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**Decontamination Systems Information
and Research Program**

**Quarterly Technical Progress Report
for Period July 1 through September 30, 1993**

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

For
U.S. Department of Energy
Office of Fossil Energy
Morgantown Energy Technology Center
P. O. Box 880, Collins Ferry Road
Morgantown, West Virginia

By
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October 1993

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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 fourth Quarterly Technical Progress Report for Year 1 of the Agreement. This report reflects the progress and/or efforts performed on the nine (9) technical projects encompassed by the Year 1 Agreement for the period of April 1 through June 30, 1993.

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.

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 presented in September and October of 1993. This presentation lasted roughly 3 hours.

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 are appended in draft form; the SARS is to be completed by 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.

On June 29, 1993, proposed Annual Projects for next year were submitted to METC. Projects of interest to METC were denoted on August 2, 1993, at which time the authors were notified to develop full proposals and preliminary budgets. More proposals were of interest to METC than could be funded, but a preliminary list with approximate budgets was submitted in late August. Full proposals were submitted on September 15, 1993. The chosen proposals were transmitted by Wu Lan in early October, the researchers notified and NEPA documentation submitted. The composition of the final program will be reported in the next Quarterly Report.

B. PROJECT VARIANCES, ACCOMPLISHMENTS AND PROBLEMS

Project MC-1 (the database) is slowed due to uncertainty concerning the extent and quality of extant DOE databases. More investigation of what is available is proposed, with less development of a potentially duplicative database. The Drain project (MC-2A) has successfully sped up contaminant removal, but some unusual slowing results when surfactants are used. The sensor project (MC-7) has been slowed by poorly coated sensor units, which are far more reactive than they should be. These coatings are a supplier problem, not a WVU problem. The PCB decontamination project (MC-6) has successfully used a novel electron carrier (which is recoverable). The bioremediation project (MC-2B) appears to have few problems, except for analytical equipment breakdown which has hindered some experiments.

**A SYSTEMATIC ASSESSMENT OF THE STATE OF
HAZARDOUS WASTE CLEAN-UP TECHNOLOGIES
(Project MC-1)**

Quarterly Technical Progress Report
for Period July 1 through September 30, 1993

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No.: DE-FC21-92MC29467

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

By

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October 1993

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 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

^{*} USDOE, 1991. Environmental Restoration and Waste Management Five Year Plan. DOE/S-0090P.

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.

MEDIA	POLLUTANT CLASS		
	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 intended 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.

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 classes¹:

- 1) physical/chemical
- 2) thermal
- 3) biological, and
- 4) immobilization.

⁺⁺ EPA, 1989. Superfund Treatability Clearinghouse Abstracts. EPA/540/2-89/001.

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 ketones	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. 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.

```

* 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)

```

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 sites (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 demonstrated 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 inputting 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.

ADD EDIT SEARCH EXIT HELP

ORGANIC
INORGANIC
RADIONUCLIDE
TECHNOLOGY
DEVELOP

WELCOME TO
WEST VIRGINIA UNIVERSITY'S
ENVIRONMENTAL REMEDIATION AND RESTORATION DATABASE

please use above menu to make a selection

message

Figure 5. The Introductory Screen to the User Interface Software

The EDIT option from the main menu provides 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 inputting, 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.

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 dispsearch FROM 0,0 TO 24,79 COLOR SCHEME 5

```

```

CLEAR

```

```

*ACTIVATE WINDOW dispsearch

```

```

* 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
ENDCASE
* 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 dispsec 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
changel = 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 fhelppad IN WINDOW record
DEFINE PAD helppad OF fhelppad PROMPT 'HELP' AT 0,70
ON PAD helppad OF fhelppad 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 helptit 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 fhelph NOWAIT

  * 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-m3/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 FUNCTION
"@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 fhelpp2 IN WINDOW record
DEFINE PAD helppad OF fhelpp2 PROMPT 'HELP' AT 0,70
ON PAD helppad OF fhelpp2 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 helptit WITH BAR(),2
ACTIVATE MENU fhelpp2 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;UNKNOWN';
    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 changel 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 changel = 1
    screen = 2
    changel = 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 fhelpp3 IN WINDOW devscreen
    DEFINE PAD helppad OF fhelpp3 PROMPT 'HELP' AT 0,70
    ON PAD helppad OF fhelpp3 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 helptit WITH BAR(),3
    ACTIVATE MENU fhelpp3 NOWAIT

    * Write the current contents of the specified field on the
    * screen beside the checkboxes.
    IF m.medial = 'soil'
        m.picks = 1
        @ 5,34 SAY m.medial
    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'

```



```

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+/B
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,fieldname
* 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
ENDCASE
RETURN
*-----*

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,whichhelp
*
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 whichhelp = 1
- DEACTIVATE POPUP help1
CASE whichhelp = 2
DEACTIVATE POPUP help2
CASE whichhelp = 3
DEACTIVATE POPUP help3
CASE whichhelp = 4
DEACTIVATE POPUP help4
CASE whichhelp = 5
DEACTIVATE POPUP help5
CASE whichhelp = 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.
ELSE
  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_collolid = 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 helptit 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 fhelpp5 IN WINDOW addwater
DEFINE PAD helppad OF fhelpp5 PROMPT 'HELP' AT 0,70
ON PAD helppad OF fhelpp5 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 helptit WITH BAR(),5
ACTIVATE MENU fhelpp5 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(m3/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 fhelpp4 IN WINDOW addsoil
DEFINE PAD helppad OF fhelpp4 PROMPT 'HELP' AT 0,70
ON PAD helppad OF fhelpp4 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 fhelpp4 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 PREVIEW  
    ENDIF  
    * If water information is provided, print the water report.  
    IF mediatwo = 'water'  
        REPORT FORM C:\METC\DATABASE\RPT\WMEDIA.FRX RECORD media PREVIEW  
    ENDIF  
    * If air information is provided, print the air report.  
    IF mediathree = 'air'  
        REPORT FORM C:\METC\DATABASE\RPT\AMEDIA.FRX RECORD media PREVIEW  
    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 dispsec 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.medial = lower(m.medial)

```

```

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 pollutant 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

Technology Report

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 the turbulence 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 separate electric motor-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 housing 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

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enzyme system. Denitrification probably can occur at diminished rates in the presence of oxygen, provided that anoxic conditions had previously existed 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 donor (organic matter) must be available.

In the denitrification system a single-carbon compound would be an ideal candidate for the electron donor. In addition, if the electron donor 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 methanol, 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, methanol is the compound usually chosen when an external electron donor 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 use 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

Technology Report

grains. Another is in the void spaces, which may be filled with either liquid 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 the influent immediately. SAAS was proposed as a way of achieving 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:

Technology Report

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 exist, 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 activated 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

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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 converted 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."

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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.

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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 combustion problems, is the important limiting factor. Liquid injection combustors are of two general types, vertical and horizontal. Normal

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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 distributor plate into a vessel containing a bed of inert granular particles. Sand is typically used as the bed material. The upward flow 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

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temperatures are quite uniform and typically in the 1400-1600 degrees Fahrenheit 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 before 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 Industrial 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 efficient manner.

In the plasma arc reactor, the ultrahigh arc

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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 of 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 substances 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 psia. 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 conjunction 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 or 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

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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 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 additional 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, thereby hurting process efficiency.

Technology Report

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Biological Wastewater Treatment Theory and
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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.

**SITE REMEDIATION TECHNOLOGIES: DRAIN-ENHANCED SOIL FLUSHING (DESF)
FOR ORGANIC CONTAMINANTS REMOVAL
(Project MC-2A)**

Quarterly Report IV for Period
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ABSTRACT

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.

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 work was conducted to evaluate the proper mix of the soil to be used in the testing program. Compaction tests according to ASTM 698D and permeability tests according to ASTM D5084 were conducted using blends of kaolinite and Ottawa sand. The blends consisted of 80/20 percent by dry weight sand to kaolinite. The average coefficient of permeability varied with the moisture content of the samples and was estimated to be on the order of 1×10^{-5} to 1×10^{-4} cm/sec. Based on the results of these experiments the blend to be used in the experiment will be 80/20 sand to kaolinite.

Permeability tests using solution of the study surfactant as permeant indicated two orders of magnitudes reduction in the values of the hydraulic conductivities and this subject 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 combination of the following factors:

1. 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.
2. Sulfonate compounds such as SDS may cause a rise in the pH which results in dissolution of the silica tetrahedral and alumina octahedral layers. Precipitation of this material can cause clogging of pores leading to a drop in the hydraulic conductivity.
3. The hydraulic conductivity depends mostly on the percent of clay particles in the soil mixture. A small percentage of migrating fines under high hydraulic gradients can clog the pores of the coarse fraction.

More investigation and tests are underway to ascertain the effect of the SDS on the hydraulic behavior of the study soil. Planned tests include:

- i. Sectional grain size distribution on the soil samples to investigate potential migration of clay particles.
- ii. Sequential permeation with SDS solution and water to investigate whether this reduction in hydraulic conductivity is irreversible.

On-going testing program includes performance of batch isotherms and flexible wall soil flushing permeability tests to estimate appropriate environmental and engineering parameters for the soils, contaminants, and surfactants under consideration. In addition, several pilot scale tests using Contaminant Recovery Cells (CRC) are underway. The recovery efficiency of the PVD system will be evaluated from these tests. Analysis to be conducted include naphthalene (by GC method 8100, USEPA, SW-846).

Analytical predictive model for contaminants transport with PVD installation is formulated. Preliminary parameter study indicated that the model is robust. Expanded parameter study is planned in the next phase of the research. In addition, consultation with researchers from Petroleum engineering regarding pumping and injection gradients and rates is planned in the near future.

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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1.0 INTRODUCTION

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/m³ 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 proposal.

The effectiveness of the soil flushing process is limited by the extent that 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.

The improvement of flushing solution movement in low permeability soils (10^{-4} to 10^{-7} cm/s) is the subject of this research proposal. Specifically, the use of Prefabricated Vertical Drains (PVD), also referred to as wick drains, to decrease the flow path and travel time between flushing solution injection and extraction points will be investigated. The development of improved flushing agents (e.g., surfactant) is not within the scope of this proposal. Rather, several flushing agents will be selected based on literature and manufacturers' information and their effectiveness in extracting contaminants from soils will be evaluated in the laboratory. The most effective extracting agent(s) will then be employed to demonstrate the feasibility of using PV drains to improve the soil flushing process.

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 PAHs will be used as the study contaminant. Naphthalene will be used as the study contaminants.

In summary, the proposed research has as its objective the completion of the following three phases of study:

Phase 1: Quantifying the parameters that govern the release and transport of PAHs by and through the subsurface.

Phase 2: Development of a predictive mathematical model to simulate full-scale operation of PV drain-enhanced soil flushing systems.

Phase 3: Operation of a mesoscale pilot facility to investigate the performance of the PV drain-enhanced soil flushing technique and to calibrate the predictive model.

Specific tasks for each phase of the research program are discussed in the Investigative Approach section of this proposal.

2.0 BACKGROUND

In this section 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 system, will be 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 will focus on liquid and mass transport in the subsurface. However, a brief discussion on PAHs contaminated sites, and the fate of PAHs in the subsurface (adsorption, desorption, biodegradation, and volatilization) is included.

2.1 Soil Flushing as a Remediation Technique

In soil washing/flushing water is 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),
- 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 1 (Holden et al. 1989). Conditions adversely affecting the success of 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, 1988.

2.2 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

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surcharge. The design of prefabricated vertical drains varies according to a specific application. Key parameters usually addressed in the design include:

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

As described by Anon (1988) PV drains 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 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 reach 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.

In summary, 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 3 schematically shows a possible arrangement for the use of PVD system for recovery of subsurface pollutants in the field.

2.3 Examples of PAHs Contaminated Sites

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 Gibbs 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). PAH concentrations of 2,800, 240, and 10 mg/kg for peat, soils, and sediments, respectively, have been reported at the Pine Street Canal Superfund site in Burlington, Vermont, (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. In examining contaminated sites, a wide variety of PAHs (and other organic contaminants) are present in widely ranging concentrations. Thus, remediation research must address diverse conditions. However, because the main focus of this research project is the improvement of the liquid movement phenomenon of the soil flushing process, relatively simple PAHs (e.g., naphthalene) will be chosen as the study organics. 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).

2.4 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 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 were 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 Fiotek (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. As mentioned previously, the focus of this research is not the development of improved surfactant but rather the improvement of the movement of the flushing solution through the contaminated zone. Thus, surfactant, such as those presented in Table 2, will be selected based on literature and manufacturers' information. Their effectiveness in extracting contaminants from soils will be determined in the laboratory and the most effective and environmentally safe agents(s) will then be employed in the demonstration of the PV drains enhanced soil flushing process.

2.5 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 conduct of the proposed research, steps will be taken to minimize degradation and volatilization.

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

2.5.2 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.

2.5.3 Volatilization

PAHs are classified as semivolatile and generally have a Henry's constant lower than 10^{-4} atm/m³ mol. Organic compounds having a Henry's constant greater than 3×10^{-3} atm/m³ 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 will be accounted for by using a controlled experiments environment.

3.0 METHODOLOGY

The proposed research plan is the first phase of five year plan during which the major parameters affecting the efficiency of contaminant extraction using PV drains will be quantified, pilot scale study is performed and the project can move to field implementation. The research program for the current phase consists of column and batch studies to determine appropriate environmental and engineering parameters for the soils, contaminants, and surfactant under consideration. These experiments will be conducted during year one along with several pilot scale systems (Contaminant Recovery Cells, CRC) in which the recovery efficiency (hydraulic only) of the PV drains will be evaluated for uncontaminated soils.

3.1 Laboratory Testing

During the first year of the project, laboratory studies will be conducted to ascertain fundamental parameters of the soils, contaminant and surfactant. In addition, fundamental parameters of the recovery system will be evaluated. Laboratory work was conducted to evaluate the proper mix of the soil to be used in the testing program. A single polycyclic aromatic hydrocarbon (PAH), in this case naphthalene ($C_{10}H_8$), is chosen as the study contaminant. Preliminary laboratory

work is conducted to evaluate the proper mix of the soil to be used in the testing program. Based on the results of compaction tests according to ASTM 698D and permeability tests according to ASTM D5084 a soil blend consisting of 80/20 percent by dry weight sand to kaolinite will be used. A grain size distribution for the study soil is shown in Figure 4.

On-going testing program includes performance of batch isotherms and flexible wall soil flushing permeability tests to estimate appropriate environmental and engineering parameters for the soils, contaminants, and surfactant under consideration. In addition, several pilot scale tests using Contaminant Recovery Cells (CRC) are underway. The recovery efficiency of the PVD system will be evaluated from these tests. Analysis to be conducted include naphthalene (by GC method 8100, USEPA, SW-846), and total organic carbon or chemical oxygen demand. Compaction tests according to ASTM 698D and permeability tests according to ASTM D5084 were conducted using blends of kaolinite and Ottawa sand to select the appropriate soil mix for use in the experiments.

3.1.1 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 study surfactant. Anionic aqueous solution of sodium dodecylsulfate (SDS) was chosen as the study surfactant. The empirical formula for SDS is as follows:

which has 12 carbon chains, one sulfate anion, and one sodium ion for each SDS molecule. The anionic surfactant is negatively charged which will assist in minimizing sorption to the negatively charged kaolinite particles.

Batch tests were conducted using surfactant concentrations of 0 to 0.5 M. The analysis was conducted using an HP Series II Gas Chromatograph (GC) with a capillary column and flame ionized detector. Solubilization as a function of naphthalene concentration as shown in Figure 5. As the SDS molarity increased the solubility of the naphthalene increased with a near linear 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.

A suite of tests will be performed resulting in a matrix consisting of surfactant type and concentration, and soil contact time versus percent of contaminant removed from the soil. This information will lead to the selection of a surfactant for application in the column studies and in the contaminant recovery cells. Soils will be contaminated with Naphthalene by dissolving Naphthalene in Methanol, mixing the solution with soil, and allowing Methanol to evaporate.

The initial soil/Naphthalene concentration will then be determined.

Equilibrium isotherms will be estimated for the adsorption of naphthalene on the study soil. Also, re-adsorption of naphthalene, in the presence of the SDS surfactant, by the clean soil will be assessed. The isotherms will provide the mass of Naphthalene adsorbed to the soil versus the concentration of the surfactant solution.

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.

3.1.2 Column Studies

A series of column studies were conducted on clean soil with water and with surfactant solution to evaluate the hydraulic properties of the study soil. Clean soil studies will be used to obtain permeability characteristics of the soil types both for water and for surfactant as permeating liquids. Similar tests are underway for contaminated soil. The studies on contaminated soil columns will be 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.

Sample preparation for the columns study was as follows:

1. Samples were prepared from a mixture of 80% ottawa sand and 20% kaolinite.
2. Sieve analyses were conducted as a baseline to check the final integrity of the soil upon completion of a test.
3. Samples were compacted using standard proctor according to ASTM 698D. The samples were prepared at water content range of 6% to 11% to achieve a permeability on the order of 1×10^{-5} cm/sec.
4. Flow tests are conducted to a duration necessary to provide discharge of minimum of 5-7 pore volumes of permeant fluid.

Figure 6 (a and b) shows the variation of permeability as a function of effluent pore volume. 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 relationship between compaction density and water content for the study soil is shown in Figure 7. Maximum density of approximately 125 pcf was achieved at a moisture content of 9.5%. The variation of the permeability as measured from the flexible wall test, as a function of the molding water content is shown in Figure 8. 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 soil decreased from 3×10^{-4} for water content of 7% to approximately 2×10^{-5} 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	Moldin g w(%)	i	σ_3 (psi)	γ_{dry} (pcf)	e	n	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, σ_3 = confining pressure, e = void ratio, n = porosity, and S = degree of saturation

Figure 9 shows the effect of surfactant on the permeability characteristics. In this case, permeability tests were performed using water as a permeant and then SDS solution with concentrations between 0.0022 and 0.008 Mol. The introduction of the SDS solution resulted in reduction of the permeability value. As shown in Figure 9, this reduction was on the order of two orders of magnitude 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 10. 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.

More investigation and tests are underway to ascertain the effect of the SDS on the hydraulic behavior of the study soil. Planned tests include:

- i. Sectional grain size distribution on the soil samples to investigate potential migration of clay particles
- ii. Sequential permeation with SDS solution and water to investigate whether this reduction in hydraulic conductivity is irreversible

Naphthalene breakthrough curves using SDS solutions with variable concentrations are currently underway.

3.1.3 Procedure for Soil Extraction

The extractor procedure outlined below is based on EPA Method 3540 Soxhlet Extraction. Due to financial considerations and the scope of this project, minor alterations have been made to accommodate the University laboratory.

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.

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.

3.1.4 Contaminant Recovery Cells

Three 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. Two systems of fluid recovery will be evaluated. These include applying a vacuum to the drains and applying a stress on the surface of the soil. Both systems provide a driving force for fluid transport from the soil.

A list of the CRC's and associated test parameters is given in Table 3. Drain efficiencies for the removal

of fluids from the soils will be quantified. The time required for construction and preparation of the cells including saturation of the soils is expected to be on the order of two to three months.

Table 4. Contaminant Recovery Cells and Operating Parameters

CELL No.	% SAND/ KAOLINITE	No. DRAINS	CONTAMINANT RECOVERY	
			VACUUM (psi) 10	APPLIED PRESSURE (psi) 2 - 10
1	80/20	1	It is estimated that each recovery step will require 2-3 months	
2	80/20	2		
3	80/20	MULTIP		

The three CRC are constructed and are in operation. Figure 11 shows a picture of one of the cell. Integrity testing was conducted to confirm that the cells are leak-proof. Bentofix (clay/geotextile mating) was used as lining material to minimize side wall leakage. Soil samples were compacted in the CRC's and dye was introduced to trace the flow path. No side wall leakage was observed. Saturation of the soil samples in the CRC's took approximately six weeks to complete.

Figure 12 shows the distribution of the in-place density measured using the sand cone test. The uniformity of density distribution increased as 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 12, 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 are indicated on Figure 8. The permeability values measured from the CRC's show an excellent agreement with the values evaluated from the flexible wall column. Permeability values measured from the CRC's are on the order off 5×10^{-5} cm/sec.

4.0 Liquid Retrieval Using PVD: Model Development

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. As shown in Figure 13, 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:

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

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:

$$V_r = -K \frac{d\phi}{dr} = K \frac{ds}{dr} \quad (2)$$

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:

$$s = \frac{Q_0}{2\pi KH} \ln\left(\frac{r}{D}\right) \quad (3)$$

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.3 into Eq.2, the following equation can be obtained:

$$v_r = \frac{Q_0}{2\pi Hr} \quad (4)$$

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

$$D_r = \alpha_r v_r = \frac{\alpha_r Q_0}{2\pi Hr} \quad (5)$$

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

$$D_z = \alpha_z v_z \dots \dots \dots (6)$$

where α_z = vertical dispersivity. Substituting Eqs. 4, 5 and 6 into Eq. 1, the following model equation for axisymmetric contaminant transport can be obtained:

$$\frac{\partial C}{\partial t} = \frac{Q_0 \alpha_r}{2\pi H r} \frac{\partial^2 C}{\partial r^2} + \alpha_z v_z \frac{\partial^2 C}{\partial z^2} - \frac{Q_0}{2\pi n H r} \frac{\partial C}{\partial r} - \frac{v_z}{n} \frac{\partial C}{\partial z} - \frac{1}{n} \frac{\partial(\rho_b K_d C)}{\partial t} \dots \dots \dots (7)$$

Analytical solution of above 2-order and 4-variable partial differential equation is presented as followed. Based on Carribo's solution (1952) for a similar model, C can be expressed as:

$$C(z, r, t) = C_z(z, t) \cdot C_r(r, t) = C_z \cdot C_r \dots \dots \dots (8)$$

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

$$\frac{\partial C}{\partial t} = C_z(z, t) \frac{\partial C_r(r, t)}{\partial t} + C_r(r, t) \frac{\partial C_z(z, t)}{\partial t} = C_z \frac{\partial C_r}{\partial t} + C_r \frac{\partial C_z}{\partial t} \dots \dots \dots (9)$$

$$\frac{\partial^2 C}{\partial r^2} = C_z \frac{\partial^2 C_r}{\partial r^2} \dots \dots \dots (10)$$

$$\frac{\partial^2 C}{\partial z^2} = C_r \frac{\partial^2 C_z}{\partial z^2} \dots \dots \dots (11)$$

$$\frac{\partial C}{\partial r} = C_z \frac{\partial C_r}{\partial r} \dots \dots \dots (12)$$

$$\frac{\partial C}{\partial z} = C_r \frac{\partial C_z}{\partial z} \dots \dots \dots (13)$$

Substituting Equations 9 through 13 into Eq. 7, the following general equation can be obtained:

$$(1 + \frac{\rho_b K_d}{n})(C_r \frac{\partial C_z}{\partial t} + C_z \frac{\partial C_r}{\partial t}) = \frac{Q_0 \alpha_r}{2\pi H r} C_z \frac{\partial^2 C_r}{\partial r^2} + \alpha_z v_z C_r \frac{\partial^2 C_z}{\partial z^2} - \frac{Q_0 C_z}{2\pi n H r} \frac{\partial C_r}{\partial r} - \frac{v_z}{n} C_r \frac{\partial C_z}{\partial z} \dots \dots \dots (14)$$

$$C_r (\frac{\partial C_z}{\partial t} - \frac{\alpha_z v_z n}{n + \rho_b K_d} \frac{\partial^2 C_z}{\partial z^2} + \frac{v_z}{n + \rho_b K_d} \frac{\partial C_z}{\partial z}) = C_z (\frac{-\partial C_r}{\partial t} + \frac{Q_0 \alpha_r n}{(n + \rho_b K_d) 2\pi H r} \frac{\partial^2 C_r}{\partial r^2} - \frac{Q_0}{(n + \rho_b K_d) 2\pi H r} \frac{\partial C_r}{\partial r}) \dots \dots \dots (15)$$

Equation (15) can be separated to two equations representing vertical and radial conditions as follows::

$$\frac{\partial C_z}{\partial t} = \frac{\alpha_z v_z n}{n + \rho_b K_d} \frac{\partial^2 C_z}{\partial z^2} - \frac{v_z}{n + \rho_b K_d} \frac{\partial C_z}{\partial z} \dots \dots \dots (16)$$

with initial and boundary conditions:

$$\begin{aligned} C_z(z,0) &= C_{z0}, & z \geq 0 \\ C_z(0,t) &= 0, & t > 0 \\ C_z(\infty,t) &= 0, & t > 0 \end{aligned} \dots \dots \dots (17)$$

and

$$\frac{\partial C_r}{\partial t} = \frac{\alpha_r Q_0 n}{(n + \rho_b K_d) 2\pi H r} \frac{1}{r} \frac{\partial^2 C_r}{\partial r^2} - \frac{Q_0}{(n + \rho_b K_d) 2\pi H r} \frac{1}{r} \frac{\partial C_r}{\partial r} \dots \dots \dots (18)$$

with initial and boundary conditions:

$$\begin{aligned}
C_r(r,0) &= C_{r0}, & r \geq r_0 \\
C_r(r_0,t) &= 0, & t > 0 \\
C_r(\infty,t) &= 0, & t > 0
\end{aligned} \dots\dots\dots (19)$$

Using Laplace Transform and Laplace Inverse Transform (Marino, 1974a), Eq.18 can be solved utilizing initial and boundary conditions:

$$C_z(z,t) = \frac{C_{z0}}{2} \left[\operatorname{erfc} \left(\frac{z - \frac{v_z t}{n + \rho_b K_d}}{2 \sqrt{\frac{\alpha_z v_z n t}{n + \rho_b K_d}}} \right) + \operatorname{erfc} \left(\frac{z + \frac{v_z t}{n + \rho_b K_d}}{2 \sqrt{\frac{\alpha_z v_z n t}{n + \rho_b K_d}}} \right) \right] \dots\dots\dots (20)$$

where

$$\operatorname{erfc}(x) = \frac{2}{\sqrt{\pi}} \int_0^x e^{-\xi^2} d\xi \dots\dots\dots (21)$$

Using Laplace Transform and Laplace Inverse Transformation as described by Marino (1974a) and utilizing initial and boundary conditions, Eq.18 can be solved as follows:

$$C_r(r,t) = C_{r0} [1 - \operatorname{erfc}(h)] \dots\dots\dots (22)$$

where:

$$h = \frac{\frac{Q_0 t}{(n + \rho_b K_d) 2 \pi H}}{\sqrt{\frac{4}{3} \alpha_r n (r - r_0)^3}} \dots\dots\dots (23)$$

Substituting Eq.20 and Eq.22 into Eq.8:

$$\begin{aligned}
C(z,r,t) &= C_z \cdot C_r = \frac{C_0}{2} \left[\operatorname{erfc} \left(\frac{z - \frac{v_z t}{n + \rho_b K_d}}{2 \sqrt{\frac{\alpha_z v_z n t}{n + \rho_b K_d}}} \right) + \operatorname{erfc} \left(\frac{z + \frac{v_z t}{n + \rho_b K_d}}{2 \sqrt{\frac{\alpha_z v_z n t}{n + \rho_b K_d}}} \right) \right] C_0 [1 - \operatorname{erfc}(h)] \dots\dots\dots \\
&\dots\dots\dots (24)
\end{aligned}$$

where $C_0 = C_{r0}C_{z0}$; h and function erf are expressed by Eqs.23 and 21. A preliminary example is given to check the robustness of the solution. The example problem is set-up such that the relative contaminant concentration as a function of time is predicted for different radial distances from the injection well and as function of depth. The model configuration is shown in Figure 15. The parameters assumed in this analysis are as follows:

n	0.25
K_d	$1 \times 10^{-3} \text{ m}^3/\text{kg}$
ρ_b	2000 kg/m^3
H	10 m
α_r	5 m
α_z	1 m
v_z	0.5 m/h
Q_0	$50 \text{ m}^3/\text{h}$
C_0	200 mg/kg

This example is not representative of a particular field or laboratory conditions but is rather used to illustrate the model application. It is realized that a Q_0 of $50 \text{ m}^3/\text{h}$ is rather high value. This example will be revised in future report. The predictions utilizing the above model is shown in Figure 15. 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 movement of the subsurface liquid for retrieval can be induced using applied surface surcharge or injection and vacuum system. The theoretical model to estimate the maximum discharge ($q_{\max}$) to be recovered from the PVD in clay under surface surcharge is as follows:

$$q_{\max} = \pi r_{eq}^2 \frac{dU}{de} L \epsilon \quad (26)$$

$$U = 1 - \exp^{-\frac{2T_R}{f(n)}} \quad (27)$$

$$F(n) = \frac{n^2}{(n^2 - 1)} \ln(n) - \frac{3n^2 - 1}{4n^2} \quad (28)$$

where:

U = average degree of consolidation

ϵ = strain due to consolidation

Cr = coefficient of radial consolidation

$n = r_{eq}/r_{st}$

Modeling of the vacuum system can be achieved using the theory of wells. This effort is currently underway and is a part of the ongoing effort on model development.

5.0 CONCLUSIONS

In summary, the proposed 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. More laboratory tests are planned to estimate the physical and engineering properties of the test soil including Atterberg Limits, grain size distribution and compressibility characteristics. In parallel, columns and the recovery cells are being performed to characterize the mobility of the study contaminant and analyze the contaminant-soil interaction.

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.

More investigation and tests are underway to ascertain the effect of the SDS on the hydraulic behavior of the study soil. Planned tests include:

- i. Sectional grain size distribution on the soil samples to investigate potential migration of clay particles.
- ii. Sequential permeation with SDS solution and water to investigate whether this reduction in hydraulic conductivity is irreversible.

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 discussion is underway regarding their involvement 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.

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.

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FIGURES

30

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

Figure 1. Schematic of Conventional Soil Flushing Process

Figure 2. Field Installation Scheme of PVD System

Figure 3. Proposed Field Installation Scheme for Contaminant Recovery

Figure 4. Grain Size Distribution of the Study Soil

Figure 5. Soluability of Naphthalene Using SDS Surfactant Solution

PERMEABILITY vs PORE VOLUMES for w=6-9%

PERMEABILITY vs PORE VOLUMES for w=9-11%

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

Figure 7. Dry Unit Weight vs Molding Moisture Content

Figure 8. Variation of Peremability as a Function of Molding Water Content (w)

Figure 9. Effect of SDS Surfactant on Measured Permeability

Figure 10. Structure of Kaolinite Clay Used in this Study

Figure 11. Photograph of the Contaminant Recovery Cell (CRC)

PLAN

CRC #1

PROFILE

PLAN

CRC #2

PROFILE

41 PLAN

CRC #3

PROFILE

PLAN

CRC #4

PROFILE

Figure 12. Measured In-Place Densities from Sand Cone Tests

Figure 13. Modeling Configuration for the PVD

Figure 14. Well pattern and modeling configuration

Figure 9. Relative Contaminant Concentration as a Function of Time for Different Radial Distances from the Injection PVD

**Site Remediation Technologies:
In Situ Bioremediation of Organic Contaminants
(Project MC-2B)**

**Quarterly Technical Progress Report
for Period July 1 through September 30, 1993**

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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 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.

Three sets of anaerobic microcosm studies were completed in this quarter to evaluate the reductive dehalogenation (RD) of trichloroethylene. Two different initial TCE concentrations were used at incubation times of from 3 to 30 days. While some of the methods used are being refined, it was found that RD did occur with the formation of expected daughter products (dichloroethylenes and vinyl chloride) and with the generation of methane. Additional microcosms studies were begun but had to be aborted when it was found that the gas chromatographs in both Biochemistry and Environmental Engineering were not operating properly.

Preliminary design of the sand/soil columns was carried out. The preliminary plans are presented in this report along with a sketch. It is planned to construct and operate these columns in the next quarter. Two site visits were made to laboratories with significant experience in growing anaerobic cultures to observe techniques useful to our work.

Considerable difficulty was experienced in operation of the gas chromatographs in both laboratories for measurement of TCE which greatly reduced that rate of data generation. We are working very hard to solve this problem as noted in the report and expect that we will have at least one of the units operational by the end of October.

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1.0 INTRODUCTION

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

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

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

2.0 PURPOSE

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

3.0 BACKGROUND

A number of exciting developments are occurring in the field of environmental biotechnology (engineering applications of microbial ecology). For example, while trace concentrations of some organic contaminants cannot support microbial growth as the sole electron donor, they can still be biotransformed by engineering the system so that the microbial population obtains the majority of its energy and carbon from a different compound that serves as the primary substrate. This is sometimes referred to as *secondary utilization*. There are also many organic contaminants that are biotransformed in the environment for which no microorganisms have been found which are

able to use them as sole carbon source. This is a special case of secondary metabolism often termed *cometabolism*. Cometabolism has been defined (Dalton, 1982) as the "transformation of a non-growth substrate in the obligate presence of a growth substrate or another transformable compound". As an example, halogenated methanes, ethanes, and ethylenes are poor growth substrates for bacterial growth but may be degraded by methanotrophs growing aerobically on methane (Henson et al., 1988).

4.0 METHODOLOGY

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

Phase 1: Literature Review.

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

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

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

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

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

The methanotrophs have an obligate requirement for methane, which is complimented by the methane production of methanogenic organisms. Furthermore, the methanogens ability to dehalogenate more oxidized (more halogenated) pollutants, generating vinyl chloride, is complimented 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.

The third quarterly report included a description of our initial efforts in the initiation and maintenance of a mixed culture of methanogenic bacteria. The previous report also included a mention of our efforts in regard to developing protocols for the analysis of TCE. This analysis was to be done using gas chromatography (GC) with either flame ionization, electron capture, or electrolytic conductivity detectors. It was proposed that these protocols would be developed during the past quarter and measurements of the rate of TCE degradation by both aerobic and anaerobic cultures would be initiated. However, problems with both GC instruments (at the Engineering School and the Medical School) have delayed our progress toward measuring TCE degradation rates. This is discussed below.

5.0 RESULTS AND DISCUSSION

In order to accomplish project objectives in a timely manner, the research is being conducted in two complimentary 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 (environmental engineering) is 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.

5.1 Measurement of Volatile Organics Using Gas Chromatography

The goal of this project is to optimize the rate at which both methanotrophs and methanogens degrade TCE into innocuous byproducts. To do this, quantitative analysis of TCE and its daughter products is essential, but has recently been our major impediment. We are currently in possession of two GC instruments, one in the Biochemistry laboratory and one in the Environmental Engineering laboratory. The Biochemistry GC is a portable SRI unit with a single detector that can be converted between flame ionization (FID) and electrolytic conductivity (ELCD) detection modes. Attempts with TCE standards using the FID have proven futile for concentrations below 50,000 ppb. Since other users require the FID, we are switching to the electrolytic conductivity mode once a week.

The ELCD is specific for the detection of halogenated molecules such as TCE and, in addition, is not sensitive to the presence of water. Thus, this type of detector seems ideal for our application. Sensitivity of at least 250 ppb with high linearity of standard curves have been obtained on this instrument. However, this level of precision and sensitivity has not been reproducible each time the detector has been converted from the FID to the ELCD mode. Inspections, alterations, trial runs and phone conversations with the manufacturer have pinpointed the problem to the conductivity cell. It appears that this part of the detector is quite sensitive and vulnerable to variations each time the detector conversion is performed. Although the manufacturer insists that the detector's performance should be reproducible, we have not yet been able to achieve reproducible sensitivity. The sensitivity from week to week varies by as much as a factor of 6-10. It appears that the only option for this GC is to return it to the manufacturer for installation of a permanent ELCD detector. In the meantime, we have optimized the instrumental conditions for TCE detection and have determined the range of retention time, standard curve linearity, and minimum detection limits for this instrument. We are also exploring the use of hexane extraction of the TCE from our samples in order to concentrate the sample and lower the detection limit.

The Environmental Engineering GC is a Hewlett-Packard model equipped with an electron capture detector (ECD) and is used with a purge and trap. Attempts to obtain a flat baseline have not been successful by representatives of Hewlett-Packard, or members of our research group. A new purge and trap has been purchased from Tekmar and is currently being tested with the GC. In the meantime, we are reviewing information from other GC manufacturers regarding the potential incompatibility between a purge and trap and an ECD. In particular, we have been informed that the ECD is especially sensitive to water vapor which may reach the detector. However, since the new purge and trap contains a moisture trap, and Hewlett-Packard assures us there should be no compatibility problem, we are hopeful that this GC unit will be on line by late October. Should

the problems continue, the feasibility of having the ECD replaced with an ELCD will be investigated.

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

A great deal of time was spent this quarter setting up the SRI GC and calibrating for analysis. Unfortunately, as noted above, the instrument is still not suitable for use and hence no actual runs for aerobic TCE biotransformation could be carried out. *Methylococcus capsulatus* cultures are being grown and harvested continuously for further research work. The cells are transferred from culture plates by loop into sealed flasks containing a nitrate mineral salt media (NMS). Air is exchanged for methane at twenty percent by volume, and the flasks are maintained on a shaker inside a water bath at 42 degrees C with an air-methane exchange every 24 hours. After approximately 72 hours, the cultures are transferred into larger sealed flasks with additional media to produce further organisms. The cells are subsequently harvested by centrifugation and stored in Pipes buffer.

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

5.3.1 Maintenance Reactor Operation

As discussed in the last progress report, a 15 liter maintenance reactor was set-up and operates as an inoculum source for the anaerobic studies. The reactor continues to be fed and maintained in the manner previously described. Monitoring of gas production data reveals a healthy anaerobic microorganism population. Table 1 presents typical gas production data collected during the last quarter.

Table 1. Typical Gas Production Data

DATE	GAS PRODUCTION (ml/hr)
7/12/93	2076
7/13/93*	1088
7/14/93**	Minimal
7/21/93	1333
7/27/93**	Minimal
7/30/93	800
8/3/93	963
8/4/93*	Minimal
8/9/93	1056
8/23/93	1114
8/24/93*	Minimal
9/16/93	467
9/24/93	625
9/27/93	554
10/4/93	500

* Day following feeding

** Gas production checked prior to feeding

While gas production varies significantly depending on how long after feeding the rate of production was measured, the data generally shows an increase in the rate of gas production over that reported earlier. The culture rapidly utilizes the provided substrates (Ensure, methanol, and acetate) rapidly after feeding, and as expected the gas production rate falls off once the substrates have been consumed.

Initially, the maintenance reactor gas composition was monitored by a combustible gas indicator (MSA GASCOPE Model 60) equipped with a thermal conductivity detector and results indicated substantial methane production. Currently a GOW-MAC 550 series gas chromatograph equipped with a thermal conductivity detector is being used for gas composition analysis. Once a week a 10 ml gastight pressure-lock syringe is used to withdraw gas samples from the maintenance reactor headspace and the samples are analyzed by gas chromatography. Table 2 displays typical maintenance reactor gas composition data collected using the GOW-MAC.

Table 2. Gas Composition Data

DATE	% CO ₂	% O ₂	%N ₂	%CH ₄
9/7/93 Sample #1	36.0	1.7	12.7	47.7
9/7/93 Sample #2	36.9	1.2	11.0	49.4
9/15/93 Sample #1	34.8	1.4	12.4	47.6
9/15/93 Sample #2	36.6	0.7	9.9	49.1
9/22/93	39.5	1.1	13.3	44.8
9/29/93	36.6	1.6	15.8	44.8
10/6/93	39.6	0.5	9.6	46.4
10/14/93	39.1	0.4	9.2	50.0

The data suggest that the gas composition remains relatively consistent over time. A comparison was made between gas analysis performed previously with the combustible gas indicator (GASCOPE Model 60) and the current gas chromatograph (GOW-MAC Series 550). On 9/7/93 the combustible gas indicator was also used to analyze the maintenance reactor headspace gas and it was found to contain approximately 48% methane, which is in good agreement with the gas chromatography analysis.

The maintenance reactor displays good general system health and an adequate level of methanogenic activity. Maintenance reactor operation and analysis will continue to be performed in the present manner since no difficulties have been noted or experienced.

5.3.2 Evaluation of Reductive Dehalogenation in Liquid Microcosms

Preliminary microcosm studies were set-up and performed during this quarter in an attempt to evaluate reductive dehalogenation. As described in section 5.4.2 of last progress report, 160 ml serum bottles were used as microcosms. The first anaerobic microcosm study was initiated on 8/13/93. Samples and controls were prepared in triplicate and contained the following;

Inoculated Samples: 96 ml Maintenance Reactor Liquid
4 ml Basal Medium
50 mg/l Methanol(50ul of stock solution)
50 mg/l Acetate(50ul of stock solution)
0.75 mg/l TCE(100 ul of stock solution)

Control Samples: 100 ml D.I. Water
0.75 mg/l TCE(100 ul of stock solution)

Stock solutions of methanol (100,000 ppm), acetate (100,000 ppm), and TCE (750 ppm) were prepared with nitrogen purged organic free water. Serum bottles used in the first microcosm study were sealed with blue butyl rubber stoppers. Microcosm bottles were labeled, S1A, S1B, S1C (Samples, Set #1, Bottle A, B, & C), C1A, C1B, C1C (Controls, Set #1, Bottle A, B, & C) and stored in the dark at 25° C, under quiescent conditions, with the liquid in contact with the septa. The samples were incubated for 30 days.

A second set of microcosms were set-up on 9/8/93 and were identical to the first except that aluminum crimp caps with teflon lined gray butyl rubber septa were used to seal the serum bottles. This type of closure is felt to be superior to the butyl rubber stoppers used in Set 1 and will be utilized in all subsequent work. The second set of microcosms were labeled, S2A, S2B, S2C (Sample, Set #2, Bottle A, B, & C), C2A, C2B, C2C (Control, Set #2, Bottle A, B, & C) and stored in the same manner as the first test bottles. The Set 2 bottles were incubated for only 5 days.

Due to problems associated with our gas chromatography system (as note earlier), the first and second set of microcosm bottles were analyzed at Miles Inc. in New Martinsville, WV on 9/13/93. Microcosm bottles were transported at ambient temperatures in a closed box to avoid excessive loss of volatiles and contact with sunlight. Once at Miles, Inc. auto-sampling vials (40 ml amber vials with teflon-lined septa screw cap) were prepared. Inoculated samples were allowed to settle and no dilution was made as microcosm liquid was decanted into auto-sampling vials, and control samples were diluted 1:5 with organic-free D.I. water. Ten of the twelve

microcosms were analyzed by a HP 5890 GC-MS with an OI Corp. purge and trap concentrator. Two of the microcosms were not analyzed for VOCs, but instead were analyzed for composition of methane in the headspace. Table 3 summarizes the results of the first two microcosm studies.

Table 3. Results of Microcosms Studies Sets 1 & 2

Sample ^a	TCE (ppb)	Cis-DCE ^c (ppb)	Trans-DCE ^c (ppb)	VC ^c (ppb)	%CH ₄ ^d
S1A	93.9	2.6	0.7	ND	
S1B	86.9	3.0	0.8	ND	
S1C ^b	-	-	-	-	19.3
C1A	108.2	ND	ND	ND	
C1B	114.1	ND	ND	ND	
C1C	112.8	ND	ND	ND	
S2A	92.0	0.4	ND	0.4	
S2B	136.5	0.6	ND	ND	
S2C ^b	-	-	-	-	7.5
C2A	110.5	ND	ND	ND	
C2B	126.6	ND	ND	ND	
C2C	112.9	ND	ND	ND	

a - Sample label designation, i.e.

S1A (Sample, Set #1, Bottle A)

C2B (Control, Set #2 Bottle B)

Note: Set 1 and 2 samples were incubated respectively for
30 and 5 days.

b - Sample analyzed for %CH₄

c - Concentrations reported are at or below detection limit for analysis, however compound was detected by GC-MS analysis

d - Percent methane found in microcosm headspace

ND - Compound not detected in microcosm

From the results of the first two microcosm studies a number of observations can be made. First, it should be noted that there was apparently some loss of the highly volatile TCE. There was also a problem with respect completely solubilizing the TCE in the aqueous sample as will be discussed below. It was intended to prepare an aqueous stock solution of TCE at a concentration

of 750 ppm (750,000 ppb) not including that which partitions to the headspace. In order to estimate the amount of TCE in the headspace, a dimensionless Henry's constant of 0.458 (Long et al., 1993; Ashworth, et al. 1988; and McKay and Shiu, 1981) was used which gave the expected liquid concentration of TCE to be 514,000 ppb. Analysis of the stock solution revealed a liquid concentration of approximately 426,000 ppb which was lower than expected liquid concentration. The difference may be attributed to volatile losses, or solubility problems. It was noted at a later date when preparing a stock TCE solution that all the chemical was not dissolved in the water and it is possible that this also occurred for Sets 1 and 2. Considerable attention is now being given to insuring that all TCE is dissolved into the aqueous phase.

While lower than expected concentrations of TCE were found in the control samples, the results shown in the above table indicate some contaminant biotransformation. Microcosm set 1, analyzed 30 days after preparation, revealed not only reductions in TCE from controls to samples, but that degradation products (cis and trans DCE) were also formed. Microcosm set 2, analyzed only 5 days after preparation, showed little, if any, decrease in TCE concentration from control to sample, but again daughter products appear in the inoculated samples and not in the controls. Both set of test revealed methane production in the samples analyzed, and this would indicate that the methanogenic culture was able to utilize the substrates provided during the time of study.

A third microcosm study was set up on 9/15/93. Microcosm bottles were prepared in a similar fashion as the previous tests, however more caution was taken in preparing stock solutions and final TCE microcosm concentration were intended to be approximately 6000 ppb. Samples and controls were prepared in duplicate and contained the following;

Inoculated Samples: 96 ml Maintenance Reactor Liquid
4 ml Basal Medium
50 mg/l Methanol(50ul of stock solution)
50 mg/l Acetate(50ul of stock solution)
6 mg/l TCE(3 ml of stock solution)

Control Samples: 97 ml D.I. Water
6 mg/l TCE(3 ml of stock solution)

Stock solutions of methanol (100,000 ppm), acetate (100,000 ppm), and TCE (200 ppm) were prepared with nitrogen purged organic free water. The higher contaminant concentration was selected in an attempt to perform VOC analysis at Dr. Shiemke's (biochemistry) lab with a SRI Gas Chromatograph (GC) with an ELCD detector. At the time of this test, the GC in biochemistry (which does not have a purge and trap) was performing satisfactory at TCE concentrations for 1 to 10 ppm (1000 to 10,000 ppb). The prepared microcosms were labeled, S3A, S3B (Sample, Set #3, Bottle A & B), C3A, C3B (Control, Set #3, Bottle A & B) and store as previously described. Table 4 displays the results of the third microcosm study, which were obtained from GC analysis on 9/18/93 after 3 days of biodegradation.

Table 4. Results of Microcosm Study Set 3^b

Sample	TCE (ppb)	% CH ₄ ^a
S3A	< 1000	8.1
S3B	< 1000	7.5
C3A	3425	-
C3B	3072	-

a - Methane analysis performed after VOC analysis on 9/22/93

b - Set 3 samples were incubated for 3 days

Results from the third microcosm study reveal significant reductions of TCE from samples when compared to controls. TCE concentrations in controls are only slightly lower (16 %) than the expected liquid concentration calculated (4115 ppb, using a dimensionless Henry's constant of 0.458) and this may be attributed to volatile losses. Set 3 sample bottles A and B also revealed 8.1 and 7.5 percent methane in the headspace respectively. These results indicate that the methanogenic culture was again able to utilize the provided substrates during the time of study.

A fourth microcosm study was initiated which was identical to the third and was to serve as a check, but due to difficulties experienced with the GC's in both the environmental and biochemistry laboratories, as discussed elsewhere, the microcosms could not be evaluated.

Comparing the first and second microcosm sets to the third, it may be noted that the TCE was reduced by around 20 ppb in the first and second set bottles, while reduction of several thousand ppm was experienced in the third set bottles yielding very different kinetic rates. Further experiments need to be carried out to see if the results obtained are reproducible. The rate of removal would be expected to be higher in Set 3 since the TCE concentration was over 30 times higher than in Sets 1 and 2. There were probably also differences in biomass concentration of the initial inoculum. In subsequent experiments, initial biomass concentration will be measured. The methane composition results compare well between the individual studies. The highest percent methane (19.3%) was found to exist in the Set 1 sample (S1C), which had been undergoing methanogenic activity the longest time period (30 days) before analysis. Test samples from microcosm Set 2 (S2C) and 3 (S3A & S3B) were analyzed within similar time periods (3 to 5 days) and showed comparable results (7.5-8.1 %) for methane composition.

Microcosm studies which have been performed to date have identified various problems and concerns that must be dealt with while evaluating reductive dehalogenation. These include; solubility, volatility, partitioning, and transformation rates. However, preliminary microcosm results do suggest that reductive dehalogenation is occurring. Observations of daughter product formation and methane production are encouraging signs found during the preliminary

evaluation of reductive dehalogenation. Future experiments are planned as discussed in the following sections.

5.4 Other Project Activities

5.4.1 Anaerobic Laboratory Site Visits Two site visits were made during the quarter to laboratories experienced in anaerobic microbiological techniques. The visits were made to help us in choosing the most appropriate anaerobic protocols for our work. The Virginia Polytechnical Institute's Anaerobic Laboratory in Blacksburg, Va. was selected as the first facility to visit and the University of Cincinnati in Ohio was the second. Both of the facilities have contributed greatly to anaerobic research and the one day meetings will undoubtedly benefit the work being performed on the current bioremediation project. The following is a brief summary/ discussion of the trips.

VPI Anaerobic Laboratory

Date of Meeting - July 19, 1993

Person Contacted - Chris Peer

Objective of Meeting - Discuss general anaerobic procedures and observe media preparation, reduction and transfer.

Specific Issues Addressed - Regarding media preparation, it was noted that the indicator, resazurin, will turn from a violet color to a pink color during boiling of the solution while purging with an oxygen-free gas, but will not necessarily turn colorless until the reducing agent, i.e. cystine, sodium sulfide, is added in the appropriate amount.

It was suggested to avoid placing unreduced media into the Coy Chamber (anaerobic glovebox) because of excessive use of the platinum catalyst.

Concerns were expressed regarding the use of the teflon lined gray butyl septa with pure methanogens or other strict anaerobes. The teflon seal creates a path for oxygen contamination into the microcosm bottle. The best material to use is a black butyl rubber stopper (color is actually blue). However, the black butyl stopper does not come teflon lined and there has been concerns expressed in the literature regarding loss of very volatile compounds, i.e. PCE, TCE, VC, etc... .

In order to remove the aluminum crimp caps from the serum bottles a set of pliers was demonstrated. The caps can also be removed by hand by tearing out center disc with finger nail and pulling top while twisting bottle.

In an attempt to conserve on gas usage in the Coy Chamber gassing port, an empty bottle of appropriate size can be cleaned, sealed and placed in the port in order to take up volume and avoid excessive gas use.

It was suggested that the Coy Chamber oxygen sensing meter be recalibrated at time of installation to register approximately 3 ppm at the zero oxygen level as a extra precautionary step to maintain anaerobic conditions.

During anaerobic transfers of media, do not be too concerned with a little pink color appearing. If bottle is autoclaved or allowed to sit for a period of time the pink color should disappear and anaerobic conditions should be maintained.

In an attempt to avoid contamination of the microcosm from outside microorganisms, an ethanol lamp is used to sterilize the septa prior to penetration with syringe.

University of Cincinnati

Date of Meeting - July 23, 1993

Persons Contacted - Munish Gupta and Jiayung Cheng

Objective of Meeting - Mr. Gupta discussed general anaerobic procedures and reviewed methanogenic experiments performed in chemostats, and Mr. Cheng discussed the set-up and operation of an anaerobic respirometer.

Specific Issues Addressed -

It was noted that dilution water used during anaerobic studies should be autoclaved and purged with an oxygen-free gas prior to use. For example, during analysis of degradation products the sample from the microcosm, if diluted prior to injection into the GC.

If an abundance of sulfide is present in the inoculum, then reduced conditions should be relatively easy to maintain, however too much sulfide can be inhibitory.

It was suggested that it can be expected that for every gram COD, there would be approximately 350 ml of gas production.

Sampling of gasses was performed by placing a sampling port (in-line fitting with rubber septa) in the gas exhaust line from the chemostat to the gas measuring device.

Temperature of chemostats and microcosm studies - 35° C

pH - ~7.3

Additional issues addressed were recorded on video tape, with emphasis on the anaerobic respirometer.

5.4.2 Addition of an Additional Co-Principal Investigator Echol Cook will join Bill Sack and Drew Shiemke as a co-principal investigator on the project as of October 1, 1993. Dr. Cook is the holder of a newly established Berry Chair in the College of Engineering. He is an environmental engineer with over 25 years of experience and has published over 50 journal

articles and proceedings papers. He has worked extensively in the biotreatment area with fixed film reactors as well as with contaminated soils.

5.5 Research Planned for Next Quarter

5.5.1 Optimization of Aerobic TCE Degradation Rates Degradation of TCE by methanotrophs is initiated by the methane monooxygenase (MMO) enzyme (Little et al., 1988). The rate-limiting step in the biotransformation of TCE by methanotrophs appears to be the oxidative reaction catalyzed by this monooxygenase. MMO has an obligate requirement for oxygen and energy, in the form of reducing equivalents. In the subsurface it is likely that oxygen and methane will be rapidly depleted, and introduction of these substrates will be a difficult engineering problem, due to their low mobility. However, substances such as methanol and formate can provide energy to the organism for TCE oxidation (Henry and Grbic-Galic, 1991), and are likely to have significantly greater mobility in the subsurface than methane. Likewise, hydrogen peroxide can be converted to oxygen in the subsurface, and is also likely to have greater mobility than O₂. We have found that methanotrophs can withstand concentrations of peroxide >2000 ppm, with only slight retardation of growth, as described in the third quarterly report.

Methylococcus capsulatus cultures and culture media are ready for TCE degradation rate determination tests. 25 ml *M. capsulatus* culture and 25 ml nitrate mineral salt media (NMS), phosphate buffer and vitamin solution will be added to 125 ml amber teflon-lined silica septa bottles. Amber bottles will be used to prevent the photo-degradation of TCE. Teflon-lined silica septa will be used to allow removal of sample aliquots with minimal release of the volatile constituents. TCE will be added to each bottle by syringe to reach the desired final concentration of 5000 ppb. Methane will be added to the head space of each bottle at 20% (volume to volume ratio) by syringe. The bottles will be inverted and mixed on a shaker at room temperature in order to ensure complete mixing and equilibration between phases. It has been previous practice to determine initial TCE concentrations in the liquid phase after one hour of mixing (Long et al., 1993). In our experiments, TCE concentrations will be determined by gas chromatography after 5 minutes, 1 hour, 3 hours and then periodically until it is no longer detected. Although hexane extraction of TCE from the samples would kill the bacteria, it will be investigated as a method of concentrating the TCE and thus increasing detection sensitivity.

Head space and biomass absorption control samples will be run alongside each culture sample. The head space control will be used to determine the amount of TCE that is lost to aqueous phase detection by transfer from the liquid phase into the vapor phase under conditions duplicating that of the culture sample. This control will consist of 50 ml microbiologically pure and organic free water and a volume of stock TCE solution to match that of the final TCE concentration in the culture sample. It is assumed that any loss of TCE from the aqueous portion of this sample can be attributed to phase transfer and not biodegradation. The biomass absorption control is used to determine the amount of TCE that is removed from the water phase by absorption to bio-mass rather than biological degradation. This sample will duplicate the culture sample except for the addition of sodium azide solution to kill the bacterial culture. It

is assumed any loss of TCE from the liquid phase of this control may be attributed to either phase transfer or cell absorption rather than biodegradation. All culture and control samples will be run in triplicate and subjected to the same temperature, mixing, and sampling conditions.

It has been found that TCE is toxic to methanotrophs in concentrations of 46,000 ppb, and at concentrations >6,000 ppb TCE inhibits the methane monooxygenase enzyme (Oldenhuis, 1989). Hence, initial TCE concentrations for these degradation rate experiments will be 5,000 ppb. It is believed that when the SRI gas chromatograph is functioning reliably, detection of levels at or below 50 ppb will be possible. Once TCE degradation rates at this initial concentration are determined, similar experiments will be used to determine optimal conditions for TCE degradation using primary substrates in addition to methane (i.e. formate and methanol). Experiments using hydrogen peroxide as an alternative or additional source of reducing power will also be performed using data acquired previously that showed levels of hydrogen peroxide as high as 2600 ppm were non toxic to cultures of *Methyococcus capsulatus*.

At this stage, we will begin to examine the effect of promising compounds on the actual rate and extent of degradation of TCE. This work will be performed using glass columns containing soil, TCE, and methanotrophic bacteria. The columns will be flushed with a slow stream of methane to provide a source of carbon. A control column using nitrogen gas will also be examined to insure that the gas is not volatilizing the TCE.

To test the ability of hydrogen peroxide to serve as a source of oxygen, the gas phase will contain little or no oxygen, and a dilute solution of hydrogen peroxide will be added, either as a steady stream or in periodic aliquots. At various times, samples will be taken and analyzed for TCE and bacterial growth. In this way, the relationship between rate of growth, and rate of TCE oxidation, as a function of peroxide concentration may be determined. Similar experiments will be performed for other compounds such as formate, formaldehyde, and EDTA.

5.5.2 Evaluation of Reductive Dehalogenation Using Serum Bottle Microcosms Preliminary microcosm studies have demonstrated the ability of anaerobic cultures developed in the W.V.U. Civil/Environmental laboratories to reductively dehalogenate trichloroethylene, but testing methods and analysis were not ideal and therefore information gained was limited. Liquid microcosm studies will continue to be developed and evaluated in order to better understand factors affecting reductive dehalogenation. As previously planned, microcosm studies will be operated in a semi-continuous manner with degradation of contaminants (PCE, TCE, etc...) being evaluated over time. As the studies proceed, microcosms will receive fresh nutrients, substrates and will be respiked with contaminant. During each respiking, 5.0 ml of well mixed liquid will be removed from the serum bottle and replaced with fresh basal salts medium (containing 50 mg of methanol and 50 mg of acetate per liter) plus the contaminant stock solution.

A number of other factors, not considered during preliminary microcosm studies, will be investigated during future microcosm experiments. Measurements of total suspended solids and volatile suspended will be taken in order to establish biological transformation rates, and to help

determine biomass sorption coefficients. As noted from the preliminary studies, contaminant partitioning is an important concern that must be addressed in order to evaluate biodegradation. During future microcosm studies VOC partitioning will be evaluated and contaminant total mass will be calculated using the following relationships:

$$M_T = H' \cdot C_l \cdot V_g + C_l \cdot V_l + K_p \cdot X \cdot C_l \cdot V_l$$

"Total "Mass in "Mass in "Mass on
 Mass" Gas" Liquid" Solids"

Where:

- M_T = Total Mass; ug
- H' = Dimensionless Henry's Constant
- C_l = Concentration in the Liquid Phase; ppb
- V_g = Volume of Headspace Gas; l
- V_l = Volume of Liquid; l
- K_p = Sorption Coefficient; l/gr VSS
- X = Concentration of Biomass; gr VSS/l

To use the above relationship Henry's constants (H'), biomass concentrations (X), and sorption coefficients (K_p), must be known or found experimentally. Previous researchers (Long, et al., 1993; Ashworth, et al., 1988; & McKay and Shiu, 1981) have determined Henry's constants for the VOCs of interest and these values will be used to evaluate the partitioning between the liquid and gas phase. As previously stated, measurements will be taken to establish biomass concentration in the microcosms and these results will serve as the biomass concentration (X) parameter in the above relationship. In order to determine sorption coefficients (K_p) killed culture controls will be prepared and evaluated during future microcosm studies. The procedure for assessing sorption of VOCs to biological solids requires that the bacterial cultures not be metabolically active. Killed culture controls will be prepared in triplicate by removing mixed liquor samples from the maintenance reactor, placing the liquor into the serum bottles, and autoclaving the bottles for 30 minutes at 250° C. Once cooled, the bottles will be spiked with mercuric chloride to prevent biological activity. Finally, the killed culture controls will be spiked with contaminant (PCE, TCE, etc...) at the same concentrations as the inoculated samples and distilled water controls, and all bottles will be stored as previously described. During the time of the microcosm study liquid samples will be analyzed from the three sets of serum bottles, and using the mass balance relationship VOC partitioning will be evaluated.

5.5.3 Design and Operation of Columns for VOC Biotransformation Soil column studies planned for phase 3 of the research will be initiated by first constructing up-flow glass columns. To address concerns regarding volatile loss and adequate sampling techniques a design has been developed which utilizes glass chromatography columns fitted with threaded side ports, which may be used for recycling column flow and/or for sampling purposes. The chromatography columns (Figure 1) will be 5.0 cm in diameter and 30.5 cm long. The column will have an empty bed volume of 600 cm³ and will be operated at a flowrate ranging from 6.25 ml/hr to 25 ml/hr (1 to 4 day detention time). A peristaltic pump will be used to deliver groundwater flow,

while a syringe pump will introduce the contaminants of interest (PCE, TCE, etc.) at a ratio of 1:5 or 1:10 v/v.

Sand bed media (~ 3mm dia.) will be inoculated with maintenance reactor liquid to establish an anaerobic soil culture for reductive dehalogenation studies, while methanotrophs from Shiemke's lab will be used to develop aerobic column studies. The columns will be continuously percolated in an upflow mode under saturated conditions with groundwater amended with an anaerobic or aerobic mineral media, plus electron donors (methanol & acetate) for anaerobic test or electron acceptors (methane) and an oxygen source (hydrogen peroxide) during aerobic testing. Ultimately the testing will involve a sequential treatment train and columns will be operated accordingly.

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.

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FIGURE 1 . SOIL COLUMNS

EXCAVATION SYSTEMS FOR HAZARDOUS WASTE SITES
Dust Control Methods for In-Situ Nuclear Waste Handling
(Project MC-4)

Quarterly Technical Progress Report
for Period July 1 through September 30, 1993

Work Performed Under
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For
U. S. Department of Energy
Office of Fossil Energy
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ABSTRACT

This report covers the period of activity from July 1 through September 30, 1993 for the research project No. DE-FC21-92MC29467. Based on the literature review, the following three tasks are described for dust/vapor control during cleaning up radiologically contaminated soils and waste sites. These are: (1) in-situ vapor and radioactive gases recovery and other remediation techniques; (2) methods for decontamination and demolition of buildings, structures and equipment; and (3) dust/vapor control by using excavating equipment.

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1. INTRODUCTION

As more in-situ hazardous and nuclear waste sites need to be clean up, the methods of the dust/vapor control become more essential to protect the worker from the adverse health effects and the environment from harmful influence of radioactive vapor or hazardous dust. The strategies of dust/vapor control for in-situ nuclear and hazardous waste handling have some similarity for preventing dust form miners work. These activities include the reduction of dust/vapor generation, the suppression of dust/vapor from becoming airborne, the isolation of dust/vapor during transportation, keeping workers away from dusty environments, keeping dust away from the worker.

If contaminated buildings, structures or equipment present in the cleaning up sites, the special procedures and methodology are required to minimize the dispersion of hazardous waste dust into the air and the workers.

A main portion of this reporting period continues the tasks of the third quarterly report (April 1 through June 30, 1993) and responds to the Task manager's comments. Nineteen technologies for in-situ vapor and radioactive gases delivery and recovery are summarized. Twenty-one methods are tabulated for decontamination and demolition of buildings, structures and equipment, including the classification, the general description, advantage/disadvantage and the evaluation of these methods. Dust/vapor control by using excavating equipment instead of using other methods is addressed in this report, too.

2. IN-SITU VAPOR AND RADIOACTIVE GASES RECOVERY AND OTHER REMEDIATION TECHNIQUES

The recovery or delivery technologies are the processes that facilitate the transportation of materials either into or out of the subsurface. The processes involve recovering contaminants or delivering treating materials. Some of these technologies are currently being investigated for remedial actions, others show promise but have yet to be investigated for remedial purposes. All the technologies show promise for remedial purposes. However, only some of the technologies are useful for prevention/reduction of dust, gases and/or vapors before or during excavation. Therefore, five technologies are selected and described in third quarterly report. These five technologies for prevention of dust, gases and/or vapors are: (1) Vapor/Gaseous Extraction Technique; (2) Modified Air Flushing Technique; (3) In-Situ Steam Stripping Technique; (4) Ground Freezing Technique; and (5) Freezing Soil Technique.

Responding to the Task manager's comments, the nineteen delivery and recovery technologies are given below:

1) Colloidal Gas Aphrons

The use of gas aphrons, which are 60 to 70% by volume microscopic bubbles of vapor, has been suggested as a technique to enhance the in situ aerobic biodegradation of dissolved and dispersed organic contaminants.

2) Hydraulic Fracturing

Hydraulic fracturing is a technology that crack the rock in the neighborhood of a bore hole. The sand is pumped into the fracture at the time of opening to form a high-permeability channel ways. It is used extensively in the petroleum industry to stimulate the recovery of hydrocarbons from low permeability reservoirs to enhance the delivery of fluids in order to displace petroleum in sweeping operations.

3) Radial Well Drilling

Horizontal wells are drilled radially outward from a central borehole, which can be used to enhance access to a contaminated formation or aquifer. Many radial wells can be placed at the same level or on multiple levels in the same borehole. The potential applications of radial wells include groundwater control and in situ treatment. Horizontal wells have the ability to intersect fracture zones that are perpendicular to the ground surface or to intercept groundwater moving horizontally, allowing contaminant plumes to be entered laterally rather than vertically.

4) Ultrasonic Methods

Ultrasonic vibration is a technique that could increase the yields of recovery wells. Possible benefits from the application of ultrasonic vibration include: i) dispersing clay particles clogging pores adjacent to wells ii) reducing adsorption of contaminants onto the surfaces of clays, and iii) eliminating microorganisms clogging pores adjacent to wells.

5) Kerfing

Kerfing or borehole notching is a technique to cut a slot either normal or parallel to the axis of a borehole. Kerfing uses a high pressure jet of water, water with entrained air, water and bentonite or water and an abrasive material to cut the slot. Recent interest in kerfing has been as a technique to help stop the migration of pollutants from uncontrolled waste sites.

6) Electro-kinetics

Electro-kinetics is a technology that has potential for delivery remediating materials and recovering spent solutions or contaminants, principally metals, from contaminated soil. Other possible applications to waste sites include the creation of hydraulic flow barriers and the injection of grout.

7) Jet-induced Slurry Method

The jet-induced slurry method is a technique used to excavate an ore body by fragmenting subsurface material with a high-velocity hydraulic jet and then pumping the

slurry through a borehole to the surface. This technique offers the unique capability of recovering solid material from the subsurface at depth without removing the overburden.

8) Carbon Dioxide Injection

Carbon dioxide is injected into oil-bearing rock formations to maintain pressure and displace oil. The two principle mechanisms by which carbon dioxide mobilizes oil and (i) the reduction oil viscosity upon solution of the gas into the oil and (ii) the maintenance of reservoir pressure with the increase fluid volume in the reservoir upon CO₂ injection. Carbon dioxide flooding can be used to recover groundwater contaminants in two cases: (i) carbon dioxide dissolved in water, and (ii) contained in aphyrons. The principle mechanisms are to decrease the viscosity and increase the recovery of hydrocarbons.

9) Polymer Injection

Water-soluble polymers are added to water flooding solutions in the petroleum industry to (1) increase the viscosity of flooding fluid, thereby decreasing the viscosity contrast between the oil and flooding fluids, or (2) form highly viscous gels in situ to homogenize reservoir permeability. The homogenization of permeability is one possible application of polymers for the recovery of contaminants. Temporarily filling high-permeability channel ways with polymer gels could be used to induce flow and transport contaminants out of local zones of low permeability.

10) Vapor Extraction

A vapor extraction system (VES) involves the recovery of vapor-latent air from unsaturated soils by applying a vacuum at extraction wells. The process appears to be limited to those contaminants that exhibit significant volatility at ambient temperature.

11) Steam Stripping

In situ steam stripping is a method intended to recover not only highly volatile but also moderately low vapor pressure organic compounds from contaminated soil. The steam is injected into the contaminated soil through wells where it releases heat to the soil when it condenses. The rate of vaporization and transport of these compounds increase as a result

of increasing soil temperature following contact with the steam. The steam has two main functions. They are to vaporize the contaminants and become the transport medium for the vaporous materials. A partial vacuum (under pressure) can accelerate the rate of volatilization and speed the transport of contaminants to collection points.

12) Hot-brine Injection

Hot-brine injection could be used at uncontrolled hazardous waste sites to recover certain contaminants whose dissociation temperature decrease with an increasing salinity of pore fluid. This method is being developed to recover natural gas from solid and liquid gas-hydrate deposits. Hot-brine injection increases both the temperature and salinity of a reservoir thereby promoting dissociation reactions that drive solid or liquid gas-hydrates into a vapor phase and water for easier recovery. The applicability of this method will require a salinity dependence on the dissociation temperature of the contaminant species to be recovered.

13) In-Situ Combustion

In-situ combustion methods are used to recover highly viscous crude oil from tar sands and other deposits of viscous hydrocarbons. Similar techniques could possibly be used to recover hydrocarbons from uncontrolled hazardous waste sites. This method uses an injection and production well system to create and migrate a thermal front through an oil-bearing formation. As the front advances and the formation temperature increases, lighter oil fractions are mobilized through volatilization and reduced viscosity. Thus, the recover hydrocarbons from uncontrolled hazardous waste sites becomes possible.

14) Radio-frequency Heating

Radio-frequency (RF) heating is an in situ technique intended to recover volatile organic compounds by exposing contaminated soils to electromagnetic energy through bound-wave exciter electrodes. Two general RF heating techniques to decontaminate soils have been investigated: i) thermal vaporization and recovery of contaminants with low boiling points, and ii) the improvement of the reaction rate between the contaminants with high boiling temperatures and applied reagents.

15) Cyclic Pumping

Cyclic pumping is a delivery and recovery technique that systematically varies rates of either injection or extraction in an effort to minimize pumping costs. The pumps are turned on during an active cycle and turned off during a rest cycle. The rest cycle is to allow time for diffusion between high permeability pathways and the low permeability blocks between them. The active cycle is designed to deliver the minimum volume of nutrients or reactants or to remove the maximum possible concentration of reaction products. The optimization of pumping practices has the potential to reduce remediation costs at hazardous waste sites.

16) In-situ Soil Flushing

This method is designed to accelerate the movement of a contaminant through unsaturated materials. The efficiency is improved by i) the increase in hydraulic conductivity that accompanies an increase in water content of unsaturated soil and ii) the engineering of treatment solutions to the composition of the contaminants and the contaminated medium. In situ soil flushing is done to accelerate the movement of a contaminant through unsaturated materials. A treatment solution is applied to the soil and allowed to percolate downward and interact with contaminating chemicals. Contaminants are mobilized by the treatment solution and transported downward to a saturated zone where they are pumped to the surface.

17) Ground Freezing

When pore water freezes slowly, crystals of nearly pure ice form, and any dissolved species are concentrated in pockets or thin films of liquid around solid particles. The film around particles can be very mobile allowing ion movement to occur through diffusion. Ground freezing has potential for remediation because contaminants apparently can be concentrated ahead of freezing fronts. By concentrating contaminants, artificial ground freezing can be used to reduce the volume of contaminated soil at a site and thereby facilitate remediation.

18) Soil Freezing

The soil freezing technique has been applied in civil, mining, and petroleum filed for working safety and structure stabilization. Like the ground freezing technique, the soil freezing also is the artificial method by freezing the shallow surface. It may be possible to reduce the vapor pressure of the hazardous organic wastes and minimize the formation of radioactive gases.

19) In-situ Vacuum Excavation

In-situ vacuum excavation is to remove and to treat volatile organic compounds (VOCs) from the vadose or unsaturated zone of soils. These compounds can often be removed from the vadose zone before they contaminate groundwater. This technique has been applied at more than 400 waste sites through the United States, Europe, and Japan.

3. METHODS FOR DECONTAMINATION AND DEMOLITION OF BUILDINGS, STRUCTURES AND EQUIPMENT

The hazardous waste sites may have buildings, equipment and structures which need to be decontaminated and demolished before a site clean-up can be more effectively performed. There are twenty-one established and potential methods which have been identified and reported (Battelle Columbus Lab, 1985). The classification, general description, and advantage/disadvantage of these methods are listed in Table 1. Some of these methods are currently being demonstrated in the actual waste sites under the EPA SITE program. The potential health and safety hazards of using these methods are tabulated in Table 2. These methods are also evaluated based on the their effects on inhalation, skin noise, hand/arm, heat ultraviolet radiation, electrical, biohazard fire/explosion and physical with general comments.

Table 1 Decontaminating Methods, General Description and Advantage/disadvantage

Method	General Description	Advantage	Disadvantage
1. Asbestos Abatement			
1) Removal	Asbestos-containing building materials are removed to prevent the release of asbestos fibers into the air.	permanently eliminates the source of asbestos fibers.	costly and time-consuming; may require sealing of porous surfaces after removal.
2) Encapsulation	a chemical penetrant is spray-applied to the materials to bind together asbestos fibers instead of release into air.	does not require replacement of the asbestos-containing material.	periodic reinspection and repair are required; may make the eventual removal of asbestos-containing materials more difficult.
3) Enclosure	a permanent barrier is erected between the asbestos-containing material and all portions of occupied building.	initially, may be lower cost than removal.	periodic reinspection and repair are required; may make the eventual removal of asbestos-containing materials more difficult.
4) Special operation	cleanup, maintenance, repair and periodic reassessment are together.	initially, may be lower cost than removal.	applies only to non-friable asbestos.
2. Absorption	absorbent materials are used to pick up liquid contaminants.	Quickly contains gross contamination.	normally requires secondary decontamination.
3. Demolition	total destruction of a building, structure, or piece of equipment.	removing all contaminated building materials, structures, and equipment from site.	completely destroys the building, structure, or equipment; generates large amount of contaminated debris; may expose worker or nearby residents to airborne contamination.
4. Dismantling	physical removal of selected structures from buildings or other areas.	only those structures that are contaminated are removed.	generate large quantities of contaminated debris.

5. Dusting/ vacuuming /wiping	physical removal of hazardous dust and particles from building and equipment surfaces by common cleaning techniques.	generate small volume of contaminated debris.	may spare contamination by creating fugitive dusts; may have to be repeated until the source of contamination is controlled.
6. Encapsulation/ enclosure	contaminants or contaminated structure are physically separated by barrier.	generate small volume of contaminated debris.	may render structures inaccessible or inoperable.
7. Griblasting	a surface removal technique in which an abrasive materials are used for uniform removal of contaminated surface layer from a building or structure.	can simultaneously and readily remove paint and contaminants near the surface.	generate large quantities of contaminated dust and debris; effective only as a surface treatment.
8. Hydroblasting/ waterwashing	a high-pressure water jet is used to remove contaminated debris from surface.	inexpensively, nonhazardous surface decontamination.	not effective for the penetrated surface layer; requires collection and treatment of large amount of contaminated liquids.
9. Painting/coating	removal of contaminated lead-based paint by scraping, scrubbing, waterwashing, and repaint the surface layer.	doesn't require large investments in equipment.	involves labor-intensive operations that cannot be automated.
1) lead-base paint removal			
2) Fixative/ stabilizer coating	use of special agents to coat on contaminated residues to fix or stabilize the contaminant in place and decrease or eliminate exposure hazards.	doesn't create any hazardous waste.	doesn't remove toxic contaminants; requires lifetime monitoring.
3) Strippable coating	compounds that bind with contaminants are mixed with a polymer.	physically holds or traps the contaminant for easier handling and disposal.	may bind the surface, resulting in large volume of waters or damage to the surface.
10. Salification	use of the scarifier tool to removing up to 2.5 cm of surface layer from concrete or similar materials.	can achieve a deeper penetration (removal); is suitable for application to both large open areas and small areas.	requires resurfacing of the treated surface; restricted to use on concrete or concrete-like materials; can only be used in obstruction-free areas.

11. Radkleen	pressure-spraying of a fluorocarbon solvent onto the contaminated surface followed by collection and purification of the solvent.	permits rapid wetting of surface and easy particulate separation.	require secondary treatment of the used freon.
12. Solvent washing	an organic solvent is circulated across the surface of a building to solubilize contaminants.	can remove contaminated paint if the proper solvent is selected.	is not suitable for intricate structures; may tend to carry contaminants farther into the wall before outward movement occurs; may require removal and/or decomposition of residual solvent in building materials.
13. Steam cleaning	physically extracts contaminants from building materials and equipment surface.	inexpensive and simple, may cause thermal decomposition and/or hydrolysis to occur.	effective only for surface decontamination; is labor-intensive and costly if automated; generates large volumes contaminated water.
14. Vapor-phase solvent extraction	an organic solvent with a relatively low boiling point is heated to vaporization and allowed to circulate in a building.	enhances solvent permeability and diffusibility; is well suited to all areas of a building; can remove contaminated paint.	may require long treatment times for outward diffusion of contaminant-laden solvent.
15. Acid etching	acid is applied to a contaminated surface to promote corrosion and removal of the surface layer.	certain contaminants are decomposed as they are removed from the surface.	require a large volume of acid (hazardous) and special application equipment; is applicable only to metals that will readily corrode.
16. Bleaching	bleach formulations are applied to a contaminated surface, allowed to react with contaminants, and removed.	is an effective decontaminating agent when used against metal surfaces.	may cause corrosion of application equipment and/or the surfaces being treated; may also cause periodic clogging of application equipment.

17. Flaming	controlled high temperature flames are applied to noncombustible surfaces to thermally degrade all contaminants.	provides complete and rapid destruction of all residues contacted.	is primarily a surface decontamination technique; would probably result in extensive damage to the material if used for subsurface decontamination; can involve high fuel cost.
18. Drilling and Spelling	drilling holes approximately 2.5 dia. and 7.5 cm deep, then spreads to spall off the contaminated concrete.	can achieve deeper penetration; is good or large-scale application	require resurface; expose rebars; generates substantial amounts of contaminated debris.
19. K-20 sealant	sealing is the application of a material that penetrates a porous surface and immobilizes contaminants in place.	immobilizes contaminants in situ; doesn't generate hazardous wastes.	is in the developmental stages; has not yet gained Federal approval for widespread use.
20. Microbial degradation	microbes are applied to the contaminated area in an aqueous medium and allowed to digest the contaminants over time. the microbes are then destroyed chemically or thermally and washed away.	is specific to targeted contaminants.	would probably require supplementary treatment; may give rise to biological degradation products containing carcinogenic compounds.
21. Photochemical Degradation	an intense ultraviolet light is applied to a contaminated surface for some period of time; photodegradation of the contaminant follows.	simple or scaled-up; is inexpensive when sunlight is used as the UV light source.	will not work on contaminants imbedded in dense particulate matter; may result in exposure hazards from the use of intense UV radiation sources other than sun.

Table 2 Potential Decontaminating Methods, General Description and Advantage/disadvantage

Method	Potential Health and Safety Hazards										Comment
	Inhala-tion	Skin	Noise	Hand /Arm	Heat	Ultra-violet Radiation	Electri-cal	Bio-hazard	Fire/explo-sion	Physi-cal	
1. Asbestos abatement 1) Removal 2) Encapsulation 3) Enclosure 4) Special operation	F, V				X		X				Electrical shock; potential inhalation hazard if vapors from sealants are toxic.
2. Absorption	V	X			X				X		Hazard associated with contaminant being clean up, not with the sorbet.
3. Demolition	P		X		X				X	X	Fire and explosion hazard if the building is highly contaminated with combustible, explosive, or reactive residues.
4. Dismantling	P		X		X	X			X	X	Fire and explosion hazard if spark-proof tools are not used.
5. Dusting/vacuuming/ wiping	P				X						
6. Encapsulation/ enclosure	V	X		X	X						Skin hazard from epoxy resins in the uncured state.
7. Gritblasting	P		X	X	X				X	X	Fire and explosion hazard if combustible materials is gritblasted.
8. Hydroblasting/ waterwashing			X	X	X		X			X	Physical contact hazard from high-pressure water lines.

9. Painting/coating 1) Lead-base paint removal 2) Fixative/stabilizer coating 3) Strippable coating	V	X			X				X		Inhalation, skin, and fire hazards from paint removers containing flammable and/or toxic solvents.
10. Salification	P		X	X	X				X	X	Fire and explosion hazard if combustible material is scarified.
11. Radkleen	V	X									Inhalation and skin hazards from the use of Freon 113.
12. Solvent washing	X	X							X		Inhalation, skin, and fire hazards from the use of flammable and/or toxic solvents.
13. Steam cleaning	V	X			X						Inhalation and skin hazards from the use of toxic solvent/steam mixtures; possible steam burns.
14. Vapor-phase solvent extraction	V	X							X		Inhalation, skin, and fire hazards from the use of flammable and/or toxic solvents.
15. Acid etching	V	X									
16. Bleaching	V	X									Skin hazards from bleach agents which are strong oxidizers.
17. Flaming	V, P	X	X		X				X		Inhalation hazard from thermal decomposition products; skin hazard from contact with flames or hot surface.
18. Drilling and spelling	P		X		X				X	X	Fire and explosion hazard if pockets of combustible material are contacted.
19. K-20 sealant	V	X			X						Hazards associated with K-20 are uncertain.
20. Microbial degradation	V, P							X			Inhalation hazard from microbes and biologic degradation products.
21. Photochemical degradation	V	X					X				Eye and skin hazards from use of artificial UV light sources; inhalation and skin hazards from the use of toxic hydrogen donors.

Notes:

1. Inhalation hazards include pulmonary deposition or absorption of toxic or nuisance particulate (P), carcinogenic asbestos fibers (F), or toxic chemical vapors (V).
2. Skin hazards include dermatoses, chemical burns, percutaneous absorption of chemical, etc.
3. Ultraviolet radiation is both a skin and eye hazard.
4. Biohazard is a hazard directly due to a living organism or the byproduct of a living organism.
5. Physical contact hazards include lacerations, injuries to the eye from flying particulate, strains, sprains, impacts, etc.

4. DUST/VAPOR CONTROL BY USING EXCAVATING EQUIPMENT

When in-situ hazardous/nuclear sources and contaminated soils are fully excavated, the containments (either fugitive dust, vapor emission or both) are exposed to the atmosphere during the excavation processes. It has been well known that the mobility of contamination depends on the equipment employed, properties of hazardous wastes and matrix of contaminated soils, topography, and wind patterns. Generally speaking, after methods used for dust control in civil engineering, such as methods for fire fighting and oil spill are introduced for controlling fugitive dust and vapor emission in contaminated sites, some methods of specific application have been more recently developed for contaminate excavation. They can be summered as follows:

Before Excavation Process:

- In-situ Treatment Technologies

- Acid Gas Neutralization Additives for Vapor Control

During Excavation Process:

- Water Application

- Water/Additive Suppressants

- Inorganic Control Agents

- Organic Dust Control Agents

- Form Suppressants

- Surface Enclosures

- Self-Supporting Enclosures

- Covers, Mats, and Membranes

- Vacuum Trucks

- Windscreen

- Scheduling

After Excavation Process:

Lining Systems Such as Covers, Mats, and Membranes

Currently, using improved or innovated equipment for dust and vapor suppressions is predominantly being focused on because the primary fugitive dust and vapor emissions are generated during the excavation process and are mainly governed by used excavating equipment. In addition, some hazardous/nuclear waste sites are urged to need remediation but there are too harmful to be excavated by on-site workers.

Therefore, the concept of generated dust/vapor related to conventional equipment, and using improved and newly developed equipment to control fugitive dust and vapor emission for in-situ hazardous/nuclear materials handling are reviewed, respectively. Some comments about control of fugitive dust and vapor emission by using excavating equipment itself are drawn based on the literature study.

4.1 Dust Producing Mechanisms by Using Conventional Equipment During Excavation Process

Conventional equipment, such as backhoe, front-end loader, bulldozer, and crane with dragline or clamshell, are common to be used for excavation of contaminated sites. Conventional equipment are employed at about 85 % hazardous waste sites for in-situ materials handling. It is also reported that about 60% sites didn't take dust/vapor control into consideration under using these equipment .

To understand fugitive dust producing mechanisms with using excavating equipment, two types of conventional excavating equipment, bulldozers and front-end loaders, are detailed discussion here.

Bulldozers The use of a bulldozer is expected to result in a high rate of fugitive emission generation because it typically scraps a thin layer of soil and pushes soil in a greater distance than the other equipment available. Pushed soil is toward a loading

point where a front-end loader is used to load trucks. The use of a bulldozer maximizes newly exposed surfaces, and its tracks churn a large area of newly exposed soil as it moves. The track and blade of a bulldozer are the sources of fugitive emissions during an excavation process. Like wheels, the top and sides of the blade generate emissions as contaminate slide off. Thin layer of top of the blade can easily be carried off by the wind. Based on the study of overburden excavation in coal mines, two factors, percentage of overburden silt and percentage of overburden moisture, were considered to estimate the dust emission rate from both the track and the blade. It is calculated in the following equation (PEDCO, 1981).

$$TSP = \frac{5.7 S^a}{M^b} \quad (1)$$

where *TSP* - emission rate of total suspended particular in lb/h
 S - overburden silt ranged from 3.8 to 15.1, percent
 M - overburden moisture ranged from 2.2 to 16.8, percent
 a,b - coefficients, 1.2 and 2.3, respectively

Front-end Loaders The front-end loader can be used for excavation in place of bulldozer. It can be operated in a manner that would result in a reduced potential for excavation-related emissions. A loader can be operated at the face of a deeper excavation to limit newly exposed surfaces to little more than the size of loader bucket. To reduce emissions, rubber tire loaders can be used on firm level soils instead of track crawler loaders. Fugitive emission points for loaders include the excavation face, loader bucket, and to a lesser extent, the loader tracks or tires. Points of fugitive dust emissions from front-end loaders emanate from tracks or wheels as well as the loader bucket. The usual source of emissions from the loader bucket results from spillage as the bucket is being raised. Based on study in EPA's Compilation of Air Pollutant Emission Factors (1982) on material handling operations at a steel mill, the factor related with fugitive dust emission was developed which involved all sources

(tracks, tires, bucket, dump) as:

$$E = K (0.0018) \frac{\left(\frac{S}{5}\right)\left(\frac{U}{5}\right)\left(\frac{H}{5}\right)}{\left(\frac{M}{2}\right)^c\left(\frac{Y}{6}\right)^d} \quad (2)$$

where

- E - TSP emission factor, lb/ton
- K - particular size multiple, 0.78
- S - material silt content, %
- U - mean wind speed, mph
- H - drop height, ft
- M - material moisture content, %
- Y - dumping device capacity, yd³
- c, d - coefficients, 2 and 0.33, respectively

From previous studies on dust producing mechanisms, in addition to the contents of silt and moisture which describe the general dustiness of the material being moved, high wind speed (blowing of dirt from the dirt mass edges), greater drop height (more turbulence caused by material drop), and smaller bucket size (more dirt mass edge per unit of volume) are contributed to more dust generation. Results from studying fugitive dust producing mechanisms indicate that dust/vapor emission points related to excavation activities are equipment tracks/tires, newly exposed excavation face and newly excavated soil equipment bucket.

4.2 Improved Conventional Equipment For Dust/vapor Control During Excavation Process

Some methods were tried to implement existed dust/vapor control methods into conventional equipment.

Area Water Spraying on Surface In order to reduce dust emissions during an excavation process, spray of water or surfactant (to minimize the amount of water) were initially employed by using a mobile tower. About 20% sites used water spray to control dust/vapor emissions. The water truck is common piece of equipment at many active construction sites where fugitive dusts pose a problem. The area water spraying on surface reduces emissions from the track or wheels, and also tends to reduce contaminate emissions from the bucket and material drop. Spraying misters the soil on the surface but not all soil being moved. Although water along is used extensively (about 50 % sites using water spray among all dust/vapor control sites), such systems have several disadvantages, including less efficient dust control, higher water consumption, short-lived dust reduction and greater contribution to creating sloppy area. Its effectiveness in suppressing, however, is unexplored and may be low since the vapor emission are frequently insoluble hydrocarbons specific gravity less than one.

Water/surfactant Spraying from the Sources Mounted to Equipment Direct mounting the sparing system to bulldozers or front-end loader was tried in limited experiments. Several operational problems are identified from this approach.

- a. The equipment must either be outfitted with a large tank or an umbilical cord to a tank, neither of which is desirable.
- b. Spray nozzles must be attached to the blade/bucket or on arms reaching over the blade/bucket.
- c. Maintenance is difficult during an excavation process.
- d. Machine operator objects to working in the resulting misty conditions.
- e. The saturated surface by spraying water may cause the unstable condition for heavy equipment operation on it.

Mobil Spray Curtain To increase moisture on material being dumped, a mobil spraying curtain was constructed with a mobil foam through which a truck can drive and the track bed can be positioned under a series of nozzles. The flat spray for the nozzles

forms a "spray curtain" across the entire horizontal surface of the truck box. The spray is operated only during the actual dump, and water, surfactant, or foam can be used.

PEDCO (1984) conducted a few projects to study control effectiveness of using these approaches, the results are shown in Table 3.

Table 3 Summary of Control Effectiveness Results

Operation	Control Measure	Control Efficiency, %	
		Fine Particulate	Total Suspended Particulate
Front-end Loader (traveling & scraping)	Area spray-water (0.9 gal/yd ²)	64	42
	Area spray-Water/surfactant (0.75 gal/yd ²)	70	63
Front-end Loader (dumping)	Area spray-water (0.9 gal/yd ²)	66	69
	Area spray-water/surfactant (0.9 gal/yd ²)	62	77
	Water curtain (1.5 gal/yd ³)	56	50
	Foam curtain (0.4 gal/yd ³)	41	46

It seems that of two spray curtain measures, the water curtain provided somewhat better control of dust from the dump cycle than did the foam curtain. If one of these controls was used in conjunction with water/surfactant spray, the resulting control efficiency would probably be significantly greater than for either one alone. However, in addition to emerged several problems mentioned before, water, surfactant or foam sprays unlikely reach the goal of 100 percent control efficiency. Thus, the potential for subsequent human exposure to hazardous waste dust would still exist.

Truck Mounted Vacuum Loading Apparatus The truck mounted vacuum loading apparatus are commercially available to remove soils and sludge fluid enough to flow to the pickup nozzle. It is mounted a mobile vacuum loading apparatus on a conventional pick-up truck. This equipment, which consists of the vacuum truck and emission control device is expected to significantly reduce excavation, loading and transportation related emissions versus conventional excavator and dump trailers. But no studies were identified that quantified such vacuum truck fugitive emissions reduction. However, decreased air/waste contact and enclosure of the waste during transport should reduce the potential for emissions.

4.3 Updated or Innovated Equipment For Dust/vapor Control During Excavation Process

Computerized Excavator A latest excavator, EX300-2 as super series machine, is produced by Hitachi Company. Its high-quality, bronze tinted frond glass widow and tightly sealed against noise and shock, and simultaneous seat/level movements make deep excavation easier and more efficient due to increased visibility from the cab. The Electronic Total control System (ETS) is a microcomputer system that regulates engine speed and pump deliver flow simultaneously and switches power mode to suit job requirements. This system allows optimum operation by button control of operation modes than enhance productivity and improve fuel consumption. It is anticipated that this newest excavator will provides better and safer working conditions to machine driver, especially for excavating materials on hazardous/nuclear waste sites.

Remote Controlled Excavator Information of remote controlled excavator is released by John Deer Company (1988). It is particularly designed for using on hazardous/nuclear waste sites. This recently marketed a tele-operated remote-controlled excavation system can be used for excavating, bulldozing, heavy lifting, concrete breaking, or remote handling. Off-site operation is available with equipped

radio transmission, coaxial cable, or fiber-optic cable which provides a maximum worker safety. A cab-mounted camera allows from overall or close-up viewing of the work area from about one mile away. Although this tele-operated remote-controlled excavation system has been used in U.S. Army Corps of Engineers for the excavation of the hazardous sites, the detailed performance is not available to be released to public so far.

Pneumatic Excavation System Other updated excavation device called the pneumatic excavation system is in patent stage currently. It is particularly designed for excavating materials from the earth in which such materials are pneumatically conveyed from an excavation site. To fully avoid the fugitive dust and vapor emission from releasing to atmosphere, the excavated materials by this system is entailed in a gas and pneumatically conveyed through a long enclosed flow path from an excavation site to a collection site, remote from the excavation, where such materials separated from the entraining gas and collected. Advantages of this system is considered that it overcomes the most weak point of using the conventional or remote/man-driven excavators (i.e. created more free surface and increased more points/area for dust/vapor emissions). The pneumatic excavation system is a novel combination of pneumatic apparatus and methods which provide many advantages and contributions over mineral processing systems for on-site transporting materials from excavation. The materials is trapped and enclosed in system preventing discharge of dust, speed of excavated fragments, and run-off of toxic liquid.

The updated or innovated equipment presents their predominantly advantages than that of conventional equipment for purpose of controlling fugitive dust and vapor emissions with either worker safety or potential efficiency of dust/vapor mitigation. Some other points may also need to consider for practically using these equipment in hazardous/nuclear waste sites.

Neither computerized nor remote controlled excavator takes to avoid fugitive dust and vapor emission from releasing to atmosphere into consideration with designed

equipment itself although on-site working condition become better for the workers by using one of them. Public use of these equipment may be limited if no advanced technologies for fugitive dust and vapor emissions control methods are simultaneously cooperated with such high technique equipment.

It seems that pneumatic excavation system can solve problem of fugitive dust and vapor emissions after contaminated materials are dug up from original place. If the conventional or upgraded equipment are still required for digging-out activity prior to using the pneumatic excavation system, it may lead the higher performance of dust/vapor control by using pneumatic excavation system to become low one on practical use in sites.

5. SUMMARY AND FUTURE WORK

There are fugitive dust and vapor suppression options for common or even risk scenarios from emissions related to excavation processes. But only limited number of quantitative data is existed to correlate for accurately predicting performance for most practical control fugitive dust and vapor emissions technologies. This is especially true for the updated technologies. This may result in insufficient performance on particular sites, or in an overly conservative design.

Control of fugitive dust and vapor emissions by using excavating equipment itself is a active approach instead of passive mitigation technologies. It is possible to form a integrated dust/vapor controlled-excavation system if current techniques both dust/vapor control system and upgraded excavator is simultaneously designed.

Efficient dust/vapor controlled-excavation system should be integrated by using of other methods, such as scheduling, operation design, excavation methods, and other control technologies to minimize dust/vapor emissions.

All updated or innovated techniques should be tested on simulated sites before are put into in-situ use. Some shortcoming may be discovered during the testing stage when a complete dust/vapor controlled-excavation system is taken into account.

In order to establish a dust/vapor controlled-excavation system for in-situ nuclear and hazardous waste handling, the literature review and information compilation will be continued for next quarter research. The main tasks are scheduled for detail study on: (1) remote control excavation equipment; (2) automatic control of other material handling technologies; (3) improved conventional excavation equipment; and (4) innovative technologies, i.e. vacuum excavation systems and pneumatic excavation system for simultaneous removal of dust and gas during excavation.

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Chemical Destruction of Polychlorinated Biphenyls (Project MC-6)

Quarterly Report for Period
July 1 through September 30, 1993

Work Performed Under Contract
No.: DE-FC21-92MC29467
(MTCI No. 070)

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

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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 allowing 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. Attempts are being made to try to incorporate an amino group into the chemical structure of sterically hindered triarylboranes with the intention for easy recovery after the dechlorination process is complete.

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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

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 allowing 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. Attempts are being made to try to incorporate an amino group into the chemical structure of sterically hindered triarylboranes with the intention for easy recovery after the dechlorination process is complete.

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 effect of PCBs to a wide range of wildlife, including mink, some species of shellfish, shrimp, and fish, and especially those birds that are at the top of the food chain, such as eagles, hawks, falcons, and pelicans.² The chronic (long-term) toxicity to humans and other species is yet to be fully realized.

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 than 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

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 previously.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 then 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 volatilization 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 NiCl₂ 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 NiCl₂, 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 hydroquinones²² 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 photodechlorination 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

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

We envision that a sterically hindered triarylborane substituted with a dimethylamino group, such as 4-(dimethylamino)phenyldimesitylborane (**22**)²⁷ in Figure 11, 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 11. 4-(Dimethylamino)phenyldimesitylborane (**22**) as an Electron Carrier

We have 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 (**23**) in Figure 12 containing only one modestly congested aryl group is also very susceptible to water hydrolysis.

Figure 12. The Chemical Structure of Diphenylmesitylborane (23)

Repeated attempts to synthesize diphenyl(2,4,6-tri-*tert*-butylphenyl)borane (26) having an extremely congested aryl group by treating methyl diphenylborinate (24)²⁹ with 2,4,6-tri-*tert*-butylphenyllithium (25)³⁰ as shown in Figure 13 were unsuccessful. Perhaps 25 with two very bulky *tert*-butyl groups at the *ortho* positions is too hindered for the reaction to take place.

Figure 13. Attempted Synthesis of Diphenyl(2,4,6-tri-*tert*-butylphenyl)borane (26)

Fortunately, by using a slightly less hindered 2,4,6-triisopropylphenyllithium (27),³¹ the resulting diphenyl(2,4,6-triisopropylphenyl)borane (28) can be easily synthesized as shown in Figure 14. 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 14. Successful Synthesis of Diphenyl(2,4,6-triisopropylphenyl)borane (**28**)

Currently, we are try to place a dimethylamino group onto the structure of **28**. Recently, it came to our attention that 4-(dimethylamino)phenyldimesitylborane (**22**) is also stable to water and can be easily prepared by using the protocol outlined in Figure 15.²⁷ The presence of an amino group in **22** could greatly facilitate its recovery. We will also study the possibility of using **22** as an electron carrier for sodium metal for dechlorination of chlorinated organics and the feasibility of recovering **22** from the reaction mixture for recycle.

Figure 15. Synthetic Procedure for 4-(Dimethylamino)phenyldimesitylborane (**22**)

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 μ m 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 series 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

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 weight 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 16.

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 16. 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 17.

Figure 17. 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 18 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 18. 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 19 and 20.

Figure 19. GC/MS Ion Chromatograms of Dechlorination of Aroclor 1242 by NaDMAN

Figure 20. 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 Diphenyl(2,4,6-triisopropylphenyl)borane (28)

Diphenyl(2,4,6-triisopropylphenyl)borane (28) was successfully synthesized by treating methyl diphenylborinate²⁹ with 2,4,6-triisopropylolithium.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; ¹H NMR (CDCl₃, 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 ¹H NMR spectrum (270 MHz) and the GC/MS of diphenyl(2,4,6-triisopropylphenyl)borane (28) are shown in Figures 21 and 22, respectively.

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. 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.

Figure 21. The ^1H NMR Spectrum (CDCl_3 , 270 MHz) of Diphenyl(2,4,6-triisopropylphenyl)borane (**28**)

Figure 22. The GC/MS Ion Chromatograms of Diphenyl(2,4,6-triisopropylphenyl)borane (**28**)

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**Development of Organic Sensors:
Monolayer and Multilayer Self-Assembled Films for Chemical Sensors
(Project MC-7)**

**Quarterly Technical Progress Report
for Period July 1 through September 30, 1993**

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

**For
U.S. Department of Energy
Office of Fossil Energy
Morgantown Energy Technology Center
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Table of Contents

1.0 EXECUTIVE SUMMARY 1

1.0 EXECUTIVE SUMMARY

Work for this quarter falls in four categories:

- (a) construction and testing of the vapor generator.
- (b) further investigations of deposition of the polyion multilayer.
- (c) characterization of the SAW device in flowing dry gas.
- (d) humidity sensitivity of a polyion layer on the SAW crystal.

The results reported here are due to the efforts of Mark Phillippi, research technician, and Xiaolei Hu, M.S. candidate.

A. Construction and Testing of the Vapor Generator.

All of the parts for the vapor generator have arrived. The current design of the vapor generator is shown in Figure 1.

To avoid prohibitive costs for clean feedstock air, a purification unit for house compressed air has been designed and constructed (Figure 1A). The purification unit contains two separate towers housing 13X molecular sieves; the molecular sieves are capable of removing water vapor, carbon dioxide and small organic molecules from a gas stream. One tower is used as the primary purification unit. A portion of the purified air stream from this tower is used to purge the second tower in order to remove adsorbed impurities. After a week of operation, manual valves are set so that the purged tower becomes the primary purification unit and the original tower is purged; consequently the molecular sieves will not need replacement for many months. Both towers are protected with two filters (coarse and fine) which remove both water and oil droplets from the feedstock air (house compressed air has an abundance of both types of impurities). The air emerging from the purification tower is filtered again (coarse and fine filter) to remove any dust particles picked up from the molecular sieves. This arrangement provides a continuous air stream which has very low organic content, 0% relative humidity (R.H.), and very low particle content.

The feedstock air is divided into three streams (Figure 1B). One stream is sent to the Kintek Modular Gas Generator. This unit contains 4 ovens with digital thermostats. Each oven is capable of holding diffusion or permeation tubes which leak vapors of a pure substance at a constant rate. Air flow through each oven can be included in the air stream or sent to a dump. With this instrument it is possible to introduce controlled concentrations (in the range of 1 to 1000 ppm) of up to four substances into the air stream. The instrument also has a mass flowmeter for monitoring the total rate of air flow.

A second stream of air is sent through a humidification section. This section contains two consecutive bubblers, in which the air is forced through a frit and a column of water, and a droplet trap, in which the air is passed through a column packed with glass beads. The

bubblers and droplet trap are submerged in a regulated temperature bath (see below). Air emerging from this section is close to 100% R.H. for the bath temperature.

The third stream is used to dilute the other two streams so that control of both R.H. and chemical concentration is possible. Flow control and monitoring is provided by separate flow meters (floating weights) with high accuracy needle valves on the humid and dry air streams and the mass flow meter and needle valve on the Kintek Generator. The air mixture is then passed through a 2 meter copper coil immersed in the constant temperature bath to ensure both complete mixing and adjustment to the desired experiment temperature.

The air stream is sent to the small chamber surrounding the SAW crystals. The chamber consists of a metal block hollowed out so that sample and reference SAW crystals sit in separate compartments. The air stream only passes over the sample SAW crystal. The temperature of the metal block is controlled by passing water from the circulating water bath (see below) through an attached copper tube. The metal chamber does not surround the electronics unit which drives the SAW crystals and produces the beat frequency. That unit generates enough heat that separate temperature control of the SAW crystals is necessary.

The air exiting the chamber passes over a NIST traceable digital hygrometer/thermometer. The hygrometer provides the actual R.H. of the air stream passing over the sample SAW crystal. The air stream exits through another flow meter and into a laboratory hood. The final flow meter monitors the total flow rate (typically 1 to 2 liters/minute) and provides a check for leaks, since the flow rates of each of the three air streams are also monitored.

Temperature regulation is provided by a circulating water bath with heating and refrigeration. Water from the circulator is sent through copper coils immersed in a large water reservoir which contains the humidification assembly and the mixing coil. The water in the reservoir is stirred by a propellor blade attached to an electric motor. A portion of the water from the circulator is also sent to through a copper tube attached to the metal chamber surrounding the sample and reference SAW crystals. Temperatures between 0°C and 40°C are readily achieved.

Initial checks of the vapor generator have revealed three problems. The least of these problems is the inconsistent calibration of all of the air flow meters. The measured flow rate exiting the SAW chamber is higher than the sum of the three flow rates (dry air, wet air, organic air) going into it. Comparison of measured flow rates with actual flow rates based on timed displaced volumes of water shows that the final flow meter is reading 10% high. The remaining flow meters and the mass flow meter on the Kintek Generator display apparent flow rates within 5% of the actual flow rate. The second problem is caused by the positioning of the microbalance with the two SAW crystals outside of the water bath. The temperature of the air coming out of the mixing coil rapidly approaches the room temperature; the thermometer built into the hygrometer always registers temperatures near the ambient temperature independent of the temperature of the water bath. A related problem occurs when

the bath temperature is above ambient lab. temperature. The air stream with 100% R.H. at the bath temperature rapidly condenses water droplets in parts of the vapor generator which are downstream. Currently the generator can only be used at temperatures close to the ambient lab. temperature. Clearly the generator will have to be reconfigured so that temperature control of the air stream is maintained all the way through the SAW chamber and humidity sensor.

Future work on the gas generator will include calibration of the concentrations of each of three organic vapors (benzene, carbon tetrachloride and trichloroethylene) and incorporation computer-controlled switching for the organic vapors.

B. Further Investigations of Deposition of the Polyion Multilayer.

Multilayer deposition starts with the formation of a charged monolayer on the substrate. Our approach is silanization, in which a silane reacts with a surface silanol:

This reaction takes advantage of the protective SiO_2 layer covering the electrodes of the SAW device. The R group can contain either an amine, which in acidic solutions carries a positive charge, or a quaternary amine, which has a permanent positive charge. The first adsorbed polyion must then be a polyanion.

We have spent considerable time looking at reaction conditions for both silanization and subsequent polyion deposition. Our tools have primarily been ellipsometry and UV/VIS absorption spectroscopy. Ellipsometry yields a measurement of the thickness of the attached film. Single crystal silicon wafers with one mirror-polished face make nearly ideal model substrates for this experiment. Anticipated thicknesses are 5 - 10 Å for the silane layer and roughly 10 Å for each polymer layer. Silanization frequently leads to attached clumps of siloxane polymer; that event is manifested by rather large apparent thicknesses for the silane layer and a visible haze or cloudiness on the mirror silicon surface. UV/VIS absorption spectra can be obtained when the substrates are polished quartz slides. The Chemistry Department has a UV/VIS spectrometer (Hewlett Packard 8452) with adequate sensitivity to produce an absorption spectrum of two layers of polyion, one on each side of the quartz slide. This technique is also useful in following the buildup of multilayers of polyions. Peak absorbances at certain key wavelengths should scale linearly with the number of deposition steps.

The formation of a monolayer of silane has proven to be a troublesome process. Two extremes are often seen: the formation of polymer clumps or the presence of very little bound silane. The general protocol requires cleaning of the substrate, exposure of the substrate to the silane, and curing of the silane layer. The problem appears to be the middle step.

Cleaning on Si wafers and quartz slides is often performed by immersion in "piranha" solution, a very powerful oxidizing bath composed of 3 parts concentrated sulfuric acid to 1 part 30% hydrogen peroxide at a temperature of about 100°C. One minute in this bath followed by a water rinse produces a completely hydrophilic (water-wetted) surface, a very sensitive criterion for a surface contamination by organics. Since the SAW crystals would not survive this cleaning procedure, cleaning by argon plasma (using a commercial plasma cleaner) has also been explored. Argon plasma cleaning yields a surface which is marginally hydrophilic (some water beading), indicating that some contamination is still present. The argon plasma is capable of removing previously bonded silane layers provided that the cleaning is done for at least 30 minutes.

The reaction step is dictated to some extent by the properties of the silane. We have focused mainly on two silanes: $(\text{MeO})_3\text{Si}(\text{CH}_2)_3\text{NHCH}_2\text{CH}_2\text{NH}_2$ (abbreviated to en-silane, where en = ethylenediamine) and $(\text{MeO})_3\text{Si}(\text{CH}_2)_3\text{NMe}_3^+\text{Cl}^-$ (abbreviated to quat-silane). The first silane is volatile so that silanization can be performed in the liquid or in the vapor phase. The table below summarizes the results of various silanization methods.

Table 1
en-Silanization Reaction Conditions

<u>Conditions</u>	<u>Result</u>
Expose substrate to refluxing toluene with 5% silane	Polymer deposition
Immerse substrate in cyclohexane solution	$25 \pm 5 \text{ \AA}$ thickness
Immerse substrate in neutral water solution	No deposition
Immerse substrate in acidic water solution	No deposition
Immerse substrate in 5-10% toluene solution	7 - 26 $\text{\AA}$ thickness

Acidic conditions are tested because the acid should catalyze hydrolysis of the Me-OSi bond to the silanol HO-Si; the latter moiety is believed to be the active agent that bonds to surfaces. The last condition has proven to be the most reliable method for deposition 1 to 3 monolayers of silane; the optimum immersion time is 30 minutes.

The quat-silane is supplied as a 50% solution in methanol and is non-volatile so deposition is only performed in the liquid phase.

Table 2
quat-Silane Reaction Conditions

<u>Conditions</u>	<u>Result</u>
Immerse substrate in neutral 5% methanol solution	3-5 Å thickness
Immerse substrate in acidic 5% methanol solution	3 Å thickness
Immerse substrate in neutral 5% aqueous solution	0 - 3 Å
Immerse substrate in acidic 5% aqueous solution	No deposition

Despite the rather thin layers (probably submonolayer coverages of silane), substrates modified using the first condition successfully adsorbed a polyanion (see below).

The curing step consists of placing the substrate in a warm (100°C) oven for about 5 minutes. This step promotes formation of the Si-O-Si bond by driving off water and generally enhances stability of the silane layer.

The protocol for deposition of each polyion layer requires immersion of the silanized substrate in an aqueous solution of the polyion for a minimum of 20 minutes followed by a water rinse. The concentration of the polyion is about 0.02 M with respect to the monomer unit. If the silane layer is en-silane, then all deposition solutions are made acidic (pH 1-2) to ensure that the amine groups on the silane are protonated (and hence cationic). In all cases the polyanion is poly(styrene sulfonate) (PSS). The polycation was either poly(vinylpyridine) (PVP), poly(allylamine) (PAA) or poly(vinylmethylpyridinium) (PVPM⁺) (synthesized by reacting PVP with methyl sulfate). The first two polymers are only cationic if the solution is acidic; the latter polymer can be adsorbed from neutral solution.

We focused on demonstrating that the multilayers deposited in a layer-by-layer fashion, and on determining the approximate thickness of each layer. The latter parameter was determined either after each deposition step or after 10 layers (5 polyanion + 5 polycation) were deposited. Our general observation is that thicker layers appear to deposit if the substrate is simply rinsed with clean water after each deposition and then immersed while still wet in the next solution. Stepwise thickness measurements by both ellipsometry and UV/VIS absorption require that the substrate is dried after each deposition step. Drying the substrate sometimes leads to no adsorption of the polyion in the next deposition solution.

Table 3 shows the results of one experiment in which the substrate is silicon and ellipsometry is the probe. Thicknesses are in Å.

Table 3
Ellipsometry of PSS/PAA Multilayers

Condition	Total Thickness	Thickness Increment
en-silane layer	10	10
Adsorb PSS	27	7
Adsorb PAA	28	1
Adsorb PSS	38	10
Adsorb PAA	44	6
Adsorb PSS	57	13
Adsorb PAA	62	5
Adsorb PSS	69	7
Adsorb PAA	73	4
Adsorb PSS	82	9
Adsorb PAA	86	4

Adsorption of PSS, the polyanion, leads to a greater increase in the apparent incremental thickness than adsorption of the polycation PAA; we do not know if the PAA layer is thinner or if some of the PSS layer is removed during adsorption of the PAA. The average thickness per polyion layer is 8 Å. A similar result is obtained when the silaneWhen the deposition procedure is repeated without the drying step (i.e. ellipsometry performed after silanization and after deposition of 5 layers each of PSS and PAA), the average thickness per polyion layer is 17 Å. Other experiments using PSS + PVP yield average thicknesses of 10 - 13 Å per layer. Consequently some polyion is lost when the substrate is dried after each deposition. For comparison, Decher et al. [*Thin Solid Films* 1992, 210/211, 831-5; *Langmuir* 1993, 9, 181-6] obtained average layer thicknesses of 5 - 10 Å depending on the concentration of inert salts in the deposition solution.

When the substrate is modified with quat-silane, subsequent polyion deposition can be performed in near neutral solution (pH 7-8 using a carbonate buffer). Adsorption of alternate layers of PSS and PVPMe⁺ yields incremental thicknesses of about 2-3 Å up to the 8th layer. No further layers of PSS or PVPMe⁺ would adsorb onto the substrate. We speculate that the substrate was not evenly modified with the quat-silane, so that the polyions were not adsorbing as homogeneous layers.

Blank experiments i.e. polyion deposition without the silane layer show buildup of polyion layers only if the substrate is not dried before immersion in the next deposition solution.

Further evidence for systematic buildup of polyion layers is obtained by UV/VIS spectroscopy. Figure 2 shows the absorption spectra after deposition of the 7th, 8th, 9th and 10th polyion layers of PSS and PVP; en-silane provides the anchor for these layers. In this sequence the even-numbered layers are PVP and the odd-numbered layers are PSS. Both polyions contain aromatic groups which are expected to absorb in the 200 - 300 nm region of the spectrum. The peak at 226 nm appears upon absorption of the 1st PSS layer, while the peak at 256 nm appears upon absorption of the 1st PVP layer, so assignment of the peaks is easy. We do not have the relative molar absorptivities for these peaks, so it is not possible to convert the absorbances to concentrations and then to thicknesses. However, it is instructive to plot the peak absorbances as a function of layer number (Figure 3). The absorbances always show an increase when PSS is adsorbed, but a smaller increase or even a decrease when PVP is adsorbed. The absorbances increase linearly with layer number only for alternate layer numbers i.e. when the outermost layer is the same polyion; linear regression lines are shown for the last four data points with odd or even layer numbers respectively. Layers 1 and 2 have anomalous absorbances, so the intercept is not exactly zero. We infer from this data that adsorption of PSS results in a large increase in thickness while adsorption of PVP actually decreases the multilayer thickness. This conclusion is consistent with the ellipsometry results given above. The cause of this strange behavior is not known, nor is its relevance to chemical sensing clear.

C. Characterization of the SAW device in Flowing Dry Gas.

(need report by Mark)

One problem in sensor design is the level of background noise or drift exhibited by the sensor in the absence of the analyte. The limit of detection for a sharp pulse of analyte is set by the short term noise level, while the limit of detection for slow changes in analyte concentration depend on the drift rate of the sensor signal. A set of experiments has been performed with an uncoated SAW crystal as the sensing crystal to provide an estimation of these two parameters. In most of these experiments, both the beat frequency ($\Delta f = f(\text{sample crystal}) - f(\text{reference crystal})$) and the actual frequency of the sample crystal are monitored. The beat frequency is directly sampled by the computer with the counter/timer board and Femtometric software (resolution 1 Hz), while the sample frequency is measured with the Hewlett Packard electronic counter (resolution 10 Hz). These frequencies are converted to ppm by the equation:

$$\Delta f(\text{ppm}) = [f(\text{Hz}) - f_i(\text{Hz})]/200$$

where f_i is the initial frequency reading (typically 110 KHz for the beat frequency and 199 MHz for absolute frequency of the sample crystal). An increase in $\Delta f(\text{ppm})$ is equivalent to an increase in mass of a coating on the SAW crystal. Plotting both quantities on the same graph shows whether all of the changes in Δf are caused by changes in the frequency of the sample SAW crystal.

Figure 4 shows a most favorable case for sensitive detection. The SAW crystal has been allowed to stabilize for a half-hour in flowing argon (the air purifier was not ready at the time of this experiment). The short term noise, defined as the standard deviation of 6 points spanning 1 minute, is about ± 0.005 ppm (± 1 Hz). The beat frequency is drifting at about $+0.005$ ppm/min. Under these conditions it would be easy to detect a change of beat frequency of 0.1 ppm over 1 minute. The theoretical mass sensitivity for a 200 MHz SAW device is roughly 10^{-9} g/cm² = 50 Hz = 0.25 ppm. Since the active area of the SAW device is 0.2 cm², the SAW device can detect adsorption of 80 pg of analyte. In Figure 5, the SAW crystal has been removed from the microbalance, subjected to a 1-minute cleaning in an argon plasma, and remounted on the microbalance. The measurements of frequency immediately after mounting the sample SAW crystal show a much higher drift of Δf when the surface of the SAW crystal has been perturbed and not allowed to re-equilibrate. The initial drift rate is nearly 1 ppm/min, slowing to about 0.13 ppm/min after 20 minutes. The squares show that almost all of the drift is in the frequency of the sample SAW crystal; in this case the drift is probably due to water absorption into the silica layer protecting the electrodes. There is a small drift component associated with the reference SAW crystal during warmup of the microbalance. The much higher drift rate in Δf decreases the limit of detection by a factor of 20 or more.

D. Humidity Sensitivity of a Polyion Layer on the SAW Crystal.

We have invested considerable effort in developing the method for putting polyion layers on a Si/SiO₂ surface, as noted in the previous section. However, attempts to apply the method to SAW crystals have met with disaster. The initial step, silanization of the silica surface with en-silane, and/or the subsequent step, adsorption of the polyanion from acidic solution, cause rapid destruction (both dissolution and delamination) of the aluminum electrodes on the surface of the SAW crystal. Apparently the "protective" SiO₂ layer covering the electrodes is not adequate protection against corrosive reagents. Neither contact with pure water nor argon plasma cleaning (which is part of the pretreatment for polyion deposition) cause any visible damage to the electrodes; the SAW crystal functions after these treatments. We have also tried reaction of SAW crystals with the quat-silane; a "monolayer" of this silane permits adsorption of the polyanion from neutral aqueous solutions. However, this silane attacks the aluminum electrodes in both neutral aqueous and neutral methanolic solutions. Clearly another method for initiating adsorption of polyions onto the SAW crystal will have to be developed.

While this problem is being addressed, we have studied the response of the SAW crystal to humidity changes in the air stream. Both the uncoated SAW crystal and any polyion layers are anticipated to exhibit an affinity for water vapor, and hence it is necessary to map the response of the sensor to relative humidity. Later, when sensor response to organic vapors will be examined, relative humidity as well as temperature will be important parameters to explore.

Figure 6 shows the response of an uncoated SAW crystal to an air stream with different relative humidities; in these experiments the flow rates of the wet and dry air are adjusted so that the total flow rate is constant. At low R.H.'s the sample SAW crystal responds rapidly (within one data point, with data acquisition every 10 s) to changes in the R.H. A slower response appears at the highest R.H., suggesting slow adsorption of multilayers of water or slow changes in the visco/elastic properties of the silica protective coating over the SAW electrodes. A calibration curve (Figure 7) demonstrates that the response is nonlinear; literature reports [Alder et al., *Anal. Chim. Acta* **1991**, *248*, 337-44 and *Talanta* **1992**, *39*, 1505-9] suggest that a quadratic response of Δf to R.H. is typical. As expected, the frequency of the reference SAW crystal does not change with R.H.

In order to get a "monolayer" of a polyion on the surface of a SAW crystal, a single drop of a 10^{-5} M PSS solution (the molarity refers to the monomer unit) in water + methanol is placed on the surface of a SAW crystal and allowed to evaporate. Ellipsometry on a silicon wafer demonstrates that a single drop leaves a polyion layer approximately 20 Å thick i.e. near monolayer dimensions. Figure 8 shows the response of the coated SAW crystal to ascending and descending R.H.'s as a function of time, and Figure 9 is the corresponding calibration curve for R.H. Δf again responds very rapidly to R.H. changes, except at the highest R.H. The oscillations at the beginning of each humidity step occur as the R.H. value is being adjusted. The response is nearly reversible i.e. independent of the previous R.H, and again is roughly a quadratic function of R.H. Comparison of Figure 9 with Figure 7 shows that the presence of the very thin polyion layer almost triples the sensitivity of the SAW device to humidity changes. The maximum Δf value, 150 ppm, corresponds to about 3×10^{-8} mol/cm² of water; for comparison a "monolayer" of water is about 10^{-9} mol/cm² (NB: these estimates assume that Δf is due only to mass changes).

These preliminary experiments emphasize a rather significant problem in sensors based on polyion multilayers: how does one compensate for humidity changes? One strategy would be to coat the reference SAW crystal with a polyion multilayer which lacks the specificity of the sample SAW crystal for the analyte and to place the reference SAW crystal in the sample air stream. If the humidity response of the two multilayers can be matched, then the beat frequency will be less indicative of R.H. changes and more specific to the analyte. The extent to which this compensation can be accomplished remains to be seen.

E. Summary.

The vapor generator system is close to completion and has already been used to test the humidity response of SAW devices. An uncoated SAW crystal and a SAW crystal with a thin polyanion layer both show a quadratic dependence of the beat frequency with relative humidity; the polyanion layer greatly increases the sensitivity of the SAW crystal to water vapor. Silanization and multilayer deposition of polyions have been studied on model substrates. Polyion layers of roughly 10 Å thickness each can be deposited sequentially on a

substrate provided that 1 to 3 silane monolayers with charged groups are evenly bonded to the substrate. However, the silanization procedure results in destruction of the aluminum electrodes on the SAW crystal.

Two major issues need to be addressed: (a) how to deposit stable multilayers of polyions without destruction of the SAW electrodes, and (b) how to design selective response into the coating while compensating for changes in the relative humidity.

Arrows show air flow

Figure 1A

A-Mixing Coil
 B-Stirrer
 C -Droplet Catcher
 D/E - Bubbler

Figure 1B

Multilayer Spectra PSS/PVP

Figure 2

Multilayer absorbances PSS/PVP

Figure 3

Short term noise and drift

Uncoated SAW crystal

Figure 4

Short term noise and drift After plasma cleaning

Figure 5

Humidity Response Uncoated SAW Crystal

Figure 6

Humidity Response Uncoated SAW Crystal

Figure 7

Humidity Response Coated SAW Crystal

Figure 8

Humidity Calibration Curve Coated SAW Crystal

Figure 9

WINFIELD LOCK AND DAM REMEDIATION
(Project MC-9)

Quarterly Report IV for Period
July 1 through September 30, 1993

Work Performed Under Contract
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For
U.S. Department of Energy
Office of Fossil Energy
Morgantown Energy Technology Center
Morgantown, West Virginia

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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.

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 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).

WVU INVOLVEMENT AT WINFIELD

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 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 Umbrella Committee was formed in January 1993 and consisted of politicians and citizens whose job included overseeing and evaluating ACE operations. Since its formation, the Umbrella Group has held meetings every second and fourth Tuesday of the 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.

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.

CURRENT SITUATION

Lock and Dam

The Corps of Engineers began excavating for the lock last spring. Only noncontaminated areas have been excavated. The Corps has begun the development of the risk assessments needed to begin excavation of the contaminated soil. Current plans are for excavation (preceded by dismantling and decontamination of the buildings) to begin in November 1994 and be completed in December 1995. The bids for the temporary storage buildings have been opened and the buildings will be ready by next November. The Corps has until February to decide whether the scrubber must be added to the building. 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).

QUARTERLY ACCOMPLISHMENTS

Meeting with Army Corps of Engineers (Cincinnati, OH)

The Army Corps of Engineers (ACE), in their quest to develop a suitable remediation scheme for the Winfield site, contacted the University of Cincinnati 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 attendance 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 (since transferred to the Missouri 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 suitability 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 formidable effort in computer based site visualization 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 this summer, 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 September 14 meeting was cancelled (although I showed up) and I was in Atlanta at an ACS meeting for Emerging Remediation Technologies on September 28.

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. The full discussion of the COC report occurred in the next quarter and discussion will be deferred. The preliminary documents will largely be finished by the end of the next quarter and the risk assessment can be discussed then with some sense of perspective.

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). The Draft Survey Results are appended (Appendix I) and are self explanatory.

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 from becoming ill. In the end, the Group chose to concentrate on demanding appropriate monitoring (and, if necessary, appropriate response to exposure incidents).

WINFIELD CLEANUP SURVEY

DRAFT

Prepared By

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This project was funded by the NRCCE, West Virginia University. The authors wish to thank Ray Lovett for his assistance in funding the project, and the moral support provided to the researchers. We also wish to thank the many graduate students who helped in the initial interviews in Winfield for their assistance in developing a final version of this survey. Special thanks go to Kristie Carnine for her continued assistance in telephone interviewing, coding of questionnaires, and call backs to verify responses. Michael Goldcamp also assisted with coding and data entry on the surveys.

EXECUTIVE SUMMARY

The cleanup of the Winfield Locks and Dam site is an important issue in Putnam County, being cited by 8.3% as the most important problem overall, and by 23.3% as the most important environmental problem. Over 80% have heard of the cleanup, and about 55% are at least somewhat concerned (over 65% of those who had heard of the project). Although people are concerned, there is no one issue about which they are concerned, except for general concerns about health and safety.

The incinerator is an important issue to a strong minority of respondents. When attitudes about a temporary incinerator and a permanent one are combined, it appears that about 70% of the respondents have at least some minor opposition. Although 45% support a temporary incinerator and 17% support a permanent one, feelings appear to be unstable. Incineration in some form has greater support than long-term storage, hauling the waste away, burying it, or other solutions mentioned. There is no solution which has either widespread information or support.

Although the Federal government ranks low on the feelings scale, the Corps of Engineers does not appear to be widely distrusted in the community. Over 70% of the respondents believe the Corps has not already made its mind up about solutions. Over 17% of the respondents prefer to receive their information about the project from the Corps.

An Umbrella Committee has been formed to serve as a liaison to the community, but only 20% of the respondents had heard of it at the time of these interviews. Only 14.3% prefer the Umbrella Committee as their primary source of information about the cleanup, although 64.2% believe it should serve either an information or watchdog function. The low ratings given to PROTECT and WVCAG on preferences as sources of information indicate that the committee should work to ensure that it is not dominated by these groups. As Congressman Wise appears to enjoy high popularity (15.6% want his office to provide information on the cleanup), his office may want to take a leading role.

Despite concerns among community leaders that the schools in the area could be seriously affected by the cleanup, few respondents (only about 16%) shared that concern.

Traditional demographic variables (eg. age, income, education) do not explain very much variation in respondent's opinion about the cleanup. Respondents who are most concerned are also most opposed to any form of incineration. They are also the most risk averse of our respondents. Although distance from the site, and the presence of respondents' children

in the local schools affected their knowledge of the project (have they heard of it), it is not related to their level of concern. (There was one exception: Respondents living in the area immediately surrounding Winfield/Eleanor are the most concerned about the clean-up.) A variable labeled AVERISK (created by taking the mean of all eleven risk questions) does the best job of explaining level of concern. Surprisingly, overall an incinerator is seen as extremely risky by only 24.6% of the respondents, while living near a hazardous waste landfill is rated as very risky by 32.8%. Incinerators appear to be rated at about the same level of risk as chemical plants (23.9% said chemical plants take more than 10 years off a person's life). As the site is now virtually a landfill, and chemical plants abound in the area, the level of concern over an incinerator should be about the same as it would be if another chemical plant wanted to locate in the area, and an incinerator should be preferred to keeping the contamination in the ground.

Although concern exists among all parts of the population, it is most likely to exist among the following: females; people who are risk averse; those that have paid attention to the issue and attend meetings; those who dislike the military, and respondents that feel the government does not sufficiently regulate on environmental issues. (Additional attitudinal factors are noted in the tables). Probably the most consistent predictor of concern and attitudes on incineration is a respondent's AVERISK.

Informing the population about the issues may be difficult, as the unconcerned are also unlikely to attend public meetings. Newspapers and television are the most often used general sources of information, so television programs may be the best way to get information out to all citizens.

THE WINFIELD SURVEY PROJECT

RESEARCH DESIGN:

The questionnaire used in this study was developed from a structured personal interview which was conducted during January through February of 1993. Interviewees were important actors on this issue (i.e. members of PROTECT, WVCAG, members of the Umbrella Committee, elected officials, the county school superintendent, Chamber of Commerce personnel) and a random sample of the populations of Winfield, Scott Depot, Hurricane, and Eleanor. These interviews, which were primarily open-ended, were used to develop an understanding of the issues which were likely to be of concern to the general population. One hundred fifteen interviews were completed. Because the interview format was adjusted frequently as more information was developed, no frequencies can easily be developed.

During the months of March and April of 1993, telephone interviews were conducted with 416 citizens of Putnam County. A population list of residences was obtained from Stephen Knox Associates, an organization which develops mailing and telephone lists for survey organizations. From this list, households were randomly selected, and a telephone call sheet was created. Ten percent of the households in every community were selected, with the exception of Winfield and Eleanor. For these communities, 20% of the households were sampled. All households on the list were contacted three times unless interviews were completed or refused.

A total of 1471 numbers were sampled. Of these, contact was made with potential respondents at 959, for a response rate of 43.4%. This is a low response rate, especially for West Virginia, which traditionally has high survey response rates. For this reason our results may be biased in favor of respondents with higher levels of concern about the issue than the general population. Older citizens were particularly unwilling to respond to the survey. A complete breakdown of response rates by exchanges is provided in the Appendix.

REPORT FORMAT:

This report contains, on pages 1 through 40, the response frequencies for all questions on the Winfield Survey of Putnam County conducted in the Spring of 1993. Each question is listed along with responses and comments. Comments are added in bold print.

Contingency Tables

Two tables provide a summary of important findings of bivariate analysis. Demographic variables (gender, where people live, age, income, education and gender) are tested to determine their relationship with level of concern about the cleanup project (CONCERN), knowledge of the project (KNOW) strong opposition to any form of incineration, and attitudes about the riskiness of living near either a hazardous waste incinerator (HWINC) or a hazardous waste landfill (HAZW). In addition, variables which were

constructed by taking the mean response to all eleven risk variables (Q. 7-1 thru 7-11) AVERISK, and those activities which are involuntary (FORCED) are included in these analyses. These tables are located on pages 41 and 42.

Multivariate Analysis

In addition, we ran two multivariate regression models using Ordinary Least Squares. By using a multivariate model the effect that a particular independent variable has on a dependent variable is made more certain because the potentially confounding effects of other independent variables are held constant. Our main purpose was to determine which of the questionnaire items were statistically related to two particular dependent variables. The following dependent variables were used in the analyses.

1. Question 10c, CONCERN: How concerned are you about the Cleanup Project?

Extremely

Somewhat

Only Slightly

Not at All

Not Heard

2. Question 12a, TEMP: Do you Support or oppose a temporary incinerator?

Strongly Support

Somewhat Support

Neutral

Somewhat Oppose

Strongly Oppose

A list of over 25 of the question items from the survey was regressed on each of these dependent variables. In the report that follows those variables that were CONSISTENTLY significantly related to either CONCERN and/or opinions about a TEMPORARY INCINERATOR will be noted and discussed. (Details concerning these models are available upon request.)

Note: Two Tables are included at the end of this report on pages 43-44. Each table presents the OLS models used to substantiate the statistically significant relationships between either CONCERN or TEMP and the other independent variables noted in the report.

QUESTIONS AND FREQUENCY DISTRIBUTIONS FOR COMPLETE SURVEY

1. PROB: What is the most important problem facing your community this year?

Value Label	Frequency	Valid Percent	Cum Percent
NO PROBLEMS	42	11.3	11.3
INCINERATOR	5	1.3	12.7
WINFIELD SITE	26	7.0	19.7
CRIME DRUGS	28	7.5	27.2
ECONOMY	88	23.7	50.9
SCHOOLS	37	10.0	60.9
RAPID GROWTH	34	9.2	70.1
OTHER SOCIAL	25	6.7	76.8
LANDFILL RECYCLING	14	3.8	80.6
OTHER ENVIRONMENTAL	20	5.4	86.0
OUTSIDERS POLITICIAN	5	1.3	87.3
TAXES	25	6.7	94.1
SEWERS UTILITIES	10	2.7	96.8
AIRPORT	2	.5	97.3
OTHER	10	2.7	100.0
DK-NR	45	Missing	
	-----	-----	-----
Total	416	100.0	100.0

Respondents were given the opportunity to give two responses, but virtually no one did. If a respondent did give more than one response, and one of those responses referred to the Winfield Locks and Dam project or the cleanup, that response was coded. The economy and economic conditions, including unemployment was the response of 23.7% of the respondents. Of the respondents who gave an answer, 11.3% said there were no problems in their community. Over 10% however, said they did not know what problems faced their community. However, 8.3% of the respondents listed something about the Winfield Locks and Dam cleanup project. Only schools and related issues, problems related to growth and economic problems were cited more often.

2. ENVPROB: What is the most important environmental problem facing your community this year? Open-ended with two responses allowed. Only one was coded due to lack of response to the second probe.

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
NONE	0	50	12.0	13.5	13.5
INCINERATOR	1	10	2.4	2.7	16.2
OTHER WINFIELD SITE	2	80	19.2	21.6	37.7
AIR/WATER	3	45	10.8	12.1	49.9
TRASH LITTER	4	87	20.9	23.5	73.3
LACK OF RECYCLING	5	21	5.0	5.7	79.0
GENERAL AIR WATER	6	35	8.4	9.4	88.4
DRINKING WATER	7	13	3.1	3.5	91.9
GROWTH	8	4	1.0	1.1	93.0
ENVIRONMENTALISTS	11	5	1.2	1.3	94.3
OTHER	12	13	3.1	3.5	97.8
TIMBER	13	7	1.7	1.9	99.7
SEWAGE-SEWERS	14	1	.2	.3	100.0
	99	45	10.8	Missing	
		-----	-----	-----	
Total		416	100.0	100.0	

Again, a high percentage (22.8%) either did not know of any problems or specifically said there were no problems. Of those who did respond, 29.2% cited litter, garbage, or a lack of recycling as the most important problem, and 24.3% listed either something related to the Winfield site or the incinerator specifically.

The following questions (3A - 3E) are close-ended with five responses. Don't know was allowed, but was not given as an option to respondents. These items measure general attitudes about participation.

3A. WORRY: It is no use worrying about public affairs; I cannot do anything about them anyway.

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
AGREE STRONGLY	1	23	5.5	5.6	5.6
AGREE SOMEWHAT	2	62	14.9	15.0	20.6
NEUTRAL	3	13	3.1	3.1	23.7
DISAGREE SOMEWHAT	4	134	32.2	32.4	56.2
DISAGREE STRONGLY	5	181	43.5	43.8	100.0
DONT KNOW	9	3	.7	Missing	
		-----	-----	-----	
Total		416	100.0	100.0	

Most respondents (77.3%) disagree that they cannot do anything about public issues. This indicates a high degree of faith in citizen participation.

3B. STRICT: I think I am stricter about right and wrong than most people.

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
AGREE STRONGLY	1	141	33.9	34.3	34.3
AGREE SOMEWHAT	2	169	40.6	41.1	75.4
NEUTRAL	3	49	11.8	11.9	87.3
DISAGREE SOMEWHAT	4	42	10.1	10.2	97.6
DISAGREE STRONGLY	5	10	2.4	2.4	100.0
DONT KNOW	9	5	1.2	Missing	
		-----	-----	-----	
Total		416	100.0	100.0	

It is surprising that 75.4% of the respondents gave what is traditionally considered a conservative, hierarchical response to this question. This may indicate a strong religious, conservative component to the population.

MULTIVARIATE RESULTS:

The Multivariate results indicted that the way respondents answered this question was significantly related to their degree of concern over the clean-up. In general, those that felt stricter about right and wrong were also more likely to be concerned about t a clean-up.

3C. VISION: If people have vision and ability to acquire property they ought to be allowed to enjoy it.

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
AGREE STRONGLY	1	211	50.7	50.8	50.8
AGREE SOMEWHAT	2	165	39.7	39.8	90.6
NEUTRAL	3	21	5.0	5.1	95.7
DISAGREE SOMEWHAT	4	15	3.6	3.6	99.3
DISAGREE STRONGLY	5	3	.7	.7	100.0
DONT KNOW	9	1	.2	Missing	
		-----	-----	-----	
Total		416	100.0	100.0	

Again, this question measures belief in traditional American beliefs in individualism and property rights, which are now considered to be conservative beliefs. Over 90% of the respondents agree with the statement, indicating a strong conservative component in the population.

3D. TAX: I support a tax shift so that burdens fall more heavily on corporations and people with large incomes.

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
AGREE STRONGLY	1	166	39.9	40.8	40.8
AGREE SOMEWHAT	2	128	30.8	31.4	72.2
NEUTRAL	3	25	6.0	6.1	78.4
DISAGREE SOMEWHAT	4	48	11.5	11.8	90.2
DISAGREE STRONGLY	5	40	9.6	9.8	100.0
DONT KNOW	9	9	2.2	Missing	
		-----	-----	-----	
Total		416	100.0	100.0	

It is interesting that respondents tend to believe in property rights, but also believe in progressive income taxes. Over 70% of the respondents support higher taxes on corporations and the wealthy.

3E. CITPRT: Citizen participation in decision making is essential for solving environmental problems.

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
AGREE STRONGLY	1	197	47.4	48.5	48.5
AGREE SOMEWHAT	2	189	45.4	46.6	95.1
NEUTRAL	3	7	1.7	1.7	96.8
DISAGREE SOMEWHAT	4	10	2.4	2.5	99.3
DISAGREE STRONGLY	5	3	.7	.7	100.0
DONT KNOW	9	10	2.4	Missing	
		-----	-----	-----	
Total		416	100.0	100.0	

As indicated by Question 3A, respondents appear to have a high degree of faith in citizen involvement in policymaking, especially with regard to environmental questions. Little relationship was found between this variables and levels of concern or knowledge because there is very little variation in response.

4. GOVLIS: How often do you think government listens to what people like you think when it decides what to do?

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
ALWAYS	1	8	1.9	2.0	2.0
MOST OF THE TIME	2	19	4.6	4.6	6.6
SOME OF THE TIME	3	266	63.9	64.9	71.5
NEVER	4	117	28.1	28.5	100.0
DK	9	6	1.4	Missing	
		-----	-----	-----	
Total		416	100.0	100.0	

Despite the faith in citizen participation, respondents appear to believe that government ignores them most of the time. Only 6.6% believe government listens to them most of the time or always. Again, there was insufficient variation in response to make this question useful to our analysis.

Question five measured emotional responses toward several entities. Responses were close-ended. On page 13, responses for these items have been ranked to allow for comparison among the entities.

5A. BIGB: Emotional feelings toward big business

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
VERY POSITIVE	1	39	9.4	9.7	9.7
SOMEWHAT POSITIVE	2	155	37.3	38.7	48.4
NEUTRAL	3	116	27.9	28.9	77.3
SOMEWHAT NEGATIVE	4	68	16.3	17.0	94.3
VERY NEGATIVE	5	23	5.5	5.7	100.0
	9	15	3.6	Missing	
		-----	-----	-----	
	Total	416	100.0	100.0	

5B. FEDS: Emotional feelings toward the Federal Government

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
VERY POSITIVE	1	18	4.3	4.4	4.4
SOMEWHAT POSITIVE	2	101	24.3	24.9	29.4
NEUTRAL	3	84	20.2	20.7	50.1
SOMEWHAT NEGATIVE	4	124	29.8	30.6	80.7
VERY NEGATIVE	5	78	18.8	19.3	100.0
	9	11	2.6	Missing	
		-----	-----	-----	
	Total	416	100.0	100.0	

5C. ENV: Emotional feelings toward environmental groups

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
VERY POSITIVE	1	55	13.2	13.5	13.5
SOMEWHAT POSITIVE	2	159	38.2	39.1	52.6
NEUTRAL	3	98	23.6	24.1	76.7
SOMEWHAT NEGATIVE	4	68	16.3	16.7	93.4
VERY NEGATIVE	5	27	6.5	6.6	100.0
	9	9	2.2	Missing	
		-----	-----	-----	
	Total	416	100.0	100.0	

5D. LABOR: Emotional feelings toward labor unions

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
VERY POSITIVE	1	93	22.4	22.9	22.9
SOMEWHAT POSITIVE	2	105	25.2	25.9	48.8
NEUTRAL	3	89	21.4	21.9	70.7
SOMEWHAT NEGATIVE	4	64	20.2	20.7	91.4
VERY NEGATIVE	5	35	8.4	8.6	100.0
	9	10	2.4	Missing	
		-----	-----	-----	
Total		416	100.0	100.0	

5E. MIL: Emotional feelings toward the Military

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
VERY POSITIVE	1	146	35.1	35.6	35.6
SOMEWHAT POSITIVE	2	175	42.1	42.7	78.3
NEUTRAL	3	59	14.2	14.4	92.7
SOMEWHAT NEGATIVE	4	22	5.3	5.4	98.0
VERY NEGATIVE	5	8	1.9	2.0	100.0
	9	6	1.4	Missing	
		-----	-----	-----	
Total		416	100.0	100.0	

5F. PROF: Emotional feelings toward university professors

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
VERY POSITIVE	1	74	17.8	19.4	19.4
SOMEWHAT POSITIVE	2	150	36.1	39.3	58.6
NEUTRAL	3	126	30.3	33.0	91.6
SOMEWHAT NEGATIVE	4	24	5.8	6.3	97.9
VERY NEGATIVE	5	8	1.9	2.1	100.0
	9	34	8.2	Missing	
		-----	-----	-----	
Total		416	100.0	100.0	

5G. LEGAL: Emotional feelings toward the legal profession

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
VERY POSITIVE	1	24	5.8	5.8	5.8
SOMEWHAT POSITIVE	2	97	23.3	23.6	29.4
NEUTRAL	3	100	24.0	24.3	53.8
SOMEWHAT NEGATIVE	4	107	25.7	26.0	79.8
VERY NEGATIVE	5	83	20.0	20.2	100.0
	9	5	1.2	Missing	
		-----	-----	-----	
Total		416	100.0	100.0	

In ranking the entities toward which respondents were asked to state their emotional feelings, we find that respondents have mixed emotions.

<u>GROUP</u>	<u>PERCENT WITH SOMEWHAT OR VERY POSITIVE FEELINGS</u>
Military	78.3%
University Professors	58.6%
Environmental Groups	52.6%
Labor Unions	48.8%
Big Business	48.4%
Federal Government	29.4%
Legal Profession	29.4%

Part of the positive response to the military may be attributed to the debate about gays in the military which was in the news at the time of these interviews. Many respondents prefaced their answer with remarks indicating support for the military's position against gays. It is also possible that the fact that West Virginia University was conducting the survey may have led to more positive feelings about university professors than really exists. Perhaps most interesting is the virtual tie between labor unions and big business. This indicates that our respondents were almost evenly divided between management and labor.

MULTIVARIATE RESULTS: Three of these items proved to be significantly related to a respondents level of concern about the clean-up: 1). The more NEGATIVE a respondent felt toward the MILITARY the MORE Concerned they were about the clean-up; 2). The more NEGATIVE a respondent felt toward the FEDERAL GOVERNMENT the LESS CONCERNED they were about the clean-up; and 3). The more POSITIVE one felt about LABOR UNIONS the MORE CONCERNED they were about the Clean-up. The item that measures a respondent's attitude toward the MILITARY was also found to be significantly related to attitudes about a TEMPORARY INCINERATOR. In general, the more NEGATIVE a respondent was about the MILITARY, the more he or she OPPOSES the idea of a temporary incinerator.

6. REGS: Do you think, in general there is too much, too little, or about the right amount of government regulation and involvement in the area of environmental protection?

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
TOO MUCH	1	105	25.2	27.0	27.0
ABOUT RIGHT	2	115	27.6	29.6	56.6
TOO LITTLE	3	169	40.6	43.4	100.0
DK	9	27	6.5	Missing	
		-----	-----	-----	
Total		416	100.0	100.0	

Respondents are fairly evenly divided on this questions, although a plurality belief there are too few environmental regulations.

Multivariate Analysis: This variable was found to be significantly related to a respondents level of concern. Respondents that felt there was too little little government involvement and regulation tended to be more concerned about the clean-up.

This next series of questions were used to develop an index of respondents general level of risk aversion. A scale was created using all eleven activities, and obtaining the average response. In addition, scales were created taking the average response for risks we assume to be chosen voluntarily, i.e. smoking, abusing alcohol or drugs, keeping a handgun in the home, driving a car, or being married with children; versus those forced upon people, i.e. leaving near a garbage landfill, a hazardous waste landfill, a hazardous waste incinerator, a coal burning power plant, a nuclear power plant or a chemical plant.

7-1. SMOKE: How much do you think smoking could shorten a person's life span?

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
NO RISK	0	25	6.0	6.1	6.1
LESS THAN 1 YR OFF L	1	5	1.2	1.2	7.4
1-5 YEARS	2	77	18.5	18.9	26.2
5-10 YRS	3	143	34.4	35.0	61.3
MORE THAN 10 YRS	4	158	38.0	38.7	100.0
DK	9	8	1.9	Missing	
		-----	-----	-----	
Total		416	100.0	100.0	

7-2. GARBAGE: How much do you think living near a garbage landfill could shorten a person's life span?

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
NO RISK	0	162	38.9	40.3	40.3
LESS THAN 1 YR OFF L	1	34	8.2	8.5	48.8
1-5 YEARS	2	104	25.0	25.9	74.6
5-10 YRS	3	54	13.0	13.4	88.1
MORE THAN 10 YRS	4	48	11.5	11.9	100.0
DK	9	14	3.4	Missing	
		-----	-----	-----	
Total		416	100.0	100.0	

7-3. NUCLEAR: Living near a nuclear power plant?

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
NO RISK	0	101	24.3	25.5	25.5
LESS THAN 1 YR OFF L	1	22	5.3	5.6	31.1
1-5 YEARS	2	83	20.0	21.0	52.0
5-10 YRS	3	78	18.8	19.7	71.7
MORE THAN 10 YRS	4	112	26.9	28.3	100.0
DK	9	20	4.8	Missing	
		-----	-----	-----	
Total		416	100.0	100.0	

7-4. DRIVE: Driving a car 25 miles daily?

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
NO RISK	0	250	60.1	62.2	62.2
LESS THAN 1 YR OFF L	1	36	8.7	9.0	71.1
1-5 YEARS	2	64	15.4	15.9	87.1
5-10 YRS	3	33	7.9	8.2	95.3
MORE THAN 10 YRS	4	19	4.6	4.7	100.0
DK	9	14	3.4	Missing	
		-----	-----	-----	
Total		416	100.0	100.0	

7-5. HAZW: Living near a hazardous waste landfill?

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
NO RISK	0	34	8.2	8.6	8.6
LESS THAN 1 YR OFF L	1	16	3.8	4.0	12.6
1-5 YEARS	2	99	23.8	25.0	37.6
5-10 YRS	3	117	28.1	29.5	67.2
MORE THAN 10 YRS	4	130	31.3	32.8	100.0
DK	9	20	4.8	Missing	
		-----	-----	-----	
Total		416	100.0	100.0	

7-6. CHEM: Living near a chemical plant?

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
NO RISK	0	81	19.5	20.1	20.1
LESS THAN 1 YR OFF L	1	18	4.3	4.5	24.6
1-5 YEARS	2	108	26.0	26.9	51.5
5-10 YRS	3	99	23.8	24.6	76.1
MORE THAN 10 YRS	4	96	23.1	23.9	100.0
DK	9	14	3.4	Missing	
		-----	-----	-----	
Total		416	100.0	100.0	

7-7. HWINC: Living near a hazardous waste incinerator?

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
NO RISK	0	77	18.5	19.7	19.7
LESS THAN 1 YR OFF L	1	24	5.8	6.2	25.9
1-5 YEARS	2	103	24.8	26.4	52.3
5-10 YRS	3	90	21.6	23.1	75.4
MORE THAN 10 YRS	4	96	23.1	24.6	100.0
DK	9	26	6.3	Missing	
		-----	-----	-----	
Total		416	100.0	100.0	

7-8. DRUGS: Abusing alcohol or other drugs?

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
NO RISK	0	4	1.0	1.0	1.0
LESS THAN 1 YR OFF L	1	11	2.6	2.7	3.7
1-5 YEARS	2	69	16.6	16.8	20.5
5-10 YRS	3	142	34.1	34.6	55.1
MORE THAN 10 YRS	4	184	44.2	44.9	100.0
DK	9	6	1.4	Missing	
		-----	-----	-----	
Total		416	100.0	100.0	

7-9. GUN: Keeping a handgun in your home?

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
NO RISK	0	301	72.4	75.8	75.8
LESS THAN 1 YR OFF L	1	24	5.8	6.0	81.9
1-5 YEARS	2	36	8.7	9.1	90.9
5-10 YRS	3	20	4.8	5.0	96.0
MORE THAN 10 YRS	4	16	3.8	4.0	100.0
DK	9	19	4.6	Missing	
		-----	-----	-----	
Total		416	100.0	100.0	

7-10. COAL: Living near a coal-burning power plant?

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
NO RISK	0	219	52.6	54.1	54.1
LESS THAN 1 YR OFF L	1	21	5.0	5.2	59.3
1-5 YEARS	2	101	24.3	24.9	84.2
5-10 YRS	3	46	11.1	11.4	95.6
MORE THAN 10 YRS	4	18	4.3	4.4	100.0
DK	9	11	2.6	Missing	
		-----	-----	-----	
Total		416	100.0	100.0	

7-11. CHILD: Being married with children?

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
NO RISK	0	338	81.3	84.5	84.5
LESS THAN 1 YR OFF L	1	17	4.1	4.2	88.7
1-5 YEARS	2	19	4.6	4.7	93.5
5-10 YRS	3	13	3.1	3.2	96.7
MORE THAN 10 YRS	4	13	3.1	3.2	100.0
DK	9	16	3.8	Missing	
		-----	-----	-----	
Total		416	100.0	100.0	

AVERISK: The average level of risk assigned by respondents to all activities.

Value Label	Value	Frequency	Valid Percent	Cum Percent
0-1 YEARS	1	62	14.9	14.9
1-5 YEARS	2	197	47.4	62.3
5-10 YEARS	3	137	32.9	95.2
OVER 10 YRS	4	20	4.8	100.0
		-----	-----	-----
Total		416	100.0	100.0

Multivariate Results: This summary indicator was found to be significantly related to a respondent's level of concern. In general, the more risky a respondent perceives the world to be the more concerned they will be about the clean-up issue.

Multivariate Results: This summary indicator was ALSO found to be significantly related to a respondent's attitude toward a TEMPORARY INCINERATOR. In general, the more risky a respondent perceives the world the more they will be opposed to a temporary incinerator.

FORCED (Living near facilities):

Value Label	Value	Frequency	Valid Percent	Cum Percent
0-1 YEARS	1	72	19.7	19.7
1-5 YEARS	2	103	28.2	47.9
5-10 YEARS	3	132	36.2	84.1
OVER 10 YRS	4	58	15.9	100.0
DK	9	51		
		-----	-----	-----
Total		416	100.0	100.0

CHOSE (Drinking, Smoking, Keeping Guns, Marriage, Driving):

Value Label	Value	Frequency	Valid Percent	Cum Percent	Percent
0-1	1	57	15.4	15.4	
1-5	2	252	68.4	83.8	
5-10	3	55	14.8	98.6	
OVER 10	4	9	1.4	100.0	
DK	9	46			
		-----	-----	-----	
	Total	416	100.0	100.0	

Virtually no respondents feel voluntary risks are very risky. Forced risks are seen as far riskier by most respondents, although, as noted in the tables below, smoking and abusing alcohol and drugs are seen as the riskiest activities. Living near a hazardous waste landfill is seen as the riskiest involuntary activity. The overall ranking of activities by the percent of respondents saying it takes more than ten years off a person's life are:

(1) abusing drugs or alcohol (44.9%); (2) smoking (38.7%); (3) living near a hazardous waste landfill (32.8%); (4) living near a nuclear power plant; (5) living near a hazardous waste incinerator (24.6%); (6) living near a chemical plant (23.9%); (7) living near a garbage landfill (11.9%); (8) driving a car frequently (4.7%); (9) living near a coal power plant (4.4%); (10) keeping a handgun (4.0%); and (12) being married with children (3.2%).

The following set of questions measure attitudes about economic growth, science, technology and the tradeoff between risks and economic progress. Although 92.9% of the respondents believe economic growth is essential, only 13.4% believe the need for progress allows us to inflict risks on people without their consent.

8A. GROWTH: Economic growth is essential if society is to improve

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
AGREE STRONGLY	1	214	51.4	52.2	52.2
AGREE SOMEWHAT	2	167	40.1	40.7	92.9
NEUTRAL	3	10	2.4	2.4	95.4
DISAGREE SOMEWHAT	4	13	3.1	3.2	98.5
DISAGREE STRONGLY	5	6	1.4	1.5	100.0
DONT KNOW	9	6	1.4	Missing	
		-----	-----	-----	
Total		416	100.0	100.0	

8B. SCIENCE: Science and technology are our best hope for the future.

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
AGREE STRONGLY	1	168	40.4	40.9	40.9
AGREE SOMEWHAT	2	176	42.3	42.8	83.7
NEUTRAL	3	26	6.3	6.3	90.0
DISAGREE SOMEWHAT	4	26	6.3	6.3	96.4
DISAGREE STRONGLY	5	15	3.6	3.6	100.0
DONT KNOW	9	5	1.2	Missing	
		-----	-----	-----	
Total		416	100.0	100.0	

8C. TECH: Technological solutions often create more severe problems than the ones they solved.

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
AGREE STRONGLY	1	54	13.0	13.4	13.4
AGREE SOMEWHAT	2	180	43.3	44.7	58.1
NEUTRAL	3	59	14.2	14.6	72.7
DISAGREE SOMEWHAT	4	81	19.5	20.1	92.8
DISAGREE STRONGLY	5	29	7.0	7.2	100.0
DONT KNOW	9	13	3.1	Missing	
		-----	-----	-----	
Total		416	100.0	100.0	

8D. HW: The subject of hazardous waste is too complex for people like me to think about. It should be left to the experts.

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
AGREE STRONGLY	1	39	9.4	9.4	9.4
AGREE SOMEWHAT	2	85	20.4	20.5	29.9
NEUTRAL	3	19	4.6	4.6	34.5
DISAGREE SOMEWHAT	4	126	30.3	30.4	64.8
DISAGREE STRONGLY	5	146	35.1	35.2	100.0
DONT KNOW	9	1	.2	Missing	
		-----	-----	-----	
Total		416	100.0	100.0	

8E. RISKS: For society to survive and prosper, it is necessary that some risks and sacrifices be accepted.

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
AGREE STRONGLY	1	97	23.3	23.8	23.8
AGREE SOMEWHAT	2	226	54.3	55.4	79.2
NEUTRAL	3	21	5.0	5.1	84.3
DISAGREE SOMEWHAT	4	45	10.8	11.0	95.3
DISAGREE STRONGLY	5	19	4.6	4.7	100.0
DONT KNOW	9	8	1.9	Missing	
		-----	-----	-----	
Total		416	100.0	100.0	

8F. RCON: Even if potential benefits to society are very large it is wrong to impose risks on individuals without their consent.

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
AGREE STRONGLY	1	184	44.2	45.0	45.0
AGREE SOMEWHAT	2	170	40.9	41.6	86.6
NEUTRAL	3	25	6.0	6.1	92.7
DISAGREE SOMEWHAT	4	18	4.3	4.4	97.1
DISAGREE STRONGLY	5	12	2.9	2.9	100.0
DONT KNOW	9	7	1.7	Missing	
		-----	-----	-----	
Total		416	100.0	100.0	

Questions 9 and 9A concern proposed recycling and composting facilities which were planned for Putnam County. Not even 50% had heard of the projects, and less than 25% are supporters of it. This is in contrast to the 81.5% who have heard of the Winfield Locks and Dam project. Approximately 70% of the respondents have paid at least some attention to the locks and dam issue, but only 5.5% gave a response to "what have you heard" which mentioned more than a general notion of the issue. The most common responses were about the incinerator, and general comments that the site is contaminated.

9. BUFF: Have you heard anything about plans to build a recycling and composting facility in Buffalo?

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
YES	1	194	46.6	46.6	46.6
NO	2	222	53.4	53.4	100.0
		-----	-----	-----	
Total		416	100.0	100.0	

9A. OPINION: What is your opinion of that proposal?

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
FAVOR	1	64	15.4	44.4	44.4
FAVOR BUT DEPENDS	2	25	6.0	17.4	61.8
NEUTRAL	3	20	4.8	13.9	75.7
OPPOSE MAYBE	4	7	1.7	4.9	80.6
OPPOSE	5	28	6.7	19.4	100.0
DK	9	272	65.4	Missing	
		-----	-----	-----	
Total		416	100.0	100.0	

10. CLEAN: Have you heard anything about the proposed cleanup of land near Eleanor for the Winfield locks and dam project?

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
YES	1	339	81.5	81.5	81.5
NO	2	77	18.5	18.5	100.0
		-----	-----	-----	
	Total	416	100.0	100.0	

10A. HEARD: What have you heard?

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
GENERAL CONTAMINATION	1	110	26.4	34.7	34.7
GENERAL ON CORPS	2	24	5.8	7.6	42.3
RADICAL ENVIRONMENTA	3	30	7.2	9.5	51.7
INCINERATION	4	71	17.1	22.4	74.1
QUESTION PROBLEM EXISTS	5	7	1.7	2.2	76.3
WATER CON	6	19	4.6	6.0	82.3
PLANS TO MOVE SOIL	7	13	3.1	4.1	86.4
PLANS TO STORE	8	20	4.8	6.3	92.7
COMPLEX RESPONSE	9	23	5.5	7.3	100.0
	98	65	15.6	Missing	
DK	99	34	8.2	Missing	
		-----	-----	-----	
	Total	416	100.0	100.0	

Complex Response was the code assigned to responses which provided information about more than one facet of the cleanup project (e.g. proposed incinerator and concern about schools or water,).

10B. ATTEN: How much attention have you paid to the cleanup issue?

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
GREAT DEAL	1	73	17.5	21.0	21.0
SOME	2	219	52.6	62.9	83.9
NOT AT ALL	3	56	13.5	16.1	100.0
DK	9	68	16.3	Missing	
		-----	-----	-----	
	Total	416	100.0	100.0	

MULTIVARIATE RESULTS: Attention was found to be significantly related to a respondent's level of Concern. The more attention a respondent had paid the more concerned they were about the clean-up.

10C. CONCERN: How concerned are you about the cleanup project?

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
EXTREMELY	1	78	18.8	22.7	22.7
SOMEWHAT	2	149	35.8	43.3	66.0
ONLY SLIGHTLY	3	77	18.5	22.4	88.4
NOT AT ALL	4	28	6.7	8.1	96.5
NOT HEARD	5	12	2.9	3.5	100.0
DK	9	72	17.3	Missing	
		-----	-----	-----	
Total		416	100.0	100.0	

10D. WHATC: What primarily concerns you?

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
NOTHING	0	6	1.4	2.6	2.6
HEALTH	1	57	13.7	25.0	27.6
SAFETY OF INCINER	2	32	7.7	14.0	41.7
OTHER SAFETY ISSUES	3	21	5.0	9.2	50.9
EYESORE	4	1	.2	.4	51.3
WATER CONTAM	5	30	7.2	13.2	64.5
COST OF CLEANUP	6	13	3.1	5.7	70.2
SPEED OF CLEANUP	7	12	2.9	5.3	75.4
DIOXIN	8	4	1.0	1.8	77.2
CHEMICAL CONTAM	9	13	3.1	5.7	82.9
CORPS DO GOOD JOB	11	11	2.6	4.8	87.7
MOUNTAIN OF MOLEHILL	12	10	2.4	4.4	92.1
GENERAL UNEASINESS	15	18	4.3	7.9	100.0
	98	174	41.8	Missing	
	99	14	3.4	Missing	
		-----	-----	-----	
Total		416	100.0	100.0	

Sixty-six per cent of the respondents were at least somewhat concerned about the cleanup activities. Health issues were mentioned most often (13.7%) but the safety of a proposed incinerator was second on the list of concerns (7.7%). Almost as many respondents were concerned about the speed or cost of the cleanup (6%).

11. PROP1: What proposals have you heard about for cleaning the site?

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
INCINERATION	1	148	35.6	75.1	75.1
LONG TERM STORE	2	12	2.9	6.1	81.2
TEMP STORE	3	3	.7	1.5	82.7
OFF SITE	4	23	5.5	11.7	94.4
BURY	5	9	2.2	4.6	99.0
BIOREMEDIATION	7	2	.5	1.0	100.0
OTHER	8	10	2.4	Missing	
DK	9	209	50.2	Missing	
		-----	-----	-----	
Total		416	100.0	100.0	

11. 2ND RESPONSE: PROP2: Anything else?

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
INCINERATION	1	14	3.4	14.3	14.3
LONG TERM STORE	2	29	7.0	29.6	43.9
TEMP STORE	3	6	1.4	6.1	50.0
OFF SITE	4	46	11.1	46.9	96.9
BURY	5	2	.5	2.0	99.0
BIOREMEDIATION	7	1	.2	1.0	100.0
OTHER	8	7	1.7	Missing	
DK	9	311	74.8	Missing	
		-----	-----	-----	
Total		416	100.0	100.0	

11. 3RD RESPONSE: PROP3: Anything else?

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
INCINERATION	1	4	1.0	13.3	13.3
LONG TERM STORE	2	4	1.0	13.3	26.7
TEMP STORE	3	2	.5	6.7	33.3
OFF SITE	4	13	3.1	43.3	76.7
BURY	5	4	1.0	13.3	90.0
NEUTRALIZE	6	2	.5	6.7	96.7
BIOREMEDIATION	7	1	.2	3.3	100.0
OTHER	8	2	.5	Missing	
DK	9	384	92.3	Missing	
		-----	-----	-----	
Total		416	100.0	100.0	

Incineration is clearly the issue of greatest concern to people who have heard anything about the proposed cleanup. A total of 40% of the respondents had heard about the proposed incinerator, although they were not necessarily clear about the type or permanence of that facility. Almost 20% had also heard about off-site storage, despite the fact that is not an alternative under consideration, and 11% had heard of long-term on site storage, although the state of West Virginia does not support this alternative.

12A. TEMP: Do you support or oppose a temporary incinerator?

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
STRONGLY SUPPORT	1	60	14.4	16.2	16.2
SOMEWHAT SUPPORT	2	107	25.7	28.8	45.0
NEUTRAL	3	80	19.2	21.6	66.6
SOMEWHAT OPPOSE	4	64	15.4	17.3	83.8
STRONGLY OPPOSE	5	60	14.4	16.2	100.0
DK	9	45	10.8	Missing	
		-----	-----	-----	
	Total	416	100.0	100.0	

MULTIVARIATE RESULTS: A respondent's attitude toward a temporary incinerator was found to be significantly related to their level of concern. Respondents most opposed to an incinerator were also more likely to be concerned about the clean-up.

= 12B. PERM: A permanent incinerator?

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
STRONGLY SUPPORT	1	26	6.3	7.2	7.2
SOMEWHAT SUPPORT	2	45	10.8	12.4	19.6
NEUTRAL	3	63	15.1	17.4	37.0
SOMEWHAT OPPOSE	4	50	12.0	13.8	50.8
STRONGLY OPPOSE	5	178	42.8	49.2	100.0
DK	9	54	13.0	Missing	
		-----	-----	-----	
	Total	416	100.0	100.0	

Some concern has been expressed that respondents may have believed they had a choice between a permanent or a temporary incinerator. Call backs to a subsample of respondents indicate that opinion on the temporary incinerator is volatile. To obtain a stronger measure, we have created a variable which measures support for both, neutrality on both, and opposition to

both. A majority of respondents were found to be neutral, or to support only one or the other type of an incinerator (55.5%), 14.6% support both a permanent and a temporary incinerator, and 30.6% oppose both types. Although 33.5% of the respondents had said they supported either a temporary or a permanent incinerator, and those respondents also opposed the other type. Only respondents who opposed one type and were neutral on the other are counted under somewhat oppose, as those supporting one and opposing the other were captured under SOMEWHAT SUPPORT. This indicates that 41.1% were opposed to one or the other type of incinerator, so a total of 71.2% of the respondents expressed some degree of opposition to the concept of an incinerator. 14.1% were clearly neutral (gave a neutral response to both questions).

INCIN: TEMP + PERM:

STRONGLY SUPPORT (SUPPORT BOTH)	14.6%
SOMEWHAT SUPPORT (SUPPORT ONE)	33.5%
NEUTRAL (ON BOTH)	14.1%
SOMEWHAT OPPOSE (OPPOSE ONE, NEUTRAL ON OTHER)	7.6%
STRONGLY OPPOSE (OPPOSE BOTH)	30.1%

On-site long term storage and hauling the waste to another site are not viable alternatives. Questions were asked about them because respondents to open-ended interviews had indicated that they were potential alternatives. As no agency has proposed these solutions, it is a little surprising that over 40% of the respondents would find each alternative to be acceptable. Only 25% were even neutral about burying the waste, although that had been the previous disposal method for these wastes.

12C. ONSITE: Long-term storage?

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
STRONGLY SUPPORT	1	35	8.4	9.0	9.0
SOMEWHAT SUPPORT	2	61	14.7	15.6	24.6
NEUTRAL	3	61	14.7	15.6	40.3
SOMEWHAT OPPOSE	4	86	20.7	22.1	62.3
STRONGLY OPPOSE	5	147	35.3	37.7	100.0
DK	9	26	6.3	Missing	
		-----	-----	-----	
	Total	416	100.0	100.0	

12D. HAUL: Hauling the waste to another site?

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
STRONGLY SUPPORT	1	54	13.0	13.8	13.8
SOMEWHAT SUPPORT	2	71	17.1	18.2	32.0
NEUTRAL	3	67	16.1	17.1	49.1
SOMEWHAT OPPOSE	4	84	20.2	21.5	70.6
STRONGLY OPPOSE	5	115	27.6	29.4	100.0
DK	9	25	6.0	Missing	
		-----	-----	-----	
	Total	416	100.0	100.0	

Multivariate Results: A respondent's attitude about HAULING was significantly related to his/her attitude concerning a TEMPORARY INCINERATOR. Those that supported Hauling the waste to another site were most opposed to a temporary incinerator.

12E. QE1: Bioremediation?

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
STRONGLY SUPPORT	1	6	1.4	30.0	30.0
SOMEWHAT SUPPORT	2	3	.7	15.0	45.0
NEUTRAL	3	3	.7	15.0	60.0
SOMEWHAT OPPOSE	4	2	.5	10.0	70.0
STRONGLY OPPOSE	5	6	1.4	30.0	100.0
DK	9	396	95.2	Missing	
		-----	-----	-----	
Total		416	100.0	100.0	

12F. QE2: Burying the waste?

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
NEUTRAL	3	1	.2	25.0	25.0
STRONGLY OPPOSE	5	3	.7	75.0	100.0
DK	9	412	99.0	Missing	
		-----	-----	-----	
Total		416	100.0	100.0	

12G. QE3: Other ideas?

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
NEUTRAL	3	1	.2	50.0	50.0
STRONGLY OPPOSE	5	1	.2	50.0	100.0
DK	9	414	99.5	Missing	
		-----	-----	-----	
Total		416	100.0	100.0	

Because early interviews indicated that many people believed the Corps of Engineers had already decided to build an incinerator, this question was asked to determine general feeling in the community about the Corps plans. Over 70% believe the Corps has not already decided about the best cleanup method. Less than 5% of the respondents believe the Corps has already made up their minds. Other respondents suggested alternatives which the Corps has already rejected, but they also gave explanations, i.e. the alternative was a bad idea.

13. CORPS: Do you think the Corps of Engineers will ignore any suggestions?

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
NO	1	214	51.4	73.0	73.0
YES, ALREADY DECIDED	2	14	3.4	4.8	77.8
Yes, BAD IDEAS	3	7	1.7	2.4	80.2
DEPENDS ON IDEA	4	7	1.7	2.4	82.6
STORAGE	5	20	4.8	6.8	89.4
Hauling AWAY	6	30	7.2	10.2	99.7
INCINERATION	7	1	.2	.3	100.0
DK	9	123	29.6	Missing	
		-----	-----	-----	
Total		416	100.0	100.0	

14. UMB: Have you heard anything about the Umbrella Committee?

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
YES	1	83	20.0	20.0	20.0
NO	2	332	79.8	80.0	100.0
DK	9	1	.2	Missing	
		-----	-----	-----	
Total		416	100.0	100.0	

14A. UMBH: What have you heard?

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
Know it exists	1	48	11.5	61.5	61.5
Positive comments	2	15	3.6	19.2	80.8
Negative comments	3	11	2.6	14.1	94.9
Mixed opinion	4	4	1.0	5.1	100.0
No Answer	9	338	81.3	Missing	
		-----	-----	-----	
Total		416	100.0	100.0

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14B. UMBC: How do you feel about the composition of the Umbrella Committee

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
OK with as is	1	13	3.1	59.1	59.1
Too many politicians	2	4	1.0	18.2	77.3
Not Enough locals	4	1	.2	4.5	81.8
Other additions	6	3	.7	13.6	95.5
Other deletions	7	1	.2	4.5	100.0
No Answer	9	394	94.7	Missing	
		-----	-----	-----	
Total		416	100.0	100.0	

Only 20% of the respondents had heard of the Umbrella Committee. Of those who had heard of it, the opinions were fairly mixed. Most people had no opinions about the committee's makeup. When asked what they believe its purpose should be, 45.6% said informational and another 32.5% said watchdog. Only 6.7% listed as its purpose to stop the incinerator, and 10.2% said it should evaluate technical information. Respondents appear to believe it should have a similar function to other "watchdog" community groups which watch and report to the community, rather than performing any real policy function.

15. PURPOSE: What do you think the purpose of the committee should be?

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
TECHNICAL	1	35	8.4	10.2	10.2
INFORMATIONAL	2	156	37.5	45.6	55.8
WATCHDOG	3	111	26.7	32.5	88.3
PREVENTION	4	23	5.5	6.7	95.0
OTHER	5	17	4.1	5.0	100.0
	8	1	.2	Missing	
DK	9	73	17.5	Missing	
		-----	-----	-----	
Total		416	100.0	100.0	

16-1. INFO1: Who would you like to receive your information from about the cleanup?

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
WVU	1	89	21.4	22.4	22.4
ACE	2	70	16.8	17.6	39.9
PROTECT	3	23	5.5	5.8	45.7
WVCAG	4	39	9.4	9.8	55.5
LOCAL POLS	5	9	2.2	2.3	57.8
UMBRELLA COMMITTEE	7	57	13.7	14.3	72.1
CONGRESSMAN WISE	8	62	14.9	15.6	87.7
ACF	9	2	.5	.5	88.2
SENATOR BYRD	10	27	6.5	6.8	95.0
OTHER	11	20	4.8	5.0	100.0
	98	1	.2	Missing	
	99	17	4.1	Missing	
		-----	-----	-----	
Total		416	100.0	100.0	

16-2. INFO2: A second source?

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
WVU	1	52	12.5	17.1	17.1
ACE	2	44	10.6	14.5	31.6
PROTECT	3	14	3.4	4.6	36.2
WVCAG	4	21	5.0	6.9	43.1
LOCAL POLS	5	6	1.4	2.0	45.1
UMBRELLA COMMITTEE	7	50	12.0	16.4	61.5
CONGRESSMAN WISE	8	68	16.3	22.4	83.9
ACF	9	3	.7	1.0	84.9
SENATOR BYRD	10	26	6.3	8.6	93.4
OTHER	11	20	4.8	6.6	100.0
	98	38	9.1	Missing	
	99	74	17.8	Missing	
		-----	-----	-----	
Total		416	100.0	100.0	

In order to determine how best to inform the community, respondents preferences were asked. Almost 40% wanted information to come from West Virginia University, and 32% wanted it to come from the Corps of Engineers. Almost 40% also considered Congressman Wise to be a good source of information. Least useful appear to be ACF (1.5%), local politicians (4.3%),

THE NUMBERING FOR QUESTION 17 WAS OMITTED.

18. MOLEHILL: Do you think the issues have been blown out of proportion by personality conflicts?

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
VERY LIKELY	1	111	26.7	28.5	28.5
SOMEWHAT LIKELY	2	159	38.2	40.9	69.4
SOMEWHAT UNLIKELY	3	65	15.6	16.7	86.1
VERY UNLIKELY	4	54	13.0	13.9	100.0
DK	9	27	6.5	Missing	
		-----	-----	-----	
Total		416	100.0	100.0	

Almost 70% believe the issue has been at least somewhat blown out of proportion.

Multivariate Results: The analysis indicated that this variable was significantly related to a respondents level of concern. Respondents who tended to feel that the issue HAD NOT BEEN BLOWN OUT OF PROPORTION also were more likely to feel concerned about the Clean-up.

19. SCHLE: Have you heard about potential effects on schools from cleanup?

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
YES	1	72	17.3	17.3	17.3
NO	2	343	82.5	82.7	100.0
	8	1	.2	Missing	
		-----	-----	-----	
Total		416	100.0	100.0	

19A. SCHLC: Any problems concern you?

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
No	0	14	3.4	21.5	21.5
Health from burning	1	17	4.1	26.2	47.7
Water contamination	2	9	2.2	13.8	61.5
Dust in air	3	16	3.8	24.6	86.2
Evacuation procedures	4	7	1.7	10.8	96.9
Other issues	5	2	.5	3.1	100.0
DK	9	351	84.4	Missing	
		-----	-----	-----	
Total		416	100.0	100.0	

19B. SCHLC2: How concerned are you about these effects?

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
VERY CONCERNED	1	48	11.5	49.5	49.5
SOMEWHAT CONCERNED	2	32	7.7	33.0	82.5
NOT VERY CONCERNED .	3	8	1.9	8.2	90.7
NO CONCERN	4	9	2.2	9.3	100.0
DK	9	319	76.7	Missing	
		-----	-----	-----	
Total		416	100.0	100.0	

Although the proximity of several schools to the site is a major issue to some people, the majority of the population appear to be unconcerned. Only 19.2% are somewhat or very concerned. Only 1.7% mentioned evacuation procedures as a cause for concern.

The following questions are demographic variables which are used in most political analyses to determine whether there are population differences which affect political opinions.

20. LIVE: Where do you live?

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
WINFIELD	1	63	15.1	15.2	15.2
ELEANOR	2	45	10.8	10.9	26.1
HURRICANE	3	108	26.0	26.1	52.2
POCA	4	19	4.6	4.6	56.8
BANCROFT	5	12	2.9	2.9	59.7
BUFFALO	6	17	4.1	4.1	63.8
CULLODEN	7	3	.7	.7	64.5
FRAZIERS BOTTOM	8	7	1.7	1.7	66.2
HOMETOWN	9	15	3.6	3.6	69.8
REDHOUSE	11	35	8.4	8.5	78.3
SCOTT DEPOT	12	20	4.8	4.8	83.1
TEAYS VALLEY	13	13	3.1	3.1	86.2
LIBERTY	14	9	2.2	2.2	88.4
MAPLE WOOD	15	1	.2	.2	88.6
MARINA PARK	16	2	.5	.5	89.1
MIDWAY	17	5	1.2	1.2	90.3
NITRO	18	13	3.1	3.1	93.5
PARADISE	19	7	1.7	1.7	95.2
PLINY	20	2	.5	.5	95.7
RAYMOND CITY-ROBERTS	22	5	1.2	1.2	96.9
ST. ALBANS	23	1	.2	.2	97.1
ROCK BRANCH	25	3	.7	.7	97.8
GRANDVIEW RIDGE	26	4	1.0	1.0	98.8
OTHER	97	5	1.2	1.2	100.0
	98	2	.5	Missing	
Total		416	100.0	100.0	

Residents of Winfield and Eleanor were oversampled in this study, as they live in closest proximity to the site.

Multivariate Results: Where one lives was found to be statistically related to whether or not one was concerned about the clean-up. We suspect this significant relationship (which only appears in the multivariate analysis) is caused by the unique opinions of residents living in our second residential zone. This zone includes the towns: Bancroft, Fraziers Bottom, Hometown, Redhouse, Midway, and Plymouth. The simple bivariate correlation between LIVE and CAUSE proved to be insignificant.

22. AGE: (What year were you born. Recoded into age.

18-25	1	53	9.9	9.9
26-35	2	99	22.2	32.1
36-50	3	139	31.3	63.4
51-65	4	92	23.9	87.3
Over 65	5	41	12.8	100.0

MULTIVARIATE RESULTS: AGE was found to be related to respondents' attitudes toward a TEMPORARY INCINERATOR. In general, the older the respondent the more supportive they were of a temporary incinerator.

23. INCOME

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
<10,000	1	58	13.9	15.6	15.6
10-25,000	2	102	24.5	27.5	43.1
25-50,000	3	140	33.7	37.7	80.9
50-80,000	4	59	14.2	15.9	96.8
>80,000	5	12	2.9	3.2	100.0
NR	9	45	10.8	Missing	
		-----	-----	-----	
Total		416	100.0	100.0	

24. EDUC: Level of education achieved

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
LESS THAN H SCHL	1	63	15.1	15.2	15.2
HIGH SCHOOL	2	176	42.3	42.4	57.6
SOME COLLEGE	3	97	23.3	23.4	81.0
COLLEGE DEGREE	4	43	10.3	10.4	91.3
POST COLLEGE	5	36	8.7	8.7	100.0
NR	9	1	.2	Missing	
		-----	-----	-----	
Total		416	100.0	100.0	

26. PARTY: Do you consider yourself -

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
REPUBLICAN	1	127	30.5	31.0	31.0
DEMOCRAT	2	191	45.9	46.6	77.6
INDEPENDENT	3	71	17.1	17.3	94.9
NOT INTERESTED	5	21	5.0	5.1	100.0
DK	9	6	1.4	Missing	
		-----	-----	-----	
Total		416	100.0	100.0	

26a. REP: If Republican

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
STRONG	1	56	13.5	43.4	43.4
NOT VERY STRONG	2	73	17.5	56.6	100.0
DK	9	287	69.0	Missing	
		-----	-----	-----	
Total		416	100.0	100.0	

26b. DEM: If Democrat

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
STRONG	1	62	14.9	32.5	32.5
NOT VERY STRONG	2	129	31.0	67.5	100.0
DK	9	225	54.1	Missing	
		-----	-----	-----	
Total		416	100.0	100.0	

26c. IND: If Independent

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
CLOSER TO REP	1	17	4.1	23.6	23.6
CLOSER TO DEM	2	21	5.0	29.2	52.8
NEITHER	3	34	8.2	47.2	100.0
	9	344	82.7	Missing	
		-----	-----	-----	
Total		416	100.0	100.0	

The following series is used to develop a variable (PARTIC) which counts the number of activities in which respondents say they had engaged during the past year. The unacceptably high response on voting indicates some bias in these responses, but we assume that the overall variable is a fairly accurate measure of respondent's activism.

27a. COUNCIL: In the past year have you attended a city council meeting?

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
YES	1	43	10.3	10.3	10.3
NO	2	373	89.7	89.7	100.0
		-----	-----	-----	
	Total	416	100.0	100.0	

27b. PUBLIC: Attended public hearings?

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
YES	1	83	20.0	20.0	20.0
NO	2	333	80.0	80.0	100.0
		-----	-----	-----	
	Total	416	100.0	100.0	

27c. WRITE: Written or called an elected official to express your opinion?

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
YES	1	162	38.9	38.9	38.9
NO	2	254	61.1	61.1	100.0
		-----	-----	-----	
	Total	416	100.0	100.0	

27d. VOTE: Voted in the last election?

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
YES	1	299	71.9	71.9	71.9
NO	2	117	28.1	28.1	100.0
		-----	-----	-----	
	Total	416	100.0	100.0	

27e. CITGRP: Joined a local citizen group?

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
YES	1	21	5.0	5.1	5.1
NO	2	393	94.5	94.9	100.0
DK	9	2	.5	Missing	
		-----	-----	-----	
	Total	416	100.0	100.0	

27f. ENVGRP: Joined a national environmental group?

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
YES	1	21	5.0	5.0	5.0
NO	2	395	95.0	95.0	100.0
		-----	-----	-----	
	Total	416	100.0	100.0	

27 E-A. CITGRPJ: What citizen group?

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
PROTECT	1	2	.5	8.3	8.3
Greenpeace	3	4	1.0	16.7	25.0
Other environmental	5	6	1.4	25.0	50.0
Other general	6	12	2.9	50.0	100.0
DK	9	392	94.2	Missing	
		-----	-----	-----	
	Total	416	100.0	100.0	

27F.A. ENVGRPJ: Second Group?

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
PROTECT	1	2	.5	20.0	20.0
WVCAG	2	1	.2	10.0	30.0
Sierra Club	4	2	.5	20.0	50.0
Other environmental	5	2	.5	20.0	70.0
Other general	6	3	.7	30.0	100.0
DK	9	406	97.6	Missing	
		-----	-----	-----	
	Total	416	100.0	100.0	

Respondents who belong to one group are extremely likely to belong to a second group, so these two variables are probably measuring the same respondents.

28-1. NEWS: How important are newspapers as a source of information on environmental issues?

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
VERY IMPORTANT	1	228	54.8	55.1	55.1
SOMEWHAT IMPORTANT	2	147	35.3	35.5	90.6
NOT VERY IMPORTANT	3	27	6.5	6.5	97.1
NOT IMPORTANT	4	12	2.9	2.9	100.0
DK	9	2	.5	Missing	
		-----	-----	-----	
Total		416	100.0	100.0	

28-2. TV

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
VERY IMPORTANT	1	233	56.0	56.3	56.3
SOMEWHAT IMPORTANT	2	143	34.4	34.5	90.8
NOT VERY IMPORTANT	3	30	7.2	7.2	98.1
NOT IMPORTANT	4	8	1.9	1.9	100.0
DK	9	2	.5	Missing	
		-----	-----	-----	
Total		416	100.0	100.0	

28-3. RADIO

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
VERY IMPORTANT	1	105	25.2	25.5	25.5
SOMEWHAT IMPORTANT	2	173	41.6	42.0	67.5
NOT VERY IMPORTANT	3	93	22.4	22.6	90.0
NOT IMPORTANT	4	41	9.9	10.0	100.0
DK	9	4	1.0	Missing	
		-----	-----	-----	
Total		416	100.0	100.0	

28-4. FRIENDS

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
VERY IMPORTANT	1	84	20.2	20.5	20.5
SOMEWHAT IMPORTANT	2	195	46.9	47.7	68.2
NOT VERY IMPORTANT	3	97	23.3	23.7	91.9
NOT IMPORTANT	4	33	7.9	8.1	100.0
DK	9	7	1.7	Missing	
		-----	-----	-----	
Total		416	100.0	100.0	

28-5. PROTECT: Interest groups like PROTECT or Sierra Club

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
VERY IMPORTANT	1	53	12.7	13.2	13.2
SOMEWHAT IMPORTANT	2	144	34.6	36.0	49.2
NOT VERY IMPORTANT	3	95	22.8	23.7	73.0
NOT IMPORTANT	4	108	26.0	27.0	100.0
DK	9	16	3.8	Missing	
		-----	-----	-----	
Total		416	100.0	100.0	

28-6. PTA: Community organizations like PTA

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
VERY IMPORTANT	1	87	20.9	21.2	21.2
SOMEWHAT IMPORTANT	2	156	37.5	38.0	59.3
NOT VERY IMPORTANT	3	82	19.7	20.0	79.3
NOT IMPORTANT	4	85	20.4	20.7	100.0
DK	9	6	1.4	Missing	
		-----	-----	-----	
Total		416	100.0	100.0	

28-7. FORUM: Public meetings/forums

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
VERY IMPORTANT	1	101	24.3	24.7	24.7
SOMEWHAT IMPORTANT	2	166	39.9	40.6	65.3
NOT VERY IMPORTANT	3	62	14.9	15.2	80.4
NOT IMPORTANT	4	80	19.2	19.6	100.0
DK	9	7	1.7	Missing	
		-----	-----	-----	
Total		416	100.0	100.0	

28-8. OTHER: Other sources?

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
VERY IMPORTANT	1	31	7.5	66.0	66.0
SOMEWHAT IMPORTANT	2	13	3.1	27.7	93.6
NOT VERY IMPORTANT	3	1	.2	2.1	95.7
NOT IMPORTANT	4	2	.5	4.3	100.0
DK	9	369	88.7	Missing	
		-----	-----	-----	
	Total	416	100.0	100.0	

By ranking these sources of information on the "very important" response, we have created a new table - PRIORITY.

Per Cent Listing as Very Important

Television	56.3%
Newspapers	55.1
Radio	25.5
Public Forums	24.7
Community Organizations	21.2
Friends	20.5
Interest Groups	13.2

Typically, television is the most important source of information to the respondents, with newspapers being second. Radio, public forums, and community organizations and friends are closely ranked. Groups like PROTECT, WVCAG and environmental groups appear to be unimportant to most respondents for providing information.

29. OCCUP: What is your primary occupation?

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
CHEM LABOR	1	14	3.4	3.4	3.4
CHEM MANAGMENT	2	11	2.6	2.7	6.1
OTHER ENV LABOR	3	7	1.7	1.7	7.8
OTHER ENV MANAGMENT	4	9	2.2	2.2	10.0
ENV STATE AGENCY	5	1	.2	.2	10.2
OTHER STATE AGENCY	6	28	6.7	6.8	17.1
TEACHER	7	16	3.8	3.9	21.0
PROFESSIONAL	8	35	8.4	8.5	29.5
OTHER MANAGEMENT	9	48	11.5	11.7	41.2
OTHER LABOR	10	139	33.4	33.9	75.1
HOUSEWIFE	11	56	13.5	13.7	88.8
STUDENT	12	18	4.3	4.4	93.2
RETIRED	13	8	1.9	2.0	95.1
SELF-EMPLOYED	14	19	4.6	4.6	99.8
	15	1	.2	.2	100.0
NR	99	6	1.4	Missing	
Total		416	100.0	100.0	

30. ACF: Has anyone in your household been employed by ACF

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
YES	1	12	2.9	2.9	2.9
NO	2	398	95.7	97.1	100.0
	8	3	.7	Missing	
DK	9	3	.7	Missing	
Total		416	100.0	100.0	

31. CHILDR: Do you have children under age 18 living at home?

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
YES	1	196	47.1	47.2	47.2
NO	2	219	52.6	52.8	100.0
DK	9	1	.2	Missing	
Total		416	100.0	100.0	

31A. SCHL1: Do they attend Winfield or Eleanor Schools

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
NO	0	341	82.0	82.0	82.0
YES	1	75	18.0	18.0	100.0
		-----	-----	-----	
	Total	416	100.0	100.0	

Perhaps one reason that few people were concerned about the proximity of schools to the site, was that only 18% had children in those schools (including respondents who listed grandchildren).

31b. SCHLO: Attend school elsewhere?

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
NO	0	289	69.5	69.6	69.6
YES	1	126	30.3	30.5	98.2
	9	1	.2	Missing	
		-----	-----	-----	
	Total	416	100.0	100.0	

33. GENDER

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
FEMALE	1	206	49.5	49.5	49.5
MALE	2	210	50.5	50.5	100.0
		-----	-----	-----	
	Total	416	100.0	100.0	

RESULTS OF BIVARIATE ANALYSIS

Table 1: Level of Knowledge and Concern by Demographics

	Percent of Respondents	
	<u>Extremely or Somewhat Concerned</u>	<u>Knowledgeable About Cleanup</u>
<u>Closeness to Site</u>		
Winfield/Eleanor	66.6%	85.2% ***
10 miles	83.1%	85.1%
20 miles	65.8%	74.4%
over 20 miles	60.0%	64.9%
<u>Gender</u>		
Female	72.6%	67.0
Male	64.8%	85.2 ***
<u>Education</u>		
High School or Less	67.0	75.7
Some College	70.7	73.2
College	69.9	82.2
<u>Income</u>		
Under \$25,000	69.3	72.5 *
\$25,000-\$50,000	69.5	80.7
Over \$50,000	67.2	80.3
<u>Age</u>		
Under 25	65.2	56.1
25-50	70.0	78.4
Over 50	66.7	79.0 **
<u>Risk Aversion</u>		
Low Level	65.8	76.5
High Level	82.3 ***	74.6
<u>Involuntary Risk Aversion</u>		
Low Level	59.6	76.2
High Level	85.8 ***	76.1

NOTE: * indicates significance of less than .10

** indicates significance of less than .05

*** indicates significance of less than .01

Table 2: Attitudes about Incinerators and Hazardous Waste Landfills

	<u>Opposition to Incineration</u>	<u>Hazardous Waste Incinerator Risky</u>	<u>Hazardous Waste Landfill Risky</u>
<u>Closeness to Site</u>			
Winfield/Eleanor	27.4%	41.2%	56.1%
10 miles	40.6%	51.5	66.2
20 miles	27.5	47.0	68.3
Over 20 miles	28.9% *	51.6 *	61.1
<u>Gender</u>			
Female	35.9	61.3	69.2
Male	25.0 *	34.2 ***	55.7 **
<u>Education</u>			
High School or Less	27.7	51.8%	61.4%
Some College	40.7	48.4	71.7
College and +	24.7	34.2 **	53.9 *
<u>Income</u>			
Under \$25,000	28.9	57.0	68.8
\$25,000-\$50,000	34.2	45.1	58.0
Over \$50,000	25.0	30.3 ***	59.1
<u>Age</u>			
Under 25	30.6	55.0	65.0
25-50	33.0	43.9	62.3
Over 50	25.4	51.8	62.1
<u>Risk Aversion</u>			
Low Level	27.9	37.8	55.5
High Level	42.6 **	96.9 ***	97.0 ***
<u>Involuntary Risk Aversion</u>			
Low Level	23.0	29.0	46.4
High Level	46.9 ***	91.5 ***	97.4 ***

Table 3: Regression Analysis of Levels of Concern about Cleanup

OLS Regression

DEPENDENT VARIABLE = CONCERN

INDEPENDENT VARIABLES	Coefficient	t-test	Significance Level
LIVE	.0975	2.465	.01
STRICT	.1671	3.546	.0005
LABOR	.0773	1.873	.06
TEMP	-.1035	-2.796	.005
PARTIC	-.1788	-4.171	.0001
MOLEHILL	-.1191	-2.425	.02
FEDS	.0931	2.176	.03
AVERISK	-.2783	-3.991	.0001
ATTEN	.2862	3.276	.001
INCOME	.0857	1.628	.11
MIL	-.1382	-2.500	.01
REGS	-.1202	-1.905	.06
Constant	2.319		
R ² = .37			

The larger the coefficient, and closer to .00 the significance level, the more important the variable in explaining level of concern. AVERISK and Attention to the cleanup project are the best predictors in this model, although STRICT, PARTIC, and TEMP are also important.

Table 4: Regression Analysis of Variables Affecting Attitudes About The Temporary Incinerator

OLS Regression

DEPENDENT VARIABLE = TEMP

Independent Variable	Coefficient	t-test	Significance Level
HAUL	-.1383	-2.898	.004
AVERISK	.3519	3.958	.0001
AGE	-.1125	-1.873	.06
MIL	.1525	2.132	.03
STRICT	.1345	2.004	.05
CONSTANT	2.311		
R ² = .09			

Almost no variables remained in this model. Again AVERISK is the most important predictor of attitudes about the temporary incinerator, and attitudes about hauling the material away is the second most important variables. Respondents who oppose hauling material away are more likely to support a temporary incinerator.

APPENDIX

The Winfield Locks and Dam and Clean-up Survey

Overview: The Winfield Locks and Dam and Clean-up Survey is designed to assess public opinion toward the clean-up project near the Winfield Locks and Dam. The survey describes current opinion and attempts to understand why these opinions are held.

Survey Development: The survey was developed during the first three months of 1993 using 100 preliminary surveys. These preliminary surveys were conducted with a random sample of Winfield/Eleanor residents as well as citizens that were deemed to be both aware of the problem and aware of public concerns. This latter group included members of the umbrella committee, various community organizations and local interest groups.

The Survey: The Winfield Locks and Dam and Clean-up Survey was conducted during the months of April and May, 1993. A random sample of residential phone numbers from Putnam county were selected from a list that included all residential phone numbers in the county. Numbers were randomly selected by phone exchange (i.e., the first three digits) with an emphasis on oversampling the Winfield/Eleanor exchange (586). In all, there were 404 complete surveys conducted and 555 legitimate refusals for a response rate of 42%. ($404/959 = 42.1\%$)

Listed below is the response rate in each of the five exchanges and detailed information about the nature of the calling in each exchange.

Summary of Response Rate for the Winfield Project

The following exchanges were called at least once.

<u>EXCHANGE</u>	<u># CALLED</u>	<u>% of TOTAL</u>	<u>% of ALL COMPLETED</u>
586	582	39.6%	47.3%
562	371	25.2%	25.9%
755	276	18.8%	12.1%
757	154	10.5%	8.9%
937	<u>88</u>	5.9%	5.7%

TOTAL 1471 calls

COMPLETED 404 surveys

(ACTUAL RESPONSE RATE = 42.1%) SEE LAST PAGE OF REPORT

The vast majority of exchanges were called more than once. Usually they were called until a final disposition was decided.

Exchange Response Rate

EXCHANGE 586

Total calls : 582 (In this exchange)

<u>FINAL DISPOSITION</u>	<u>% of calls in exchange</u>	<u>N</u>
Completed calls:	32.8%	191
Refusals:	40.0%	233
Complete vs Refusal RESPONSE RATE: 191/424 = 45.0%		

NEVER TALKED TO: Answering Machine, No Answer, Busy, Disconnected)	17.9%	104
---	-------	-----

Call-backs (not re-contacted) (Busy, No Answer, etc., after initial contact)	6%	35
---	----	----

NON-PUTNAM CO. TERMINATED:		0 2
-------------------------------	--	--------

(IF PERCENTAGES ARE LESS THAN 100 the remainder is an "other" category. Includes "Send Mail Survey", "No Males" etc.)

EXCHANGE 562

Total calls : 371 (In this exchange)

<u>FINAL DISPOSITION</u>	<u>% of calls in exchange</u>	<u>N</u>
Completed calls:	28.3%	105
Refusals:	37.2%	138
Complete vs Refusal RESPONSE RATE: 105/243 = 43.2%		

NEVER TALKED TO: (Answering Machine, No Answer, Busy, Disconnected)	22.9%	85
--	-------	----

CALL-BACKS (Not re-contacted)	7.3%	27
-------------------------------	------	----

Non-PUTNAM Co.		2
TERMINATED:		5

EXCHANGE 755

Total calls : 276 (In this exchange)

<u>FINAL DISPOSITION</u>	<u>% of calls in exchange</u>	<u>N</u>
Completed calls:	17.7 %	49
Refusals:	32.2%	89
Complete vs Refusal RESPONSE RATE: 49/138 = 35.5%		

NEVER TALKED TO: (Answering Machine, No Answer, Busy.)	18.1%	50
--	-------	----

Call-Backs (NOT re-contacted)	5.4%	15
-------------------------------	------	----

Non-Putnam Co.	21.0%	58
----------------	-------	----

TERMINATED:		1
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EXCHANGE 757

Total calls : 154 (In this exchange)

<u>FINAL DISPOSITION</u>	<u>% of calls in exchange</u>	<u>N</u>
Completed calls:	23.4 %	36
Refusals:	38.9%	60
Complete vs Refusal RESPONSE RATE:	36/96 = 37.5%	
NEVER TALKED TO: (Answering Machine, No Answer, Busy.)	24.0%	37
Call-Backs (NOT re-contacted)	9.1%	14
Non-Putnam Co.		0
TERMINATED:		0

EXCHANGE 937

Total calls : 88

<u>FINAL DISPOSITION</u>	<u>% of calls in exchange</u>	<u>N</u>
Completed calls:	26.1%	23
Refusals:	39.8%	35
Complete vs Refusal RESPONSE RATE:	23/58 = 39.7%	
NEVER TALKED TO: (Answering Machine, No Answer, Busy.)	13.6%	12
Call-Backs (NOT re-contacted)	6.8%	6
Non-Putnam Co.	12.5%	11
TERMINATED:		0

OVERALL COMPLETE VS REFUSAL RESPONSE RATE

COMPLETE: 404
 REFUSALS: 555 404/959 = 42.1%

**ASSESSMENT OF TECHNOLOGIES FOR HAZARDOUS WASTE SITE REMEDIATION:
NON-TREATMENT TECHNOLOGIES AND PILOT SCALE TEST FACILITY
IMPLEMENTATION
(Project MC-10)**

Quarterly Report IV for Period
July 1 through September 30, 1993

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

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

By

Harry R. Johnson
BDM Federal, Inc.
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Morgantown, West Virginia 26505

October 1993

Project 1: Assessment of Environmental Remediation Storage Technologies

The objective of this project is to determine waste storage technologies that may be applicable to storage of hazardous wastes extracted from the Winfield site in Putnam County, West Virginia.

A list of hazardous chemicals found at the Winfield site was obtained from a report prepared by the US Army Corps of Engineers. This list was used as guidance in reviewing published material regarding storage technology for the various chemicals found on the site. A functional analysis was then used to define the storage technology requirements based on the site-specific characterizations.

Very few published reports on storage technologies is reported in the open literature or in published patents on this subject. The available literature largely documents the results of projects supported by the Government.

A literature description was obtained of one temporary storage technology that is potentially applicable to the Winfield site. Additionally, BDM developed four new storage technology scenarios which also could be applicable to the Winfield site. The analyses shows that on-site storage of the material extracted will require liners to prevent the migration of the chemicals off-site or downward to the ground-water at a depth of 60 feet. Additionally, permanent storage in a building has health and safety enhancements over a temporary storage building.

The Draft report was completed within three months from the project start date and submitted for review to WVU/NRCCE (*appended*). An initial informal set of comments was received requesting additional reference materials. BDM is currently finding and documenting those references.

Project 2: Assessment of Environmental Remediation Excavation Technologies

The objective of this project is to evaluate excavation technologies that could be applicable to the Winfield site. A number of excavation technologies were identified from a literature review, and the technologies evaluated against a set of screening criteria with respect to operations that would be conducted at the Winfield site.

Loose Bulk excavation technology was ranked as the best suited to the Winfield site. A long-boomed back hoe was suggested as the equipment of choice for this operation adjacent to the Kanawha river. While this unit would reduce the generation of fugitive dust, additional research on dust suppression needs to be undertaken.

BDM recommends that consideration be given to testing a new "Pneumatic Excavator" which removes VOC's liberated during the excavation process. This technology is particularly well suited for sites with rather high emission levels of VOC's.

The Draft report was completed within three months from the project start date and was submitted to WVU/NRCCE for review and comment (*appended*). Currently BDM is examining additional references relative to a recently developed Track-Hoe which was requested to be included in the list of equipment studied under the project. This work is in progress.

Project 3: Assessment of Environmental Remediation Monitoring Technologies

The objective of this study was to investigate and evaluate proven technologies for monitoring a hazardous waste site during remediation operations. The study was initiated with a literature search to determine equipment and vendors who have demonstrated equipment operations at sites similar to the Winfield site.

A functional analysis was used to determine requirements for equipment and to help generate screening criteria for ranking and selection of appropriate equipment. Gas Chromatography/Mass Spectrometry is the most widely accepted method for generating quantitative data for characterization sites similar to the Winfield site. However, the analysis completed for this project suggested that the Fourier Transform Infrared Spectroscopy would be more functional at the Winfield site. BDM recommends that both the CG / MS unit and the FTIR unit be evaluated for use at the Winfield site.

The Draft report was completed within three months from the project start date and submitted for review and comment to WVU/NRCCE (*appended*). In response to that review, BDM is in the process of obtaining additional information on monitoring equipment and vendors.

Project 4: Assessment of Research Projects Planned to be Installed in the B 17 Building

Two major projects are under consideration to guide the BDM planning under this project. The first represents research projects that would support engineering studies for a circulating air barrier for the Hanford Site, and the second is a series of experiments supporting the development of barrier materials protocols for testing barrier materials.

Lists of equipment generic to both project types are in preparation. Space requirements will be defined and the SARS reports prepared. The draft final report is scheduled to be completed in December 1993.

DRAFT

**ASSESSMENT OF ENVIRONMENTAL REMEDIATION
STORAGE TECHNOLOGY**

**Final Report
August 31, 1993**

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

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

**By
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AUGUST 1993

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ASSESSMENT OF ENVIRONMENTAL REMEDIATION STORAGE TECHNOLOGY

1.0 EXECUTIVE SUMMARY

The objective of this research is to examine the body of literature available on hazardous and toxic waste storage technology to determine that which would be applicable to the Winfield Site located in Putnam County, West Virginia. This information will then be made available to the WVU resource group for examining problems at the Winfield Site for planning purposes and as they occur during the actual remediation operations.

Three projects were established to examine key aspects of the remediation operation at any site, but which should have application to Winfield. These activities are excavation, monitoring, and storage technologies. This report examines only the storage technologies.

The published Characterization Report prepared by the U. S. Army Corp of Engineers was examined in detail to determine the types and location of hazardous chemicals and materials present at the site. A list of the most hazardous chemicals was prepared and those found at the Winfield site identified in Tables 2 and 3. A review of the open literature was conducted and revealed very few published reports on storage technologies. Published Patents were also examined with identical results. Published reports documenting Government projects was the largest source of literature available.

A functional analysis was conducted to identify storage technology requirements based on site characterization results and remediation plans or options. A set of criteria was developed based on the functional analysis results these were used to prioritize the identified storage technologies. A list of key words was developed to search the literature.

Literature description of only one temporary storage technology which was applicable to Winfield site was found. BDM developed four additional possible storage technology scenarios which could be applicable to the Winfield site. Because of the nature of the toxic chemicals found at Winfield (Dioxins) all of the proposed solutions required liners to prevent migration of the chemicals downward toward the groundwater which is found at a rather shallow depth of only 60 feet. A patent description of a permanent building that could be used for temporary storage made up the total of six technologies identified. The most secure technology from public health and safety perspective is the utilization of a permanent storage building as revealed by the functional analysis. A building provides an easier method of monitoring and controlling VOC's which are present as the most prominent hazardous chemical contaminant at Winfield. If the level of VOC's present does not justify the building of a large permanent building, then technology no. four (4) Temporary Storage Building with containerized storage of toxic materials (Dioxins) and covered storage of soils excavated. This method was ranked almost as high as temporary storage in a permanent building.

Storage technologies become important when there are delays in selecting the remediation technology because of problems perceived or real which may exist at the site or in adjacent populated areas. A suggested area to consider for future study is the possibility of conducting some remediation operations on the stored material for some or most of the contaminant species. For example, stored soil from Winfield could be inoculated with bacteria and provided nutrients which could remediate many or most of the hydrocarbon compounds contained in the soil. Other problems to consider for further study is the potential for remediation during the storing process during storage operations. If conveyor belt systems are used for storing operations inside a storage building, dehalogenation using multiple "Lark" units could be employed to initiate remediation of VOC's.. Another suggested area for research is the development of blocks of soil with strength enough to allow them to be stacked as high as 20 feet but still retaining porosity and permeability so that bioremediation could be promoted within the blocks.

2.0 INTRODUCTION

2.1 PURPOSE AND SCOPE

The purpose of this study is to assess the state-of-the-art of storage technology as related to environmental remediation applications. A further purpose is to determine which of the storage technologies reviewed would be applicable to the Winfield site of the U. S. Corp of Engineers for use in remediating contaminated soils when excavated in the near future for construction of a new Lock and Dam at the site. The scope of the studies is to review the results of characterization studies to identify storage methodologies and equipment which can be used at any environmental remediation site but more specifically at the Winfield site on the Kanawha River in Putnam County, West Virginia. The project is to provide fundamental information to the WVU Hazardous Waste Site Remediation Resource Group to address questions and concerns that may be encountered during the actual remediation project at the Winfield Lock and Dam.

2.2 BACKGROUND

The U. S. Army Corp of Engineers (COE) is responsible for construction projects which control traffic on the navigable inland waterway systems in the U. S. territories and possessions. The COE has determined that new or improved facilities were required to service traffic at the Winfield Lock and Dam site in Putnam County, West Virginia. Acreage adjacent to the present site was acquired by "Declaration of Taking" from American Car and Foundry (ACF) which had operated the 21.81 acre facility from 1952 until March of 1986. The facility was used to service and repair a fleet of tank cars and covered gondola cars used to transport liquid and solid chemical materials.

The COE discovered that a colored liquid leaking into an excavation pit left after earlier (1989) remediation operations by ACF contained contaminants which were supposed to have been removed. Sampling and analysis indicated that the land was still contaminated with several hazardous chemicals including volatile organic compounds (VOC's), polychlorinated biphenols (PCB's) and dioxins. A detailed characterization study was conducted and a remediation plan prepared and submitted for public comment. The local population did not approve of the remediation plan and research into alternative supporting technologies was commissioned by the Department of Energy (DOE) at the request of Senator Byrd. A contract to conduct such research was given to West Virginia University (WVU) and BDM in turn was contracted to provide support to WVU. BDM was requested to provide support in examining recent developments in excavation, storage, and monitoring technologies which might have potential application at the Winfield site.

2.3 STUDY TECHNICAL APPROACH

Three projects were established to examine storage, extraction, and monitoring technologies. This project report is concerned with temporary storage of soils until remediation activities can be conducted and completed.

The approach for this study is to review the site characterization studies that provide indications of the types of operations that will have to be conducted to comply with federal regulations during remediation. A functional analysis will reveal the types of technologies that can be utilized for generic sites and the Winfield site. Once the technologies have been identified, then key word descriptors will be identified to support conducting a literature search that will review the S-O-A for the selected technology. A detailed analysis will determine the advantage and disadvantages for the selected technologies. A list of potential problems that have not been resolved relative to the technology will be prepared for consideration for future research projects.

3.0 HAZARDOUS MATERIALS WHICH MAY REQUIRE STORAGE

3.1 REVIEW OF EPA LISTS

As requested by the statement of work, a review was made of the EPA lists of hazardous materials and chemical compounds. This list identified compounds, substances, and mixtures which if spilled in the environment required immediate notification of State and Federal authorities. BDM reviewed the list and compiled a list which we believe contains the most significant compounds which are those which must be reported if 100 lbs or less are spilled. Those compounds with reporting requirements of 1000 to 5000 lbs were not included on the list. There were only 30 compounds not included on the list. This list of extremely hazardous substances if found in soils would require remediation and/or storage until remediation could be performed.

The list presented in table A-1 (Found in APPENDIX A), was obtained from EPA publication "The Emergency Planning and Community Right-to-Know Act of 1986, List of Extremely Hazardous Substances", 40 C.F.R. Part 355 (Sections 302 and 304), dated March 1, 1988.

3.2 VOLATILE ORGANIC COMPOUNDS

From the same EPA source, a list of volatile organic compounds was compiled and is presented in table A-2 (APPENDIX A). Also listed and marked with an asterisk are the contaminant compounds found at the Winfield site as reported by the COE report.

3.3 SEMIVOLATILE ORGANIC COMPOUNDS

Table A-3 (APPENDIX A) presents a list of semi-volatile organic compounds which may require remediation and/or storage for later remediation operations. Those compounds found at the Winfield site are indicated by an asterisk.

3.4 PESTICIDES

Table A-4 presents a list of chemical pesticides which may require remediation and/or storage for future remediation operations.

There is currently indications of few pesticides listed having been detected at the Winfield Site. Those detected during analysis are indicated with an asterisk.

4.0 FUNCTIONAL ANALYSIS OF STORAGE TECHNOLOGY

Functional analysis is a method of determining if a planned project will perform all of the functions that is required to accomplish the goals and objectives established by the planning operation. In the case of storage technology, the specific character of the site must be determined to identify storage technology needs. A review of the Winfield Site characterization studies was performed to satisfy this requirement.

4.1 WINFIELD CHARACTERIZATION STUDIES

The Winfield site is a 21.81 acre tract of land adjacent to the right descending bank of the Kanawha River in Putnam county, West Virginia. It is immediately upstream of the Winfield Locks and Dam. The site is currently controlled by the United States Corps of Engineers (COE). It was acquired from its prior owner, American Car and Foundry Industries, Inc. (ACF), in preparation for the planned expansion of the Winfield Locks.

4.1.1 Background

The former American Car and Foundry Industries, Inc (ACF) 21.81 acre tract is located near Red House, WV, which is approximately 20 miles northwest of Charleston, WV. The site is adjacent to the right descending bank of the Kanawha River immediately upstream of the Winfield Locks and Dam. Prior to 1952 the site was prime agricultural land. From 1952 until the facility closed in March 1986, ACF used the property to repair and service a fleet of tank and covered hopper railcars. At the height of operations, ACF maintained over 47,000 railcars that were leased to various companies for hauling liquid and solid chemical commodities.¹

On December 8, 1989 the U.S. Army Corps of Engineers (COE) filed a Declaration of Taking in U.S. District Court for the tract of land then owned by ACF. Property acquisition was initiated to support proposed construction of an expanded lock and gate bay at the Winfield Locks and Dam. Following a limited excavation and removal activity administered by ACF, the COE took possession of the property on May 1, 1990.

In May 1990, COE representatives observed discolored water seeping from excavation pit walls in the area of the ACF removal activity. The soil in this area was also observed to be discolored and was characterized by a phenolic odor. This discovery was followed by sampling activity in an effort to define the limits and nature of the suspected contamination.

Water samples collected from the seeps exiting the excavation pit walls confirmed the presence of contaminants including volatile organics and base/neutral acid extractables. Subsequent investigations confirmed the presence of pesticides, polychlorinated biphenyls (PCBs), and dioxins in this area.

In September 1990, the COE planned an initial site investigation. This site investigation was designed to include soil gas surveys, soil sampling, and any necessary ground water monitoring. Due to the nature of the contaminants identified the confirmation activities were expanded to include a total site characterization. Samples for all environmental site investigations administered by the COE were analyzed using appropriate EPA SW-846 methods and utilized a quality assurance/quality control (QA/QC) program in an effort to provide legally defensible data.

Soil gas surveys indicated that Volatile Organic (VOC) and semi-volatile organic (SVOC) contamination was present over a large portion of the site. Soil sampling data were relatively consistent with the soil gas results, i.e., high concentrations of VOCs and SVOCs were detected in several areas of the site. In addition to these contaminants, pesticides, PCBs, and dioxins were detected. Given the number and concentrations of contaminants found in the soil matrices, it was evident that groundwater contamination was possible and must be investigated. Due to the environmental significance of dioxin, additional sampling was required to determine if dioxin contamination was localized or widespread.

Initial groundwater monitoring at this site was accomplished by the installation of four groundwater monitoring wells, sampling each of these wells and three existing water supply wells in the area. Three of the monitoring wells were installed at the top of rock (approximate depth of 60 feet), and one was installed in shallow perched water (approximate depth of 15 feet). Low concentrations of VOCs were detected in the shallow perched water, while no contaminants were detected in the deeper aquifer, which is the drinking water supply source.

A draft EPA procedure (SOW 1290) was used for the analysis of the additional soil samples selected to be analyzed for dioxin. This procedure is similar to SW 846 method 8280 but requires more strict laboratory quality control. The Tetrachlorodibenzodioxin (TCDD) toxicity equivalence values calculated indicated over 50% of the samples were identified with dioxin contamination at a significant level. This confirmed that dioxin contamination was widespread and present in concentrations of sufficient level to be a major concern. Due to the disposal problems associated with dioxin contaminated soils, it was necessary to perform a total site characterization.

4.1.2 Current Status

Currently another round of sampling and analysis has taken place and the results are being discussed by the COE, ACF, and the general public concerning the amount and severity of the contamination of the site.

4.1.3 Contaminants

The contaminants found at the site as reported by the Core of Engineers are indicated with a asterisk (*) in tables 2,3 and 4. The presence of dioxins as reported by the COE adds considerable complexity to all remediation operations and supporting functions such as monitoring to protect the health and safety of workers on site and the general public, and storage operations.

4.2 SCOPE

The scope of the functional analysis of storage technology is to determine the the basic functions that must be performed by any EPA acceptable technology which will provide for storage of contaminated soils until remediation is initiated while protecting the public and the environment.

4.3 OBJECTIVES

The objective is to identify functions, requirements, issues , concerns, unknown, and uncertainties relative to identifying and qualifying a suitable storage technology.

4.4 REQUIREMENTS

4.4.1 Federal Government Regulatory Requirements

The following federal government regulations are deemed to be applicable to the COE Winfield Site:

- Resource Conservation Recovery Act (RECRA)
- Air Quality Standards (AQS)
- National Pollutant Discharge Elimination System (NPDES)
- Clean Water Act - Section 404 (CWA)
- Safe Water Drinking Act (SWDA)
- National Environmental Protection Act (NEPA)
- Fish and Wildlife Conservation Act (FWCA)
- Executive Order # 11988

4.4.2 State Government Regulatory Requirements

The State of West Virginia has several parallel environmental protection and control acts which are believed applicable to the Winfield Site., which are listed as follows:

- Air Pollution Control Act
- Clean Water Act
- Toxic and Hazardous Materials Control Act

4.5 INTERFACES

The Temporary Storage Plan will have to be consistent and interface with the Excavation Plan, Remediation Plan and the Site Closure Plan. The Storage Plan may or may not contain provisions for monitoring operations, depending upon remediation activities that may remove some of the contaminants such as VOC's. Special provisions may need to be taken for separate storage in special containers of dioxin laden soils. A careful review of the interfacing activities of the various plans will need to be made prior to implementation of any of them.

4.6 ISSUES AND CONCERNS

A primary issue relative to worker and public safety is the rate of liberation of VOC's during excavation and storage operations. A high rate of emission could result in a class B operation at the site.

A further concern is that if VOC's are not vented by drilling vent holes prior to excavation operations, will there be a need for a monitoring system that will provide the public with a warning when high levels are emitted during the storage operation that can affect public health.

4.7 ASSUMPTIONS

It is assumed that a leachate collection system will be installed for operation with which-ever storage technology is deemed acceptable in accordance with the applicable regulations and the contaminant conditions encountered during the excavation operations.

VOC levels in the soil will be monitored during excavation and the appropriate action taken when regulatory limits are exceeded.

Venting of VOC's from storage facilities will only be allowed as long as the rates are in compliance with EPA and WV clean air regulations.

Waste minimization plans will be prepared and implemented whenever possible and allowable by the regulations.

Cost benefit analysis will be an important aspect of selection of storage technology to be implemented at the Winfield Site.

4.8 INTERFERENCES

Care should be taken to locate storage facilities in a position on site (required for dioxin) which will not be disturbed by, or interfere with, excavation or remediation activities.

4.9 UNKNOWN / UNCERTAINTIES

Does project schedule impact the storage and/or remediation technology selected or recommended for the site?

Does the VOC content of the soil require treatment before being vented from the facility?

What effect will weather have on the release of VOC's from the soils stored in the storage facility?

Will there be adequate facilities (fencing) to protect the public and wildlife in the area during storage operations?

4.10 EVALUATION CRITERIA FOR STORAGE TECHNOLOGY

The development of criteria to evaluate alternative storage technologies is derived from several different sources. Primary among these are the Federal and State guidelines. Of particular importance are the Resource Conservation Recovery Act (RCRA), Clean Water Act (CWA), and the Safe Water Drinking Act (SWDA). Functional criteria on environmental protection, as well as health and safety were developed with guidance from these and other related sources (attachment 1).

Important aspects of each technology to be evaluated for application to a generic site or the Winfield Site is to determine how well they meet the basic functional requirements, and how well they meet the evaluation criteria. The following discussion considers the functional analysis criteria for storage technology considerations.

4.10.1 Performance

Temporary storage technologies are evaluated in terms of their ability to inhibit the migration of contaminants from existing hazardous materials to the surrounding ecosystem. This evaluation includes but is not limited to contamination of associated surface water systems, ground-water systems, uncontaminated soils, and air emissions. Specific criteria include:

Associated ground-water and surface-water systems must be protected from migration of contaminants from the temporary storage site.

Temporary storage technology must exhibit positive control of contaminant migration generated by associated run-on and runoff.

Specification of storage technology, to include but not limited to containers, tanks, surface impoundments, and/or waste piles, will comply with existing government regulations.

The storage facility will be equipped with a control location of center for monitoring of gas vapors, water pressure, and/or leakage as required.

The temporary storage facility must be constructed in such a way as to minimize the potential contaminant migration through wind dispersion.

Temporary storage site will require an impervious liner and/or associated containment system compatible with known site contaminants.

4.10.2 Reliability

Effectiveness and reliability of the temporary storage technology to control contaminant migration to the surrounding ecosystems. Specific criteria include:

Storage technology controls contaminant migration to limit associated containment levels of off-site ecosystems at or below EPA limits for contaminants contained within the storage site.

Monitoring and treatment of gas emissions is provided to prevent VOC migration to surrounding ecosystem.

Temporary storage facility will provide positive control of associated run-on and run-off, as well as monitoring, and treatment of leachate from the site.

Temporary storage facility will provide positive control of dust emissions through either a suitable cover system or by treatment of associated contaminated materials.

Reliability of the storage technology will be maintainable for the duration of remediation activities at the site.

4.10.3 Implementability

Temporary storage facility may be procured and introduced to the site within existing time and economic limitations. Specific criteria include:

Temporary storage technology is currently available and has been demonstrated as effective in controlling contaminant migration at sites containing similar contaminant profiles.

Technology may be procured and introduced to the site within allowable time constraints.

Technology will not hinder associated site activities.

4.10.4 Environmental Safety and Health Considerations

The temporary storage technology must minimize both the short-term and long-term health and safety risks to both personnel associated with site activities as well as the general populous. Specific criteria include:

Configuration of the storage facility must prohibit physical contact with waste materials by persons (unknowing or unauthorized) or livestock. May include but not limited to surveillance, barriers, controlled entry and/or posted warnings.

Allowances must be made for the separation of ignitable, reactive or incompatible waste materials.

Facility must allow for the control of collection, processing, release and monitoring of water and gas emissions.

Materials and constructions techniques must minimize possibility of fire, explosion, or unplanned release of hazardous waste contaminants.

Storage site is able to support the development and maintenance of contingency plans and emergency procedures to include fire fighting, spill control, decontamination, and routine movement of work crews and equipment.

Site configuration supports flow and monitoring of the hazardous waste stream.

Temporary storage facility will have a minimal visual impact, to include dust, noise and litter.

Transportation to and from the facility will have a minimal impact on existing traffic patterns and construction activities at the site.

Temporary storage facility will be visually unobtrusive.

4.10.5 Legal and Regulatory Compliance

Temporary storage technology supports remediation of contaminated materials and site-closure procedures. Technology supports excavation and storage of all contaminated materials to include but not limited to soils, above ground structures, vertical construction, underground utilities and storage structures. Specific criteria include:

Storage technology complies with existing Federal and State legal and regulatory guidance with regards to air standards, water standards, noise standards, and land use and planning.

Configuration of temporary storage facility supports efficient storage, handling and processing of contaminated materials.

Storage configuration supports monitoring of materials prior to, during and after remediation activities.

Storage system configuration will allow for the unobstructed movement of vehicles and personnel during storage and remediation activities.

Contaminated materials are configured in a form that supports site storage, handling, and remediation.

4.10.6 Economics

Temporary storage technology fulfills environmental, health and safety, and remediation criteria with minimized capital expenditures. specific criteria include:

Temporary storage technology allows for expedient construction, remediation and site closure.

Facility will minimize impact on associated site construction activities.

Temporary storage facility will minimize requirements for associated support systems such as but not limited to barriers, monitors, roadways, utilities, drainage, and treatment.

4.10.7 Interferences

The storage technology selected should pose the least problems in the form of interferences with planned operations. The storage system configuration should allow for the unobstructed movement of vehicles and personnel during storage and remediation operations

4.11 STORAGE TECHNOLOGIES

4.11.1 Background

Storage technologies related to hazardous wastes had their beginning in the early 1940's when the various Atomic Weapons plants were manufacturing uranium and plutonium . Radioactive and other types of liquid wasted were stored in large concrete and steel lined tanks which were usually buried several feet underground similar to the single shell tanks located at the Hanford Facility near Richland, Washington.

The need for storage space for more conventional hazardous and toxic wastes did not become apparent until the initiation of the Super Fund program where large sites with extensive lists of chemical had

been disposed of and now had to be cleaned up. During these early years the material as piled up until hauled off for remediation activities.

As EPA procedures became more stringent, the need or potential need for temporary storage of toxic chemicals and contaminated material became apparent. Most of the activities relative to development of storage technologies has occurred in the last five years. During this period, EPA has required excavators of soils to store the excavant on rubber or plastic liners that would prevent contaminated liquids and leachate fluids from escaping and getting into groundwater supplies. The importance of liners and how they are constructed, or manufactured and the type of material becomes of considerable interest when considering the concept of storage technology, either temporary or permanent., thus the following discussion on liners was considered important by BDM investigators.

4.11.2 Liner Technologies

The success of almost any hazardous/toxic waste storage technology is dependent on its ability to reduce the potential for spread of contaminants. The use of an effective liner system is common among many of the successful storage technologies. The function of a liner system at a waste storage site is to prevent the movement of polluting constituents that are contained in the waste from entering the associated ground water or surface water systems. This function is accomplished in two ways.

First, the liner system impedes the flow of polluting constituents into deep-water aquifers and/or surface water systems, and;

Second, it absorbs or reduces suspended or dissolved pollutants, both organic and inorganic, so that concentrations in the deep-water aquifers and/or surface water systems remain within EPA guidelines.

Most liners perform both of these tasks, dependent on the composition of the liner and the waste constituent at the site. Liners may be classified by various methodologies. For the purposes of this summary the following classes will be utilized.

CLASSES	TECHNOLOGIES
Soil Liner	Soils and clays
Engineered Liner	Admixes
Manufactured Liner	Polymeric membranes
Engineered Liner	Sprayed-on materials
Engineered Liner	Soil sealants
Chemical Liner	Chemisorptive materials

4.11.2.1 Review and Discussion

Compacted Soils and Clays are the first alternative considered for liners because of their availability and low cost. Effective liners of this class contain a relatively large portion of fines (smaller than 2 μm). These clay-sized particles are required in the soil to limit permeability. A good soil liner will be comprised of approximately 25-28% clay by weight.

Although soil and clay liners have a large absorption capability, their permeability is higher than other man-made liners. While some sites have existing natural clay deposits that function as a liner and limit movement of the contaminants into the ground-water system, increased activity at a site can fracture this clay layer. The increased potential for ground-water contamination caused by load stress at the Winfield Site necessitates the need for monitoring of water quality prior to, during and after excavation and construction activity. Any storage at the site will require additional liners to control the potential for migration of any contaminants.

Admixed Liners include asphalt, concrete, soil cement and soil asphalt, all of which are hard-surface materials that are formed in-place at the waste site. The EPA has done some exposure testing¹, but there is limited experience with these lining technologies.

Hydraulic Asphalt Concrete (HAC) is a mixture of hot asphalt cement and high quality mineral aggregate. It is usually of a harder grade (6.5-9.5) than paving asphalt. Desirable characteristics include resistivity to water damage and to stresses caused by temperature extremes. It is stable on slopes, flexible and may be applied with conventional paving equipment. Due to the effects on liner permeability, inconsistencies in mixing and compaction, a 4-inch thickness may be required², although a 2-inch thickness has been successful³ in some applications. Asphalt's are water resistant. They are also resistant to acids, bases, inorganic salts (with up to 30% concentrations) and to some organic compounds commonly found in industrial wastes. They are not resistant to organic solvents and certain chemicals (particularly hydrocarbons), so they do not make an effective liner technology for sites containing petroleum-derived wastes.

Soil Cement is a compacted mixture of Portland Cement, water, and selected in-place soils. They form a low-strength Portland-Cement-like concrete, with greater stability than natural soils. Permeability varies, based on soil type, but may be enhanced through application of an epoxy asphalt or epoxy coal-tar coating. The preferable soil type will have a clay content of 35%⁴. Higher clay contents will reduce the ability of the cement to produce a homogeneous layer and increase its permeability. A Soil Cement liner has excellent aging and weathering characteristics. It resists the degradation effects produced with wet-dry and freeze-thaw cycles. Degradation has been observed in highly acidic environments⁵. Soil Cements do resist moderate amounts of alkali, organic matter, and inorganic salts. This liner technology does exhibit a tendency to crack and shrink on drying.

Soil Asphalt is a mixture of liquid asphalt and available on-site soil. The best soils have 10-25% silky fines, with a low plasticity. Permeability of this liner will be variable, based on the degree of compaction. Soil Asphalts made with asphalt emulsion do not exhibit sufficient impermeability characteristics. They usually require a water-proof seal, such as a hydrocarbon-resistant or bituminous seal⁶.

Polymeric Membranes exhibit extremely, low permeability. They have been used successfully in water impoundments, sanitary landfills and various waste disposal facilities. The technologies associated with polymeric membranes are varied. Materials may be altered so their physical and chemical properties match the individual site. The general classification of these polymers include:

Rubbers (elastomers) which are generally vulcanized.

Plastics, such as PVC.

High-crystalline plastics, such as polyolefins.

Thermoplastic elastomers, which are not generally vulcanized.

Butyl rubber was first used for potable water impoundments⁷. The liner material is comprised of isobutylene (97%) and a small amount of isoprene. It performs well as either a liner or top cover, exhibiting low gas/water vapor permeability, thermal stability, and chemical resistance. It is swollen by hydrocarbon solvents and other petroleum oils, but is only slightly affected by oxygenated solvents. Butyl is highly resistant to mineral acids. After 13 weeks of immersion in 70% sulfuric acid, a butyl compound showed little loss in tensile strength or elongation⁸. These liners have a high tolerance to temperature extremes, and exhibit good tensile-strength and elongation qualities. Application is limited, however, due to the difficulty in seaming and repair.

Chlorinated Polyethylene (CPE) is produced by a chemical reaction between chlorine and high-density polyethylene. It is not susceptible to ozone, and weathers well, making it a suitable top cover. It also has good tensile and elongation strength, and is resistant to many corrosive and toxic chemicals. These liners may be formulated to withstand intermittent contact with aliphatic hydrocarbons and oils. CPE

will swell in the presence of high concentrations of aromatic hydrocarbons and oils, so they are not recommended for these contaminants. This compound is suitable as a base material for a broad spectrum of liners because it can be bounded with other polymers. It is easier to seal using solvent welding or dielectric heat sealing⁹.

Chlorosulfonated Polyethylene (CSPE) forms the basis for a family of polymers prepared by reacting polyethylene in solution with chlorine and sulfur dioxide. Generally tougher than other thermoplastics commonly used as elastomers, CSPE will soften more rapidly as temperatures are increased¹⁰. CSPE is characterized by ozone resistance, good weatherability and resistance to deterioration from acids and alkalis. Usually it is reinforced to improve its tear-resistance when used on sloops. It can be seamed by heat sealing, dielectric heat sealing, solvent welding, or by using bodied-solvent adhesives. It does exhibit a low tensile strength and will shrink from exposure to sunlight. It has a poor resistance to oils.

Elasticized Polyolefin is a blend of rubbery and crystalline polyolefins. It is highly resistant to weathering, alkalis, and acids¹¹. Difficulties have been encountered in low temperature and high winds, in oily environments, and with adhesion to structures.

Epichlorohydrin Rubbers (CO and ECO) are saturated, high-molecular-weight, aliphatic polyethers with chloromethyl side chains. They are resistant to hydrocarbon solvents, fuels, and oils. They exhibit good weathering, and low rates of gas and vapor permeability. Homopolymer performs well at a temperature range of 0 to 325°F.

Ethylene Propylene Rubber (EPDM) is a vulcanized compound that has excellent resistance to weather and ultraviolet exposure. It may be configured to improve its resistance to abrasion and tears. Because of its excellent weatherability and resistance to ozone, minor amounts of EPDM is sometimes added to butyl liners to improve their weather resistance characteristics. EPDM liners are resistant to dilute concentrations of acid, alkalis, silicates, phosphates, and brine, but are not recommended for petroleum solvents (hydrocarbons) or for aromatic or halogenated solvents. Vulcanized EPDM membranes require the use of special cements for seaming.

Neoprene is a generic name for synthetic rubber. It parallels natural rubber in mechanical properties, but is superior in its resistance to oils, weathering, ozone, and ultraviolet radiation. Neoprene is satisfactory for the containment of waste-containing hydrocarbons. Vulcanizing cements and adhesives must be used for seaming.

Polyethylene can take the form of either a low-density or high-density liner. Polyethylene liners can degrade quickly when exposed to the elements, but this can be corrected by the addition of 2-3% Carbon Black. They exhibit superior resistance to oils, solvents, and permeation by water vapor and gases. Membranes of low-density polyethylene have been used for years¹², but have proven to be hard to handle. They puncture easily under impact, such as when being loaded with waste materials. Buried polyethylene membrane linings exhibit good serviceability. Linings of high-density polyethylene are more resistant to damage, but are very stiff when compared to most alternative materials. Special equipment is required for field seaming.

Polyvinyl Chloride is produced from vinyl chloride monomer (VCM). It may be modified to alter its physical characteristics. These modifications may be necessary to prevent liner degradation due to plasticizer loss through volatilization, extraction and microbiological attack. The PVC polymer itself is not affected by these conditions, but can degrade due to ultraviolet exposure. It is not recommended for a surface cover. PVC membranes are the most widely-used of all polymeric membranes for waste impoundments, since they exhibit resistance to many inorganic chemicals¹³. They are susceptible to degradation when exposed to certain organic compounds, particularly hydrocarbons, solvents and oils. Special compounds of PVC are available that possess higher resistance to oil.

Thermoplastic Elastomers (TPE) form a class of rubbery materials that range from highly polar materials, such as polyester elastomers, to nonpolar materials, such as ethylene-propylene block polymers. They generally behave in a manner similar to vulcanized rubber. Some blends have excellent

oil, fuel, and water resistance with high tensile strength. They also weather well. Their durability in various chemical environments remains to be tested.

Sprayed-on liners are liquids that are sprayed onto a prepared surface where they solidify. Air-blown asphalt is widely used. It will provide a seam-free liner that will retain its flexibility indefinitely when properly covered and protected from mechanical damage¹⁴. The addition of 3-5% rubber improves the characteristics of the liner. Surface preparation is required, and in soils with irregular rocks, a layer of fine sand is desirable to improve the ease of liner application.

Membranes of Emulsified Asphalt may be applied at ambient temperatures, which makes them easier to apply, but they are not as resilient as hot air-blown asphalt membranes. Toughness and dimensional stability can be achieved by spraying the emulsion onto a supporting fabric such as jute or synthetic fibers. The supporting fabric seams must be secured prior to application of the emulsified asphalt.

Urethane-modified Asphalt may be manually spread or sprayed into place, and must cure for 24 hours before use. The liner exhibits good weatherability and low temperature ductility. It is not recommended for prolonged exposure to hydrocarbons or organic solvents. Care must also be taken in proper preparation of the surface prior to application.

Rubber and plastic latexes may also be used as spray-on liners. They result in a fairly resilient film with good soil-sealing capabilities..

Soil sealants, as a class of liners, exhibit high permeability, but this permeability can be significantly reduced by the application of various chemicals or latexes. The sealing effect is limited to the upper few centimeters of soil, and will degrade under continued wet-dry or freeze-thaw cycles.

Chemical absorptive liners are efficient in the removal of contaminants from the seepage as it moves through the liner. Various mixtures of absorptive agents may be required to control the migration of pollutants at sites containing chemical mixes. Some chemicals may also function to stabilize the soil contaminants. When Hydrophobized "quicklime" (DCR Lime) is mixed with water and oil contaminated materials the hydrocarbons are absorbed and fixed. The mixture hardens on exposure to air. It can be compacted to form a low permeability liner that is chemically and physically stable. The process has been used overseas since 1975, but has not been used extensively here in the United States.

4.11.2.2 Analysis of Liner Technologies

Based on the danger that the current equilibrium and natural clay barriers will become fractured during excavation and construction activities at the Winfield Site, a man-made liner technology will be required to control pollutant migration into the ground water. Technology selection will be influenced by the cover system selected (i.e. permanent or temporary structure, liner material to control VOC gases and dust etc.). Pretreatment of contaminated materials will also influence liner requirements.

Independent of the top cover, and pretreatment technologies, polymetric membranes appear to present the most favorable combination of low permeability and ability to contain site specific contaminants.

Monitoring of air and ground-water pollutants must be conducted prior to, during and after operations at the site are underway. This includes the extraction, storage and remediation of the waste materials and the construction and subsequent operation of the expanded Winfield lock and dam.

5.0 LITERATURE REVIEW

5.01 OBJECTIVE

The objective of the literature review was to compile a body of literature that describes the current S-O-A of technology which deals with the storage of hazardous or toxic chemical, and materials.

5.02 PURPOSE

The purpose of the review is to evaluate a number , or all of the currently available technologies for storage of toxic and hazardous materials, and to evaluate those technologies to determine which may be applicable to the Winfield site as is, or which may be modified by additional research for application to Winfield and similar sites.

5.03 PROCEDURES:

A list of Key words was compiled to initiate the literature search with. The search was started by using the key words on periodicals published since 1983 (a ten year period to insure current technology). The search was then expanded to include published patents and books.

Finally, government publications lists such as NTIS, GPO, and EPA were included in the search.

5.03.1 Key Words

The controlling Key words were listed first in the hierarchy and the focus continued to zoom in based on the functional analysis results. (See Figure 5.1)

5.03.2 Sources

The data was gleaned from a computer searching of a list of journals compiled at the Evansdale Branch of the WVU Library (see table B-5.1 in APPENDIX B). A computerized database containing a list and abstracts of published patents was anothe source of material for review . The same key words were used to compile a list of abstracts to review for selection of patents to review in a more detailed study.

Books were more difficult to deal with in the search. Books on these topics often contain a wide variety of associated topics. A number of books of the most recent publication date were examined and reviewed. On the subject of storage technology, few books are available which discuss this topic in any detail. Most of the data was found in journal articles.

5.03.3 Results

Several hundred documents were examined to compile notes on the various storage technologies currently in use by the remediation industry. This material is contained in APPENDIX B of this report.

5.1 STORAGE FACILITY LITERATURE

Literature specifically discussing storage facilities, either drums, tanks, or buildings is somewhat limited. A total of only (9) articles discussing buildings or other storage facilities with particular potential application to the Winfield site were located and reviewed for discussion. There are more numerous articles written about the use of underground storage tanks for storage of hydrocarbons, and radioactive wastes but ther were no real parallels to the requirements at the Winfield site.

5.1.1 Portable Buildings

Temporary storage of relative small volumes of toxic or hazardous materials can be accompolished by utilizing small portable buildings made of steel¹ which can hold 55 gallon drums for safe storage of many hazardous wastes. The use of steel as building material provides some security

and safety aspects relative to explosion hazards. The portable nature allows the movement to isolate it from the general public during storage.

There is some potential application for some type of portable storage building to house , perhaps in fiber glass or epoxy resin drums, the dioxin contaminated soils at Winfield. Portable buildings are being used to store hazardous materials and chemicals at State owned and operated landfills² in Florida and California. A firm named Safety Storage of Cupertino CA manufactures the buildings in several sizes, but 8 ft. by 22 ft. seems to be a standard size.

Temporary buildings can also be constructed of thermoplastics and lighter crosslaminated vinyl plastics (PVC) attached to tent like wooden or aluminum frames. These buildings (Sprung Instant Structures for example) could be used to cover excavation operations as reported at the Mc Coll Site,³ or to cover part of an open cast storage facility built on a constructed or manufactured liner to provide temporary storage for contaminated or VOC laden soils.

5.1.2 Permanent Buildings

Permanent buildings have been suggested as a solution to the long time storage requirements for dioxin contaminated soils which generally have to be incinerated as the only acceptable remediation technology. This method is now receiving strong disapproval by locals in the Winfield area which may lead to need for utilization of a permanent type storage building. One invention, U. S. Patent 4,875,805, "Toxic Waste Storage Facility", is a shell building which is lined with blocks constructed of clay and earth containing the contaminants. This type of building would have a potential application at the Winfield Site for temporary or permanent Storage operations. Figure 5.1 is a reproduction of one of the drawings from the patent description.

Permanent buildings when coupled with a remediation process that could be researched at the Winfield Site could lead to a less costly solution to the remediation activities there.

5.2 STORAGE FACILITY ATMOSPHERE MONITORING

The activity of excavating transporting, and stowing soil materials can generate significant contamination of the air from fugitive dust and gaseous vapors. To protect the health of site workers, monitoring of the atmosphere on the site and inside of temporary or permanent storage buildings is necessary, if only to determine that monitoring may not be necessary on a continuing basis.

5.3 CONTAINMENT MATERIAL MONITORING

The soils that will be stored will need to be sampled and monitored to determine the level of contaminants that workers will be exposed to during stowing operations. Conventional sampling and monitoring techniques should suffice for these operations until experience is gained in storage operations to determine other wise.

6.0 STORAGE TECHNOLOGY - REVIEW AND PRIORITIZATION

6.1 CRITERIA

Federal and state laws and regulations stipulate requirements for protection of the public based on the results of specific site characteristic studies. COE administered site analysis using appropriate EPA SW-846 methods. Drivers for material excavation, storage, monitoring, and remediation were identified dioxins, VOCs and semi-VOCs. The primary driver is the dioxins.

6.2 PROCEDURES

Initial inquiries into the available storage technologies for storage of hazardous and toxic wastes yielded information in the areas of permanent storage and temporary storage at a waste generating site. Permanent storage of contaminated materials is an option at some locations, but is precluded at the Winfield site due to the projected construction efforts and the presents of dioxins in the soils. For these reasons most of the materials available in peer-reviewed publications is not applicable. EPA research in the area of storage is also focused on long term disposal. Additional materials were found in the area of temporary site storage at sites where contaminated materials are stored. Limitations on quantity of material and duration of the storage prior to removal precluded application of these technologies to the Winfield site.

Investigation of general classes of temporary storage technologies yielded more promising results. Specific storage systems were grouped into specific classes based on their life-span (temporary or permanent) and their ability to handle contaminated materials. These classes (follows) were then evaluated based on the previously discussed functional analysis criteria.

6.3 TEMPORARY STORAGE TECHNOLOGY CONCEPTS:

6.3.1 Open Storage

Existing contaminated materials have stabilized at the site. The increased activity at the site increases the potential for contamination migration to the surrounding environmental systems. Specific concerns center around migration of contaminants to the ground and surface water systems, and the release of VOCs and semi-VOCs.

Additional protection against spread of contaminants may be offered through utilization of an open storage (figure 6.1) area that includes both a plastic or rubber liner to contain leachate and a plastic top cover to contain dust and exclude water. This open storage area would be located at the site, but away from the planned construction for the expanded Winfield Locks and Dam. This storage system would be considered a viable candidate for temporary storage operation with a planned duration of a few months. The chance for bad weather conditions that could compromise the top cover would be very strong beyond six months. Previsions could be made to monitor for gases liberated by the soils beneath the top cover.

FIGURE 6.1

6.3.2 Open Storage With Constructed Base

When longer term storage is a requirement, then construction of a more efficient and serviceable facility can be accomplished as shown in figure 6.2. This storage facility has a dual liner system (constructed and manufactured elastomer) and leachate collection system. The top cover (plastic) can be anchored to insure integrity over a longer period of time than the open storage facility. Special arrangements could be made to install plastic conduit pipe under the top cover to collect gas for monitoring for VOCs.

FIGURE 6.2

6.3.3 Open Storage With Constructed Base and Cover

Disturbing the contaminated materials may result in an increase in emissions of VOCs. For control of emissions during short term storage, a capping liner may be installed over a metal frame extending a very short distance above the soil pile to collect and ventilate (or treat) VOCs (figure 6.3). A temporary containment wall may be required to support the frame for capping the contaminated materials.

FIGURE 6.3

6.3.4 Storage in a Temporary Building

When a longer term of storage estimated to be several years in duration is required, then construction of a temporary building may meet all of the requirements. The nature of the site contaminants may also require the separation of soils to insure safe handling during storage and remediation. All or some of the materials may be stored in impermeable containers (figure 6.4). A combination of storage technologies may also be used. Highly toxic materials, such as dioxins, may be containerized while the remaining less toxic waste materials are stored in bulk under a temporary cover.

Temporary Storage Technology #4: Containerized Storage

FIGURE 6.4

6.3.5 Open Storage in a Landfill

Open storage in a landfill type of construction has shown to be a viable option for percent disposal of hazardous materials. Even though long term plans are for the remediation of all site materials, a landfill system (figure 6.5) could be utilized. The system would include a constructed liner and leachate collection system, and a constructed cover to reduce water influx.

Temporary Storage Technology #5: Landfill

FIGURE 6.5

6.3.6 Storage in a Permanent Building

The most involved storage technology would be the construction of a permanent building to contain soils and confine leachate (figure 6.6). Most likely materials include a concrete pad, block retaining walls and a metal or metal frame roof. The structure would be constructed to handle monitoring and treatment of VOCs as well as future remediation activities .

Temporary Storage Technology #6:
Permanent Building

FIGURE 6.6

6.4 Evaluation of Storage Technologies:

Each of the storage technologies identified was evaluated based on the previously discussed functional criteria (ref. 4.10). The technology was judged as High, Medium, or Low based on its ability to meet the requirements of each functional criteria. A technology was judged to be High in relation to a specific functional criteria if all criteria requirements could be met with existing technology, and with moderate cost and time expenditure. A grade of Medium was given if the technology was able to meet the functional criteria, but would require greater investment in either cost or time. A grading of Low was given when there was a reasonable degree of doubt as to the ability of the technology to fully meet the functional criteria.

Point values were assigned to each level. High equates to a point value of 9, Medium to 3, and Low to 1. The point value for each technology, along with the point value of the specific functional criteria (again given as High, Medium and Low) would be multiplied together to arrive at a numerical representation of the technologies ability to meet specific functional requirements. For example (figure 6.7), we can see that storage technology 1, Open Storage was rated as Low in relationship to the functional criteria of environmental protection. The numerical value for this interaction will be calculated at a Low for the ability of an open storage technology to meet environmental requirements, multiplied by a High for the importance of this specific functional criteria category. This will equal 1 times 9 for a total of 9 points. This multiplication of technology interaction ratings times the functional criteria rank continues for each functional criteria category. The calculated values are then summed to arrive at a total score for the technology. In the case of Open Storage the score is equal to 60. A given storage technologies score will depend on its ability to meet all the functional criteria requirements, with emphasis placed on the functional criteria judged to be High in importance (i.e. High ranking on chart).

Evaluation of Temporary Storage Technologies

Functional Criteria	Rank	Technologies					
		1	2	3	4	5	6
Environmental Protection	H	○	○	◐	●	○	●
Health and Safety	H	○	○	◐	●	○	●
Technology Performance and Reliability	H	○	◐	◐	●	◐	●
Implementation	M	●	◐	◐	○	◐	◐
Interferences and Remediation	M	○	◐	◐	●	○	●
Economics	L	◐	●	◐	○	●	●
		60	72	102	274	66	288

Storage Technology Key

- 1 Open Storage
- 2 Open Storage w/ Constructed Base
- 3 Constructed Top Cover and Base
- 4 Containerized Storage
- 5 Landfill
- 6 Permanent Building

- Technology vs functional criteria interaction is LOW
- ◐ Interaction is MEDIUM
- Interaction is HIGH

FIGURE 6.7

The general storage technology that performed the best in relationship to the other technologies was the use of a permanent building. It received a total of 288 points. Also, the concept of using some type of containerized storage performed well, with a score of 274. The primary advantage of the permanent building concept over containerized storage is the reduced cost and ease of implementation. A combination of these two storage technologies may be possible. Highly contaminated soils could be stored and controlled by use of containers, while the bulk of less contaminated materials could be stored using a permanent building.

7.0 IDENTIFIED PROBLEM FOR FUTURE R & D

7.1 GENERIC PROBLEMS

The primary focus of research activities in the management of hazardous and toxic materials has been in remediation and monitoring. Minimal work has been done on temporary storage technologies.

Federal regulations identify when and what materials may be placed in temporary storage prior to final disposal. Generally the guidance is focused on storage of contaminated materials as the generation site until transportation to a final disposal site. Most industrial concerns may file for a permit to maintain a 90 day temporary storage facility to house site generated contaminants. Only materials generated on that site may be stored and only for a maximum of 90 days.

Other developments in hazardous waste storage have been geared towards long-term storage at a disposal site. Research in this area has been focused on methods of storage that minimize the potential for contaminant migration into the surrounding ecosystem.

Temporary storage facilities that have been developed are usually a semi-permanent or permanent structure that has an associated top cover and leachate monitoring and collection system. Specific characteristics of the facility are driven by the specific contaminants found in the materials.

7.2 WINFIELD SITE

Specific problems identified relating to the Winfield site storage operations are few. The excavated material will have to be transported a few hundred feet to the location of the storage facility. If no prior attempts to remove VOC's have been made then WVU should take the opportunity to plan and exercise one or more research projects which would examine the rate of evolution of VOC's when stored in either a permanent or a temporary building, and the facilities to trap or collect gases are available.

Such an experiment could use a scanning FTIR unit to record the spectra of all of the contaminants moving across a five foot section of a stowing conveyor belt to record evolution of VOC's. Storage air ventilation rates required to remove and extract the VOC's in a scrubber unit could be calculated based on readings from the FTIR unit in an attempt to maximize efficiency of operation. That is, use only the required fan thruput to optimize recovery and provide safe ventilation for workers.

Another set of experiments would be to conduct controlled remediation experiments with stowing methods inside the storage facility. Stowing should be attempted to provide even density distribution of the soils so that bacteria and nutrients can be inoculated into the soil for remediation in storage. Another storage experiment would be centered around constructing blocks of soil with a designed porosity and permeability to allow or promote while in storage.

Experiments could be conducted with different kinds of binders that would promote the remediation process. One such material with special properties is hydrophobized lime which reacts with the contaminating hydrocarbons to create a binder like material which isolates and confines the contaminant.¹ This process could also be examined as a method of dehalogenating PCB's and other volatile organic compounds.² Literature reports that the resulting material passes EPA TCLP requirements.

8.0 SUMMARY AND ANALYSIS

As a technology class, a permanent or semi-permanent structure with associated top cover and leachate monitoring and collection system is the most effective. This technology provides the maximum protection to the environment, as well as insures the health and safety of individuals working at the site and living in the surrounding community. It also provided an effective method of handling materials ranging from contaminated soils, to barrels, broken pavements and underground utilities. Although the economics associated with erection of the structure are poor, maintenance and repair costs in relationship to other temporary storage technologies should be low.

Additional work should be done to tailor the structure to match site contaminants. Requirements generated by the presence's of VOCs and semi-VOCs may require the addition of an air handling and processing system. At a minimum the structure will require the installation of a monitoring system to

continually check for gaseous emissions. A leachate monitoring and collection system will also be required. The top cover should preclude the introduction of precipitation, however, the stored materials will include some level of moisture.

An additional advantage of this system is the longevity. If remediation activities required an extended period of time the storage facility will be able to continue to provide service with minimal cost. Performance is not expected to degrade significantly with age.

9.0 APPENDICES

APPENDIX A

TABLE A-1 - ALPHABETICAL LIST OF EPA IDENTIFIED HAZARDOUS MATERIALS¹ WHICH HAVE A REPORTABLE QUANTITY THRESHOLD OF 100 POUNDS OR LESS.

CHEMICAL NAME	CAS#
Acetone Cyanohydrin	75-86-5
Acetone Thiosemicarbazide	1752-30-3
Acrolein	107-02-8
Acrylonitrile	107-13-1
Acrylyl Chloride	814-68-6
Adiponitrile	111-69-3
Aldicarb	116-06-3
Aldrin	309-00-2
Allyl Alcohol	107-18-6
Allylamine	107-11-9
Alluminum Phosphide *	20859-73-8
Aminopterin	54-62-6
Amiton	78-53-5
Amiton Oxalate	3734-97-2
Ammonia	7664-41-7
Amphetamine	300-62-9 ¹
Aniline, 2,4,6-Trimethyl	88-05-1
Antimony Pentafluoride	7783-70-2
Antimycin A	1397-94-0
ANTU	86-88-4
Arsine	7784-42-1
Azinphos-Ethyl	2642-71-9
Azinphos-Methyl	86-50-0
Benzenamine, 3-(Trifluoromethyl)-	98-16-8
Benzene, 1-(Chloromethyl)-4-Nitro-	100-14-1
Benzenearsonic Acid	98-05-5
Benzimidazole, 4,5-Dichloro-2-(Trifluoromethyl)-	3615-21-2
Benzothrichloride	98-07-7
Benzyl Chloride	100-44-7
Benzyl Cyanide	140-29-4
Bicyclo[2.2.1]Heptane-2-Carbonitrile, 5-Chloro-6-(((Methylamino)Carbonyl)Oxy)Imino)-, (1S-(1-alpha, 2-beta, 4-alpha, 5-alpha, 6E))-	15271-41-7
Bis(Chloromethyl)Ketone	534-07-6
Bitoscanate	4044-65-9
Boron Trichloride	10294-34-5
Boron Trifluoride	7637-07-2
Boron Trifluoride Compound With Methyl Ether (1:1)	353-42-2
Bromadiolone	28772-56-7
Bromine	7726-95-6
Cadmium Oxide	1306-19-0
Cadmium Stearate	2223-93-0

Camphechlor	8001-35-2
Cantharidin	56-25-7
Carbachol Chloride	51-83-2
Carbamic Acid, Methyl-,O-(((2,4-Dimethyl-1,3 Dithiolan-2-Y1) Methylene)Amino)-	26419-73-8
Carbofuran	1563-66-2
Carbon Disulfide	75-15-0
Carbonphenothion	786-19-6
Chlordane	57-74-9
Chlorfenvinfos	470-90-6
Chlorine	7782-50-5
Chlormephos	24934-91-6
Chlormequat Chloride	999-81-5
Chloroacetic Acid	79-11-8
Chloroethanol	107-07-3
Chloroethyl Chloroformate	627-11-2
Chloromethyl Ether	542-88-1
Chloromethyl Methyl Ether	107-30-2
Chlorophacinone	3691-35-8
Chloroxuron	1982-47-4
Chlorthiophos	21923-23-9
Chromic Chloride	10025-73-7
Cobalt, ((2,2'-(1,2-Ethanediy1bis (Nitrilomethylidyne)) Bis(6-Fluorophenolato))(2-)-N,N',O,O')-	62207-76-5
Cobalt Carbonyl	10210-68-1
Colchicine	64-86-8
Coumaphos	56-72-4
Coumatetralyl	5836-29-3
Crimidine-	535-89-7
Crotonaldehyde	4170-30-3
Crotonaldehyde,(E)-	123-73-9
Cyanogen Iodide	506-78-5
Cyanophos	2636-26-2
Cyanuric Fluoride	675-14-9
Cycloheximide	66-81-9
Cyclohexylamine	108-91-8
Decaborane(14)	17702-41-9
Demeton	8065-48-3
Demeton-S-Methyl	919-86-8
Dialifor	10311-84-9
Diborane	19287-45-7
Dichloroethyl Ether	111-44-4
Dichloromethylphenylsilane	149-74-6
Dichlorvos	62-73-7
Dicrotophos	141-66-2
Diepoxybutane	1464-53-5
Diethyl Chlorophosphate	814-49-3
Diethylcarbamazine Citrate	1642-54-2
Digitoxin	71-63-6
Diglycidyl Ether	2238-07-5
Digoxin	20830-75-5
Dimefox	115-26-4
Dimethoate	60-51-5
Dimethyl Phosphorochloridothioate	2524-03-0

Dimethyl Sulfate	77-78-1
Dimethyl Sulfide	75-18-3
Dimethyldichlorosilane	75-78-5
Dimethylhydrazine	57-14-7
Dimethyl-p-Phenylenediamine	99-98-9
Dimetilan	644-64-4
Dinitrocresol	534-52-1
Dinoterb	1420-07-1
Dioxathion	78-34-2
Diphacinone	82-66-6
Diphosphoramidate, Octamethyl-	152-16-9
Disulfoton	298-04-4
Dithiazanine Iodide	514-73-8
Dithiobiuret	541-53-7
Emetine, Dihydrochloride	316-42-7
Endosulfan	115-29-7
Endothion	2778-04-3
Endrin	72-20-8
EPN	2104-64-5
Ergocalciferol	50-14-6
Ergotamine Tartrate	379-79-3
Ethanesulfonyl Chloride, 2-Chloro-	1622-32-8
Ethanol, 1,2-Dichloro-, Acetate	10140-87-1
Ethion	563-12-2
Ethoprophos	13194-48-4
Ethylbis(2-Chloroethyl)Amine	538-07-8
Ethylene Fluorohydrin	371-62-0
Ethylene Oxide	75-21-8
Ethyleneimine	151-56-4
Ethylthiocyanate	542-90-5
Fenamiphos	22224-92-6
Fenitrothion	122-14-5
Fensulfothion	115-90-2
Fluometil	4301-50-2
Fluorine	7782-41-4
Fluoroacetamide	640-19-7
Fluoroacetic Acid	144-49-0
Fluoroacetyl Chloride	359-06-8
Fluorouracil	51-21-8
Fonofos	944-22-9
Formaldehyde Cyanohydrin	107-16-4
Formetanate Hydrochloride	23422-53-9
Formothion	2540-82-1
Formparanate	17702-57-7
Fosthietan	21548-32-3
Fuberidazole	3878-19-1
Furan	110-00-9
Gallium Trichloride	13450-90-3
Hexachlorocyclopentadiene	77-47-4
Hexamethylenediamine, N,N'-Dibutyl-	4835-11-4
Hydrazine	302-01-2
Hydrocyanic Acid	74-90-8
Hydrogen Chloride (Gas Only)	7647-01-0
Hydrogen Fluoride	7664-39-3
Hydrogen Peroxide (Conc>52%)	7722-84-1
Hydrogen Selenide	7783-07-5

Hydrogen Sulfide	7783-06-4
Hydroquinone	123-31-9
Iron, Pentacarbonyl-	13463-40-6
Isobenzan	297-78-9
Isobutyronitrile	78-82-0
Isocyanic Acid,3,4-Dichlorophenyl Ester	102-36-3
Isodrin	465-73-6
Isofluorophate	55-91-4
Isophorone Diisocyanate *	4098-71-9
Isopropyl Chloroformate	108-23-6
Isopropyl Formate	625-55-8
Isopropylmethylpyrazolyl Dimethylcarbamate	119-38-0
Laconitrile	78-97-7
Leptophos	21609-90-5
Lewisite	541-25-3
Lindane	58-89-9
Lithium Hydride *	7580-67-8
Manganese, Tricarbonyl	12108-13-3
Mechlorethamine	51-75-2
Mephosfolan	950-10-7
Mercuric Acetate	1600-27-7
Mercuric Chloride	7487-94-7
Mercuric Oxide	21908-53-2
Methacrolein Diacetate	10476-95-6
Methacrylic Anhydride	760-93-0
Methacrylonitrile	126-98-7
Methacryloyl Chloride	920-46-7
Methacryloyloxyethyl Isocyanate *	30674-80-7
Methamidophos	10265-92-6
Methanesulfonyl Fluoride	558-25-8
Methidathion	950-37-8
Methiocarb	2032-65-7
Methomyl	16752-77-5
Methoxyethylmercuric Acetate	151-38-2
Methyl 2-Chloroacrylate	80-63-7
Methyl Disulfide	624-92-0
Methyl Hydrazine	60-34-4
Methyl Isocyanate	624-83-9
Methyl Isothiocyanate	556-61-6
Methyl Mercaptan	74-93-1
Methyl Phenkapton	3735-23-7
Methyl Phosphonic Dichloride *	676-97-1
Methyl Thiocyanate	556-64-9
Methyl Vinyl Ketone	78-94-4
Methylmercuric Dicyanamide	502-39-6
Methyltrichlorosilane	75-79-6
Metolcarb	1129-41-5
Mevinphos	7786-34-7
Mitomycin C	50-07-7
Monocrotophos	6923-22-4
Mustard Gas	505-60-2
Nickel Carbonyl	13463-39-3
Nicotine	54-11-5
Nicotine Sulfate	65-30-5
Nitric Oxide	10102-43-9

Nitrocyclohexane	1122-60-7
Nitrogen Dioxide	10102-44-0
Nitrosodimethylamine	62-75-9
Norbormide	991-42-4
Organorhodium Complex (PMN-82-147)	0
Ouabain	630-60-4
Oxamyl	23135-22-0
Oxetane,3,3-Bis(Chloromethyl)-	78-71-7
Phorate	298-02-2
Phosacetim	4104-14-7
Phosfolan	947-02-4
Phosgene	75-44-5
Phosmet	732-11-6
Phosphamidon	13171-21-6
Phosphine	7803-51-2
Phosphonothioic Acid, Methyl-, O-Ethyl O-(4-(Methylthio) Phenyl)Ester	2703-13-1
Phosphonothioic Acid, Methyl-,O-(4- Nitrophenyl)O-Phenyl Ester	50782-69-9
Phosphorothioic Acid O,O-Dimethyl- S-(2-Methylthio) Ethyl Ester	2665-30-7
Phosphorus	7723-14-0
Phosphorus Pentachloride *	10026-13-8
Phosphorus Pentoxide *	1314-56-3
Physostigmine	57-47-6
Physostigmine, Salicylate (1:1)	57-64-7
Picrotoxin	124-87-8
Piperidine	110-89-4
Piprotal	5281-13-0
Pirimifos-Ethyl	23505-41-1
Potassium Cyanide *	151-50-8
Potassium Silver Cyanide *	506-61-6
Promecarb	2631-37-0
Propargyl Bromide	106-96-7
Propiolactone, Beta-	57-57-8
Propionitrile	107-12-0
Propiophenone, 4-Amino-	70-69-9
Propyl Chloroformate	109-61-5
Propylene Oxide	75-56-9
Propyleneimine	75-55-8
Prothoate	2275-18-5
Pyridine, 2-Methyl-5-Vinyl-	140-76-1
Pyridine, 4-Nitro-, 1-Oxide	1124-33-0
Pyriminil	53558-25-1
Salcomine	14167-18-1
Sarin	107-44-8
Selenious Acid	7783-00-8
Selenium Oxychloride	7791-23-3
Semicarbazide Hydrochloride	563-41-7
Silane, (4-Aminobutyl) Diethoxymethyl-	3037-72-7
Sodium Cacodylate	124-65-2
Sodium Cyanide (Na(CN))	143-33-9

Sodium Fluoroacetate	62-74-8
Sodium Pentachlorophenate	131-52-2
Sodium Selenate	13410-01-0
Sodium Selenite	10102-18-8
Sodium Tellurite	10102-20-2
Stannane, Acetoxytriphenyl-	900-95-8
Strychnine	57-24-9
Strychnine, Sulfate	60-41-3
Sulfotep	3689-24-5
Sulfoxide,3-Chloropropyl Octyl	3569-57-1
Sulfur Dioxide	7446-09-5
Sulfur Tetrafluoride	7783-60-0
Sulfur Trioxide *	7446-11-9
Tabun	77-81-6
Tellurium	13494-80-9
Tellurium Hexafluoride	7783- 80-4
TEPP	107-49-3
Terbufos	13071-79-9
Tetraethyllead	78-00-2
Tetraethyltin	597-64-8
Tetramethyllead	75-74-1
Tetranitromethane	509-14-8
Thallium Sulfate	10031-59-1
Thallous Carbonate	6533-73-9
Thallous Chloride	7791-12-0
Thallous Malonate	2757-18-8
Thallous Sulfate	7446-18-6
Thiocarbazide	2231-57-4
Thiofanox	39196-18-4
Thionazin	297-97-2
Thiophenol	108-98-5
Thiosemicarbazide	79-19-6
Thiourea, (2-Chlorophenyl)-	5344-82-1
Thiourea, (2-Methylphenyl)-	614-78-8
Titanium Tetrachloride	7550-45-0
Toluene 2,4-Diisocyanate	584-84-9
Toluene 2,6-Diisocyanate	91-08-7
Trans-1,4-Dichlorobutene	110-57-6
Triamiphos	1031-47-6
Triazofos	24017-47-8
Trichloroacetyl Chloride	76-02-8
Trichloroethylsilane	115-21-9
Trichloronate	327-98-0
Trichlorophynylsilane	98-13-5
Trichloro(Chloromethyl)Silane	1558-25-4
Trichloro(Dichlorophenyl)Silane	27137-85-5
Triethoxysilane	998-30-1
Trimethylchlorosilane	75-77-4
Trimethylolpropane Phosphite	824-11-3
Trimethyltin Chloride	1066-45-1
Triphenyltin Chloride	639-58-7
Tris(2-Chloroethyl)Amine	555-77-1
Valinomycin	2001-95-8
Warfarin	81-81-2
Warfain Sodium	129-06-6
Xylylene Dichloride	28347-13-9
Zinc, Dichloro(4,4-Dimethyl-5	58270-08-9

(((Methylamino) Carbonyl Oxy)Imino)
Pentanenitrile)-(T-4)-
Zinc Phosphide *

1314-84-7

APPENDIX A

TABLE A-2 - LIST OF VOLATILE ORGANIC COMPOUNDS WHICH MAY REQUIRE STORAGE AND / OR REMEDIATION WHEN FOUND IN SOIL

ORGANIC COMPOUND	CAS NO.
Chloromethane	74-87-3
Bromomethane	74-83-9
Vinyl Chloride	75-01-4
Chloromethane	75-00-3
Methylene Chloride*	75-09-2
Acetone	67-64-1
Carbon Disulfide	75-15-0
1,1-Dichlorethene*	75-35-4
1,1-Dichlorethane	75-34-3
1,2-Dichloroethene*	540-59-0
Chloroform*	67-66-3
1,2-Dichlorethane*	107-06-2
2-Butanone	78-93-3
1,1,1-Trichlorethane	71-56-6
Carbon Tetrachloride	56-23-5
Bromodichloromethane	75-27-4
1,2-Dichloropropane	78-87-5
cis-1,3-Dichloropropene	10061-01-5
Trichloroethene*	79-01-6
Dibromochloromethane	124-48-1
1,1,2-Trichloroethane*	79-00-5
Benzene*	71-46-2
trans-1,3-Dichloropropene	10061-02-6
Bromoform	75-25-2
4-Methyl-2-Pentanone	108-10-1
Hexanone	591-78
Tetrachloroethene*	127-18-4
1,1,2,2-Tetrachloroethane*	79-34-5
Toluene*	108-88-3
Chlorobenzene*	108-90-7
Ethylbenzene*	100-41-4
Styrene	100-42-5
Xylene	1330-20-7

* - Organic compounds detected at Winfield Site

TABLE 2 CONTINUED - LIST OF VOLATILE ORGANIC COMPOUNDS WHICH MAY REQUIRE STORAGE AND / OR REMEDIATION WHEN FOUND IN SOIL

ORGANIC COMPOUND	CAS NO.
-------------------------	----------------

TABLE 3 - LIST OF SEMI-VOLATILE ORGANIC COMPOUNDS WHICH MAY REQUIRE STORAGE AND/ OR REMEDIATION

ORGANIC COMPOUND	CAS NO.
Phenol	108-95-2
bis(2-Chloroethyl)ether	111-44-4
2-Chlorophenol	95-57-8
1,3-Dichlorobenzene	541-73-1
1,4-Dichlorobenzene	106-46-7
2-Methylphenol	95-48-7
2,2'-oxybis(1-Chloropropane)	108-60-1
4-Methylphenol	106-44-5
N-Nitroso-di-n-propylamine	621-64-7
Hexachloroethane	62-72-1
Nitrobenzene	98-95-3
Isophorone	78-59-1
2-Nitrophenol	88-75-5
2,4-Dimethylphenol	105-67-9
bis(2-Chloroethoxy)methane	111-91-1
2,4-Dichlorophenol	120-83-2
1,2,4-Trichlorobenzene	120-82-1
Napthalene	91-20-3
4-Chromoaniline	106-47-8
Hexachlorobutadiene	87-68-3
4-Chloro-3-methylphenol	59-50-7
2-Methylnapthalene	91-57-6
Hexachlorocyclopentadiene	77-47-4
2,4,6-Trichlorophenol	88-06-2
2,4,5-Trichlorophenol	95-95-4
2-Chloronapthalene	91-58-7
2-Nitroaniline	88-74-4
Dimethylphthalate	131-11-3
Acenaphthylene	208-96-8
2,6-Dinitrotoluene	606-20-2
3-Nitroaniline	99-09-2
Acenaphthene	83-32-9
2,4-Dinitrophenol	51-28-5
4-Nitrophenol	100-02-7
Dibenzofuran*	132-64-9
2,4-Dinitrotoluene	121-14-2
Diethylphthalate	84-66-2
4-Chlorophenyl-phenylether	7005-72-3
Flourene	86-73-7
4-Nitroaniline	100-01-6
4,6-Dinitro-2-Methylphenol	534-52-1
N-Nitrosodiphenylamine	86-30-6
4-Bromophenyl-phenylether	101-55-3
Hexachlorobenzene	118-74-1
Pentachlorophenol	87-86-5
Phenanthrene	85-01-8

* Organic Compounds Found at the Winfield W. V. Site

TABLE 3 CONTINUED - LIST OF SEMI-VOLATILE ORGANIC COMPOUNDS WHICH MAY REQUIRE STORAGE AND/OR REMEDIATION

ORGANIC COMPOUND	CAS NO.
Anthracene	120-12-7
Carbazole	86-74-8
Di-n-butylphthalate	84-74-2
Fluoranthene	206-44-0
Pyrene	129-00-0
Butylbenzylphthalate	85-68-7
3,3-Dichlorobenzidine	91-94-1
Benzo(a)anthracene	56-55-3
Chrysene	218-01-9
bis(2-Ethylhexyl)phthalate	117-81-7
Di-n-Octylphthalate	117-84-0
Benzo(b)fluoranthene	205-99-2
Benzo(k)fluoranthene	207-08-9
Benzo(a)pyrene	50-32-8
Indeno(1,2,3-cd)pyrene	193-39-5
Dibenz(a,h)anthracene	53-70-3
Benzo(g,h,i)perylene	191-24-2

* Organic Compounds Found at the Winfield W. V. Site

TABLE A-4 - LIST OF ORGANIC PESTICIDES WHICH MAY REQUIRE STORAGE / OR REMEDIATION WHEN FOUND IN SOIL

COMPOUND	CAS NO.
alpha-BHC	319-84-6
beta-BHC	319-85-7
delta-BHC	319-86-8
gamma-BHC	58-89-9
Heptachlor	76-44-8
Aldrin	309-00-2
Heptachlor epoxide	1024-57-3
Endosulfan	959-98-8
Dieldrin *	60-57-1
4,4' -DDE	72-55-9
Endrin *	72-20-8
Endosulfan II	33213-65-9
4,4' -DDD	72-54-8
Endosulfan Sulfate	1031-07-8
4,4' -DDT	50-29-3
Methoxychlor	72-43-5
Endrin Ketone	53494-70-5
Endrin aldehyde	7421-36-3
alpha Chlordane	5103-71-9
gamma Chlordane	5103-74-2
Toxaphene	8001-35-2
Arochlor-1016	12674-11-2
Arochlor-1221	11104-28-2
Arochlor-1232	11141-16-5
Arochlor-1242	53469-21-9
Arochlor-1248 *	12672-29-6
Arochlor-1254	11097-69-1
Arochlor-1260	11096-82-5

* Organic Compounds Found at the Winfield W. V. Site

APPENDIX B

Table B -5.1 - Literature Search, Journal Codes and Locations

TITLE	LOCATION	CODE
American Industrial Hygiene Assoc.	Health Sciences	0022MF
American Waterworks Assoc. Journal	Evansdale	T1.AM37J
Analytical Chemistry	Evansdale	T1.AN13
Aviation Week & Space Technology	Evansdale	1098 MF
Chemical & Engineering News		
Chemical Engineering	Evansdale	814 MF
Chemical Engineering Progress	Evansdale	1248 MF
Chemistry & Industry	Evansdale (to 1982)	TLC419
Civil Engineering	Evansdale	344 MF
Combustion Science & Technology	METC	
Critical Reviews Environmental Control		
Energy (Oxford England)	Evansdale	T1.EN15
Environmental Science & Technology	Evansdale	T1.EN13
Industrial Finishing		
JA P C A	Evansdale	Ti.J115
Journal of Environmental Engineering	Evansdale	T1.J824705
Journal of Environmental Health	Evansdale	T1.J82471
Journal of Geotechnical Engineering	Evansdale	T1.J82486
Journal of Hazardous Materials	NIOSH Library	
Journal of Microwave Power & Electr.	Evansdale	T1.J82623
Journal of Air & Waste Management	Evansdale	T1.S8295
Journal of Air Pollution Control Assoc.		
Machine Design	Evansdale	S1.N473
Nuclear & Chemical Waste Managem.		
Nuclear Engineering International		
Photogrametric Engineering & Remote		
Pollution Engineering	Evansdale	T1.P767
The Chemical Engineer		
Water Environment & Technology	Evansdale	T1.W29135
Water Environment Research		

* Reactive Solid

¹ Engineering Evaluation / Cost Analysis for Removal of Contaminated Soil at the Former ACF Industries Site Red House, West Virginia, U.S. Army Corp of Engineers , Nashville TN, May 5, 1992

¹ Haxo, H., Haxo, R., and White R. 1977. Liner Materials Exposed to Hazardous and Toxic Sludges - First Interim Report. EPA-600/2-77-081. U. S. Environmental Protection Agency, Cincinnati, Ohio. 63 pp. PB 271-013/AS.

² Haxo, H., and White, R. 1976. Evaluation of Liner Materials Exposed to Leachate - Second Interim Report. EPA-600/2-76-255. U.S. Environmental Protection Agency, Cincinnati, Ohio. 52 pp. PB 259-913/AS.

³ Styron, C.R.III., and Fry, Z.B. 1979. Flue Gas Cleaning Sludge Leachate/Liner Compatibility Investigation - Interim Report. EPA-600/2-79-136, U.S. Environmental Protection Agency, Cincinnati, Ohio. 78 pp. PB 80-100480.

⁴ Stewart, W.S. 1980. Butyl - The Original Water Saver Elastomer. Presented at the H.C. Remsburg Memorial Educational Symposium, "The Role of Rubber in Water Conservation and Pollution Control" during the 117th Meeting of the Rubber Division, ACS., Las Vegas, Nevada.

⁵ Stewart, W.S. 1978. State-of-the-Art Study of Land Impoundment Techniques. EPA 600/2-78-196, U.S. Environmental Protection Agency, Cincinnati, Ohio. 76 pp. PB 291-881.

⁶ The Asphalt Institute. 1974. Specification for Paving and Industrial Asphalt. (SS-22). College Park, Maryland.

⁷ Smith, W.S. 1980. Butyl - The Original Water Saver Elastomer. Presented at H.C. Remsburg Memorial Educational Symposium, "The Role of Rubber in Water Conservation and Pollution Control" during the 117th Meeting of Rubber Division, ACS., Las Vegas, Nevada.

⁸ Morton, M., ed. 1973. Rubber Technology. 2nd ed. Van Nostrand Reinhold company, New York. 603 pp.

⁹ Stewart, W.S. 1978. State-of-the-Art Study of Land Impoundment Techniques. EPA 600/2-78-196, U.S. Environmental Protection Agency, Cincinnati, Ohio. 76 pp. PB 291-881.

¹⁰ Morton, M., ed. 1973. Rubber Technology. 2nd ed. Van Nostrand Reinhold Company, New York. 603 pp.

¹¹ Haxo, H., and White, R. 1976. Evaluation of Liner Materials Exposed to Leachate - Second Interim Report. EPA-600/2-76-255. U.S. Environmental Protection Agency, Cincinnati, Ohio. 53 pp. PB 259-913/AS.

¹² Hickey, M.E. 1969. Investigation of Plastic Films for Canal Linings. Research Report No. 19. Bureau of Reclamation, U.S. Department of the Interior, Washington, D.C. 35 pp.

¹³ Chan, P., et al. 1978. Sorbents for Fluoride, Metal Finishing and Petroleum Sludge Leachate Contaminant control. EPA-600/2-78-024. U.S. Environmental Protection Agency, Cincinnati, Ohio. 83 pp. PB 280-696/AS.

¹⁴ The Asphalt Institute. 1976. Asphalt in Hydraulics. (MS-12). College Park, Maryland. 65 pp.

¹⁵ Valkenburgh, Gary Van, "Storing Hazardous Wastes Safely", Chemical Engineering, September 1991, pp 203-204.

¹⁵ "Prefab Buildings Answer Need For Storing Household Hazardous Wastes", Public Works, Sept. 1988, pp 112-113.

³ "Demonstration of a Trial Excavation at the McColl Site", EPA/540/AR-92/015, Oct. 1992.

¹ Payne, J. R., R. W. McManus, and F. Boelsing (1992). "DCR -Mediated treatment of oily Wastes and Contaminated Soils" , in Proceedings of R & D 92-- National R & D Conference on Control of Hazardous Materials, Feb 4-6, 1992, San Francisco CA, pp 297-394

² Sound Environmental Services, Inc., "DCR-Mediated Dehalogenation of PCB's in Clay Soils From a California Superfund Site, Oct. 1992

¹⁵¹ EPA publication "The Emergency Planning and Community Right-to-Know Act of 1986, List of Extremely Hazardous Substances", 40 C.F.R. Part 355, Mar. 1, 1988.

DRAFT

**ASSESSMENT OF ENVIRONMENTAL REMEDIATION
EXCAVATION TECHNOLOGY**

**Final Report for Period
June 1 through August 31, 1993**

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

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

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August 1993

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1.0 EXECUTIVE SUMMARY

A copy of the Core of Engineers Characterization and Cost Evaluation Report for the Winfield site was obtained and examined in detail. A technical approach was determined whereby a functional analysis was prepared to determine the functions to be conducted during the excavation phase of the remediation operations. a literature search was conducted using the key words generated as a results of the functional analysis. A number of excavation technologies were identified from the literature. A set of screening criteria was developed that would examine the utility and ranking of the technologies with respect to the operations that needed to be conducted at the Winfield site. These criteria were performance, reliability, implementability, environmental safety, public health, and legal and regulatory compliance.

The Loose Bulk excavation technology was ranked as the best technology applicable to the Winfield site. This technology is ordinarily applied with a drag line, but because of the location along a river with steep banks, a long-boomed backhoe would appear to be the equipment of choice. The long-boomed backhoe can be placed so that it may not have to be moved but one or twice while removing the dioxin contaminated soils, thus reducing the amount of movement and fugitive dust generation.

The literature was also examined to determine the success of various methods of controlling fugitive dust. The foams that have been tested were not very successful because they were not tailor made for the soil and materials found at the excavation sites. Foams as a method of suppression of dust need more R & D work perhaps in an attempt to relate to formulations that will work on specific soil types or mixtures. Soil samples from the Winfield site should be collected and formulations for dust suppression tested before excavation operations begin.

Depending upon any changes in the results of chemical analyses, or prior remediation of the VOC's from the vadose zone, consideration should be given to testing a new "Pneumatic Excavator" which removes the VOC's liberated during the excavation process as they outgas from the soil. This equipment however would not be needed on locations with low levels of VOC emissions.

2.0 INTRODUCTION

2.1 Purpose and Scope

The purpose of this study is to assess the state-of-the-art of excavation technology as related to environmental remediation applications. A further purpose is to determine which of the excavation technologies reviewed could be used by the U.S. Corp of Engineers in remediating contaminated soil to be excavated in the near future for construction of a new Lock and Dam at Winfield, WV. The study is designed to identify excavation methodologies and equipment which can be used at any environmental remediation site but more specifically at the Winfield site on the Kanawha River in Putnam County, West Virginia.

2.2 Background

Proposing to construct a new lock and dam at Winfield, the U.S. Army Corps of Engineers (COE) filed a Declaration of Taking in U.S. District Court on December 8, 1989. The Declaration of Taking was for a 21.81-acre tract of land located directly upstream from the existing locks and dam along the Kanawha River. This property was formerly owned by the American Car and Foundry Industries, Inc. (ACF) and is located 20 miles northwest of Charleston, WV, near the communities of Eleanor and Red House. The ACF facility's main functions were to repair and service both tank and hopper covered railcars which were leased to chemical companies for transportation purposes.

The 28.81-acre tract of land is geologically located upon a Kanawha River flood plain. Two groundwater zones exist under the site. The first is a 30-foot perched water zone which has been sealed from downward water flow. The second zone is a water table aquifer consisting of 30 feet of sandstone. It is this second aquifer which is recharged by the Kanawha River and serves as a water source for the town of Eleanor one mile away.

The COE took possession of this property on May 1, 1990 following a limited site remediation project undertaken by ACF. The remediation operations included excavation of 9,151 cubic yards of toxic soil for disposal at the Enviro-safe chemical landfill in Toledo, Ohio. The nontoxic soils were disposed of at the Wetzel County, WV special waste landfill. Also, about 100 empty containers (most 55

gallon drums) were excavated, crushed, and sent to the EnviroSAFE chemical landfill.

After a May 27-28, 1990 rainstorm, COE personnel discovered discolored water seeping from the newly excavated pit walls. This liquid exhibited a phenolic odor and it was noticed that the soil was also discolored in this area. Immediately, sampling activities were begun to attempt to determine the bounds and nature of the suspected contamination. The tests of the discolored water revealed the presence of volatile organic compounds (VOCs) and acid/base neutral extractables, among others.

In a separate incident, occurring on August 17, 1990, a COE construction contractor came into contact with a skin irritant while removing pavement with a backhoe from the ACF site. Irritation of the worker's throat and skin was evident. It was this incident which accelerated site characterization studies.

In September of 1990, the COE instituted a total site characterization plan through soil gas surveys, soil sampling, and groundwater monitoring. All sampling procedures followed the appropriate EPA SW-846 methods which utilize a quality assurance and quality control program. By using this method, the COE was attempting to gather legally defensible test results.

The results of the soil gas surveys and the soil sampling indicated the presence of VOCs and semi-volatile organic (SVOC) contaminants over a large portion of the site. Soil sampling also detected pesticides, polychlorinated biphenyls (PCBs), and dioxins. Due to the presence of dioxin, it was necessary to obtain additional soil samples in order to characterize the extent of the contamination. It was determined that over 50% of the samples contained levels of Tetrachlorodibenzodioxin (TCDD) contamination greater than one part per billion (ppb).

Groundwater monitoring activities including installing four monitoring wells. Each of these wells was to be sampled as were the existing water supply wells for the town of Eleanor. Three of the four monitoring wells were installed into the rock top (depth of 60 feet) while the other was placed in shallow perched water (depth of 15 feet). The shallow monitoring well detected low levels of VOC concentrations while no contaminants were detected in the deeper monitoring wells.

The COE final assessment for remediation of the ACF site was for excavation of 60,000 cubic yards of contaminated soil. The soil is then to be placed in a temporary storage facility to await further processing.

2.3 Study Technical Approach

The approach for this study was to review the site characterization studies that provided indications of the type of operations that will have to be conducted to comply with federal and state regulations during excavation. A functional analysis was prepared to reveal the types of technologies that can be utilized for generic sites and for the Winfield site. Once the technologies were identified, key word descriptors were identified to support a literature search to review the state-of-the-art for the selected technology. A detailed analysis was then conducted to determine the advantages and disadvantages for the selected technologies. A list of potential problems that have not been resolved relative to the technology was also prepared for consideration for future research projects.

2.3.1 Winfield Characterization Studies

The COE have already quantified and characterized the chemicals present at the Winfield site by conducting soil sampling and soil gas surveys. Chemicals present at the Winfield site include VOCs, SVOCs, PCBs, pesticides, and dioxins. Besides remediation of the chemicals, railroad tracks and a small building must be demolished and remediated.

The site's geology and hydrology have been carefully screened through the use of four groundwater monitoring wells. The well drilled to 15 feet intersected the perched water zone while the other three wells were drilled into the rock top at a depth of 60 feet. The shallow well showed traces of VOC concentrations. No contaminants were detected in the 60 foot wells which intersect the water aquifer for the town of Eleanor.

Put in Geologic Cross Section Here

2.3.2 Literature Review

A literature review was initiated in order to compile a technology base for state-of-the-art excavation technologies. Literature reviewed included open literature, which consists of books and periodicals, federal government projects, and patents. Besides excavation technologies, information was also sought concerning dust suppression and atmospheric dust and gas monitoring.

In order to begin the literature search, a key word hierarchy was constructed. This enabled the search to zoom in on the necessary literature. Figure XXX contains a breakdown of the hierarchy used.

2.3.2.1 Open Literature

The West Virginia University Library System (WVULS) was utilized for an open literature search. This search included technical journals, magazines, and books. Through the use of a CD ROM software package, which allows searching through periodical key words and topics from 1983 to present, a list of available articles was generated. See appendix XXX for the article lists.

Although the generated search lists were quite involved in order to limit the search to specific relevant articles, most of the gathered articles were found to be rather general.

The WVULS' card catalog was searched, both manually and by computer, for topics relating to excavation and hazardous waste excavation. No books were found relating to hazardous waste excavation. However, there were a few books which dealt with general excavation technologies.

2.3.2.2 Federal Government Projects Literature

In order to obtain government reports relating to hazardous waste excavation, a government document search was conducted. The Department of Energy's Morgantown Energy Technology Center (METC) library was utilized for this search.

Again, a CD ROM computer software package was utilized to gather government document titles and abstracts covering the past ten years. Once the results were viewed, it was determined that only a small number of government project documents existed that were not merely government "records of decisions". Relevant technical documents were obtained and reviewed. The topic list is contained in appendix XXX.

2.3.2.3 Patent Literature

The WVULS was utilized to search for patent information on excavation, but only a few patents were found. Of these, only one patent was determined to be an excavation method of hazardous waste. This patent relates to pneumatic excavation. The search results are in appendix XXX.

2.3.4 Atmosphere Monitoring for Fugitive Dust and Waste Gases

Literature was gathered and reviewed concerning the monitoring of atmospheric emissions of hazardous waste gases (such as VOCs) and fugitive dusts. Open literature, as well as government project documents, government regulations, state regulations, and patents were investigated. The search results are contained within the open literature, patent, and government projects appendices.

2.3.3 Excavation Technologies

Through the use of published materials relating to excavation of hazardous and toxic materials from a site, it was determined how well various excavation technologies handle the removal of hazardous and toxic materials. More specific was the technology's ability to safely excavate soils containing dioxins and volatile materials. Thus, each technology's advantages and shortcomings could be compared when related to the Winfield site.

Eight basic technologies for excavation of materials have been identified. Following, is a summary of each of these basic types of excavation and the key pieces of excavation equipment used.

2.3.3.1 Bulk-Pit Excavation

Bulk-pit excavation is primarily an excavation of considerable depth and of considerable material. It is used when site limitations such as buildings or streets cause excavating in a vertical manner and when the pit that is to be created will result in a large quantity of earth removal. The most efficient piece of equipment for bulk-pit excavation is the power shovel.

2.3.3.2 Bulk Wide-Area Excavation

Creating a pit that is much shallower than it is wide, bulk wide-area excavation is mainly a leveling process. It may be used for highway construction, airfield grading, removal of overlying earth layers (i.e., strip mining or quarrying), or moving high ground to lower areas. Also, bulk wide-area excavation may be of a large total bulk volume and of a considerable depth. The scraper plays a major role during bulk wide-area excavation.

2.3.3.3 Loose Bulk Excavation

Loose bulk excavation involves excavation of loose unconsolidated soils. These processes might include excavation of channels, canals, trenches, underwater soils, and overburden. Since no equipment may operate from the loose uncontrolled earth, it follows that excavation would be conducted from adjacent solid ground. The most effective piece of excavating equipment is the dragline. However, a long-boomed backhoe may also be used for this type of excavation.

2.3.3.4 Limited-Area, Vertical Excavation

During limited-area, vertical excavation, the spoil must be lifted vertically out of the pit. This is due to the material being of a loose, wet, or unconsolidated nature which results in the pit walls needing shoring or sheathing. The equipment best suited for this type of excavation is the clamshell. Also, hand excavation using picks and shovels as well as rotary drilling can be classified as limited-area, vertical excavation.

2.3.3.5 Trench Excavation

The main concern in trench excavation is linear footage dug via a series of interconnected vertically dug

holes. This is rather contrary to conventional excavation, where the main concern is cubic yardage dug. After placing a conduit into the trench, the trench is then backfilled. Backhoes and trenchers are the key pieces of equipment used in digging trenches. Trenches may be excavated for exploratory purposes.

2.3.3.6 Tunnel Excavation

Tunnel excavation, as discussed here, is an underground process where the width and depth the tunnel may reach as excavation continues is limited. Tunnel Boring Machines or the various microtunneling devices may allow for the needed diameter of the tunnel. Tunnel excavation is usually associated with utility operations such as sewers, water lines, telephone cables, etc.

2.3.3.7 Dredging

Considered a variant of loose bulk excavation, dredging is concerned with the excavation and transportation of underwater soils. To accomplish the excavation and transportation of these soils, an excavating rig is mounted upon a barge. Then, the barge moves to the spot of excavation where the excavating equipment is used to dig the soils out of the water and to deposit them onto the barge. The barge is then used as the transport medium to final deposition site.

2.3.3.8 Longwall Mining

Usually applied in consolidated mineral environments, longwall mining is the preferred technique for underground coal mining throughout the world. A longwall mining system utilizes a roof support which will allow the material to be removed via some mechanical device, such as a plow or shearer. Longwall mining could also be used to remove unconsolidated soils for placement of a solid barrier material to contain contaminated materials. It would generally be considered for excavation at depths of several hundred feet below the surface.

2.3.4 Unknowns/Uncertainties

As with any study, there remains some questions relating to the Winfield site remedial operations which need to be answered. They are:

- WV Division of Environment's position on protection of groundwater during excavation or remediation activities.
- Will excavation of the contaminated materials release contaminants from the perched water zone?
- Because testing was limited, is the dioxin contamination localized or spread out over a significant area?
- Does the soil's VOC content require prior removal and/or treatment on the excavation site?
- Does the project schedule impact the storage and/or remediation technology selected for the site?

2.3.5 Assumptions

In order to review and rank each excavation technology, some basic assumptions must be made and held constant during the ranking process. It was assumed that VOCs, leachate, and dust emissions would be controlled during soil removal operations. Also, it was assumed that worker health and safety would be maintained. Further, there was a need to conduct excavation operations at a reasonably fast pace. These assumptions enabled the selection of the basic excavation technology required for the Winfield site.

3.0 EXCAVATION TECHNOLOGY-REVIEW

Each basic excavation technology summary has been further summarized below. The technologies are those that are applicable to the Winfield Site.

3.1 Loose Bulk Excavation

Loose bulk excavation involves excavation of loose unconsolidated soils. These processes might include excavation of channels, canals, trenches, underwater soils, and overburden.

Because this process involves the removal of wet clays and silts in unconsolidated formations, it is obvious that neither a power shovel nor a scraper would be of use because these pieces of equipment operate over the surface in question. In this situation, the most effective pieces of excavating equipment are the dragline and the long boomed backhoe. Since no equipment may operate from the loose uncontrolled earth, it follows that excavation would be conducted from adjacent solid ground.

The optimum placement for dragline equipment is such that the drag bucket may be dragged straight up any slope. The drag bucket has but its own weight to prevent deflections from the true course, and if excavation is done diagonally up or down a slope, the bucket will have a tendency, because of its weight, to slide sideways down the slope.

However superior the dragline is in excavating loose soils, it has limitations in its disposal operations. The loading of hauling trucks is the major disadvantage because of the difficulty in controlling the loosely suspended bucket. Considerable amounts of soil may spill when lading the hauling trucks from the drag bucket.

The long-boomed backhoe has been used for loose bulk excavations when the use of a dragline is not practical. These long-reach excavators provide more control over loading the haul trucks than the dragline and a longer reach to enable large quantities of excavation to be accomplished before the equipment needs to be moved.

The backhoe may be placed in a manner that would allow large quantities of toxic material to be excavated before the backhoe needs to be moved. Thus, the backhoe would need to be decontaminated fewer times which would be time and cost conserving.

3.2 Bulk-Pit Excavation

Bulk-pit excavation is an excavation of considerable depth and of considerable material. Primarily, bulk-pit excavation is used when site limitations such as buildings or streets cause excavating in a vertical manner and when the pit that is to be created will result in a large quantity of earth removal. The

equipment is operated against the earth bank's face (called the digging face) leaving vertical or nearly vertical faces. The excavant is then loaded into and hauled away by dump trucks.

During bulk-pit excavation, the rate of spoil production is the only function of cost. That is, as the pit yardage increases, the cost of moving equipment onto and off the site will decrease. Therefore, the piece of equipment chosen for the excavation is critical.

If the soil can sustain standing banks and the quantity of earth to be moved is large, the power shovel is the most efficient piece of equipment that can be used. The power shovel will excavate materials such as cemented gravels and other hard compacted materials that other equipment will not move. Also, the loading of the dump trucks can be carried out faster and more accurately than by using any other piece of excavating equipment.

However, if the soil is noncohesive and will not sustain banks, the power shovel will not be satisfactory for excavation. This is due to the fact the shovel must operate from the bottom of these banks and will be besieged by the sliding material. Materials with good drainage characteristics, such as wet soils which lie below the ground-water table, may be sufficiently dried up to meet banking requirements, but, wet, fine grained soils may not.

The two basic cuts the power shovel will make are the parallel approach and the frontal approach. The parallel approach allows for cutting across and parallel to the digging face. It is considerably helpful in creating highway cuts where continuous straight line loading is required. The frontal approach excavates in a series of overlapping circles and allows for the full width of the digging face to be utilized.

The frontal approach has several advantages over the parallel approach. (1) Two or more power shovels may be operated simultaneously with no confusion over the dump trucks, (2) two positions for haul units exist so that one may be entering its position while another is being loaded, (3) the average angle of swing is shorter, and (4) the shovel stands farther back from the bank reducing the risk of engulfment during sliding.

3.3 Bulk Wide-Area Excavation

Bulk wide-area excavation may be defined as an excavation method that creates a pit that is much shallower than it is wide. This is because the method is a leveling process. It may be used for highway construction, airfield grading, removal of overlying earth layers (i.e., strip mining or quarrying), or moving high ground to lower areas. Also, bulk wide-area excavation may also be of a large total bulk volume and of a considerable depth.

Bulk wide-area excavation differs from bulk-pit excavation in two ways. First, bulk wide-area excavation allows for access to the site from several sides whereas bulk-pit excavation allows for limited access to the site. Second, bulk wide-area excavation is more concerned with the excavant and does not allow for depth as the most important factor as does bulk-pit excavation. So bulk wide-area excavation is usually shallower in depth than bulk-pit excavation but larger in area.

Generally, bulk wide-area excavation handles far fewer classes of earth than other types of excavation. Here, materials that may be suitably compacted are of primary interest. This is because bulk wide-area excavation is concerned with the fill material that it is excavating.

The excavating equipment used for this operation is a scraper. Its designed function is to load a thin strip of earth and to unload it in the same manner. The scraper may be either tractor-drawn or self-propelled. When used to excavate loose, dry sands and rock or wet, sticky clays, the scraper may also exhibit difficulties in loading or unloading, respectively. Another major limitation of the scraper deals with its traction. Traction problems may be overcome by using a crawler tractor to push the self-propelled scraper during material loading. Scraper loading may be accomplished, in the direction of the loading, using three methods.

Back-track loading can be used if the loading area is short and wide. After each push through the loading zone, the tractor makes a wide, time consuming, 180 degree turn.

Chain loading is to be used if the loading area is long and narrow and may be worked from end to end. Multiple scrapers may

be loaded before the tractor needs to return to the starting point. The tractor turns which are involved here are small 90 degree turns.

Shuttle loading can be used if the loading area is limited or short and wide. Because turning scrapers in the loading area takes up space, access is required from the loading area from two directions. In all loading scenarios, the material is transported by the scraper to the unloading area.

3.4 Trench Excavation

Unlike conventional excavation, where the main concern is cubic yardage dug, trench excavation is concerned with linear footage dug via a series of interconnected vertically dug holes. Backhoes and trenchers are the key pieces of equipment used in digging trenches. Also, the key difference between trenches and ditches lies in the fact that ditches are slots cut in the earth and trenches are temporary scars in the earth into which a conduit is placed and then buried.

A key method in determining which piece of equipment to use is to limit the width of the trench in relation to the conduit diameter. Most trenches are dug with sloped back banks to control sliding and caving. Then, the trench width only has to be limited immediately above the conduit. Other considerations to be made in choosing trenching equipment and attachments include, the type of conduit to be used, the depth of the trench, the soil conditions, and the surface conditions.

3.5 Limited-Area, Vertical Excavation

During limited-area, vertical excavation, the excavant must be vertically lifted out of the pit. This is due to the material being of a loose, wet, or unconsolidated nature which results in the pit walls needing shoring or sheathing.

The equipment best suited for this type of excavation is the clamshell. Requiring close supervision, the clamshell may be used during any of the previously mentioned excavation operations as a secondary unit. That is, the clamshell could be used to remove the ramp used in bulk-pit excavation, or to clean up the rock and other debris generated during bulk wide-area excavation. As a primary piece of equipment, the clamshell could operate in

restricted areas such as city streets with underlying utilities present. It is also used for excavating foundations, trenches, footings, and cellars.

With both halves of the clamshell bucket in the open position, the clamshell is operated by dropping it from the boom of a crane onto the material to be excavated. The bucket is then closed and the material is enclosed within the bucket. The clamshell may then deposit the material into the hauling truck.

The clamshell may operate (digging or dumping) at above or below its working area. However, its working range is limited to a small circle directly under the boom-point sheave pin. Also, the clamshell operates at a higher boom angle than that of the dragline to maximize the holding line's lifting power.

Since limited area excavating relates to confined areas where very little mechanical operating equipment may be used, it is necessary to include hand labor as a form of useful operating equipment. These procedures would include the use of shovels, and picks. The use of rotary drilling also falls within limited area excavating.

4.0 FUNCTIONAL ANALYSIS

Functional analysis criteria were created to aid in selecting an excavation remediation technology. Several concerns were addressed during the creation of the functional analysis criteria. Among the key criteria were performance, reliability, environmental safety, and legal and regulatory compliance. The review of the technologies was conducted by grading and ranking the removal processes. Also, the pertinent regulatory requirements were discerned as well as the issues and concerns, interfaces, requirements, and unknowns/uncertainties.

Several operational requirements must be met while removal operations are being conducted upon the contaminated soils. The site workers health and safety must be protected as well as the plant and animal life. The nearby population must also be protected from all detrimental health hazards that may occur during excavation operations at the Winfield site. Finally, all federal, state, and local regulations must be complied with.

Based upon government regulations, the site remediation plan will consist of an excavation technology, a means for monitoring the site, a means of storing the material, and a site closure plan. Each of these technologies will somewhat overlap the other. During excavation and transportation operations, due care must be observed so as not to allow contamination of the air with VOCs, contamination of the groundwater or river with dioxin, or the compromising of the workforce's or the public's health and safety.

4.1 Evaluation Criteria for Excavation Technology

The following is a breakdown of the functional analysis selection criteria for excavation remediation technologies.

4.1.1 Performance

The performance of the excavating technology will play a major role in determining which technology to utilize. For the Winfield site, the excavation will be concerned with removing contaminated soils. As, these soils are removed VOC emissions will need to be controlled as will fugitive dust emissions. Also, liquid contaminants may be present within the spoil. Therefore, liquid contaminant loss during excavation and transportation will need to be controlled.

4.1.2 Reliability

The reliability will be based on past demonstrated performances of the technology. Operational and maintenance requirements, operational complexity, and monitoring requirements will also need to be considered. The excavation technology will need to have a certain degree of flexibility to enable it to accommodate variations between the design criteria and the field operations.

4.1.3 Implementability

Here, the ease of execution must be considered as an important factor. A difficult technology to implement may cause difficulty in maintaining the project throughout. The time required after execution for the technology to meet the excavation objectives is important. The ability to deliver the excavant to a storage media was considered.

4.1.4 Environmental Safety

The potential risk to the environment in the event of system failure was considered. Also, the potential risk to the plants, animals, groundwater, surfaced waters, etc., during initial system construction and operation was weighed.

4.1.5 Public Health Considerations

Public health considerations such as noise, air, pollution, odor, use of natural resources, aesthetics, and interferences with public services of local businesses were considered important. The environmental risks may include acute or chronic toxic effects on plant or animal life, alteration of wildlife habitat, and threats to endangered species.

4.1.6 Legal and Regulatory Compliance

Several groups of regulations and codes must be adhered to prior to, during, and after excavation. These include air standards, water standards, noise standards, land use and zoning codes, and any federal, state, or local laws which may be pertinent. Therefore, the excavation plan, remediation plan, and closure plan should be adhered to as closely as possible to alleviate any regulatory problems which might occur during operations.

Several federal regulatory guidelines which relate to the Winfield site have been discerned as follows:

- Resource Conservation Recovery Act (RECRA)
- Air Quality Standards (AQS)
- National Pollutant Discharge Elimination System (NPDES)
- Clean Water Act (CWA, Section 404)
- Safe Water Drinking Act (SWDA)
- Fish and Wildlife Conservation Act (FWCA)
- Nation Environmental Protection Act (NEPA)
- Executive Order #11988

The following are West Virginia regulatory requirements which relate to the Winfield site:

- Air Pollution Control Act

- Clean Water Act
- Toxic and Hazardous Materials Control Act

4.1.7 Cost

Cost must be considered to meet the budgetary constraints of the project. That is, there is no reason to select equipment which is much more expensive to operate for a job when there is existing equipment which performs the same function for a lesser cost. Installation, operation, and maintenance are included within the cost framework.

4.1.8 Interferences

Several interferences exist at the Winfield site such as buried containers and railroad tracks. These interferences might cause problems during excavation. Thus, it is important to look at the effects of surface structures, buried containers, and buried utility lines.

4.2 Analysis

It is important to note that this analysis was carried out for the Winfield site and is, therefore, site specific. With this in mind, three excavation technologies were eliminated from the analysis because they are impractical for use at the Winfield site. These technologies are tunneling, dredging, and longwall mining.

It is also important to note that each excavation remediation technique was ranked on the basis of total site use. That is, it was assumed that the technology would be the only one used at the Winfield site although it may be necessary to utilize other technologies in some isolated cases where the contamination may be considerably higher.

Each of the functional criteria were ranked on a high, medium, or low basis. A high ranking meant the functional criteria was highly important with regards to the choice of the excavation technology. A low score meant the functional criteria was less important with regards to the excavation technology.

Then, each of the remaining five excavation technologies were ranked against each of the eight functional analysis criteria

and given a score of high, medium, or low. A high score implied total compliance with the criteria and, conversely, a low score implied little or no compliance with the functional criteria.

Finally, values were given to the high (9 points), medium (3 points), and low (1 point) technology review. These values were then multiplied by the functional analysis criteria. The scores were then summed for each technology to yield a ranking with respect to the functional analysis criteria.

4.2.1 Performance (Value = 9)

Each technology was rated on its expected performance at the Winfield site. Since bulk-pit, bulk wide-area, and loose bulk excavation could move large quantities of earth quickly, they received scores of nine. On the other hand, both trenching and limited-area, vertical excavation could not move large quantities of earth quickly and were given scores of three.

4.2.2 Reliability (Value = 9)

Bulk-pit excavation was given a score of nine because it met all requirements and the power shovel's history of reliability was exceptional. However, the other four pieces of excavating equipment, the scraper, clamshell, long-boomed backhoe, and trencher/backhoe, were determined to be not as reliable. These ability deficiencies included the past demonstrated reliability of each technology. Also, the scraper requires some maintenance and the clamshells need constant monitoring. It was determined that limited-area, vertical excavation and trenching would be the least reliable excavation technologies.

4.2.3 Implementability (Value = 3)

One key point which was considered was ease and speed of execution. Bulk-pit, bulk wide-area, and loose bulk excavations were determined to possess the ability to complete the removal operations quickly. Limited-area, vertical excavation and trenching would take longer.

Scrapers would experience difficulty in moving the excavant from the scraper to a storage media (i.e., dumptruck or temporary storage shelter). Also, clamshells are very sloppy

loaders. Thus, bulk-pit received a score of nine and loose bulk, received a score of three. Bulk wide-area, trenching, and limited-area, vertical excavation received scores of one due to their slow execution and sloppy unloading of materials.

4.2.4 Environmental Health Considerations (Value = 9)

The functional analysis criteria for environmental safety and public health considerations were found to grade out identically. Thus, they will be spoken of jointly.

Potential health risks to the public, plants, animal, and worker safety were shown to exist if the excavant was loaded messily or if they were transported sloppily. For example, clamshells have difficulty in unloading while scrapers are not designed to retain any liquid materials that may leach out during travel to a storage facility.

Because of its ability to control loading of materials and leachate, loose bulk excavation received a score of nine. For their limited abilities to control loading and leachate problems, bulk-pit, trenching, and limited-area, vertical excavation received scores of three. Since the scraper has significant troubles with leachate and unloading, bulk wide-area excavation was given a score of one

4.2.5 Legal and Regulatory Compliance (Value = 3)

For legal and regulatory compliance to be attained, the excavation technology should leave the excavated site in such a manner that no hazardous waste is present. Thus, how well the excavating equipment loads the hazardous spoil and any leachate will become a primary issue.

Because of the loading and unloading characteristics of the scraper and clamshell, bulk wide-area and limited-area, vertical excavation were given scores of three. This is due to the fact contaminants could be spread in this manner. All other technologies were thought to comply and were given scores of three.

4.2.6 Cost (Value = 1)

On the basis of earth moving capacity, no other piece of equipment is as cost effective as the power shovel. For this reason, bulk-pit excavation was given a score of nine. Scrapers (bulk wide-area) and long-boomed backhoes (loose bulk) were thought to be nearly as fast and given scores of three. Trenching and limited-area, vertical excavation were considered poor options for cost effectiveness and given scores of one.

4.2.7 Interferences (Value = 3)

Interferences such as surface structures and buried objects can pose problems during excavation. Since scrapers and clamshells have difficulty in controlling the precise point of excavation, buried interferences can be ruptured or broken releasing any contents. For these reasons, bulk wide-area and limited-area, vertical excavation were given scores of one. Trenching was determined to be outperformed by both bulk-pit excavation methods and loose bulk excavation because of ability of the equipment to tolerate interferences such as the buried containers on the site.

4.2.8 Results

When all the scores were converted to numbers, multiplied, and summed, loose bulk excavation received the highest score (336 points). In a close second, bulk-pit excavation received 306 points. Bulk wide-area, trenching, and limited-area, vertical excavation followed with 144, 130, and 106 points, respectively. The results are shown in Figure XXX.

5.0 SCREENING CRITERIA

The problems at the Winfield site are not one of a kind. There are many other hazardous waste sites that have nearly identical site characteristics when compared to the Winfield site. That is, the other sites may have soils contaminated with VOCs, dioxins, or PCBs. These characteristics include:

- The site is adjacent to a major river.
- The site is overlying a primary water aquifer.

- The site is contaminated with volatile organic compounds such as benzene, chlorobenzene, chloroform, dichloroethene, dichloroethane, ethylbenzene, toluene, tetrachloroethane, tetrachloroethene, trichloroethene, and methylene chloride.
- There is a potential for fugitive dust emissions during excavation.
- The site is contaminated with dioxins such as TCDD.
- The site is contaminated with PCBs.
- The site is contaminated with metals such as silver, mercury, lead, cadmium, manganese, barium, arsenic, selenium, iron, and chromium.

5.1 Health and Safety Concerns

The Winfield site contains several problem areas. Since the site is lying adjacent to the Kanawha River, the potential exists for the spread of contaminants into the river. Also, the primary water aquifer for the area lies sixty feet below the surface of the site. The primary health and safety concern is to protect the water supply during excavation remediation operations. Other health and safety concerns include the potential for VOC liberation during excavation, dioxin liberation during excavation, and fugitive dust emissions during excavation.

5.2 Contaminant Issues

There are four primary families of contaminants located at the Winfield site. They are VOCs, PCBs, metals, and dioxins. These contaminants must be excavated taking care to avoid exposing workers, plant and animal life, and the residential public to the contaminants by either airborne emissions or by accidentally spreading the contaminants over the ground.

6.0 IDENTIFICATION OF PROBLEMS FOR FUTURE R&D

Future research and development in the field of hazardous waste excavation technologies will center on one of three items.

These are new excavation equipment, fugitive dust suppression, and liberated gas suppression.

In the field of new excavation equipment, breakthroughs have been made. There exists the potential to operate basic excavation equipment by means of remote control. This would allow hazardous waste excavation to occur up to 2000 feet away from equipment operation thereby taking site workers away from potential exposure sites.

A pneumatic excavation system also exists whereby excavant is entrained in a gas and moved through an enclosed system to a temporary storage medium. This method reduces VOC and fugitive dust emissions from the site. The pneumatic excavation system can be coupled with a pneumatic transport system to a processing/temporary storage area where health and safety issues are more manageable.

Temporary shelters have been designed and used during excavation. Excavation is conducted within the temporary shelter and the shelter may be equipped with an air purification system to treat the air before it is discharged into the atmosphere.

Various patents exist for fugitive dust suppression within the coal industry, some of which may be applicable to hazardous waste excavation.

6.1 Generic Problems

The following will attempt to summarize the aforementioned technologies which BDM believes should be the focus of future research and development in the field of environmental remediation technology. If available, the first test site is included.

6.1.1 Pneumatic Excavation System

U.S. Patent 5,120,165 describes a pneumatic excavator, where fragmented excavated material is entrained in a gas and is pneumatically conveyed to a remote site (which may be a truck and trailer) for separation of material from the gas. The enclosed flow path will consist of a series of separation points which may include a separator with HEPA filtering apparatus for capturing toxic dust and toxic gases during toxic cleanup. Therefore

the excavant is trapped within the system preventing the discharge of dust into the air, the spread of excavated fragments, and the runoff of toxic liquid.

6.1.2 Teleoperated Equipment

Two separate pieces of remote controlled excavation equipment were found in the literature. The first was developed jointly by DOE and the US Army for the purposes of excavating wastes using remotely operated equipment and remote retrieval of unexploded ordnance, the Small Emplacement Excavator (SEE) is an existing US Army backhoe converted to teleoperated control. The SEE will (1) increase safety by removing on-site personnel from hazardous areas, (2) remotely acquire real-time data from multiple sensors, (3) increase cost-effectiveness and productivity by partial automation of the data collection process and by gathering and evaluating data from multiple sensors in real time, and (4) reduce costs for other waste-related development programs through joint development efforts and reusable standardized subsystems.

The second piece of equipment was created by Spar Aerospace Limited. It is a Hitachi model EX200LC backhoe which has been converted for remote controlled operation. This allows the excavation of hazardous or radioactive wastes, using a joystick with four degrees of freedom, from as far away as 2000 feet via a telemetry cable or radio frequency link. Movement in the three spatial directions as well as bucket rotation may be controlled remotely. Within the cab of the excavator, the operating levers have been replaced with the same joystick. Besides a conventional bucket, the excavator may use various other attachments that can also be operated remotely. These include shears, grapples, and jackhammers.

These technologies are currently available but should be considered for sites with extremely hazardous chemicals.

6.1.3 Excavation Within a Temporary Shelter

A trial excavation of 137 cubic yards was conducted by a track hoe at the McColl site in Fullerton, CA in October of 1992. The trial excavation was conducted within a temporary enclosure from which air was exhausted through a wet

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scrubber and an activated carbon-bed absorber to lesson toxic emissions (sulfur dioxide and VOCs) from the excavation operation. Also, vapor suppressing foam was used to attempt to reduce emissions from the raw waste being excavated.

6.1.4 Fugitive Dust Suppression

Since the potential for creating airborne dusts is high during earth moving operations, fugitive dusts are an important factor which must be considered during excavation operations. There are many ways to suppress dust during excavation. Water has probably been used most frequently. However, there are several new methods becoming available for fugitive dust suppression.

Several patents have been located describing dust suppression through the use of water based Newtonian non-viscous fluids, aqueous foamed solutions, and mixtures of polyacrylic acids. Therefore, the ability to choose the best dust suppression system for each site is available.

6.2 Winfield Site

New technologies that are applicable for the Winfield site include nearly all the aforementioned excavation techniques. Excavation under a temporary shelter with an air treatment system to enable the VOCs to be treated as they are liberated figures to be a technology of use. Also, fugitive dust suppression techniques and robotic equipment figure to be applicable to the site.

7.0 SUMMARY AND ANALYSIS

By generating a functional analysis criteria, BDM was able to target eight basic excavation techniques and review each technology for its applicability to the Winfield site. It was determined that loose bulk excavation using a long-boomed backhoe was only a slightly better option than bulk-pit excavation with a power shovel. The other six technologies lagged far behind in their applicability to the site. In fact, dredging, tunneling, and longwall mining were not even graded during the functional analysis review because they were not considered applicable to the Winfield site.

Several new target areas have been identified for future research and development in environmental remedial excavation.

These are fugitive dust suppression, liberated gas cleansing, and new and improved pieces of excavation equipment.

Functional Analysis Criteria Ranking Results

Technology	1	2	3	4	5
Performance (H)	●	●	●	◐	◐
Reliability (H)	●	◐	◐	○	○
Implementability (M)	●	○	◐	○	○
Environmental Safety (H)	◐	○	●	◐	◐
Public Health (H)	◐	○	●	◐	◐
Legal Compliance (M)	●	◐	●	◐	●
Cost (L)	●	◐	◐	○	○
Interferences (M)	●	○	●	○	◐
Totals	306	144	336	106	130

KEY		
●,H = High	◐,M= Medium	○,L= Low
1 - Bulk-Pit Excavation		
2 - Bulk Wide-Area Excavation		
3 - Loose Bulk Excavation		
4 - Limited-Arear, Vertical Excavation		
5 - Trench Excavation

DRAFT

**ASSESSMENT OF ENVIRONMENTAL REMEDIATION
MONITORING TECHNOLOGY**

**Final Report for Period
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**For
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PROJECT 3 REPORT

ASSESSMENT OF ENVIRONMENTAL REMEDIATION MONITORING TECHNOLOGY

1.0 EXECUTIVE SUMMARY

The objective of this study was to investigate and evaluate existing proven technologies for the monitoring of hazardous waste sites during remediation activities and to protect the health and safety of all related entities while complying with government regulations. The study began with a literature search to determine manufacturers and related instrumentation which would be applicable to the most complex (in terms of toxicity and mediums affected) sites. Criteria for monitoring and analyses were established and a functional analysis was performed to select the most appropriate instrumentation available.

Gas Chromatography/Mass Spectrometry is the most widely accepted method for generating quantitative data given the characterization of the Winfield site. Bruker Instruments, Inc. of Billerica, Maine has a field proven mobile GC/MS system which is not only accepted by the EPA but also by the U.S. Army Nuclear, Biological, Chemical Reconnaissance Systems (NBCRS) Program. The functional analysis performed assigned second place to a mobile GC/MS system.

Fourier Transform Infrared Spectroscopy, while not a new technology, has the distinct advantage of measuring simultaneously hundreds of gaseous pollutants which can also be sparged from water and this technology received the highest score as per the functional analysis. MDA Scientific of Norcross, Georgia is one supplier of FTIR instrumentation which submitted documentation by the DuPont Company demonstrating positive results. It has not been verified in the literature that the EPA has declared equivalency to reference techniques for this technology.

The conclusion of this study is to evaluate both the mobile GC/MS and FTIR systems simultaneously in identical operating conditions. Such a demonstration would prove invaluable in establishing guidelines for future monitoring considerations.

2.0 INTRODUCTION

2.1 Purpose and Scope

To investigate proven technologies available to monitor hazardous substances as applicable to site restoration activities in an effort to protect the health and safety of site personnel, the general public, and the environment.

2.2 Background

The former American Car and Foundry Industries, Inc (ACF) 21.81 acre tract is located near Red House, WV which is approximately 20 miles northwest of Charleston, WV. The site is adjacent to the right descending bank of the Kanawha River immediately upstream of the Winfield Locks and Dam. From 1952 until the facility closed in March 1986, ACF used the property to repair and service a fleet of tank and covered hopper railcars. ACF leased those railcars to various companies for hauling liquid and solid chemical commodities.

On December 8, 1989 the U.S. Army Corps of Engineers (COE) filed a Declaration of Taking in U.S. District Court for the 21.81 acre tract of land then owned by ACF. Acquisition of this property was necessary to construct the upstream approach for a new lock and gate bay at the Winfield Locks and Dam. Following a limited excavation and removal activity administered by ACF the COE took possession of the property on May 1, 1990.

In May 1990, COE representatives observed discolored water seeping from excavation pit walls in the area of the ACF removal activity. The soil in this area was also observed to be discolored and was characterized by a phenolic odor. This discovery was followed by sampling activity in an effort to define the limits and nature of the suspected contamination.

Water samples collected from the seeps exiting the excavation pit walls confirmed the presence of a wide range of contaminants including volatile organics and base/neutral acid extractables. Subsequent investigations confirmed the presence of pesticides, polychlorinated biphenyls (PCBs), and dioxins in this area.

In September 1990, the COE planned an initial site investigation. This site investigation was designed to include soil gas surveys, soil sampling, and any necessary ground water monitoring. Due to the nature of the contaminants identified the confirmation activities were expanded to

include a total site characterization. Samples for all environmental site investigations administered by the COE were analyzed using appropriate EPA SW-846 methods and utilized a quality assurance/quality control (QA/QC) program in an effort to provide legally defensible data.

Soil gas surveys indicated that Volatile Organic (VOC) and semi-volatile organic (SVOC) contamination was present over a large portion of the site. Soil sampling data were relatively consistent with the soil gas results, i.e., high concentrations of VOCs and SVOCs were detected in several areas of the site. In addition to these contaminants, pesticides, PCBs, and dioxins were detected. Given the number and concentrations of contaminants found in the soil matrices, it was evident that ground water contamination was possible and must be investigated. Due to the environmental significance of dioxin, additional sampling was required to determine if dioxin contamination was localized or widespread.

Initial ground water monitoring at this site was accomplished by the installation of four ground water monitoring wells, sampling each of these wells and three existing water supply wells in the area. Three of the monitoring wells were installed at the top of rock (approximate depth of 60 feet), and one was installed in shallow perched water (approximate depth of 15 feet). Low concentrations of VOCs were detected in the shallow perched water, while no contaminants were detected in the deeper aquifer, which is the drinking water supply source.

A draft EPA procedure (SOW 1290) was used for the analysis of the additional soil samples selected to be analyzed for dioxin. This procedure is similar to SW 846 method 8280 but requires more strict laboratory quality control. The Tetrachlorodibenzodioxin (TCDD) toxicity equivalence values calculated indicated over 50% of the samples were identified with dioxin contamination at a significant level. This confirmed that dioxin contamination was widespread and present in concentrations of sufficient level to be a major concern. Due to the disposal problems associated with dioxin contaminated soils, it was necessary to perform a total site characterization.

2.3 Technical Approach

The majority of contamination of the ACF site is limited to the soil matrices. Due to the high solubility and mobility of certain identified organic compounds there is a potential threat to the local ground water system. The primary mechanisms for contaminant transport are vertical migration through the soil and horizontal migration due to leaching or

surface runoff during periods of saturating rainfall. Other mechanisms include wind erosion and surface runoff from explored areas.

Potential routes of exposure for contaminants associated with the ACF site include: (1) Direct contact with waters, sediments, and soils on or adjacent to the site that have been contaminated by surface runoff and erosion processes. (2) Consumption of ground water or surface water down gradient of the site. (3) Inhalation of contaminated dust that becomes airborne due to wind erosion or anthropogenic activities. (4) Direct contact of river water downstream of the site. The primary routes of concern are the potential dermal absorption and ingestion of contaminated surface water, ground water, and soil.

In lieu of (and consideration of magnification by excavation) the aforementioned mentioned, it is necessary to implement a monitoring system which is applicable to air, soil, and water which is capable of detection and analysis of VOCs, PCBs, and dioxin.

3.0 LITERATURE REVIEW

3.1 Open Literature

3.1.1 Purpose and Scope

To evaluate currently available technologies and regulations applicable to monitoring for the presence or migration of hazardous substances in air, soil, and water and to evaluate those technologies to determine which may be applicable, with or without modification, to the Winfield, WV and similar sites.

3.1.2 Procedure

A list of key words was compiled to initiate the literature search and was applied to periodicals published and was expanded to ensure resulting application as to compliance with government regulations.

The controlling key words and consequential functional analysis hierarchy is as follows:

- I. Hazardous Substance
 - A. VOCs
 - B. PCBs
 - C. Dioxin

1. Air
2. Soil
3. Water
 - a. Monitoring
 - b. Sampling
 - c. Analysis

II. EPA Regulations

- A. VOCs
- B. PCBs
- C. Dioxin
 1. Air
 2. Soil
 3. Water
 - a. Monitoring
 - b. Sampling
 - c. Analysis

3.1.3 Sources

The available data was assimilated via a computer generated investigation at the WVU Evansdale Branch, NIOSH, and METC Libraries.

3.1.4 Results

Literally, thousands of publications are available pertaining to hazardous substances and several hundred we examined to determine applicability of technologies available in monitoring, sampling, and analysis feasible as to remediation activities. To facilitate the minimization of complexity, the search narrowed the investigation to field proven methodologies.

3.2 Federal Governments Projects Literature

3.2 Patent Literature

3.3 Monitoring of Site Atmosphere - Equipment

3.4 Excavated Material Monitoring - Equipment

3.5 Monitoring Equipment Suppliers

The following is a list of manufacturers and suppliers of the various types of analytical equipment utilized in monitoring technology operations for

site remediation. All of these units have been demonstrated on government sponsored projects. BDM felt it might be a waste of our time to examine instruments that had not been tested in similar types of field operations. The following is a list of manufacturers grouped according to the type of sensor or detector used in the analysis.

FIDs: (Flame Ionization Detector)

Foxboro Co.
MSA/Baseline
Ratfische Instruments Ltd.
Rosemount Analytical/La Habra
SRI Instruments Inc.
Thermo Environmental Instruments Inc.

PIDs: (Photo Ionization Detector)

HNU Systems Inc.
MSA/Baseline
Photovac International Inc.
SRI Instruments Inc.
Sentex Systems Inc.
Thermo Environmental Instruments Inc.

Portable GC: (Gas Chromatograph)

Foxboro Co.
HNU Systems Inc.
Microsensor Systems Inc.
MTI Analytical Instruments
Photovac International Inc.
Sentex Systems Inc.
Thermo Environmental Instruments Inc.

Transportable GC/MS: (Gas Chromatograph / Mass Spectrometer)

Fisons Instruments/VG
Hewlett/Packard
Perkin-Elmer
Varian Associates Inc.
Viking Instruments

Mobile MS:

Bruker Instruments

FTIR Technology: (Fourier Transform Infrared Spectrometer)

KVB/Analect

Perkin-Elmer Corp.
Nicolet Instruments Corp.

Open Path FTIR Monitors:
MDA Scientific Inc.,
MIDAC Corp.
Nicolet Instruments Corp.

FTIR CEM:
KVB/Analect
Rosemount Analytical/Orrville

Portable Fiberoptics:
Lawrence Livermore

X-ray Fluorescence Analyzers:
HUN Systems Inc.
Spectrace Instruments Inc.
Outokumpu Electronics
TN Technologies

ICP-MS: (Inductively Coupled Plasma - Mass Spectrometer)
Fisons Instruments/VG
Perkin-Elmer/Sciex
Thermo-Jarell Ash

4.0 FUNCTIONAL ANALYSIS OF MONITORING TECHNOLOGY

4.1 Winfield Characterization Studies

4.2 Scope

To adhere to EPA regulations concerning the monitoring, analysis, and sampling of VOCs, PCBs, and dioxin in air, soil, and water.

4.3 Objectives

To define the functions that monitoring equipment must perform, and the manner and restrictions under which they must perform to be acceptable to the EPA.

4.4 Requirements

4.4.1 Regulatory

The regulatory requirements for functioning of monitoring equipment which present results of chemical analyses performed on air, soil, or water samples for VOCs, PCBS, and dioxin are identified in summary in 40 CFR sections as follows:

Method 1624, Revision B - Volatile Organic Compounds by Isotope Dilution GC/MS

Scope and Application: This method is designed to determine the volatile toxic organic pollutants associated with the 1976 Consent Decree and additional compounds amenable to purge and trap gas chromatography/mass spectrometry.

The chemical compounds listed may be determined in municipal and industrial discharges by this method and it is designed to meet the survey requirements of Effluent Guidelines Division (EGD) and the National Pollutants Discharge Elimination System (NBDES) under 40 CFR 136.1 and 136.5.

Method 608 - Organochlorine Pesticides and PCBs

Scope and Application: This is a GC method applicable to the determination of certain organochlorine pesticides and PCBs in municipal and industrial waste water discharges as provided under 40 CFR 136.1. When this method is used to analyze unfamiliar samples for any or all of the compounds listed, compound identifications should be supported by at least one additional qualitative technique. This method describes analytical conditions for a second gas chromatographic column that can be used to confirm measurements made with the primary column. Method 625 provides GC/MS conditions appropriate for the qualitative and quantitative confirmation of results for all of the parameters listed, using the extract produced by this method.

Method 613 - 2,3,7,8-Tetrachlorodibenzo-p-dioxin

Scope and Application: This is a GC/MS method applicable to the determination of 2,3,7,8-TCDD in municipal and industrial waste water discharges as provided under 40 CFR 136.1. Method 625 may be used to screen samples for 2,3,7,8-TCDD, however, when the screening test is positive, the final qualitative confirmation and quantification must be made using Method 613.

4.4.2 Air

4.4.3 Groundwater

4.4.4 River (Surface Water)

4.4.5 Remediation

4.5 Interfaces

The plan for identification and utilization of monitoring equipment to perform chemical analyses of air, soil, and water samples must be applicable and compatible with the approved plans of operation for excavation, storage, remediation, and closure.

4.6 Issues and Concerns

4.7 Assumptions

4.8 Interferences

4.9 Unknowns / Uncertainties

4.10 Evaluation Criteria for Monitoring Technology

Criteria selected for use in the analysis of the functional requirements of monitoring technologies are as follows:

- I. Protect the environment
 - A. Air, land, ground water, surface water
 - B. People, plants, animals
- II. Protect the health and safety
 - A. Site personnel
 - B. General public
- III. Adherence to legal and regulatory compliance
 - A. Air, land, ground water, surface water
 - B. People, plants, animals
- IV. Performance of basic functions
 - A. VOCs - monitor, sample, analyze

- 1. Air
 - 2. Soil
 - 3. Water
 - B. PCBs - monitor, sample, analyze
 - 1. Air
 - 2. Soil
 - 3. Water
 - C. Dioxin - monitor, sample, analyze
 - 1. Air
 - 2. Soil
 - 3. Water
- V. Applicability to activities
 - A. Baseline data collection
 - B. Excavation
 - C. Storage
- VI. Implementation
 - A. Ease of operation (man hours required)
 - B. Quality of data
 - C. Reliability
- VII. Economics
 - A. Acquisition
 - B. Operation
 - C. Maintenance

4.11 Monitoring Technologies

Technologies here are identified as the class of instruments used to perform identification and quantization functions of sample material having different physical states such as liquids, solids, and gases. There were other technologies that were examined but only those deemed directly applicable to the Winfield site are presented here for evaluation in the functional procedure.

- A = Chemical tests
- B = Gas Chromatography
- C = Gas Chromatography/Mass Spectrometry
- D = Fourier Transform Infrared Spectroscopy

4.12 Analysis

Each of the technologies were evaluated against the screening criteria established. The conducted functional analysis considered the objectives and relative performance of the analytical technologies. Parameters were scored on the basis of high (9 points), medium (3 points), and low (1 point) in terms of priority, applicability, and performance. The results are tabulated as follows:

Criteria		Technology			
		A	B	C	D
I-9		1-9	1-9	3-27	9-81
II-9		1-9	1-9	3-27	9-81
III-3	3-9	3-9	9-27	3-9	
IV-3		3-9	3-9	9-27	9-27
V-3		1-3	1-3	3-9	9-27
VI-9		1-9	1-9	3-27	9-81
VII-1		3-3	3-3	1-1	3-3
		51	51	145	309

4.13 Conclusion

When evaluating monitoring technologies, primary considerations emphasized were the analysis of all compounds in all mediums, continuous operation with total site coverage, minimal manpower in terms of sampling, operation, and maintenance, and overall cost for the duration of activities.

As is evidenced by the cumulative scores for each technology, gas chromatography/mass spectrometry is more applicable to the Winfield site over physical chemical tests or gas chromatography and Fourier transform infrared spectroscopy is considered more encompassing than GC/MS.

FTIR is extremely sensitive, accurate, and response time is very fast (5 seconds). With a proper integrated network, the system can monitor the total site during all remediation activities. Neither calibration nor physical operator attendance is necessary (other than at implementation) and field tests have demonstrated that maintenance is minimal. Although this is not a new technology, it was determined its high visibility (enhanced perhaps with streamers paralleling beam paths) would generate a desirable positive relationship between site activities and the general public.

The results of the analysis have clearly identified technology D (FTIR) as

Figure 4.1 - Functional Analysis Criteria Ranking Results

the technology that meets the established criteria the best.

5.0 SCREENING CRITERIA

The screening criteria developed for use in establishing the best technology applicable had to address the most important issues relative to operating on the site, the environment, the public, and protection of site workers.

Screening Criteria: *

- I. Baseline Data Collection Monitoring Requirements
 - A. Detect and analyze VOCs, PCBs, and dioxin
 - 1. Air, soil, surface water, ground and water
- II. Excavation and Remediation Operations Requirements
 - A. Detect and analyze VOCs, PCBs, and dioxin
 - 1. Air, soil, surface water, ground and water
- III. Transportation and Storage Operations Requirements
 - A. Detect and analyze VOCs, PCBs, and dioxin
 - 1. Air, soil, surface water, and ground water

* Assumption: Meteorological assessment has enabled determination of optimal monitoring equipment locations. Due to the fact that the Winfield site has already been characterized, the main consideration was concentrated on the monitoring and analysis of air and surface/ground water.

5.1 Site Requirements Issues

The site requirement issues are those that are dictated by federal and state government regulations and policies of the COE which is the Operating Entity.

5.2 Health and Safety Issues

Health and safety issues are those required by NIOSH under federal regulation relevant to remediation activities and conventional work operating issues for excavation, transportation, and remediation of hazardous and/or toxic waste materials as identified in 40 CFR.

5.3 Contaminant Issues

The results of the characterization studies indicate the Dioxin is a contaminant found in several soil samples and the highly toxic nature of

this contaminant requires the most stringent of regulations be implemented relative to all other health and safety issues and requirements for remediation and closing operations. This in turn requires the monitoring equipment selected for use must meet the strictest requirements for detection and performance.

5.3.1 Analytical Methods

40 CFR Part 136 establishes the following test procedures for the analysis of pollutants, predominantly in point monitoring. Fourier transform infrared spectrometry (FTIR) has been implemented in fence line monitoring.

I. VOCs

- A. Chemical Tests
- B. Gas Chromatography (GC)
- C. Gas Chromatography/Mass Spectrometry (GC/MS)
- D. FTIR

II. PCBs

- A. Chemical Tests
- B. GC
- C. GC/MS
- D. FTIR

III. Dioxins/Furans

- A. Chemical Tests
- B. GC
- C. GC/MS
- D. FTIR

5.3.1.1 Positives/Negatives

Chemical Tests:

+/- Accuracy

- Human error possibilities
- Site coverage
- Sample collection time
- Sample preparation time
- Analysis time
- Training

GC:

- + Acceptable method for VOCs, PCBs
- Acceptable method for screening for dioxin
- Site coverage
- 45 minutes/sample
- Calibration necessary
- Maintenance
- Training

GC/MS:

- + Acceptable method for VOCs, PCBs, Dioxin
- Site coverage
- 45 minutes/sample
- Calibration necessary
- Maintenance
- Training

FTIR:

- +/- Analysis of VOCs, PCBs, Dioxin
- + Site coverage
- + 5 seconds/sample
- + Calibration necessary one time only
- + Maintenance
- + Training

6.0 MONITORING TECHNOLOGY - REVIEW AND PRIORITIZATION

6.1 Chemical Tests

6.1.1 Millipore Corporation - Envirogard PCB Immunoassay Test Kit

6.1.1.1 Scope

This polychlorinated biphenyl (PCB) immunoassay test kit performs rapid analysis of PCBs in soils. Soil sample extracts are added to test tubes coated with antibodies that bind PCB molecules. The soil extracts are washed away after incubation, and a PCB conjugate, which mimics free PCB molecules, is added to the tubes. Unoccupied antibody binding sites bind the PCB conjugate. Excess PCB conjugate is washed away. An enzyme substrate and a coloring agent are added to the test tube. The color intensity is measured at 405 nanometers using a small, portable

spectrophotometer. The color intensity is inversely proportional to the PCB concentration in the soil sample. The results obtained from the soil samples are compared against three calibrators of 5, 10, and 50 ppm.

PCB concentrations can be semi-quantitatively classified as below 5 ppm, between 5 and 10 ppm, between 10 and 50 ppm, and greater than 50 ppm. Up to 6 sample analyses (in duplicate) can be performed in about 15 to 20 minutes. The developer can provide optional protocols to perform a more detailed quantitative analysis.

6.1.1.2 Advantages

- * Rapid analysis of PCBs in soil and water
- * Correlation with quantitative analyses

6.1.1.3 Disadvantages

- * Semi-quantitatively analyzes PCBs in soil and water only
- * Not applicable to PCBs in air without sampling system
- * Not applicable to VOCs or dioxin analysis
- * Labor intensive

6.1.1.4 Conclusion

As with all chemical tests, application is restricted to specific compounds. While relatively in-expensive for test kit components, all chemical tests are labor intensive and require technical expertise, extensive sampling and sample preparation, and can only be considered continuous when continually manned.

6.2 Gas Chromatograph Portable Monitoring Equipment

6.2.1 SRI Instruments - Portable Gas Chromatograph

6.2.1.1 Scope

A compact Bench-top or field portable instrument delivering the same performance and using the same columns as a full sized laboratory GC but rugged and field transportable for analysis of VOCs and PCBs in air, soil, and water. Sampling is achieved automatically or manually. Accessories include "peak simple" software, a built-in "purge-and-trap", air compressor, and vacuum pump. The GC's large column oven is designed for packed (1/8") and capillary columns with coil diameters up to eight inches. The column oven is multi-ramp programmable from ambient to 300

C for fast analysis times and optimum resolution. Seven detector options are available and any combination or all seven can be plumbed in series/parallel for any EPA or ASTM method. Detection limits range from ppt to percent levels. The GC is issued with A/D boards and "peak simple" software which converts any IBM PC compatible into a powerful multi-channel data acquisition system.

6.2.1.2 Detectors

Thermal Conductivity Detector (TCD) - The TCD is typically used for gas analyses and simple mixtures where the concentrations of each analyte is between 0.1 and 100 percent.

Flame Ionization Detector (FID) - The FID is the most commonly used GC detector because it detects virtually all hydrocarbon containing molecules with a lower detection limit down to 100 ppb with linear response as the amount increases to almost 100%. SRI's FID is unique because it has a state of the art ceramic ignitor which remains permanently glowing thus preventing "flame-outs".

Nitrogen-Phosphorous Detector (NPD) - The NPD is typically used to analyze nitrogen containing herbicides or phosphorous containing pesticides like malathion.

Electron Capture Detector (ECD) - The ECD is used for detection of electro-negative molecules, especially chlorinated, fluorinated or brominated compounds such as carbon-tet, bromoform, PCBs, and pesticides such as DDT at femto-gram levels for some compounds.

Photo-Ionization Detector (PID) - The PID uses a 10.2 eV ultraviolet lamp to ionize and detect most aromatic molecules such as benzene, toluene and xylene, many aliphatic molecules such as hexane, but not some chlorinated compounds such as trichloroethane. The high voltage lamp power supply is adjustable so the lamp current can be optimized for highest sensitivity or longest life. With a standard 10.2 eV lamp, detection limits are in the 10 ppb range for aromatics.

Electrolytic Conductivity Detector (ELCD) - The ELCD consists of a high temperature reaction furnace which heats the column effluent to 1800 C in the presence of hydrogen or air to convert halogenated molecules (chlorinated solvents, PCBs, pesticides) to hydrochloric acid. The highly conductive HCl is micro-extracted into a low conductivity aerosol of n-propanol temporarily increasing the electrical conductivity. Only

halogens respond.

Flame Photo-Metric Detector (FPD) - The FPD is widely used for sulfur gas analysis such as H₂S and SO₂, and for organo-phosphate pesticides. The FPD is more stable than the NPD.

6.2.1.3 Accessories

EPA Style Purge and Trap - The purge and trap is a device which allows organic molecules in air, soil, and water to be concentrated on an absorbent trap. The absorbent trap is then heated to release the concentrated organics onto the GC's column. Purge and trap is required because most GC detectors are not sensitive enough to detect ppb or ppt levels, nor can you inject 10 ml. of soil or water onto a GC column. By concentrating the organics present onto a trap, then heating the trap, all the original organics are injected on the column. This lowers the detection limit by a factor of 1000 and enables detection limits in the ppt range.

SRI uses two entirely separate traps in conjunction with a 10 port valve to reverse the order of the two traps during desorption. Because each trap can be heated to its optimum temperature, desorption efficiency is maximized.

The purge and trap system can be fitted with a 10 position auto sampler for soil and water and a 42 vial liquid auto sampler for water analyses.

Built-in Air Compressor and Vacuum Pump - The air compressor supplies FID combustion air, purge gas when using the purge and trap, and necessitates the need for only one gas cylinder (hydrogen for carrier and FID combustion) for field operation. The vacuum pump is used for sucking samples through the gas sampling valve loop

6.2.1.4 Advantages

- * Quantitative analysis of VOC's and PCB's in air, soil, and water
- * Totally portable with manual or automatic sampling
- * Packed or capillary columns can be heated isothermally or ramped to 180 degrees
- * Lap-Top PC controlled
- * Dual detector capabilities (AID/ECD for VOCs and PCBs)

6.2.1.5 Disadvantages

- * Not applicable to dioxin analysis
- * ECD detector contains radio-active Nickel-63 as a beta particle energy source
 - Requires license and bi-annual wipe-tests
- * Not applicable to continuous soil or water analysis

6.2.1.6 Conclusion

Because the unit does not quantitatively analyze dioxin its use relative to the Winfield site is only applicable used in conjunction with additional instrumentation with this capability. Additional deficiencies are the necessities of manual soil and water sampling for analysis.

6.2.2 Sentex Systems Inc. - Portable Gas Chromatograph

6.2.2.1 Scope

Totally portable GC designed to provide on-site field analysis with laboratory GC quality of VOCs and PCBs in air, soil, and water. Sampling is achieved either automatically through an internal pump, or manually through injection into a heated injection port. Accessories include a portable purge and trap system, soil gas sampler, and stack monitor. Efficient compound separation is accomplished with the use of a variety of commercially available columns, either packed or capillary. Columns can be heated isothermally or ramped to temperatures up to 180C to create optimum conditions for maximum results. Five detector options are available for tailoring the most effective system for each application, general or specific. Detection limits can range from ppt to percent levels. Internal battery and gas supply make the units totally portable, however, AC adapters are available for prolonged use. A detachable lap-top PC controls the system operation and conducts the sample analysis, storing the results on an internal disk for future recall and documentation.

The GC identifies and quantifies specific compounds by comparing the retention time and peak integration values obtained for compounds during analysis, with retention time and peak integration values obtained for a calibration standard previously analyzed. Up to 48 compounds can be identified at one time using this direct calibration method. Matches are identified by compound names and concentrations. Unidentified peaks are labeled as "unknowns". "Unknown" compounds can be identified using a calibration library, consisting of up to 48 chemicals previously analyzed

by the GC under the same operating conditions. The library is updated using a single chemical as a calibrant during the calibration run. "Unknowns" obtained during the analysis run are screened by the library for their names and concentration levels.

6.2.2.2 Detectors

Argon Ionization Detector (AID) - The AID provides sensitive detection of organic compounds having an ionization potential of 11.7 eV or below, which are poorly detected by other common field detectors. The AID is capable of detecting compounds down to low ppb levels. It can also be easily switched to operate as an Electron Capture Detector.

Micro Argon Ionization Detector (MAID) - The MAID is a small volume, higher sensitivity version of the AID. It is ideal for use with capillary columns with detection limits at the one ppb level.

Electron Capture Detector (ECD) - The ECD is a selective detector used for the detection of halogenated hydrocarbons, PCBs, pesticides, and nitro-based compounds only. Its sensitivity can reach low ppt levels.

Thermal Conductivity Detector (TCD) - The TCD is used primarily for the detection of natural gases in concentrations ranging from 100 ppm to percent levels.

Photo-Ionization Detector (PID) - The PID uses an ultraviolet lamp to ionize and detect hydrocarbons having ionization potentials of 10.6 eV or less with sensitivity approaching the one ppb level.

6.2.2.3 Accessories

Automatic Purge and Trap Units - Enables analysis of water and soil samples for VOCs rapidly and accurately on-site. The GC batteries provide the power.

Water samples are collected in 40 ml vials or placed in sample cups and are purged with inert gas. The VOCs in the purged sample are collected on a trap located inside the GC. They are then desorbed from the trap to the GC system for separation, identification, and quantification of the components present. All times are set on the operating parameters menu and precisely controlled automatically. Soil samples can be analyzed, using the same system, by placing a few grams of soil in pure water. The water extracts the volatiles from the soil, which are then purged from the water. An automatic "on-line" version is available to provide continuous

monitoring of a water source. Also powered by the GC, both calibration and sample are pumped into a purge cell where they are then automatically processed.

Soil Gas Sampler - Allows the automatic collection of head space vapors of soil from up to 10 feet away. The sample is pumped into a holding chamber from a pre drilled or punched hole in the soil. It is then automatically sampled by the GC for the identification and quantification of VOCs.

Stack Gas Monitor - Designed to draw a sample of stack gas coming out of a stack down to the GC. This allows the GC to operate in a less severe environment while checking samples coming off the stack at temperatures of 300F to 400F from as much as 100 feet away.

6.2.2.4 Advantages

- * Quantitative analysis of VOCs and PCBs in air, soil, and water
- * Totally portable with manual or automatic sampling
- * Packed or capillary columns can be heated isothermally or ramped to 180C
- * Five detector options with detection limits to ppb
- * Lap-top PC controlled
- * Dual detector capabilities (AID/ECD for VOCs and PCBs)

6.2.2.5 Disadvantages

- * Not applicable to dioxin analysis
- * Both AID and ECD are easily saturated at higher ppm concentrations
 - Dual detector system operates best at 10 to 1000 ppb range
- * Dual detector system uses radioactive tritium foil as beta energy source
 - A modified NRC License available through Sentex is required
- * Not applicable to continuous soil analysis

6.2.2.6 Conclusion

Because the unit does not quantitatively analyze dioxin its use relative to the Winfield site is only applicable used in conjunction with additional instrumentation with this capability. An additional drawback is the necessity of manual soil sampling for analysis.

6.3 Portable GC/MS

6.3.1 Bruker Instruments, Inc. - Mobile Environmental Monitor

6.3.1.1 Scope

A new fast fieldable GC/MS system (EM 640) for qualitative and quantitative analyses will be introduced (in addition to the MEM (MM-1) system proven and accepted) aiming at more than 100 quantitative sample analyses per shift. The instrument is designed for rapid analysis procedures for organic volatiles, semivolatiles, and pesticides, deviating from EPA procedures only where necessary for reasons of speed. The external laptop data system will produce analysis reports according to EPA standards.

The GC/MS system Bruker EM 640 is highly modular and can be adapted for several analytical tasks. It consists of a small mass spectrometer box including all pumps, an on-top modular micro-GC with an universal electronics module for several peripheral instruments, and the external PC data system.

The MS box will be small, light, and energy saving: 35 cm X 45 cm X 55 cm, 45 kg, 250 W, 24 V. The external PC laptop data system interfaces to the operator and takes over the task of data evaluation and presentation, whereas the complete internal control is performed by several powerful transputer microprocessors. The EM 640 system operates in a wide range of shock, vibration, and temperatures and has built-in capabilities for complete self-testing. The company standard inlet connector takes up, in a few seconds changing time, a variety of different samplers including flexible air probes and superfast modular miniaturized GCs.

Any type of quantitative analysis of pollutants in air, soil, or water can be performed by a variety of GC modules. These modules can be combined to a superfast short-column GC or a fast medium-length column GC, with either manual injection, manual sorption tube oven, automatic sorption tube station, or water spray and trap probe. Filtered air or bottled nitrogen may be used as carrier gas. The fast GCs offer complete GC/MS cycle times down to 3 minutes for the 3.5 meter short-column GC, and down to 6 minutes for the 20 meter medium-length GC. All the different kinds of GCs which can be combined by these modules, can be operated by the universal peripheral electronics with its own transputer microprocessor system. The spray and trap water probe, and other future peripheral equipment, can also be operated by the universal peripheral electronics module.

Soil sample head-space VOC analyses are as well possible as soil extraction SVOC analyses (automatic extraction stations are planned). Air can be continuously monitored and low ppt trace analyses of water may be performed by a special spray and trap technique.

The external PC data system controls the GC/MS, and evaluates the measurement data, substantially in agreement with EPA's CLP regulations, but necessarily deviating in requirements for column length, extraction procedures, and so on, to enable much faster sample analyses procedures. EPA type output formats are used for reporting.

6.3.1.2 Sampling Accessories (MM-1)

Combination Air/Surface Sampling Probe - Consists of a large heated silicone membrane head followed by a 3.5 meter capillary GC column encased in an elongated temperature programmable heated tube, ending at the membrane separator inlet to the MS ion source. This configuration allows for the probe head to be easily moved to the area measured. A continuous flow through the column enables the continuous measurement of ambient air, vaporization of solvent extracts, as well as direct contact thermal desorption of a surface which transfers the organic analytes into the MS ion source without any sample preparation.

Gas Chromatograph Oven - A mini GC oven which is temperature programmable houses a capillary column up to 30 meters in length. It is equipped with a thermal desorption chamber which allows the introduction of standard sorbent tubes, as well as providing direct injection capabilities of standards and solvent extracts. This oven is advantageous when a complex mixture of analytes needs to be separated and detected. Filtered ambient air is used as the carrier gas.

Ultra Fast Soil Sampler - The soil sampler is the same 3.5 meter capillary GC column configuration as the combination air/surface sampling probe (including probe head) but without the flexible tube. The capillary column is encased in an oven equipped with a cooling fan for extremely rapid heating and cooling. The auto-sample injection platform allows for reproducible injections.

Automatic Air Sampler - This computer controlled device can be attached to the GC oven. An internal pump passes air samples through a sorbent tube for enrichment. Analytes are then desorbed from the tube and transferred to the GC column for analysis. Unattended operation of an

unlimited number of air, soil, and water samples can be automatically performed.

Spray Extractor Water Sampler - The spray extractor is an alternative to the conventional purge and trap technique. In spray and trap, instead of bubbling air through a sparging vessel, the liquid is sprayed through a nebulizer resulting in tiny water droplets being formed. This provides a larger contact surface between the liquid and the air to achieve a highly efficient extraction of VOCs. The analytes are then concentrated on a sorbent tube followed by desorption into the GC oven. This system is advantageous because very large sample volumes can be tested (lakes, streams, rivers) to yield sub ppb detection limits.

6.3.1.3 Advantages

- * Provides qualitative and quantitative analyses of VOCs, PCBs, and dioxin in air, soil, and water
- * Totally portable with continuous monitoring and analysis
- * Simultaneous analysis in low ppb levels
- * Sample preparation and analysis simplified with available accessories
- * Proven and acceptable by government agencies

6.3.1.4 Disadvantages

- * High acquisition cost
- * Intensive operator training mandatory
- * More than one unit necessary for site coverage

6.3.1.5 Conclusion

Demonstrations (SITE) involving a direct comparison of results generated with the MM-1 to data generated from similar conventional techniques verifies providence of data of acceptable quality for a variety of data quality objectives. The major objection is that more than one unit would be necessary for total coverage of remediation activities.

6.4 Fourier Transform Infrared Spectrometer

6.4.1 MDA Scientific, Inc. - Fourier Transform Infrared Spectrometer

6.4.1.1 Scope

This technology is based on the fact that every gas has its own unique absorption spectrum. The FTIR Remote Sensor monitors the entire infrared spectrum and compares that which is detected with a 120+ gas spectra library maintained for quantitative measurements with sensitivity in low parts per billion. The instrument collects all data in the mid-infrared spectral region (700 cm⁻¹ to 5000 cm⁻¹). The analysis is performed in selected atmospheric window regions to reduce interference caused by environmental factors such as water vapor, dust, fog, rain, and snow. Quantitative results can be produced in less than 5 seconds. The FTIR Remote Sensor eliminates the costs for multiple gas specific monitors and their calibration. Further, it provides continuous path coverage up to 1000 meters, which would require many single point sensors. The unit is so portable it can be set up and be on-line in 15 minutes or less and can be alarm equipped.

6.4.1.2 Accessories

An automated scanning system enables monitoring many different paths of up to 200 meters, in any sequence, with one instrument. The Scanner is a modular design and can be retro-fitted to existing single line of sight FTIR Remote Sensors. Multiple Retroreflectors can be placed anywhere within a 200 meter radius of the Scanning FTIR System, and any monitoring sequence defined. An integrated remote control camera and video display allow for easy horizontal and vertical initial path alignments.

6.4.1.3 Advantages

- * Programmable (assumption) for quantitative analysis of VOCs, PCBs, and dioxin in air and water
- * Totally portable with continuous monitoring and analyses
- * Measurements of emissions from point, area, or mobile sources
- * Simultaneous analysis of most gaseous air toxics in low ppb concentrations
 - As per 1990 Clean Air Act Amendments

6.4.1.4 Disadvantages

- * Not applicable to soil analysis
- * High acquisition cost (\$200,000.00)

6.4.1.5 Conclusion

This unit with accessories would be applicable to total areal coverage of the site during excavation, and properly situated, would enhance a feeling of propriety in the general public. Coupled with instrumentation for soil and water analysis, this technology would eliminate point source monitoring instrument placement.

7.0 IDENTIFIED PROBLEM FOR FUTURE R & D

7.1 Generic Problems

Monitoring of hazardous waste technologies are literally continually progressing. Most types of instrumentation and analytical techniques are tailor made to specific areas of investigation and these generally address situations of least complexity. For example, chemical tests are usually applicable to specific compounds in soil and water, Gas chromatography focuses on VOCs in air, gas chromatography/mass spectrometry (while possessing total monitoring and analytical capabilities) is considered in terms of controlled laboratory investigations, and Fourier transform infrared spectroscopy is predominantly concentrated on air stream applications.

Very few of the manufacturers of monitoring equipment have addressed the problems of total site coverage during all phases of remediation activities and of monitoring and quantitatively analyzing a myriad of toxic wastes in all mediums (air, soil, surface water, and ground water). Many of the larger manufacturers have the most sophisticated laboratory instrumentation technically feasible, however, they have not considered the necessity of applying these technologies in a harsh and hostile environment, i.e., field activities.

7.2 Winfield Site

While certainly not unique in toxicity, the Winfield site is challenging (in terms of monitoring and analytical procedures) in that:

- 1) The site is relatively large (21.81 acres)
- 2) Similarity of contaminants are not confined to specific locations
- 3) Difficult to handle materials (railroad rails and ties, buildings) are contaminated
- 4) VOCs, SVOCs, PCBs, and dioxin are all present
- 5) Air, soil, surface water, and perched ground water are all contaminated

- 6) The aquifer supplying nearby population areas is threatened by contamination
- 7) The close proximity of the Kanawha River makes possible the migration and increase in areal extent of contamination

In lieu of the aforementioned, complete site coverage could therefore require many different types of monitoring equipment and consequentially a tremendous amount of time and manpower for operation. Leading edge manufacturers should be obligated to address sites such as Winfield and equipment "packages" to enable total site coverage for all aspects of remediation provide activities.

8.0 SUMMARY AND ANALYSIS

In consideration that the Winfield site is contaminated by VOCs, SVOCs, PCBs, and dioxin in air, soil, surface water, and groundwater, it is imperative that a GC/MS system be utilized during remediation activities. A FTIR system equipped to analyze air and water with scanner and retroreflectors enabling total site coverage would greatly enhance the GC/MS system analytically and with its high visibility would promote a public awareness that their safety is of utmost importance relative to site operations.

The investigator does not know of any site demonstrations where these two technologies were simultaneously evaluated under identical operating conditions. To provide these manufacturers the opportunity for such a demonstration could only prove advantageous to government agencies and the industry. Positives, negatives, and cost comparison data would be invaluable in future monitoring of hazardous waste evaluations.

9.0 APPENDICES

- 9.1 COE Report - Winfield Site
- 9.2 Literature search key word results
- 9.3 Literature search selected articles
- 9.4 40 CFR Part 136
- 9.5 Manufacturers of monitoring equipment

9.6 Specifications selected manufacturers

9.7 SITE demonstrations

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

**Quarterly Report for Period
July 1 through September 30, 1993**

**Work Performed Under Contract
No.: DE-FC21-92MC29467
(MTCI No. 070)**

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

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October 1993

ABSTRACT

The work accomplished during this period consisted of evaluating the PDU for Pressure Operations.

The existing two-tube gasifier was leak-tested up to 10 atm, twice the operating pressure, to determine the modifications required to retrofit the system for pressurized operations. The test indicated that the design, fabrication and installation of a new vessel that could be operated safely at 5 atm pressure and 1500°F temperature was required. Additional stress calculations were also performed on the existing S/S 8-inch reactor. It was decided not to modify the reactor for high pressure, but to design and procure a new refractory-lined reactor for the pressure testing. However, the rest of the process equipment can be utilized as it is for the high-pressure program. The reactor top section will have a 26-inch diameter ID. The reactor is also equipped with an internal cyclone.

The reactor vessel design has been sent to a vendor for fabrication quotes.

The preliminary process design has been completed and an analysis of the process has been initiated.

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1. TECHNICAL BACKGROUND

Steam reforming has been employed for many years for the efficient production of hydrogen from more complex hydrocarbons. In steam reforming larger hydrocarbon molecules, a hydrogen-rich product gas is obtained having predominantly a mixture of H_2 , CO_2 , CO and some CH_4 . Little to no higher hydrocarbons are found in the product gas when the steam-reforming processes are conducted under proper conditions (temperature, pressure, with or without catalysts, etc.).

Sulfur containing (mercaptans) and chlorinated hydrocarbons are also steam reformed in such processes, giving rise to primarily H_2S and HCl gases in the reformat product gas. These gaseous forms are easily removed from the product gas in one or both of two approaches. Using a sorbent in the steam reformer, such as limestone, has been employed by MTCI for example to capture sulfur and chlorine. Furthermore, venturi scrubber packed beds and/or static mixer methods have also been employed to remove sulfur and chlorine from the product gas.

In the MTCI thermochemical reactor, the reactor is a steam fluidized fluid bed heated indirectly (no partial oxidation) by resonance tubes of pulsating combustors. This thermochemical reactor technology has already been employed to steam reform dioxin-laden paper mill sludge, chlorinated hydrocarbon plastic laden sludge, sewage sludge, and toxic spent liquor effluents from pulp mill operations.

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).

The inherent low NO_x pulse burners used to provide the heat of reaction for the steam reformer also provides significant environmental advantages for system performance in pressure boost, low NO_x production, and less CO_2 emissions because of its higher overall thermal system efficiency. And because the system is indirectly heated, temperatures of operation for waste destruction are lower than in incinerator systems and flue emissions from the combustors providing the endothermic heat of reaction to the steam reformer do not emit any of the toxics

or metallics in the waste. The modularity of the system makes it ideal for transportation, setup and operation at distributed sites or for incorporation as a unit operation for waste minimization and energy and process chemical recovery. A further extension of the process for the treatment and reduction of low-level nuclear waste containing organics is also a distinct possibility for either the atmospheric or pressurized systems. The choice being primarily dependent upon radiation safety considerations.

2. EXPERIMENTAL METHODOLOGY

The objective of this Phase I effort is to establish the design basis for a pressurized indirectly heated gasifier based upon the MTCI steam-reformer technology currently being operated at atmospheric pressure and at industrial process scale (1 to 5 tons/hr). The effect of pressure enhancement of the technology would be to increase the capacity of the system substantially. This increase would result in reductions in capital and operating cost and would be especially beneficial for processing large quantities of toxic-bearing soils such as that present at the ACF site.

A pressurized system could offer a great deal of potential as a modular system that could effectively process non-nuclear hazardous waste for DOE site remediation projects and for integration into sanitary and other waste generating processes at the source. The modularity of the system also makes it ideal for mobile use or for small capacity operations where the cost of steam reforming or incineration technologies and their associated environmental control equipment would be prohibitive.

All modifications required for the existing laboratory steam-reforming unit to operate at high pressure will be evaluated and analyzed. The existing process unit will be used and modified for operation at about 4 atmospheres. The modifications required are especially necessary for the reactor and the scrubber on the gasifier side and the air gas inlets on the combustor side as well as all fittings, piping and penetrations in the system. Once the design has been evaluated, the system will be modified and prepared for a series of laboratory-scale tests to obtain the data required to define and predict the parameters necessary to optimize the pressurized system and to determine the cost effectiveness and process efficiency of the pressurized system as compared to the atmospheric unit.

A quantity of solid or liquid feedstock waste will be obtained for the test. The waste will be characterized by an independent analytical laboratory. Utilizing the feedstock analysis, a comparative or similarity analysis will be made with respect to the composition and deposition of major species in prior industrial and municipal waste testing work to determine process efficiency and product composition of the waste in its bench-scale reactor.

A preliminary test plan matrix will be prepared for experiments to be conducted in the pressurized indirectly heated steam reformer using the aforementioned feedstock. Three primary

independent test variables have initially been identified for the Phase I effort and are listed below:

- Reformer temperature
- Pulse combustor pressure
- Reformer pressure

If it is assumed that the independent variables are each tested at two value levels, then the complete 2^3 factorial matrix would require 4 separate test runs. A fractional factorial design has been selected based on the method of Plackett and Burman.⁽²²⁾ In this method, a reduced number of assemblies are selected from the complete factorial design in a specific manner which allows estimation of individual component effects with the maximum degree of statistical accuracy.

The test plan consists of two identical Plackett-Burman matrices. Table 1 shows the proposed test matrix for Phase I.

Table 5-1:

**Values of High and Low Levels for Independent
Variables In Plackett-Burman Design Matrix**

<u>Independent Variable</u>	<u>High Level (+)</u>	<u>Low Level (-)</u>
Temperature (°F)	1,600	1,400
Reformer Pressure	4	1
Pulse Combustion Pressure	4	1

The component effects for each independent variable will be calculated with regard to the following dependent variables:

- Char gasification rate
- Heat transfer rate

Statistical methods will be used to evaluate the effect of each independent variable on each of the dependent variables listed above. A t-distribution approach will be used to determine the statistical significance of each effect. Correlations using regression analysis will be derived when applicable.

The pulse combustor will be fired with natural gas, and no recycling of product gas will be employed. Steam and/or nitrogen will be used as the fluidizing medium. Gasification yields of gas, liquid and char will be measured. The gases will be analyzed with a gas chromatograph. Liquid and char products will be subject to independent ultimate analyses.

Gas samples will be collected by Truesdail Laboratories, of Tustin, California, for dioxin analysis (EPA method number 613). An insert containing special resin will be placed inside the gas stream. Dioxin will be adsorbed on the resin where it will be leached with a weak acid. The concentration of toxic organics such as Polychlorinated biphenyls (PCBs), Polychlorinated dibenzo furans (PCDFs), and Polychlorinated dibenzo dioxins (PCDDs) will be determined. Also liquid and bed solid samples will be collected and analyzed for the above toxic organics by Truesdail Laboratories. Truesdail Laboratories is certified by the California Department of Health and Services for priority pollutant analyses of water and waste samples. They are also certified by the California Air Resources Board for air pollution testing. The distribution of toxics in each stream will be used to analyze the destruction efficiency of the system. If possible and appropriate, a quantity of the soil-bearing toxics from the locks and dam site will be processed in the system.

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

3.1 Process Description

Figure 1 shows the process flow diagram for the hazardous waste steam reformer test unit. It consists of a pressurized, refractory-lined steam reformer (R-1). Three pulse heaters (H-1, H-2, & H-3) are immersed in the fluid-bed steam reformer. The reformer is fluidized using steam as the media. The steam is generated in a boiler (H-6) and superheated in the steam superheater (E-5) prior to going to the reactor (R-1). The hazardous waste is fed to the reactor through a metering pump if liquid or a solid screw with metering bin and link hopper if solid (items not shown).

A catalyst (lime) is used inside the reactor as the bed media. The hazardous waste is reacted with the steam inside the reactor where the endothermic heat of reaction is provided indirectly through the combustor fire tubes (pulse heater). The gas and steam generated inside the reactor enter a high efficiency internal cyclone (C-1), where the coarse particulates are removed and recycled back to the reactor.

**FIGURE 1: PROCESS FLOW DIAGRAM FOR PRESSURIZED
HAZARDOUS WASTE STEAM REFORMER**

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The product gas leaving the internal cyclone is cooled in a product gas waste heat recovery boiler (E-1) before going to a second cyclone (C-2). The second cyclone further removes the solid particulates that are collected in the cyclone catch (C-3).

The product gas pressure is reduced from 5 to atmospheric before entering the venturi scrubber (VS-1). The venturi scrubber further cools the product gas, condenses the steam, and removes the remaining particulates. The condensed water and solid particulates are collected in the venturi scrubber tank (C-4). The venturi scrubber water is filtered through the filter (F-1) to collect the solid particulate for chemical analysis and mass balance purposes and, also, to reduce fouling in the heat exchanger (E-2).

The venturi scrubber water is circulated in that shell and tube heat exchanger to cool the water and to reject the heat before being returned to the venturi scrubber. The gases leaving the venturi scrubber all flared in H-5 and there cooled in the cooling tower (C-5) before venting into the atmosphere. The cooling tower (C-5) is also a packed column where acid gases (if any) can be scrubbed.

The heat of reaction indirectly supplied to the fluid-bed reactor via the three pulse combustors are immersed in the fluid bed. The pulse combustor operates at 5 atm, the same as the fluid-bed reactor to reduce pressure differential between the two components. Natural gas will be used as a fuel source for the pulse combustor, although other fuels such as propane, product, can be used. In the operational system the product gas may be used to supplement the fuel for the combustors if a sufficient quantity is produced. Otherwise, it will be flared as described above.

The flue gas leaving the pulse combustor enters the steam superheater (E-5) where it indirectly superheats the steam. The flue gas is further cooled in a waste heat recovery boiler (E-3) to less than 400°F before entering the pressure-reducing valve. The flue gas at atmospheric pressure enters the cooling tower (C-5) prior to being vented into the atmosphere. The hot return water from the waste heat recovery boilers E-1 and E-3 are cooled in an air-cooled fin from the exchanger.

3.2 System Analysis for Pressure Operation

The existing two-tube gasifier was leak-tested up to 10 atm, twice the operating pressure, to determine the modifications required to retrofit the system for pressurized operations. The test indicated that the design, fabrication and installation of a new vessel that could be operated safely at 5 atm pressure and 1500°F temperature was required. Additional stress calculations were also performed on the existing S/S 8-inch reactor. It was decided not to modify the reactor for high pressure, but to design and procure a new refractory-lined reactor for the pressure testing. However, the rest of the process equipment can be utilized as it is for the high-pressure program. The reactor top section will have a 26-inch diameter ID. The reactor is also equipped with an internal cyclone.

The reactor vessel design has been sent to a vendor for fabrication quotes.

3.3 Pressurized Fluid-Bed Reactor

Figure 2 shows a schematic of the pressurized reactor bottom section. The reactor is a 36-inch carbon steel shell with a refractory-lined unit and wall. The refractory wall is 5 inches thick. Two types of refractory material are used: a 2-inch thick, high-density material for strength and a 3-inch thick, low-density material for insulation. The height of the bottom section is 86 inches. Fluidization media enters the reactor through the sparge tubes donated by #1, located at the bottom of the reactor. The bottom is dished and a drain line provided to empty the reactor for maintenance purposes. The shell liquid feed port (#2) is located above the sparge tubes. Three 16-inch ports (#7, #4 & #10) are provided for three tube bundles. Initially, only one tube bundle will be fabricated and tested but two additional ports are provided to install two more tube heaters. A bed overflow port is provided to remove the bed; this is essential when contaminated soil is fed to the reactor. The clean soil (free of contaminants) will be removed through this port.

Figure 3 shows the top section of the reactor. The top section is 58 inches long and refractory-lined. The product gas leaves the reactor through the internal cyclone. Additional ports are provided in both the top and bottom sections for instrumentation and gas/solid sampling.

3.4 Two-Tube Pressurized Pulse Combustor Heater Bundle

The heater bundle consists of two resonance tubes (only one shown), a refractory-lined combustion chamber, an aerodynamic valve, and an air plenum as shown in Figure 4.

Natural gas and air enter the pulse combustor where combustion takes place. The pulse combustor chamber is refractory-lined and the tube sheet facing the fluid bed reactor is steam cooled. The combustion gases leave the pulse combustor through two resonance tubes (1½" dia.). A one-inch tube is inside the 1½-inch resonance tube to lower the surface temperature of the outer tube. This reduces the overheating of the outer tube. The first pass of the resonance tube is straight whereas the second pass is coiled. Designing the resonance tube this way will maximize the heat transfer area and at the same time reduce the internal flow area of the reactor, thus reducing the amount of steam required for fluidization. The exhaust gas leaves the resonance tubes and enters the steam superheater as described earlier.

Figure 5 shows the steam reformer bottom section with three pulse heaters inserted into it. As discussed previously, only one pulse heater will be fabricated and tested but the reactor design allows for two additional heaters.

4. CONCLUSIONS

The fabrication of the reactor's top and bottom sections are 20% complete. The pulse heater design is 70% complete.

ITEM	DESCRIPTION	ELEVATION INCHES FROM ZERO	DEGREES
1	SPARGE TUBE	1"	
2	FEED PORT - 6" OD. SCH 40. CS PIPE. 6" LONG	12"	270
3	6". CS. SOF. RF. 150#		
4	H-3 PORT. 16" DIA. SCH 80. CS. PIPE 6" LONG	43"	180
5	16". CS. SOF. RF. 150#		
6	16". CS. BF. RF. 150# WITH A PLUG		
7	H-1 PORT. 16" DIA. SCH 80. CS. PIPE. 6" LONG	235	0
8	16". CS. SOF. RF. 150#		
9	16". CS. BF. RF. 150# WITH A PLUG		
10	H-2 PORT. 16" DIA. SCH 80. CS. PIPE. 6" LONG	625"	0
11	16". CS. SOF. RF. 150#		
12	16". CS. BF. RF. 150# WITH A PLUG		
13	3". SS 304. SCH 80. PIPE 12" LONG		225
14	3". CS. SOF. RF. 150#		
15	3". CS. BF. RF. 150# WITH A PLUG		
16	6". CS. SCH 40. PIPE. 6" LONG	N/A	N/A
17	6". SOF. RF. 150# WITH A PLUG	N/A	N/A
18	6". CS. BF. RF. 150# WITH A PLUG	N/A	N/A
19	TC PORT. 3/4" - CS. HALF COUPLING THREADED	6"	315
20	TC PORT. 3/4" - CS. HALF COUPLING THREADED	18"	315
21	TC PORT. 3/4" - CS. HALF COUPLING THREADED	30"	315
22	TC PORT. 3/4" - CS. HALF COUPLING THREADED	42"	315
23	TC PORT. 3/4" - CS. HALF COUPLING THREADED	54"	315
24	TC PORT. 3/4" - CS. HALF COUPLING THREADED	66"	315
25	PRESSURE PORT. 1/2". CS. HALF COUPLING THREADED	4"	315
26	PRESSURE PORT. 1/2". CS. HALF COUPLING THREADED	24"	315
27	PRESSURE PORT. 1/2". CS. HALF COUPLING THREADED	60"	315
28	36" OD. CS. 1/2" WALL PIPE	N/A	N/A
29	36". CS. 150#. SOF. RF.		
30	36". CS. HI-CROWN TANK HEAD. 1/2" WALL		
31			
32			
33			
34	3/4" HEAT FLUX METER PORT. CS. HALF COUPLING	21"	315
35	3/4" HEAT FLUX METER PORT. CS. HALF COUPLING	40"	315
36	3/4" HEAT FLUX METER PORT. CS. HALF COUPLING	52"	315
37	3/4" HEAT FLUX METER PORT. CS. HALF COUPLING	68"	315

FIGURE 2: BOTTOM SECTION OF PRESSURIZED STEAM REFORMER

ITEMS	DESCRIPTION	ELEVATION FROM ZERO	DEGREES
1	36", 150#, CS. SOF. RF	N/A	N/A
2	36" OD, 1/2" WALL, CS. PIPE	N/A	N/A
3	36" OD, 1/2" WALL, HI-CROWN TANK HEAD	N/A	N/A
4	6", CS. SCH 40, PIPE	N/A	N/A
5	6", CS. SOF. RF, 150#	N/A	N/A
6	6", CS. BF, RF, 150# WITH PLUG	N/A	N/A
7	TC PORT, 3/4", CS. HALF COUPLING THREADED	12"	315
8	TC PORT, 3/4", CS. HALF COUPLING THREADED	24"	315
9	PRESSURE PORT, 1/2", CS. HALF COUPLING THREADED	18"	315
10	CYCLONE EXIT PORT, 10", CS. SCH 40, PIPE, 8" LONG	N/A	N/A
11	10", CS. SOF. RF, 150#	N/A	N/A
12	3", CS. SCH 40, PIPE	N/A	N/A
13	3", CS. SOF, 150#	N/A	N/A
14	3", CS. BF, 150# WITH PLUG	N/A	N/A

**FIGURE 3: TOP SECTION OF
PRESSURIZED STEAM REFORMER**

FIGURE 4: TWO TUBE PULSE COMBUSTOR HEATER BUNDLE (Side View)

**FIGURE 5:
REACTOR BOTTOM SECTION
WITH PULSE COMBUSTOR
HEATERS INSERTED**

PLANS FOR NEXT REPORTING PERIOD

- Finish fabrication of the reactor,
- Complete the tube heater design and fabrication, and
- Design the internal and external cyclone.

**DATE
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10 / 3 / 94

END