLIC: ☐

3. WHO COLLECTED THE DATA PRESENT IN THE DATABASE?

NUMBER OF PERSONS WHO ENTERED DATA:

4. IS DATA COMPILATION AN ONGOING PROCESS?

YES: ☐
NO: ☐

5. MAY WE HAVE ACCESS TO THE DATA FILES(S)?

YES: ☐
NO: ☐

6. ARE YOU INTERESTED IN INTEGRATING YOUR DATABASE WITH OTHERS THAT EXIST AT GOVERMENT AGENCIES?

7. WHO DEVELOPED THE PROGRAM / DATABASE?

NAME:

TITLE / EDUCATION:

QUESTIONS FOR THE DEVELOPER(S) (6):

1. WHAT COMPUTER PLATFORM AND OPERATING SYSTEM IS THE DATABASE / PROGRAM DESIGNED FOR, AND WHY?

2. WHAT WAS THE COST OF THE DATABASE?

3. WHAT DATABASE SOFTWARE WAS SELECTED?

MANUFACTURER:

4. WHAT KINDS OF USER INTERFACES DOES THE PROGRAM POSSESS?

5. IS THE SYSTEM DESIGNED FOR REMOTE ACCESS, AND IF SO, HOW?

YES NO

6. HOW WAS THE STRUCTURE OF THE DATABASE AND INFORMATION FIELDS SELECTED?

FURTHER CONTACTS:

ADDITIONAL COMMENTS:

APPENDIX D

Completed Survey Form Examples

CROSSWALK

CALLER: K RINKUS

PHONE NUMBER: (303) 248 6566 EXT.

DATE: 3 /24/ 94 TIME: 11.15 [✓ AM] PM

CONTACT NAME AND TITLE:

JERRY DAUB - RUST GEOTECH
Grand Junction COLORADO

REFERRED BY:

Alan Browne, Energetics

INFORMATION SYSTEMS CATALOG

GENERAL QUESTIONS (9):

1. WHAT IS THE INTENDED PURPOSE OF THE DATABASE?

PRESENT: LISTING Env. Rest. Problems in DOE -
- OTDs - suggestor problems

FUTURE PLANS: UNK.

2. WHO USES THE DATABASE?
IN HOUSE USE ONLY: ☐
OPEN TO THE PUBLIC: ☒

3. WHO COLLECTED THE DATA PRESENT IN THE DATABASE?

Rust Geotech
G.J. Projects office, DOE

4. WHEN WAS THE DATABASE DEVELOPED?

1991 - Updates - 1993

5. IS DATA COMPILATION AN ONGOING PROCESS?
YES: ☒
NO: ☐

6. ARE THE DATA FILES PUBLIC ACCESS? YES ☒ NO ☐

7. IF NOT, WHAT IS THE COST OF THE SYSTEM? ☐

8. ARE YOU INTERESTED IN INTEGRATING YOUR DATABASE WITH OTHERS THAT EXIST AT GOVERMENT AGENCIES?

yes, with us

9. WHO DEVELOPED THE PROGRAM / DATABASE?

NAME: Jerry Daub

TITLE / EDUCATION:

QUESTIONS FOR THE DEVELOPER(S) (5):

1. WHAT COMPUTER PLATFORM AND OPERATING SYSTEM IS THE DATABASE / PROGRAM DESIGNED FOR, AND WHY?

Paradox, IBM

2. WHAT DATABASE SOFTWARE WAS SELECTED?

Paradox **MANUFACTURER:**

3. WHAT KINDS OF USER INTERFACES DOES THE PROGRAM POSSESS?

KEYWORD SEARCH program
-in DOS
problems, technologies

4. IS THE SYSTEM DESIGNED FOR REMOTE ACCESS, AND IF SO, HOW?

YES [✓ NO]

5. HOW WAS THE STRUCTURE OF THE DATABASE AND INFORMATION FIELDS SELECTED?

- visited each DOE site @ complex
- Engineers, investigators
- worksheet completion

FURTHER CONTACTS:

① ENVIROTRADE
② PROTEC -
③ Tech. Catalog -
④ Remedial Info. Tech service -
⑤ NETAC - pittsburgh -

ADDITIONAL COMMENTS:

sending

information systems catalog
+ other information

EMMI

CALLER:	K Rinkus
PHONE NUMBER:	(202) 260-7134
EXT.	—
DATE:	3/28/94
TIME:	10:30 [✓ AM] PM

CONTACT NAME AND TITLE:

Bill Telliard
EPA, office of water

REFERRED BY:

Susan

GENERAL QUESTIONS (9):

1. WHAT IS THE INTENDED PURPOSE OF THE DATABASE?

PRESENT: official list of analytical methods
multimedia → regulatory controls

FUTURE PLANS: 900-2200 methods expansion
chemical ⇒ biological - risk assessment
now additions

2. WHO USES THE DATABASE?
IN HOUSE USE ONLY: ☐
OPEN TO THE PUBLIC: ☒

3. WHO COLLECTED THE DATA PRESENT IN THE DATABASE?

Office of water
Bill telliard - contractors

4. WHEN WAS THE DATABASE DEVELOPED?

1986-87 - hardcopy 4 yrs - software in 89

5. IS DATA COMPILATION AN ONGOING PROCESS?
YES: ☒
NO: ☐

6. ARE THE DATA FILES PUBLIC ACCESS?

YES ☐
NO ☑

7. IF NOT, WHAT IS THE COST OF THE SYSTEM?

NTIS 385⁼⁼

[illegible]

8. ARE YOU INTERESTED IN INTEGRATING YOUR DATABASE WITH OTHERS THAT EXIST AT GOVERMENT AGENCIES?

yes, but, info. owned by them (EPA
programming was not.

9. WHO DEVELOPED THE PROGRAM / DATABASE?

NAME: Bill Telliard / Contractors

TITLE / EDUCATION:

QUESTIONS FOR THE DEVELOPER(S) (5):

1. WHAT COMPUTER PLATFORM AND OPERATING SYSTEM IS THE DATABASE / PROGRAM DESIGNED FOR, AND WHY?

System "J" - language
-speed - J is very fast
→ export into "D-base" file

2. WHAT DATABASE SOFTWARE WAS SELECTED?

"J" MANUFACTURER: Joel Kronstfki

3. WHAT KINDS OF USER INTERFACES DOES THE PROGRAM POSSESS?

?

4. IS THE SYSTEM DESIGNED FOR REMOTE ACCESS, AND IF SO, HOW?

YES [✓ NO] but can be. Used by any modem
Lan card when the program is set up.

5. HOW WAS THE STRUCTURE OF THE DATABASE AND INFORMATION FIELDS SELECTED?

? contractor designed

FURTHER CONTACTS:

Cincinatti - Risk Reduction Eng. Lab.
513 - 569 - 7418

OREL - pub. off 7772 - Public affairs office
513 569 - 7562

ADDITIONAL COMMENTS:

Windows has asked for
an opportunity to redo system
for its own format.

E[illegible]TRADE

CALLER:	[illegible] HERRMANN		
PHONE NUMBER:	([illegible]) 903-7930	EXT.	
DATE:	/ /	TIME:	AM PM

CONTACT NAME AND TITLE:

EnviroTrade (Environmental Tech[illegible] Remediation Action Data Exchange)
Susan Johnson, DOE/EM-523
DOE [illegible] Manager

REFERRED BY:

Summary Table of Federal Databases

GENERAL QUESTIONS (9):

1. WHAT IS THE INTENDED PURPOSE OF THE DATABASE?

PRESENT: Under DOE's Office of Technology Development (OTD), EnviroTrade was created to accelerate its technology development thru international cooperation among gov entities, private industry & educational institutions. Exchange of environmental [illegible] [illegible] & waste management jobs. General Geographical, Developing, Matching & Transferring techno.

selection [illegible] partner [illegible] [illegible] DOE

FUTURE PLANS: partnership opportunity. Y94. (Aug. Y95) (plans have been renewed). [illegible] 2 weeks... cooperative agreement.

2. WHO USES THE DATABASE? IN HOUSE USE ONLY: ☒ OPEN TO THE PUBLIC: ☐

3. WHO COLLECTED THE DATA PRESENT IN THE DATABASE?

can we load your data? Use our hardware?
Once the partner is selected - we could possibly.

4. WHEN WAS THE DATABASE DEVELOPED?

1992

5. IS DATA COMPILATION AN ONGOING PROCESS? YES: ☒ NO: ☐

6 ARE THE DATA FILES PUBLIC ACCESS? YES ☐ NO ☐ [illegible]

7. IF NOT, WHAT IS THE COST OF THE SYSTEM? ☐

8. ARE YOU INTERESTED IN INTEGRATING YOUR DATABASE WITH OTHERS THAT EXIST AT GOVERMENT AGENCIES?

9. WHO DEVELOPED THE PROGRAM / DATABASE?

NAME: Charlene Harlan / Marie Harrington, Org. 6907
(hardware) (software)

TITLE / EDUCATION: Designer
Harlan: (505) 844-8164
Harrington (505) 844-4221

QUESTIONS FOR THE DEVELOPER(S) (5):

1. WHAT COMPUTER PLATFORM AND OPERATING SYSTEM IS THE DATABASE / PROGRAM DESIGNED FOR, AND WHY?

SPARC, UNIX workstation, running INFORMIX.

It can go PC easily.

{ON-line service / CORIN[illegible]} possibilities.

2. WHAT DATABASE SOFTWARE WAS SELECTED?

DevGuide/ARCHVIEW/ARCHINFO /C/ MANUFACTURER:

3. WHAT KINDS OF USER INTERFACES DOES THE PROGRAM POSSESS?

4. IS THE SYSTEM DESIGNED FOR REMOTE ACCESS, AND IF SO, HOW?

YES NO

5. HOW WAS THE STRUCTURE OF THE DATABASE AND INFORMATION FIELDS SELECTED?

Sandia - combo. off of things that were available.

GIS = ARCVIE, ARC INFO

INFORMEX

Originally designed for DOE < site mang. / lab.

FURTHER CONTACTS:

Andrew Paratore

SAIC in support to EM.

(301) 924 6154

ADDITIONAL COMMENTS:

Tech. Connection

CALLER:	K Rinkus
PHONE NUMBER:	[redacted]
	[illegible]
EXT.	[illegible]
DATE:	3/24/94
TIME:	11:30 [✓ AM] PM

CONTACT NAME AND TITLE:

Dale Pflug
Argonne Natl. labs

REFERRED BY:

Alan Browne @ Energetics

GENERAL QUESTIONS (9):

1. WHAT IS THE INTENDED PURPOSE OF THE DATABASE?

PRESENT: ~~Industry~~ group support for [illegible] support — viable technology database — pilot work — [illegible] — validation of tech } [illegible] — [illegible] communicated [illegible]

FUTURE PLANS: improvements — 50-60 databases.
— expand into solid waste from Remed.

2 WHO USES THE DATABASE? IN HOUSE USE ONLY: ☒ OPEN TO THE PUBLIC: ☐

3. WHO COLLECTED THE DATA PRESENT IN THE DATABASE?

Argonne personnel

4. WHEN WAS THE DATABASE DEVELOPED?

1992

5. IS DATA COMPILATION AN ONGOING PROCESS? YES: ☒ NO: ☐

6. ARE THE DATA FILES PUBLIC ACCESS?

YES: ☐
NO: ☑

7. IF NOT, WHAT IS THE COST OF THE SYSTEM? —

8. ARE YOU INTERESTED IN INTEGRATING YOUR DATABASE WITH OTHERS THAT EXIST AT GOVERMENT AGENCIES?

Unknown [illegible] that
[illegible] specific to DOE.
[illegible] of databases [illegible]

9. WHO DEVELOPED THE PROGRAM / DATABASE?

NAME: Dale Pflug [illegible]

TITLE / EDUCATION:

QUESTIONS FOR THE DEVELOPER(S) (5):

1. WHAT COMPUTER PLATFORM AND OPERATING SYSTEM IS THE DATABASE / PROGRAM DESIGNED FOR, AND WHY?

macintosh - hypercard
familiarity - opportunity to show [illegible] of
drawings, etc.

2. WHAT DATABASE SOFTWARE WAS SELECTED? hypercard

MANUFACTURER: mac

3. WHAT KINDS OF USER INTERFACES DOES THE PROGRAM POSSESS?

Search on technologies or problem

Restoration

treat
characterization
decontamination
} - Techs

4. IS THE SYSTEM DESIGNED FOR REMOTE ACCESS, AND IF SO, HOW?

YES NO [illegible]

5. HOW WAS THE STRUCTURE OF THE DATABASE AND INFORMATION FIELDS SELECTED?

personnel/
mission experience in
data + info was needed

FURTHER CONTACTS:

US - ARMY
- AIR FORCE
- NAVY
DOD.

ADDITIONAL COMMENTS:

exist dbs - not good - [illegible]
references

- Sending Information

APPENDIX D

Existing Database and Contacts

Database Name	Funding / Designer	Comments
Aqualine	British Water Research Centre	waste water analysis, treatment and remediation
Biennial Reporting System (BRS)	U.S. EPA	tracks trends in hazardous waste generation and management
Chemical Abstracts	American Chemical Society	organic, inorganic, and biological chemical information
Chemical Information System (CIS)	Chemical Information Systems Inc.	online access to a series of chemical databases
Chemical Safety News Base (CSNB)	The Royal Society of Chemistry, Great Britain	database contains information on risk analysis, waste management, and chemical hazards
Chemtox Online	Resource Consultants Inc.	computerized access to CHEMTOX information
Comprehensive Environmental Response, Compensation and Liability Information System. (CERCLIS)	U.S. EPA, Office of Emergency and Remedial Response (Superfund)	database contains extensive information on all aspects of hazardous waste sites on the National Priorities List
Computerized Online Information System - SITE Applications Analysis Reports	U.S. EPA / RREL Releases Control Branch	helps researchers select appropriate treatment techniques for cleanup of hazardous waste sites
Department of Defense Gateway Information System	Department of Defense	contains 7 waste databases
Department of Energy Waste Information Network	Department of Energy	contains 3 waste databases
ENERGY Database	Department of Energy	worldwide database covering energy and waste related information
ENERGYLINE	Bowker Electronic Publishing	contains energy and environmental related records
Energy, Science, and Technology Database	Department of Energy	bibliographic and technical information on hazardous waste
ENVIROLINE	R. R. Bowker Company	access to information relating to all aspects of the environment
ENVIROFATE	Unknown	Provides information on chemical behavior in the environment
Environmental Financing Information Network (EFIN)	U.S. EPA	database covering financing mechanisms for both state and local environmental projects

Database Name	**Funding / Designer**	**Comments**
Environmental Technical Information System (ETIS)	University of Illinois at Urbana-Champaign, Department of Urban and Regional Planning	a collection of 9 databases covering all types of environmental information
Environmental Technical Information Center (ETIC)	Department of Energy	Provides information of the DOE's Environmental Restoration and Waste Management Technology Programs
Federal Research in Progress (FEDRIP)	National Information Technical Service	provides information on currently funded research programs
Geographic Information System	United States Geographical Survey	contains detailed geographical information on the united states
HAZARDLINE	Occupational Health Services Inc.	comprehensive information 4000 substances
Hazardous Chemicals Information and Disposal (HAZINF)	unknown	emergency and disposal procedures for a variety of chemicals
INFOLINK	Department of Energy, Civilian Radioactive Waste Management Information Center	provides information on spend nuclear fuel
Integrated Risk Information System (IRIS)	U.S. EPA	contains a risk assessment database
Integrated Technical Information System (ITIS)	Department of Energy	contains 11 databases that relate to remediation and waste technology
International Nuclear Information System	Department of Energy	database includes information on waste management, safety and technology applications
ITEMS	Cannonic Environmental Systems	compiles and analyzes environmental data
Japanese Information on Scientific and Technical Topics (JAPINFO)	Eurobrokers	this information system contains information on environmental concerns.
MacSITS	Department of Energy	database of information on the Yucca Mountain Hazardous Waste Storage Site
National Uranium Resource Evaluation (NURE)	unknown	contains information on water analysis, waste disposal sitings, and environmental studies
Nuclear Science Abstracts	Department of Energy	collection of nuclear science and technology literature

Database Name	Funding / Designer	Comments
Oil and Hazardous Materials Technical Assistance Data System (OHMT ADS)	U.S. EPA	emergency response toxicity and cleanup data on a variety of different chemical substances
ORBIT	Maxwell Online	contains over 100 databases that concentrate on science, technology and patents
PRELIM	Information Technology systems, Melbourne Australia	management of trade waste information
Reach File	U.S. EPA	uses the GIS system to model groundwater flow across the US
Records of Decision System (RODS)	U.S. EPA	contains full text of Superfund records of decision for all national priority sites
Regulated Materials Database (REGMAT)	unknown	indexes all chemical substances listed in federal regulations
SESAME	Commission of the European Communities	includes information on the treatment and management of radioactive waste
Soil Transport and Fate Database	U.S. EPA Center for Subsurface Modeling Support	contains information on degradation, and transformation of soil and the reactions of chemical / soil mixtures
Soil Treatment Evaluation Program (STEP)	Woodward-Clyde Consultants	database attempts to screen inappropriate remediation choices from an entered waste site scenario
Solid Waste Information Clearinghouse and Hotline (SWITCH)	U.S. EPA, Office of Solid Waste	includes information on source reduction, recycling, composting and other technologies
STORET	U.S. EPA	atrazine use database
Thermal Treatment Technology Database	IWTIC	Bibliographic information on thermal treatment
TOXLINE	U.S. National Library of Medicine	Toxicological data
Unknown	University of Ljubljana, Slovenia	the database is a compilation of specialty waste management systems
WasteInfo	Waste Management Information Bureau	extensive bibliographic database containing waste treatment information

Database Name	Funding / Designer	Comments
Waste Information Data Management System	Westinghouse, Hanford Co.	database contains all waste sites at Hanford WA.
Waste Management Information System	Department of Energy	contains treatment information for waste generated at DOE sites

In addition to the above mentioned database leads, there is a number of personnel that are on the list of contacts that have no databases associated with them. The purpose of calling them is to reveal if any undiscovered databases exist outside our search effort. The list of personnel contacts is shown below.

Name:	Unknown
Title:	Unknown
Company:	Council on Environmental Quality
Phone No.:	(202) 395-5750
Reason To Call:	Possible source of databases

Name:	Robert W. Niblock
Title:	Oceans and Environment Program Manager
Company:	Office of Technology Assessment, U.S. Congress
Phone No.:	(202) 224-8713 or 224-9241
Reason To Call:	Possible source of databases

Name:	Unknown
Title:	Deputy Asst. Secretary for Planning and Resource Mgmt.
Company:	Dept. of Energy
Phone No.:	(202) 586-2295
Reason To Call:	Possible Database Sources in: Weapons/Waste Cleanup Programs Environmental Restoration and Waste Management Civilian Radioactive Waste Management

Name:	Unknown
Title:	Unknown
Company:	Office of Solid Waste and Energy Response, US EPA
Phone No.:	(202) 260-4610
Reason To Call:	Possible source of databases

Name:	Unknown
Title:	Unknown
Company:	Office of Research and Development, US EPA
Phone No.:	(202) 260-7676
Reason To Call:	Possible database source

Name: Paul A. Wohllben
Title: Acting Director, Information Resources Management
Company: US EPA
Phone No.: Unknown
Reason To Call: Possible database source

Name: Fredrick W. Allen
Title: Acting Director, Office of Strategic Planning and Environmental Data
Company: US EPA
Phone No.: Unknown
Reason To Call: Possible database source

Name: James A. Hanlon
Title: Acting Director, Office of Science and Technology
Company: US EPA
Phone No.: Unknown
Reason To Call: Possible database source

Name: Richard J. Guimond
Title: Asst. Administrator for Solid Waste
Company; US EPA
Phone No.: Unknown
Reason To Call: Possible database source

Name: Margret M. Kelley
Title: Acting Director, Office of Technology Innovation
Company: US EPA
Phone No.: Unknown
Reason To Call: Possible database source

Name: Sylvia K. Lowrance
Title: Director, Office of Solid Waste
Company: US EPA
Phone No.: Unknown
Reason To Call: Possible database source

Name; Henry L. Longest II
Title: Director, Office of Emergency and Remedial Response
Company: US EPA
Phone No.: Unknown
Reason To Call: Possible data source

Name: Susan H. Wayland
Title: Acting Deputy Asst. Administrator for pesticides and toxic substances
Company: US EPA
Phone No.: Unknown
Reason To Call: Possible data source

DUST CONTROL METHODS FOR INSITU NUCLEAR AND HAZARDOUS WASTE HANDLING
(MC-4)

Quarterly Technical Progress Report
for Period January 1 through March 31, 1994

Work Performed Under
Contract Number: 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

By

Felicia F. Peng, Mineral Processing Engineering Department
Syd S. Peng, Mining Engineering Department
West Virginia University

May 1994

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ABSTRACT

This report covers the period of activity from January 1, to March 31, 1994 for the research project No. DE-FC21-92MC29467. A main portion of this reporting period has been devoted to continuously build up the necessary information to design the excavation system combined with dust and vapor suppression/treatment technologies. The major tasks are: 1) to obtain the knowledge and information from literatures and directly contact the manufactures for innovative technologies of excavation equipment emphasized on the dust/vapor control and workers' safety; 2) to design a preliminary plan for an integrated excavation system; 3) to evaluate and develop a guideline for selection of dust control technologies for vapors and dust control based on current available and innovative technologies; 4) to design the database program to store the knowledge obtained for excavation, and on-site dust and vapor control/treatment during excavation;

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1. PRELIMINARY DESIGN OF ALTERNATIVE-PIT EXCAVATION SYSTEM

To mitigate the dust and vapor emission problems during in-situ waste material excavation, one of the approaches is to develop a integrated excavation system. The integrated excavation system include the well planned excavating sequences combined with selected dust and vapor suppression/treatment technologies. There are four major components involved in the integrated excavation system. They are described below:

1.1 Excavation Process

The excavation site should be divided systematically into many pits similar to the grid work for the mineral reserve estimation. The length of the excavation site can be divided into several panels or rows. For illustration purpose, the depth of each row or panel for the excavation site is assumed to be 60 feet and the width of each panel has 120 feet as shown in Figure 1. Individual panel is then divided into three pits which has 40 feet width. The size of each pit is determined by the selected excavation equipment, the depth of contaminated soil, overburden strength, and the selection of enclosure or open operation system.

As shown in Figure 1, the excavation equipment must be placed on an undisturbed and unmined pit. To start an excavating operation for very first panel, the excavator is located at pit No.3. The pits are then alternatively excavated, i.e., from pit No. 1 and then pit No. 2. The excavated contaminated soil is unloaded/loaded and transported away to the designated storage area. To excavate pit No. 3, the excavator must advance to the next row

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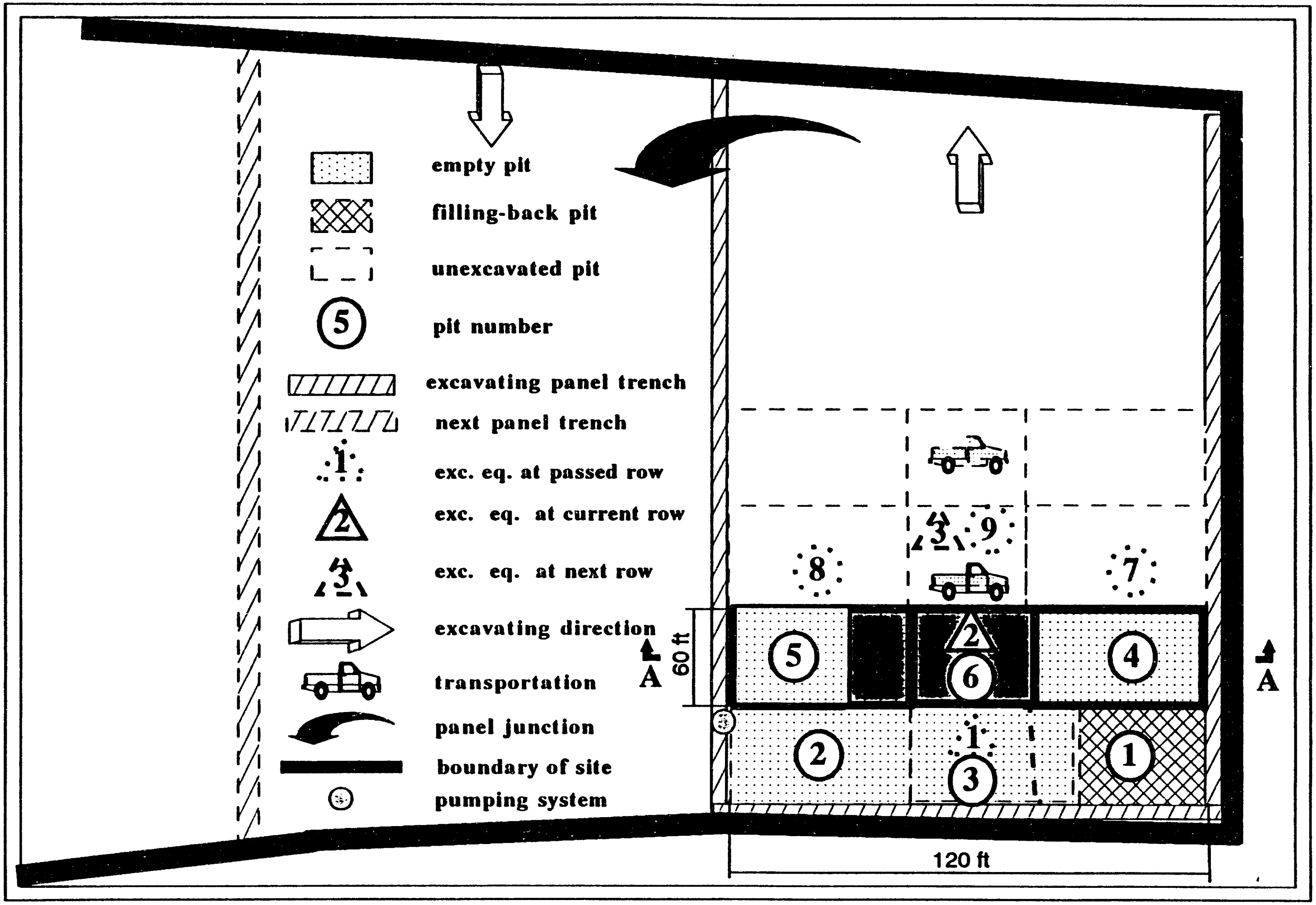

Figure 1 Schematic Diagram of Alternative-Pit Excavation System

or panel, i.e., pit No. 6 on next panel. The material handling and transportation equipmentare always in front of the excavator and moves forward with the advancing excavator. The sequences for the excavation process consist of alternatively removal of contaminated soil on the right, rear and left sides of the excavator, i.e., from pit No. 3, pit No. 4 and then pit No. 5. When the specified three pits are completely excavated, the excavator is advanced to the next panel. From alternatively extraction of contaminated soils from specified three pits, to the excavator advancing to the next panel completes a cycle of excavation. The same excavation process is repeated until completely extraction of the contaminated soil in the site.

This alternative-pit excavation system can be used not only to excavate small and isolated waste sites, but also to excavate the large wast sites. In case of the contaminated soil needed to be excavated exceeds 50 feet but less than 100 feet depth, double working levels can be designed and excavated.

1.2 Drainage System

Trenches and drains around the excavation panels must be designed to install pipes and pumps to collect runoff from the spray water/other for dust control, rain water and ground water. The trenches may be constructed alone the sides of the panels prior to the excavation, and the bottom of the excavated pits after excavation.

1.3 Pit Backfilling

In case where backfilling of excavated pits with clean soil becomes necessary during excavation, the clean soil can be brought in by trucks after excavation. The clean soil is backfilled into pits using the combination of loader(s) and dumping truck(s). The excavation and backfilling operations can be conducted simultaneously.. However, it should be noted that the backfilling operation may be delayed and started after a few pits have been excavated, to avoid the backfilling materials being contaminated by unexcavated material.

1.4 Dust and Vapor Suppression

The dust and vapor control technologies may be integrated with the alternative-pit excavation system to suppress the dust and vapor emission. The spray equipment including pipes, water or foam delivery devices may be installed on the sides of the panel. The aim of the sprays should form a certain angle to form a water or foam curtain for more effective wetting or covering the selected area, as shown in Figure 2. The availability of dust and vapor suppression and treatment methods are detailed in section 2 of this report.

Under a certain condition, the enclosure structure over the contaminated site for excavation may become necessary for better dust and vapor control. The air ventilation and pollution control devices are needed for the enclosed structure. Special attention should also be given to the aerosol and fume, smoke control devices for the excavator and other material handling equipment using diesel fuel. For excavation, and dust and vapor control, the innovative excavator should be introduced. They include the remote control excavator, pneumatic excavator, or tele-operating excavator. These innovative excavators are outlined in the following section and detailed in the 5th quarter report. Alternatively, combination of conventional excavator with power vacuum truck should be used to control the dust and vapor

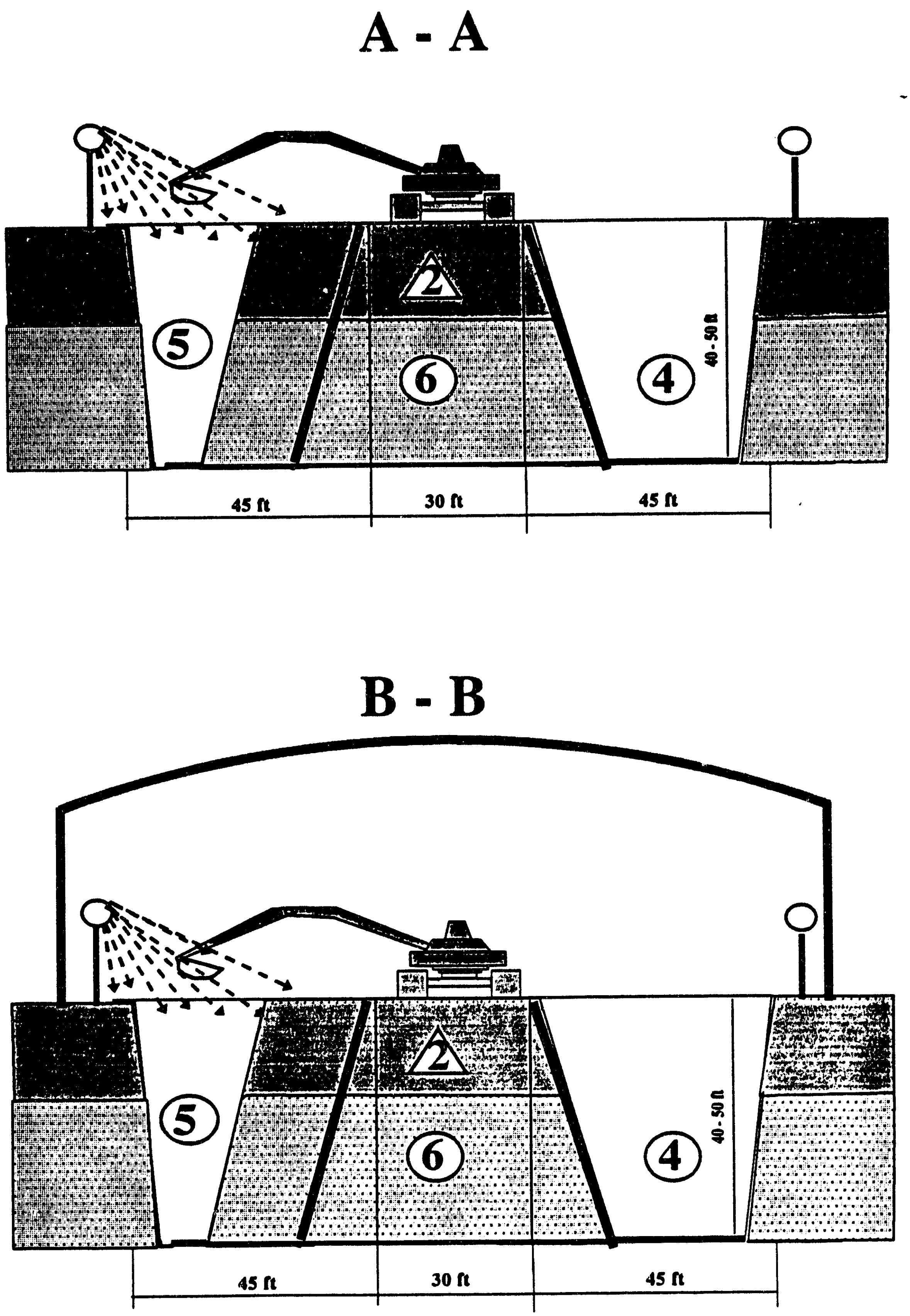

Figure 2 Example of Spray Angles to the Pits for Effective Dust and Vapor Control

during excavation.

2. EVALUATION AND GUIDELINES OF SELECTING DUST AND VAPOR SUPPRESSION TECHNOLOGIES

In this quarter, we are continuing search for the technologies, information and innovative excavation system for dust and vapor control, which can be used alone or in combination with all other suppression technologies. Thirteen available technologies for on-site dust and vapor suppression and/or treatment were identified. They are briefly described as follows:

2.1 Technologies for In-situ Dust and Vapor Control during Excavation

1. Water:

The addition of water to soils and excavations for dust control continues to be one of the most common suppression techniques for dust and chemically contaminated particles. Water is applied topically to increase the density and cohesion of soils, thus preventing release to the atmosphere. Repeated applications are necessary due to evaporative losses.

2. Water Additives:

Water additives are typically surfactants and other water extenders that increase the penetration and staying power of topical applications in order to reduce the frequency of application and the attendant labor costs relative to waste alone. Adhesive type polymers such as latexes, acrylics, and waste-derived lignosulfonates are typical examples of this class of dust suppressant. Numerous commercial formulations are available. However, there are not many of them actually being applied on the contaminated soils.

3. <u>Inorganic:</u>

Hygroscopic inorganic salts such as calcium chloride have long been used to control dust on unpaved roads. These salts absorb and chemically bind moisture. When integrated into a roadway with the proper soil particle size distribution, the salt retains moisture over a long period of time and reduce the release of dust to the atmosphere. Alternatively, pozzolanic material such as cement and lime can be incorporated into the soil. These pozzolans react with water to provide higher soil cohesion and strength, thus reducing the release of dust. The disadvantage of using hygroscopic salts of suppressants is the soluble nature of the salts, which is easily be washed off by rain water and needed to repeat applications.

4. <u>Organic:</u>

Oils, waste oils, bitumens, and vegetable gums have historically been used to wet and bind particles together to resist entrainment by blowing winds and drafts created by earth moving equipment. These materials have an affinity for soils and a low vapor pressure than water, and thus remain effective longer than water.

5. Foams:

Vapor and dust suppression has been demonstrated by foams which are produced by air entrapping water additives. This relatively new technology was originally developed for fire fighting and several available products are modifications of fire fighting foams. Blankets of the foam products suppress the evolution of particles and vapors by physically blocking escape routes and insulating the soil from the effects of the sun and wind. Stabilizer are commercially available to extend the life of these foams to several day. Specialized nozzles or conventional fire fighting foam producing nozzles are used. special care must be taken to select the chemicals used in the generation of foams, which may react with the contaminants in the soils. This technology has the great potential to applied not only in suppression of dust/vapor, but also to treat the contaminants on the particulates and vapor. However, the fundamental of neutralization of contaminants in the bubbles (foams in three phase systems) are not quite understood. The research and development of this area are needed.

6. Air-Supported Structures:

Commercially available air supported membranes have been applied to enclose areas under going excavation. The membrane provides a barrier which prevents uncontrolled release to the atmosphere. In conjunction with air lock entrance and exhaust stream dust and vapor pollution control equipment, these structures have the capability for relatively high effectiveness where site conditions permit their use.

7. In-Situ Treatment:

Seventeen technologies are currently available for in-situ treatment of volatile organic compounds which could be applied to remove vapors prior to, or in lieu of, excavation. These seventeen technologies have been detailed reported in the 3rd and 4th quarterly reports.

8. Self-Supporting Enclosures:

A variety of relatively inexpensive enclosure have potential application for containing dust and vapor during excavations. These can provide a barrier to release of contaminants from the work area. Unlike air supported structures, the building can be operated at or slightly below atmosphere pressure for the purpose of directing purge air to air pollution control devices. Dual radius arch frames supporting corrugated steel or textile covers, geodesic domes, and construction equipment hangers may fined successful application during excavations. One reported application included a moving self-supported structure that advanced on rails along side the excavation as the work proceeded.

9. Vacuum Trucks:

Commercially available vacuum trucks with liquid and/or dust separation and control equipment can be used to remove soils and sludges fluid enough to flow to the pickup nozzle. In these cases it can provide a more controlled alternative to excavation and loading. Similarly, pave roads can be swept clean and vacuumed to control dusts.

10. Covers, Mats, Membranes:

Various systems are available for covering soil with physical barriers. These include thin plastic sheets, i.e., 4-6 mills, thicker coves, i.e., 30-40 mills, mats, geotextiles, and bulk materials, i.e., stray, wood chips, and sludges. Some barriers are applied from rolls which are held in place and later recovered during excavation. These only effective for controlling the release of dust and vapors between active soil handling unit operation, i.e., inactive excavation, stockpiling, transport in truck, etc. Others which are applied in bulk, such as paper mill sludges, straw, aged manure or other adsorbent materials, can be removed for disposal along with the soil.

11. Innovative Equipment:

Innovative equipment including new and improved excavating equipement, and dust control equipment on material loading/unloading equipment. The computerized excavator can be operated easily by the driver due to installation of electronic total control system on the excavator for on-site operation. The operator's compartment have also been impoved to shield off the dust. The conventional excavation equipment can also be upgraded to computer controlled excavator. The tele-operated remote controlled excavator are operated by using radio transmission, or fiber-optic cable for off-site operation to provide maximum worker saftey. The pnumatic excavator equiped with pnumatic transport system for trapping the particulates and vapor during excavation. No information is availabe for commercial size of the unit. The detailed of these innovative equiment are described in the 5th quaterly report. The improved designer curtains and imporoved atomizing spray system, with or withoud selected dust suppressants using in the underground mining and processing plants can be used in dust control.

12. Windscreens:

The windscreens have been practised to reduce windshear over soils to control the amount of soil erosion. Similar methods can find use in controlling emissions from excavations and temporary waste storage piles. Design guidelines and effectiveness measurements are currently available commercially.

13. Seasonal Scheduling:

Planning excavations according to the seasons can reduce the overall potential for emissions by taking advantage of lower temperature and wind speeds, and avoiding excessively dry weather. In addition, monitoring the emissions downwind during remediation activities can also be used to adjust daily work schedules and, if necessary, stop work or apply additional dust or vapor controls as meteorological conditions and observed emission levels vary.

2.2 Evaluation and Guideline for Selecting Dust and Vapor Control Technologies

These dust and vapor control technologies are evaluated and given in Table 1.

3. INFORMATION STORAGE BASE

Computer with plentum-90, laser printer and database software are ordered. The knowledge and information obtained and generated from this research project will be systematically stored in the database program. This will be useful to retrieve the formation needed to develop and design the dust and vapor control remediation techniques during excavation using currently best available, and/or advanced/innovative technologies.

Table 1 Evaluation of Dust and Vapor Control Technologies

Technology	Dust Control	Effectiveness for Vapor Control	Constrains in Use	Benefits of Use	Relative Costs
1 Water	Yes	L.E.[1]	Runoff; May react with pollutants; Costly repeated applications; Time consuming; Low-effectiveness with vapors	Cost-effective method; Widely available	Low
2. Water Additive	Yes	L.E.	May react with pollutants; Limited availablility; Low effectiveness with vapors	Extended benefits of water by reducing costs for repeated applications	Low
3. Inorgnics	Yes	L.E.	May react with pollutnats; Effective only on relatively non-disturbed soils; Low effectiveness with vapors	Cost-effective method that required infrequent application	Low
4. Organics	Yes	Yes	May react with pollutants; Material handling constraints; Application temperature dependent	Effective in dust suppression. May add BTU value to soil Manu provide tough dimensionally stable continous membrane; May be used with geotextiles	Low-Moderate
5. Forams	Yes	Yes	May react with pollutants; Specialized applicators; Material handling constraints; Relatively short life; some toxic decomposition products upon heating	Existing marketing toward HW site use overnight vapor suppression; May produce stable blankets; Slow drainage rate; May resist product pickup.	High
6. Air-Supported Enclosuress	Yes	Yes	Cost may restric use to smaller sites; potential greenhous effect	Available nationwide for lease/purchase; No chemicals introduced into sytem	High
7. In-Situ[2] Treatments	Yes	Yes	Effective on lhighly permeaclbe soil used oa limited group of compounds; Effectiveness dependent on characteristics of soils and contaminants;	Removes vapors before excavation may obviate need for excavation	High

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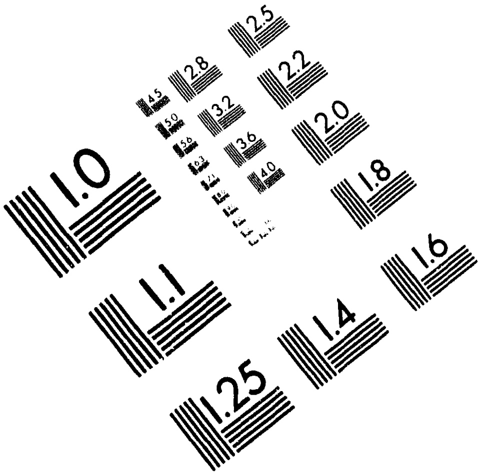

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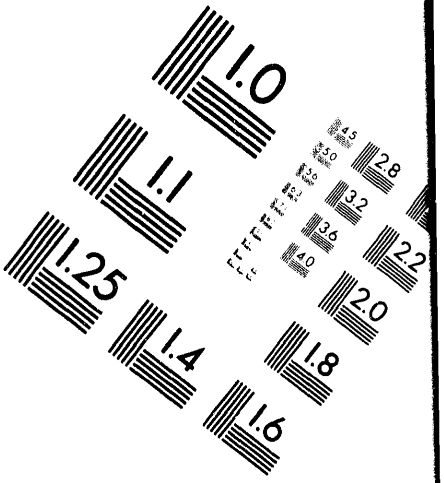

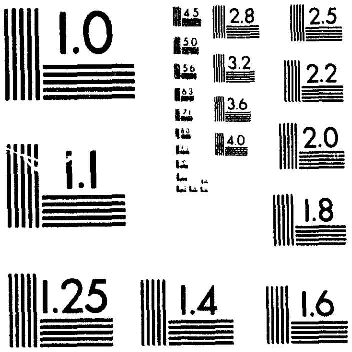

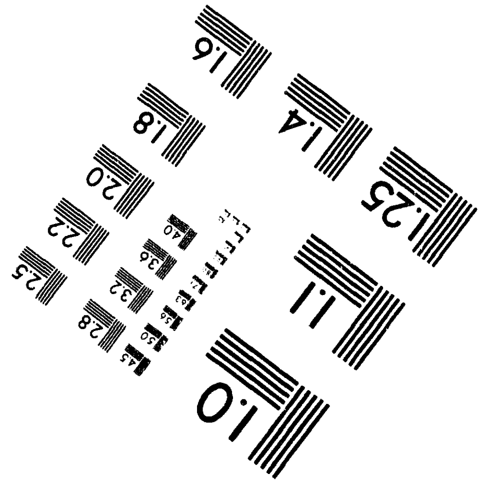

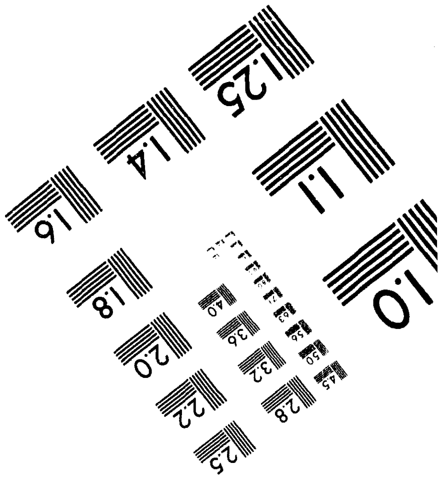

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Table 1 Evaluation of Dust and Vapor Control Technologies (continued)

Technology	Dust Control	Effectiveness for Vapor Control	Constrains in Use	Benefits of Use	Relative Costs
8. Self-Supporting Enclosure	Yes	Yes	Cost may restrict to specific site use	Effective containment of dust and vapor	High
9. Vacuum Trucks	Yes	Yes	Requires control of airborne pollutant; Limited to applicable materials, i.e., sludges, loose granular material	No additional chemicals used	High
10. Covers, Mates and Liners	Yes	Yes	Must be removed during active material handling; Mat/liner failure	Ease of application; Effective control in many situations	High
11. Innovative Material Handling Equipment	Yes	Yes	Availability of technologies; Availability of commercialized equipment and auxiliary units	Effective control for in-situ and ex-situ mitigation	
12. Wind-screens	Yes	No	Subject to wind direction; Marginally effective	-	Low-Moderate
13. Sche-dulling	Yes	Yes	Stockpiles; Dependent on weather conditions; rigorous timing constraints	Seasonal scheduling; Least costly method; Can be applied on contingency basis	Very Low

Notes:

1) Low Effectiveness
2) There are seventeen methods under in-situ treatment technologies. They can only be evaluated one by one for site specifics.
3) The materials used for dust/vapor suppression varies widely. The cost of materials per unit acre are (1988 prices), for examples, $ 230 for Calcium Chloride (Low); $ 480 for Vinyl Acetate Resins (Low); $ 1,100 for Asphalt Emulsion (moderate); $ 8,400 for polyurethane-polyurea foam (High); $ 26,000 for Sodium Bentonite Clay and Geotextile fabric (Very High).

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FUTURE WORK

A specifics site is selected at Windfield Lock/Dam site, Red House, West Virginia for implement the knowledge obtained from this research project. The soil at the site were contaminated by low concentration of dioxin and other volatile organic compounds. The dioxin is known to have low solubility and non-reactive natures at ambient temperature and pressure. The hazardous waste site is located along Monongalia river and on the Robert C. Byrd lock/dam site. Although personnel protective equipment can be used to mitigate adverse on-site exposure to the dust and vapor, this measure cannot typically be extended to mitigate potential adverse off-site exposures. Thus, dust and vapor control during excavation of contaminated soil at Winfield site will become paramount important. As topographic map, contaminant characteristics and distribution, and other information of Winfield site are made available for us from Corp of Engineering, the design of the generic excavation system will be further refined and developed for the Windfield site.

For the dust control methods for site specifics, the summary of the current practical technologies which have been actually implemented to mitigate the adverse off-site exposures at the Superfund sites will be reported. The performance of the older conventional control methods for dust appears more firmly understood. However, the performance of the newer vapor and particulate suppression technologies, such as in-situ treatments and foam application are much more uncertain at this time. This uncertainty suggests additional research and development are needed in these areas for dust and vapor control during excavation. For a specific site, prior to application of newer methods such as utilizing foam for dust and vapor suppression, the forms must be tested for their effectiveness and safety.

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WINFIELD LOCK AND DAM REMEDIATION
(MC-9)

Quarterly Technical Progress Report
for Period January 1 through March 31, 1994

Work Performed Under
Contract Number: 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

By

Raymond J. Lovett
National research Center for Coal and Energy
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West Virginia University

May 1994

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10. EXECUTIVE SUMMARY

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. In order to efficiently develop and communicate the necessary technical information, a resource group has been developed at WVU which is charged with developing enhanced technical (and other) capability to enhance the WVU effort. The members of this group have traveled, read and otherwise devoted some of their time to enhancing their knowledge of remediation. Some have provided insightful comments concerning published ACE plans and specifications (P&S). Other WVU faculty have developed site opinion surveys and studied social, political and economic issues associated with community involvement in hazardous waste site remediation.

A second portion of the WVU effort is directed towards actually supplying assistance in development of a remediation strategy for the site. The ACE does not have a particularly clear idea of what to do if incineration is not used and they have requested help from WVU and other parties in investigating their options. Such assistance involves an expanded effort by WVU to investigate the state of the art of remediation and begin development of some new technologies. These investigations are being conducted by the National Research Center for Coal and Energy (NRCCE) staff and WVU faculty.

This quarter was relatively quiet at the site. Most new construction will begin this summer. Most of the effort this period concerned improving our understanding of the technologies needed for remediating the site and becoming acquainted with the new technical advisor for the Umbrella Group. New information for this quarter is in boldface type near the end of this document.

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2.0 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 establishment of a Resource Group and 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).

3.0 WVU INVOLVEMENT AT WINFIELD

Early Developments

West Virginia University first became aware of Winfield and the problem existing there in August 1992. Representatives of WVU traveled to the site to discuss the problem with the ACE. The site was viewed from the outside and the history of the site and the nature of the lock expansion project were discussed.

In September 1992, the magnitude of concern for the remediation problem became more obvious. A representative of the NRCCE, Raymond J. Lovett, was chosen to become involved in the situation to provide technical and other assistance to the community. At the time, the concerned community consisted largely of an environmental group, P.R.O.T.E.C.T., and the town government of Eleanor. Eleanor contains three schools close to the site and Winfield has another three schools

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somewhat farther away, although Winfield is east of the site and more likely to be downwind.

On October 16, 1992, P.R.O.T.E.C.T. sponsored an appearance by Dr. Paul Connett, a chemist from Clarkson University in Potsdam, NY. Dr. Connett is an outspoken opponent of incineration, and organochlorine compounds, in any form. His talk was a, self proclaimed, polemic against incineration and the hazards of dioxin (which is actually used as a catchall descriptor of two classes of compounds, dioxins and furans, both of which are chlorinated). He in particular discussed the toxicity of 2,3,7,8 tetrachloro-p-dioxin, the most potent congener. Following Dr. connett's talk, contact was made with both the ACE and ACF Industries, which promised as much assistance as needed to help the WVU efforts. Discussions with the area citizens, including P.R.O.T.E.C.T. members and public officials revealed that although P.R.O.T.E.C.T. members were adamantly opposed to incineration, other community members and officials were willing to accept incineration if it were shown to be the best option.

On November 4, 1992, a trip was made to Eleanor to visit with concerned citizens and, the next day, with some state Department of Environmental Protection, Congressman Bob Wise's staff and Paul Hill from the National Institute for Chemical Studies (NICS). The visit to Eleanor consisted of talks with Marlene Carr, a town of Eleanor councilwoman, the mayor of Eleanor, Lloyd Jividen, and the P.R.O.T.E.C.T group. The P.R.O.T.E.C.T. group gave me a copy of the complete record of the site, all 17 volumes. That evening I dined with Missy Woolverton of the WV Citizen's Action Group (WVCAG); we discussed the situation at Winfield. The discussion on November 5, 1992 with the WVDEP included Dave White and Lucy Pontiveros of the Office of Air Quality, Lewis Baker of the Office of Solid Waste and Ken Ellison, an assistant director of OSW. The conversation generally concerned the roles of WVU and the state in the remediation. As with most of these early discussions, the WVU role was ill-defined and the agencies were attempting to determine exactly the course WVU would take. Following the DEP talks, a meeting with Susan Small of Congressman Bob Wise's staff and Paul Hill of NICS took place. In this meeting, aside from trying to develop the role of WVU, Susan revealed a plan to form an umbrella group from citizens in the area to coordinate the local effort. Shortly after the visit to Charleston, the ACE called and asked me to come to Huntington to discuss the role of WVU. The ACE notes of that meeting on November 16 and a subsequent meeting in Morgantown on December 15 provide information on the remediation and the relationship between the Corps and WVU. The relationship is one of assistance and cooperation, but with the maintenance of distinctly separate identities.

The Winfield Lock and Dam Umbrella Committee

The Umbrella Committee was formed in January 1993 and consists of politicians and citizens whose job included overseeing and evaluating ACE operations. Since its formation, the Umbrella Group has held meetings almost every second and fourth Tuesday of each month. They are divided into a number of committees, including health and safety, technology and project watch. Each meeting consists of a committee report followed by new business; sometimes the ACE is invited to explain its latest plans. The health and safety committee has concerned itself with airborne problems and the safety of school children. They have requested a local health assessment from WVU, negotiations on which are in progress. The technology committee reviews ACE plans and specifications and risk assessments. The project watch committee oversees activity at the site.

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WVU interaction with the ACE has largely been devoted to definition of role and technical review of their plans. Among the plans published are the air monitoring plans, the storage building P&S, and the demolition and decontamination P&S and risk assessment documents. When published, the plans are submitted to the Umbrella Group and WVU. The plans are distributed to members of the Resource Group at WVU for evaluation. Those evaluations are distilled by the NRCCE and submitted to the ACE.

Interaction with political units has largely been confined to Eleanor. The Corps of Engineers is going to buy the Eleanor water supply, due to potential contamination from the site. WVU assisted the town (largely financially) in obtaining an independent valuation of their supply so that they could appropriately consider the ACE offer.

Meeting with Army Corps of Engineers (Cincinnati, OH) (June 30 1993).

The Army Corps of Engineers (ACE), in their quest to develop a suitable remediation scheme for the Winfield site, contacted the University of Cincinnati (UC) to discuss a possible role for them in the Winfield project. I was also invited to the meeting, held June 30, 1993 at the Center Hill facility in Cincinnati. In attendence were Jerry Roberto and Larry Murdock (UC) and Gen. Albert Genetti and Richard Conner (ACE). Gen. Genetti was the commanding officer of the Ohio River Division and Richard Conner is the Chief of the Engineering Division at the Nashville ACE office, which is the Division center for environmental excellence.

The University of Cincinnati used to operate the EPA Treatability facility at Center Hill (the contract has since been vacated). Although they performed lab tests to determine the suitablility of various remediation methods for various soils, their greatest efforts have been devoted to in-situ remediation. Specifically, UC has devoted much effort to hydrofracturing and steam enhanced vapor extraction, which they have tested on site. Such strategies are not particularly of interest at Winfield, since the soil will be excavated. The University of Cincinnati group also has a formidible effort in computer based site vizualization software, which is very impressive.

The meeting largely was informational, nothing was decided. I was however invited to visit Nashville, which will be discussed below.

Umbrella Group

A number of meetings were missed in the summer of 1993, due to trips or vacations taken by Group members or me. The Group elected a President (Tim McCoy) and adopted a set of by-laws. They discussed their vision for a health study and commented on the two ACE documents that were released this summer, a preliminary exposure scenario and a constituents of concern (COC) document. The group received a $25,000 grant from Gov. Caperton's office to support a technical assistant, which they plan to use to hire Fred Youngs' Citizens for Jobs in the Environment group. Additionally, they appear poised to receive $100,000 from the U.S. Congress to support another expert who will help develop remediation plans. These issues and others are discussed in the trip report for the one summer meeting I attended (August 24). There was no meeting held on August 10.

The August 24 meeting concerned the preliminary exposure scenario, which detailed the extent to which possible exposures would be assessed. The meeting was somewhat acrimonious, with most of the animosity directed towards the ACE subcontractor, Dames and Moore. The meeting was attended by Dr. Alan Ducatman of the WVU Department of Occupational and Environmental Medicine, who is savvy about risk assessments. The Dames and Moore Baseline risk assessment process is being broken down into parts to allow continuous input into the baseline risk assessment by the Umbrella Group. The Baseline risk assessment will detail the hazard of the site in the absence of remediation (i.e its intrinsic health risk). The constituent of concern portion used a series of criteria to limit the chemicals to be evaluated in the risk assessment. About 83 were chosen for further consideration, which is a large number as these sorts of analyses go.

Opinion Survey

Last winter, Dr. Susan Hunter of Political Science at WVU was commissioned to conduct an opinion survey to determine the actual state of mind of the county citizens. The survey was initiated due to the general lack of knowledge concerning the thoughts of the vast majority of the citizens (although certain citizen thoughts had been widely broadcast through PROTECT and other groups).

Health Survey

The Umbrella Group has been concerned about how to evaluate the effects of the site and the clean-up. A number of conversations with Dr. Alan Ducatman were conducted over the last few months, which resulted in a decision by the Group to focus their energies on ensuring adequate monitoring at the site. Dr. Ducatman indicated that monitoring would be the best direct assurance that their health was not (or was) threatened. If an incident occurred, knowledge of the identity of the chemical would allow directed evaluation of exposed individuals, facilitating treatment. Lack of airborne exposure is the objective. The only other sort of evaluation that may make sense is a complete medical monitoring study, which would necessarily involve a large number of citizens (1/3 or more). The medical surveillance would require periodic medical exams and long term evaluation of site proximity and other possible exposures. Dr. Ducatman predicted that the outcome would be negative (indicating no long term health effects), but assured the Umbrella Group that that was the only way to discern any health effects if they were to occur.

The Umbrella Group had initially wanted an epidemiological study, then possibly a health survey (oral), to determine the baseline health. Dr. Ducatman indicated that such a survey is biased at best and would not provide any useful information to protect health, much less indicate any long term effects. The argument that the area was already unhealthy (a possible finding of the survey) would provide no more convincing argument against emissions from the site than would a simply declaration that emissions should be minimized to prevent healthy people form becoming ill. In the end, the Group chose to concentrate on demanding appropriate monitoring (and, if necessary, appropriate response to exposure incidents).

4.0 CURRENT SITUATION

Lock and Dam

The Corps of Engineers began excavating for the lock in the spring of 1993. Only noncontaminated areas have been excavated, downstream of the ACF site. The Corps has released the preliminary risk assessment for the removal action (dismantling and excavation) at the site. Current plans are for excavation (preceded by dismantling and decontamination of the buildings) to begin in April 1995 and be completed in Early 1996. The plans and specifications for the removal action will be available in early July. The bids for the temporary storage buildings have still not been awarded due to a protest. A decision on the scrubber will be made soon, which should resolve the bid issue. The baseline risk assessment has been delayed due to incorporation of future land use considerations in the document. This delay is due to new ways in which the government will conduct cleanups, largely based on risk assessments to provide cleanup criteria. The entire construction project will be finished by January 1997, but remediation of the soil will take longer (in fact no completion date is postulated for the end of the remediation).

Umbrella Group

The Umbrella Group now has officers, but attendence has been declining. They have hired an expert for review of future Corps plans, Fred Youngs of the Citizen's Analytical Laboratory of Boston, MA. Of the months ahead will be the plans for excavation and monitoring; there has been little action on site since the sampling by ACF and Dames and Moore last spring.

5.0 QUARTERLY ACCOMPLISHMENTS

Umbrella Committee Meetings

Umbrella Committee Meeting of September 14, 1993.

Cancelled

Umbrella Committee Meeting of September 28, 1993.

I was in Atlanta, GA at a meeting on Emerging Technologies in Hazardous Waste Treatment.

Umbrella Committee Meeting of October 12, 1993.

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The meeting was held at the Eleanor Town Hall at 7:00 P.M., I also attended the Technology and Health committees meetings starting at 6:00 P.M. The Corps of Engineers arrived at 8:00 P.M. Only the Huntington representatives were there.

At the technology committee meeting, I reported on a visit to Clean Sites in Alexandria, VA. I had originally been apprised of Clean Sites by Mark Kessinger of the Huntington COE. I had encountered Sarah Medearis of Clean Sites in Atlanta at the ACS Emerging Technologies meeting and arranged a visit (on 10-7). The Umbrella Group wanted to know how Clean Sites felt they would interact with the Winfield Project. Based on my conversations at Clean Sites I reported that their involvement, if any, would largely lie in the technology decision stage, not at any earlier stage. No plans exist at all for the involvement of Clean Sites at this time.

I also discussed my plans to visit the Nashville, TN COE office with the Group. In particular I inquired if they would like treatability studies conducted at the site; they were enthusiastic. My trip to Nashville (10-19) revealed that the COE is eager for such tests as well and that Nashville will evaluate proposed tests, but Col. Richardson in Huntington will make the eventual decisions.

The Health and Safety committee discussed the meeting they had with Dr. Alan Ducatman and I (and others) at WVU on October 6. Based on those discussions, they voted to concentrate their efforts on assuring that adequate monitoring is installed when site work begins. These committee meetings occupied the normal meeting time as well. The subjects shifted when the Corps arrived.

The Corps will help with the school shelter in place program and the Group and the COE discussed some details. It was noted that the scrubber issue must be decided by February, in order to activate the option on it. A discussion on Environmental impact statements ensued, Mark Kessinger subsequently sent me copies. The Corps contractor, Dames and Moore, will show up on November 9 [actually November 30] to discuss new documents they have prepared. Current documents are the Constituents of Concern, Exposure Assessment and Air Monitoring Study. Discussion of the constituent of concern document was directed mostly towards me. I indicated that the criteria used appeared sensible and that every class of compound was still represented on the list (of 83). The Umbrella Group appeared confortable with the list, but will reserve their comments until Dames and Moore appear. Since Dames and Moore are contractors of Nashville, the Group recognizes that comments directed to Huntington are not as effective as comments to Dames and Moore directly or representatives from Nashville.

Umbrella Committee Meeting of October 26, 1993.

Cancelled

Umbrella Committee Meeting of November 9, 1993.

Cancelled

Umbrella Committee Meeting of November 30, 1993.

The Corps of Engineers and Dames and Moore attended the meeting. The major topics of discussion were the interim risk assessments. The initial discussion concerned the oral report

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presented by ACF in August and their follow-up in September. The ACF conclusion that large amounts of soil from the lock site could be disposed of in landfills was disputed by the Corps. Landfills contacted by the Corps said that they would be prohibited from accepting dioxin contaminated soil by, generally, state regulations.

The discussion of the Dames and Moore documents largely centered on whether the risk is adequately evaluated. Once again the Umbrella Committee expressed concern over the absence of specific consideration of school children in the documents. D&M explained that children are implicitly considered; the Committee wanted more definite consideration. The risk analysis used EPA models, looked at average values not pulse releases of hazardous materials. The air dispersion process was discussed. The results lead to the estimated exposure with distance. The Umbrella Committee cannot dispute the models until they can hire their expert.

Umbrella Committee Meeting of December 14, 1993.

Missed

Umbrella Committee Meeting of December 28, 1993.

No meeting scheduled.

Umbrella Committee Meeting of 11 January 1994

The meeting was held at the Eleanor Town Hall at 7:00 P.M. Only a few of the Umbrella Committee (7) were in attendance. The removal action risk assessment was discussed briefly. Comments are due to the Corps of Engineers by January 18. Citizens are still concerned about the scrubbers on the storage buildings and discussed strategies to acquire them. They do not have strong direct technical arguments for installing scrubbers, most ideas were of the "what if" type.

The group discussed what to do about disinterested committee members (they will remove them after suitable warning and replace with others). Any new members must be appointed by the appropriate political unit (town, county, etc.).

The hiring of a consultant received only one bid and Del. Debbie Phillips must ascertain whether a consultant can be hired if only one bid is received.

The meeting adjourned at 8:30 P.M.

Umbrella Committee Meeting of 25 January 1994

Cancelled.

Umbrella Committee Meeting of 8 February 1994

Concerned only new members issues, did not attend.

Umbrella Committee Meeting of 22 February 1994

Cancelled.

Umbrella Committee Meeting of 8 March 1994

The meeting was held at the Eleanor Town Hall at 7:00 P.M. The Health and Safety Committe report (Barbara Davis) discussed emergency plans. Seven schools are involved and all will have plans soon. Dr. Sentelle (Superintendent of schools for Putnam County) confirmed that the plans are being rewritten. The committee wants them in place before the soil is moved.

The Corps of Engineers has a new timetable (attached), which extends the time for the baseline risk assessment and delays excavation until April of 1995.

The Umbrella Group voted to hold monthly meetings (first Tuesday) until such time as semimonthly meetings are again justified. This meeting is the second since January, the February meeting concerned only issues related to Group membership and I did not attend. The next meeting is April 12, 1994.

The Group has been able to hire a consultant through the efforts of Debbie Philips (a state delegate) and Gov. Caperton. The $25,000 was used to hire Fred Youngs of the Citizen's Environmental Laboratory of Boston, MA. I first met Fred last year in Atlanta. Fred was introduced to the Group and I was asked discuss the prospective interaction between Fred and WVU.[I had talked to Fred the night before and earlier that day]. As the technical expert, Fred will develop issues of concern to the Umbrella Group. Technical information needed to fully answer the questions can be provided by WVU as part of its charge to protect the health and safety of the citizens and assist in the choice of remediation technology.

I was then asked to briefly explain why the Baseline Risk Assessment was delayed. The Corps told me that they wanted to develop risk assessments based on various end use scenarios, which is one of the manifestations of risk based clean-up requirements so newly of interest in D.C.

Susan Small indicated that Bob Wise is attempting to provide technical assistance money to all communities near a Federal Defense Site (non-NPL clean-ups).

The issue of school children's health arose again. Jack Kelley from ASTDR will go to Eleanor on March 21 to evaluate the situation. I was asked to see if Dr. Ducatman could find any articles on child specific reponse to pollutants. This issue concerns whether children are especially affected by chemicals by other than body weight arguments (i.e. they have special metabolic sensitivity since they are growing).

The scrubber issue must be resolved soon. Susan Small urged that many letters expressing a desire for the scrubbers be sent to the Corps (in D.C.).

The meeting adjourned at 8:15PM.

Corps of Engineers Meetings

Nashville Office Meeting of October 19, 1993.

On October 19, 1993 I visited the Corps of Engineers office in Nashville, TN. The purpose of the vist was to generally discuss the Winfield situation and determine what would be necessary for WVU to initiate technology evaluations at the site. After general discussion, I learned that any plans for evaluating a technology at the site would first involve review by the Nashville Office (which is the Division Center of Excellence for Environmental Remediation). The recommendations of Nashville would be considered by Col. Richardson in Huntington, who would make the final decision. The initial application would be written and the technology would require a fairly high level of test data to show feasibility. The written request should also include space requirements and detailed plans on managing and executing the feasibility study.

Visit to Waterways Experiment Station, Vicksburg, MS on November 23, 1993.

Representatives of the Huntington Corps, WVU and the Morgantown Energy Technology Center visited the Waterways Experiment Station in Vicksburg. This site is where most Corps of Engineers research in hazardous waste remediation is conducted. The vist began with a discussion of the capabilities, followed by a tour of the facilities. Most of the work at Vicksburg concerns ex-situ treatment methods. Technologies included substantial efforts in bioremediation (much in reactors), an ultraviolet pump and treat system, a Roy F. Weston thermal desorber unit, and some early work with electrokinetics. They discussed previous work with chemical dechlorination as well.

Subsequent tours displayed the Ecological Risk assessment research program for dioxin and a roundtable discussion of the issues involving Winfield that must be answered.

Other Meetings

Town Meeting in Eleanor, WV on November 2, 1993.

This meeting was held by AE Environmental to explain the results of the ACF confirmatory sampling program. In general, AE agreed wiith most of the ACF conclusions. The most controversial conclusion was that the site contained not 60,000 cubic yards of contaminated material, but 5-10,000 cubic yards. ACF concluded that the rest of the allegedly contaminated material could be landfilled [this is disputed by the Corps]. AE recommended that a new, more statistically valid, sampling program be initiated at the site. The ACF study focussed on areas that the Corps found to be contaminated; the study did not evaluate areas which had been declared free of contamination. In effect, ACF attempted to assert whether the Corps had erred in their positive analyses, but did not make any attempt to determine whether the Corps had erred in their negative analyses. AE recognized this flaw.

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Western Governor's Assoc. DOIT Committee Meeting in Washington, DC on February 1, 1994.

This meeting concerned the report of the Western Governor's DOIT Committee, which has been assigned to help get the west cleaned up. The meeting reported on efforts to develop mixed waste, mining, military base, and munitions innovative technology demonstrations. Both the organization and objectives of DOIT were discussed and the reports of the committees were distributed. As an example, the mixed waste committee recommended five technologies for demonstration, fixed plasma hearth treatment, thermal desorption, minimum additive waste stabilization (MAWS), microwave solidification, and a two stage advanced oxidation unit. None of the projects is funded specifically, but the DOD and DOE pledged support. The meeting provided a concise overview of the nature of the problem and what may be required to solve it.

EPA Risk Reduction Engineering Laboratory (RREL) Conference in Cincinnati, OH from March 14-16, 1994.

This meeting concerned the display of the latest EPA sponsored research and technology for hazardous waste clean up, as might be needed at the Winfield site. Included were posters and presentations on various physical, biological and chemical methods of remediation. Most of the research is in the late research , early pilot stage and not of immediate use for an actual remediation. A list of the proceedings abstracts is appended.

APPENDIX A

EPA/600/R-94/011
March 1994

20TH ANNUAL RREL RESEARCH SYMPOSIUM

ABSTRACT PROCEEDINGS

Coordinated by:

Science Applications International Corporation
Ft. Washington, PA 19034

Contract No. 68-C2-0148
Work Assignment No. 2-7

Work Assignment Manager:

Emma Lou George
U.S. Environmental Protection Agency
Risk Reduction Engineering Laboratory
Cincinnati, OH 45268

RISK REDUCTION ENGINEERING LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OH 45268

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PART ONE

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PART TWO

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SOCIO-ECONOMIC ASSESSMENT OF ALTERNATIVE ENVIRONMENTAL RESTORATION TECHNOLOGIES (MC-24)

Quarterly Technical Progress Report
for Period January 1 through March 31, 1994

Work Performed Under
Contract Number: 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

By

Andrew M. Isserman, Regional Research Institute
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William N. Trumbull, Economics Department
West Virginia University

May 1994

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1.0 Executive Summary

The goal of this research is to develop operational methods that can be used to assess alternative clean-up strategies. This project is the first step in that process — ascertaining the appropriate approach to applying contingent valuation methods to the problem of technology choice in a way that considers direct environmental quality impacts and health implications for the local community and permits trade-offs among criteria.

To date, the research team has compiled a sample of studies of restoration projects to determine the extent to which economic and social implications for local communities were included in the planning and implementation processes. These studies include cost effectiveness analyses that include only the costs incurred by the restoration agency. Other economic impacts that do not result in direct costs to the agency are not included in the cost effectiveness analysis although some are incorporated, in a rough measure, in the selection criteria. This part of the project provides a base with which to compare proposed improved practices.

2.0 Description of Activities

The project team met on a regular basis to outline the research tasks and develop lists of potential information sources. We contacted various EPA offices to obtain reports of activities at sites similar to the former ACF Industries site at Red House, WV. The individuals and agencies contacted are listed in table 1. The reports obtained are listed in table 2.

The capital and operating costs are outlined for all such projects as part of the restoration technology assessment process. However, none of the projects we have reviewed have attempted to explicitly include any costs external to the restoration agency in as part of the cost effectiveness criteria. Based on conversations with the individuals contacted, we believe these studies are representative of the approach taken in the analysis of alternative restoration technologies at hazardous waste sites.

Table 1: Individuals and Organizations Providing Studies of Hazardous Waste Site Restoration

Anne Marie Galaspie
Hazardous Waste Branch
EPA Region 4
Atlanta, GA
(404)-347-2643

Carol Rushin, Chief
Superfund Remedial Branch
EPA Region 10
Seattle, WA
(206)-553-4973

Elizabeth Rogers
Superfund Enforcement Branch
EPA Region 6
Dallas, TX
(214)-655-6708

Laura Screws
FOIA Specialist
EPA Region 4
Atlanta, GA
(404) 347-3931

Jack Whyte
AARP Senior Env. Employment Program
Denver, CO
(303) 293-1651

Table 2: Engineering Evaluation/ Cost Analysis Reports and Case Studies Obtained

Kluck, Patricia, ed., Environmental Decision Making: Conflict and Consensus, Colorado Center for Environmental Management, Denver CO, 1993.

EE/CA The Former ACF Industries, Inc. Site, Treatment and Removal of Contaminated Soils, Red House, WV, U.S. Army Corps of Engineers, Nashville TN, May 2, 1992.

EE/CA Cropsey Waste Pile, Beaver Mud Dump, and Cleveland Cliffs Tailings Pond Mine Pits; Summitville Minesite, Summitville, CO, Ecology and Environment, Inc., July 1993.

EE/CA Dutchtown Oil Treatment Site, Dutchtown, LA, EPA Work Assignment No. 2212-6L92, February 10, 1988.

EE/CA and Site Structure Removal Assessment, Northwest Transformer Site, Everson, WA, Landau Associates, Inc., Edmonds, WA, August 1993.

EE/CA Skyline Water System, Moses Lake, WA, Associated with Moses Lake Wellfield Contamination Superfund Site, Grant County, WA, U.S. Army Corps of Engineers, October 7, 1993.

EE/CA Solvents Recovery Service of New England, Inc. Site, Southington, CT, EPA Work Assignment No. 30-1R08, Halliburton NUS Environmental Corporation, December 1992.

EE/CA Strandley/Manning Site, Purdy WA, SCS Engineers and Seattle City Light, Seattle, WA, July 1993.

EE/CA Vertac Chemical Corporation Site, Jacksonville, Arkansas, EPA Work Assignment 224-6L04, Project No. 67910, June 12, 1989.

EPA Remedial Investigation/Feasibility Study, Ordnance Works Disposal Areas Site, Morgantown WV, January 1988.

EPA Record Of Decision, Ordnance Works Disposal Areas Site, Morgantown WV, September 1989.

DATE
FILMED

10/17/94

END