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**APPLIED RESEARCH AND DEVELOPMENT
PRIVATE SECTOR ACCOMPLISHMENTS**

**Final Summary Report
Contract No. DE-AC08-86NV10510**

by

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CONTENTS

FOREWORD	v
ACKNOWLEDGMENTS	vi
SUMMARY	1
1 BACKGROUND AND OBJECTIVES	4
2 PROCUREMENT HISTORY	5
3 PROCUREMENT RESULTS	6
4 RESEARCH SUMMARIES	9
Minimally Invasive Three-Dimensional Site Characterization System	12
A Process For Contaminant Removal and Waste Volume Reduction to Remediate Groundwater Containing Certain Radionuclides, Toxic Metals, and Organics	15
Design, Manufacture, and Evaluation of a Hydraulically Installed, Multisampling Lysimeter	18
Development of a Combined Soil-Wash/In-Furnace Vitrification System for Soil Remediation at DOE Sites	21
Fiber Optic Raman Spectrograph for In-Situ Environmental Monitoring	24
Electrokinetic Treatment of Contaminated Soils, Sludges, and Lagoons	27
Biodegradation of Chlorinated Hydrocarbons in a Vapor-Phase Reactor	30
Composting of Soils/Sediments and Sludges Containing Toxic Organics, Including High-Energy Explosives	32
Combined Air Stripper/Membrane Vapor Separation Systems	36
Predicted Performance of Systems for Bulk Soil Assay, Barrel Inspection, and Decommissioning	39
The High Resolution Shear Wave Seismic Reflection Technique	42
High Resolution Shear Wave Reflection Surveying for Hydrogeological Investigations	45
Remediation of Groundwater Containing Radionuclides and Heavy Metal Using Ion Exchange and the AlgaSORB® Biosorbent System	48

CONTENTS (Cont.)

Development of the SEAMIST™ Concept for Site Characterization and Monitoring	51
Chromate Reduction and Heavy Metal Fixation in Soil	54
Assessment of Subsurface VOCs Using a Chemical Microsensor Array	57
5 Implementation of R&D Results	60

FOREWORD

This report summarizes the results of the fiscal year 1990 procurement of contracts with the private sector for the U.S. Department of Energy's Office of Technology Development.

The contracts were awarded for the development of technologies up to, but not including, pilot plant/field demonstration. Demonstration, testing, and evaluation activities were addressed in a separate effort.

ACKNOWLEDGMENTS

The successes in this program are in large part due to the quality of the work performed by the research and development subcontractors as summarized in this report. The contractor staff, and in particular the principal investigators, deserve credit for scientific insight, perseverance, and hard work, and for their cooperation with program management.

The Argonne staff worked closely with the principal investigators as they completed their research and also assisted in the transition to the demonstration phase. We are grateful to the U.S. Department of Energy (DOE) field office staff and management and operations contractor staff at the various sites who provided technical assistance, samples, site access, and information. The authors especially appreciate the efforts of Eileen Basco, and Virginia Strezo of the Waste Management Programs Office, who provided tireless technical and administrative management support. Maria Contos, Jane Andrew, and the Argonne Document Processing Center provided effective and timely editorial support.

Many people in DOE/EM-50 deserve special credit for their guidance and support in making this program a success. We especially thank the following people: Steve Lien, Bill Schutte, Mel Shupe, and Katie Hain. Special thanks to Susan Weber, whose indefatigable support provided the impetus for publicizing the results of these research and development efforts. Finally, we thank Clyde Frank, without whose vision and determination this program would not have been possible.

**APPLIED RESEARCH AND DEVELOPMENT
PRIVATE SECTOR ACCOMPLISHMENTS:
FINAL SUMMARY REPORT**

by

N. J. Beskid, M. D. Erickson, J. S. Devgun, and M. M. Zielke

SUMMARY

Because of the nature of most U.S. Department of Energy (DOE) operations, contamination at DOE sites presents complex problems. DOE sites may have radioactive, hazardous, or mixed contamination. The major contaminants include radionuclides, volatile organic compounds (VOCs), and heavy metals. The contamination exists in soils, groundwater, and buildings and materials. DOE's special problems in site remediation have created a need for better and less costly technologies. Thus, DOE has implemented several initiatives for developing new technologies. This report describes the results of the first set of procurement contracts in this area. Similar research and development (R&D) activities are currently managed for DOE by the Morgantown Energy Technology Center.

TECHNOLOGY AREAS

The research conducted under the 15 contracts described in this report can be grouped under three major technology areas:

1. Site characterization and monitoring,
2. Remediation, and
3. Contaminant containment.

In all of these areas, significant success in technology development has been achieved. The following paragraphs briefly describe the R&D efforts in each technology area.

Site Characterization and Monitoring

Applied Research Associates, Inc., developed and tested an electric cone penetrometer (ECP), which provides a less invasive means of obtaining subsurface site characterization data. The ECP can carry a variety of instruments that can be monitored in real time to improve the interpretation of surface geophysical surveys.

Bladon International, Inc., developed a suction lysimeter that can be inserted into the area of interest in the vadose zone without requiring a predrilled hole and without

incurring exorbitant costs. Because it is hydraulically inserted, use of this lysimeter involves less risk of contamination.

EIC Laboratories, Inc., developed a field-sized Raman spectrograph that can be used with a fiber optic probe. It is 10 times more powerful than conventional Raman instruments but only one-tenth their size. Its design achieves high light-collection efficiency without sacrificing resolution.

Nuclear Diagnostics Systems, Inc., developed a neutron interrogation system to detect pollutant elements, uranium and transuranics, and gamma-ray emitters. The technology is expected to be useful for bulk soil assays, barrel inspections, and decommissioning projects.

Paul C. Rizzo Associates developed a high-resolution shear-wave surveying technology that proved effective for mapping subsurface lithology and for conducting groundwater investigations.

Science and Engineering Associates, Inc., developed a system called SEAMIST™, the Science and Engineering Associates Membrane Instrumentation and Sampling Technique. SEAMIST™ is a technique for emplacing borehole liners and instruments. It has applications in contaminant monitoring and site characterization. The SEAMIST™ system was explicitly developed to sample gas and pore fluid in the vadose zone for monitoring circumstances of particular interest to DOE.

The University of Michigan conducted laboratory investigations of the performance of arrays of microfabricated surface-acoustic-wave (SAW) chemical sensors. Such micro-sensor arrays could have potential applications in the measurement of VOCs in contaminated soil and groundwater.

Remediation

Atomic Energy of Canada Limited developed a modular process for treating contaminated groundwater. The water passes through a three-step chemical conditioning sequence that includes microfiltration after each step in the sequence.

GTS Duratek developed a combined vitrification, soil washing, and water treatment system for mixed and low-level radioactive waste streams. The combined system produced clean soil (about 90 percent of the waste stream), nonradioactive mercury, and a glass waste form.

Envirogen, Inc., demonstrated (at bench scale) a vapor-phase biological reactor for destroying the VOCs that are emitted as groundwater contaminants are volatilized.

Electro-Petroleum, Inc., developed equipment to evaluate the effectiveness of electrokinetic processes (electroosmosis, electromigration, and electrophoresis) in removing contaminants from soil without excavation. Electrokinetic migration of metals was observed

for all metals and all soils tested. Electroosmotic flow was observed in all soil types tested. Physical and chemical enhancement processes contributed to the effectiveness of the electrokinetic removal of contaminants.

The IIT Research Institute evaluated the effectiveness of composting as an alternative to incinerating soil that is contaminated with toxic organics (e.g., high explosives). In experiments with soil contaminated with explosives (from DOE's Pantex Plant near Amarillo, Texas), composting removed over 60 percent of each contaminant. Plants grown in soil containing the compost residue showed no signs of phytotoxic effects.

Membrane Technology and Research, Inc., built and operated an air-stripping system with a built-in membrane vapor separation system that removes volatile organic compounds (VOCs) from the stripper air-vent stream without generating secondary waste (i.e., spent activated carbon). The new method reduced the VOC content of the feed stream by as much as 96 percent.

Science Applications International Corp. and Bio-Recovery Systems, Inc., developed a proprietary, nonliving, immobilized algal biomass, termed AlgaSORB®, which has high affinity for heavy metal ions. Treatability studies have been conducted to select the best adsorbent and operating protocols and to investigate options for using AlgaSORB®/ion exchange technology to reduce heavy metals in contaminated groundwaters collected at three DOE sites.

Contaminant Containment

Sizemore Technical Services, Inc., developed an in-situ process in which a ferrous salt is used to reduce chromates in soil; the reduction products coprecipitate other heavy metals, and all the metals are fixed by a destabilized aqueous sodium silica solution.

TECHNOLOGY STATUS

The success of this R&D activity is clear from the fact that some of the technologies developed have begun to be implemented, as listed in Table 3. Key successes include the following programs. The SEAMIST™ technique and instrumentation are now in field use at DOE's Hanford Site and Waste Isolation Pilot Plant. The electric cone penetrometer is in use at the Hanford Site and other DOE programs. The process developed by Duratek, which combines vitrification, soil washing, and waste treatment, has led to the Minimum Additive Waste Stabilization (MAWS) program, which is being demonstrated at DOE's Fernald site.

1 BACKGROUND AND OBJECTIVES

The U.S. Department of Energy (DOE), through its Office of Environmental Restoration and Waste Management, has committed itself to efforts to reduce the cost and risk associated with the technologies used to meet DOE cleanup goals. These efforts are the responsibility of the Office of Technology Development (OTD) within the Office of Environmental Restoration and Waste Management. OTD conducts an aggressive, national program of applied research, development, demonstration, testing, and evaluation (applied RDDT&E), whose goal is to resolve major technical issues and rapidly advance beyond currently used technologies for environmental restoration and waste management operations.

Currently available technology is inadequate for assessing environmental contamination, taking permanent remedial action, and eliminating or minimizing the environmental impact of future operations. However, the technical resources for addressing these shortcomings do exist within the DOE system and the private sector. In April 1990, a request for proposals (RFP) was announced to enlist private-sector contractors for the research and development (R&D) needed to help DOE meet its cleanup goals. This action was the first step in focusing the capabilities of the private sector on the critical needs of this national-priority program. In addition, it also created an awareness of DOE needs, provided detailed technical information to the private sector, and formed a basis for broader private sector involvement in future work.

This report presents project summaries that highlight the innovative methods and technologies that were developed and tested by 15 private sector contractors to address the environmental cleanup needs of DOE.

2 PROCUREMENT HISTORY

The Office of Environmental Restoration and Waste Management was formed by Energy Secretary James T. Watkins in early 1989. By late 1989, it was clear that the private sector had both the capabilities to aid DOE in attaining its cleanup goals and interest in participation. To improve communications between DOE and the private sector, DOE hosted a Symposium on Industry and University Contract Opportunities in Applied Research, Development, Demonstration, Testing, and Evaluation in San Francisco, December 12-13, 1989. At that meeting, DOE officials committed to increasing the involvement of the private sector in technology development activities. The applied R&D contracting activity began with an announcement in *Commerce Business Daily* on April 13, 1990, and a parallel mailing of the announcement to the San Francisco meeting participants. On May 1, the RFP package was mailed to 338 potential offerors. A preproposal conference, held May 8, 1990 at O'Hare International Airport near Chicago, was attended by 160 potential offerors. All questions and answers from this conference were sent to potential offerors as an amendment to the RFP.

The RFP contained detailed instructions for submission of proposals in one of four general areas:

1. Groundwater remediation
2. Soil remediation
3. Sensing and characterization of buried objects, contamination, and/or geological/hydrological features
4. Containment of contaminated sites.

The RFP package also gave evaluation criteria and weightings of these criteria. On June 21, 1990, 147 proposals were received from 108 organizations.

These 147 proposals were evaluated by 42 technical reviewers drawn from the national laboratories, government agencies, and academia. Reviewers were screened for potential conflict of interest and signed both conflict of interest and confidentiality forms. The reviewers worked in Technical Evaluation Teams of three or four, with each team evaluating a group of 9-17 technically related proposals (Lreckenridge, Colorado, July 8-13). The results of these evaluations were presented to OTD and the Source Evaluation Board (SEB) at Argonne National Laboratory on July 18 and July 19-20, 1990, respectively. The SEB approved the recommendations of the technical evaluators and authorized Argonne to begin contract negotiations with 15 offerors for a total of \$6 million in R&D funding. Negotiations and contracts preparations were completed over the next two months, and all contracts were in place by the end of September 1990 with these 15 offerors.

3 PROCUREMENT RESULTS

Fifteen fixed-price contracts were placed with 13 private firms and one university in the United States and one government laboratory in Canada. These contracts are listed in Table 1.

The diversity of the technical areas addressed by the contracts illustrates the breadth of the capabilities of the private sector and DOE's needs for better technology.

Argonne National Laboratory provided both technical and administrative oversight to assist the contractors in meeting their milestones and in many cases effecting actual application of developing technology at specific DOE sites.

The projects summarized here were fully funded on fixed-price contracts. Further DOE funding was provided only to support those projects that successfully accomplished the transition to demonstration through OTD's site-specific Integrated Demonstration Program.

TABLE 1 Private Sector Contractors: FY 1990 Procurement

Applied Research Associates, Inc.; Albuquerque, NM

Minimally Invasive Three-Dimensional Site Characterization System

Principal Investigator: John F. Gibbons

Performance Period: 10-1-90 to 3-31-92

Atomic Energy of Canada Limited; Chalk River, ON, Canada

A Process for Contaminant Removal and Waste Volume Reduction to Remediate Groundwater Containing Certain Radionuclides, Toxic Metals, and Organics

Principal Investigator: Leo P. Buckley

Performance Period: 10-1-90 to 3-31-92

Bladon International, Inc.; Des Plaines, IL (now Oak Brook, IL)

Design, Manufacture, and Evaluation of a Hydraulically Installed, Multi-Sampling Lysimeter

Subcontractors: Institute of Gas Technology

Timco Manufacturing, Inc.

Principal Investigator: Joseph A. Scroppo

Performance Period: 10-1-90 to 3-31-92

EIC Laboratories, Inc.; Norwood, MA

Fiber Optic Raman Spectrograph for In-Situ Environmental Monitoring

Principal Investigator: Michael M. Carrabba

Performance Period: 10-1-90 to 7-31-92

Electro-Petroleum, Inc. (EPI); Wayne, PA

Electrokinetic Treatment of Contaminated Soils, Sludges, and Lagoons

Subcontractor: Lehigh University

Principal Investigators: J. Kenneth Wittle (EPI)

Sibel Pamukcu (LU)

Performance Period: 10-1-90 to 6-30-92

Envirogen, Inc.; Lawrenceville, NJ

Biodegradation of Chlorinated Hydrocarbons in a Vapor-Phase Reactor

Principal Investigator: Burt D. Ensley

Performance Period: 10-1-90 to 2-29-92

GTS Duratek Corp.; Columbia, MD

Development of a Combined Soil Wash/In-Furnace Vitrification System for Soil Remediation at DOE Sites

Subcontractors: Vitreous State Laboratory of Catholic University of America

Westinghouse Electric Corporation

Principal Investigator: Ian L. Pegg

Performance Period: 10-1-90 to 9-30-92

TABLE 1 (Cont.)

IIT Research Institute; Newington, VA

Composting of Soils/Sediments and Sludges Containing Toxic Organics, Including High-Energy Explosives

Principal Investigators: Richard C. Doyle
Judith Kitchens

Performance Period: 10-1-90 to 3-31-92

Membrane Technology and Research, Inc.; Menlo Park, CA

Combined Air Stripper/Membrane Vapor Separation Systems

Principal Investigator: Hans Wijmans

Performance Period: 10-1-90 to 5-29-92

Nuclear Diagnostic Systems, Inc.; Springfield, VA

Bulk Soil Assay System

Principal Investigators: Alfred Aitken
Charles Peters

Performance Period: 10-1-90 to 9-30-91

Paul C. Rizzo Associates, Inc.; Monroeville, PA

High Resolution Shear Wave Surveying for Hydrogeologic Investigations

Subcontractor: Bay Geophysical Associates, Inc.

Principal Investigator: William J. Johnson

Performance Period: 10-1-90 to 7-31-92

Science Application International Corp. (SAIC); Oak Ridge, TN

Remediation of Groundwater Containing Radionuclides, Heavy Metals, Inorganic Ions and/or Organics Using the AlgaSORB® Biosorbent System

Subcontractor: Bio-Recovery Systems, Inc.

Principal Investigators: Howard Feiler (SAIC)

Dennis W. Darnall (BRS) (deceased)

Performance Period: 10-1-90 to 3-31-92

Science and Engineering Associates, Inc.; Albuquerque, NM

Development of the SEAMIST Concept for Site Characterization and Monitoring

Principal Investigator: Carl Keller

Performance Period: 10-1-90 to 9-30-92

Sizemore Technical Services, Inc.; Round Rock, TX (now EET, Inc.; Austin, TX)

Chromate Reduction and Heavy Metal Fixation in Soil

Principal Investigator: Klaus Schwitzgebel

Performance Period: 9-20-90 to 2-20-92

University of Michigan; Ann Arbor, MI

Assessment of Subsurface VOCs Using a Chemical Microsensor Array

Principal Investigator: Stuart A. Batterman

Performance Period: 10-1-90 to 9-30-92

4 RESEARCH SUMMARIES

This section presents a summary of each research project and its accomplishments. A final technical report on each project gives full details of the technologies and methods used. Table 2 lists these reports, which are available from Nick Beskid, Chemical Technology Division, Building 205, Argonne National Laboratory, 9700 S. Cass Ave., Argonne, IL 60439; telephone (708) 252-6676 (until the supply is exhausted). The reports are also available to DOE and DOE contractors from the Office of Scientific and Technical Information and to the public from the National Technical Information Service (see the inside front cover of this report for addresses).

TABLE 2 List of Private Sector Contractor Reports Grouped by Technical Area

Contractor	Report No.	Report Title	Page
<i>Site Characterization and Monitoring</i>			
Applied Research Associates, Inc.	DOE/CH-9202	Minimally Invasive Three-Dimensional Site Characterization System	12
Bladon International, Inc.	DOE/CH-9203	Design, Manufacture, and Evaluation of a Hydraulically Installed, Multi-Sampling Lysimeter	18
EIC Laboratories, Inc.	DOE/CH-9205	Fiber Optic Raman Spectrograph for In-Situ Environmental Monitoring	24
Nuclear Diagnostic Systems, Inc.	DOE/CH-9210	Predicted Performance of Systems for Bulk Soil Assay, Barrel Inspection, and Decommissioning	39
Paul C. Rizzo Associates, Inc.	DOE/CH-9218	The High Resolution Shear Wave Seismic Reflection Technique	42
Paul C. Rizzo Associates, Inc.	DOE/CH-9211	High Resolution Shear Wave Reflection Surveying for Hydrogeological Investigations	45
Science and Engineering Associates	DOE/CH-9213	Development of the SEAMIST™ Concept for Site Characterization and Monitoring	51
University of Michigan	DOE/CH-9215	Assessment of Subsurface VOCs Using a Chemical Microsensor Array	57
<i>Site Remediation</i>			
Atomic Energy of Canada Limited	DOE/CH-9201	A Process for Contaminant Removal and Waste Volume Reduction to Remediate Groundwater Containing Radionuclides, Toxic Metals, and Organics	15

TABLE 2 (Cont.)

Contractor	Report No.	Report Title	Page
GTS Duratek	DOE/CH-9204	Development of a Combined Soil-Wash/In-Furnace Vitrification System for Soil Remediation at DOE Sites	21
Electro-Petroleum, Inc.	DOE/CH-9206	Electrokinetic Treatment of Contaminated Soils, Sludges, and Lagoons	27
Envirogen, Inc.	DOE/CH-9207	Biodegradation of Chlorinated Hydrocarbons in a Vapor-Phase Reactor	30
IIT Research Institute	DOE/CH-9208	Composting of Soils/Sediments and Sludges Containing Toxic Organics, Including High-Energy Explosives	32
Membrane Technology and Research, Inc.	DOE/CH-9209	Combined Air Stripper/Membrane Vapor Separation Systems	36
Science Applications International Corp.	DOE/CH-9212	Remediation of Groundwater Containing Radionuclides and Heavy Metal Using Ion Exchange and the AlgaSORB® Biosorbent System	48
<i>Contaminant Containment</i>			
Sizemore Technical Services, Inc. (now EET, Inc.)	DOE/CH-9214	Chromate Reduction and Heavy Metal Fixation in Soil	54

Project	Minimally Invasive Three-Dimensional Site Characterization System
Report No.	DOE/CH-9202
Organization	Applied Research Associates, Inc.

Description

The objective of this project was to develop a synergistic approach to site characterization that avoids the performance deficiencies of the standard drilling and sampling method. The Minimally Invasive Three-Dimensional Site Characterization System uses a relational database management system to efficiently combine the results of fully coordinated surface and subsurface exploration activities. The subsurface exploration is performed by using the electric cone penetrometer test (ECPT). For this phase of characterization, the ECPT is less invasive, faster, and cheaper than drilling. In addition to the standard subsurface characterization data, the ECPT also obtains downhole geophysical data that is used in the analysis of the surface geophysical surveys.

The methods chosen for the surface geophysical surveys were seismic profiling and electrical resistivity, although other methods may be appropriate in other applications. To link the surface and subsurface data, a relational database was developed that allows the synthesis of the large volume of data generated during a site characterization program. This method allows data to be interpreted more fully and provides faster, safer, cheaper, and more accurate site characterization. Thus, the characterization process will result in optimum placement of monitoring wells, which will provide a more reliable picture of subsurface conditions and the volume of material requiring remediation. Adoption of the Minimally Invasive Three-Dimensional Site Characterization System also would reduce the potential for site personnel to be exposed to hazardous materials. It would also minimize the hazardous material disposal problems associated with the exploration process.

Technical Performance Data

Contact

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This technology was tested at three sites: the Bethel-Royalton landfill in Vermont, the Los Lunas Volcano in New Mexico, and the Homestake Partners uranium mill site, also in New Mexico. The objective of the field evaluations was to determine the applicability of particular portions of the system to relevant site situations and to evaluate the compatibility of the components.

The ECPT survey conducted near the Bethel-Royalton landfill included tip resistance, sleeve resistance, pore pressure, and electrical

resistivity. These tests were used to evaluate the synergism between ECPT resistivity and surface resistivity measurements. Wenner array soundings were conducted at four locations along a survey line at the landfill. One ECPT was performed at each sounding point. The inversion program for analyzing the data produced a number of possible solutions to the layer depths and resistivities of the two layers.

Results of resistivity measurements in both the ECPT and the surface survey indicated that the water in the measurement locations was contaminated. While this contamination was detected by both techniques, the ECPT data fixed the depth to the contaminated zone and significantly reduced the uncertainty in the interpretation of the surface data. The extent of the contamination plume could now be quickly and inexpensively mapped with a surface resistivity survey and a few ECPT resistivity measurements.

Testing at the Los Lunas Volcano demonstrated the use of seismic reflection surveying to identify subsurface features that could be hydrologically important. It also demonstrated the synergism between the reflection survey and the ECPT seismic measurements. The reflection survey clearly identified a buried channel whose location could be verified visually in a nearby deep cut in the mesa. The depth of the channel was interpreted with the help of the seismic wave speed determined from the ECPT data.

The work at the Homestake Partners Mill demonstrated the potential of this system to characterize a hydrogeologically complex site. An ECPT survey was conducted that used the same parameters as were used at Bethel-Royalton. An electrical resistivity grid and seismic reflection survey were also conducted. The seismic reflection survey identified a buried channel in the aquiclude that was consistent with the mill owner's perception of the direction of groundwater flow. The ECPT identified water-bearing zones of low resistivity, which are likely indicative of high contamination. Inversion of the surface resistivity data was in agreement with the ECPT resistivity data.

Waste Applicability

This procedure is applicable to all subsurface waste types.

Status

On the basis of the results of this project, Applied Research Associates has applied this technology to the integrated demonstration sites at the Savannah River Site (VOC-nonarid sites) and the Hanford Site (VOC-arid sites) and conducted several full demonstrations of the system.

Potential Commercial Applications

This methodology could be used at any site having subsurface soil contamination.

Baseline Technology

Characterization of subsurface stratigraphy and the nature of existing contamination is a fundamental step in every environmental site cleanup program. The current standard procedure for site characterization involves surface geophysics, drilling, sampling, laboratory testing, and placement of monitoring wells. This process suffers, however, from a number of drawbacks: it is slow and expensive, it produces contaminated waste which must be disposed of, and its lack of interactive data analysis often results in an inaccurate interpretation of subsurface conditions.

Intellectual Property Rights

This approach does not require any patented equipment or proprietary data. Licensing is required for some of the software.

<i>Project</i>	A Process for Contaminant Removal and Waste Volume Reduction to Remediate Groundwater Containing Certain Radionuclides, Toxic Metals, and Organics
<i>Report No.</i>	DOE/CH-9201
<i>Organization</i>	Atomic Energy of Canada Limited

Description

The aim of this project was to develop and demonstrate an improved ex-situ treatment process for removing groundwater contaminants. The process will generate high-quality effluent while minimizing secondary waste volume.

A combination of process steps — sequential chemical conditioning, cross-flow microfiltration, and dewatering by evaporation or filter pressing — proved effective for treating mixed waste that had diverse physicochemical properties.

The program employed feeds containing cadmium, uranium, lead, iron, calcium, strontium-85, strontium-90, cesium-137, benzene, and trichloroethylene in simulated and actual groundwater and soil leachate solutions. Two target levels were considered for the quality of effluent generated by the process. Contaminant levels were to be (1) within one order of magnitude of the U.S. Drinking Water Limit or (2) less than the drinking water limit.

Overall test results reveal that the optimal process is a three-step chemical treatment/microfiltration sequence combined with a final dewatering step. The process includes three key chemical treatments: (1) lime is added to adjust the pH and remove heavy metals and iron by precipitation; (2) a natural zeolite ion-exchange/adsorbent powder is sequentially added to remove radionuclides, residual heavy metals, and some organic contaminants; and (3) powdered activated carbon (with or without zeolite powder) is sequentially added as a polishing step to remove organics and residual radionuclides. After each treatment the feed stream passes through a microfiltration system.

Contacts

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Technical Performance Data

The chemical conditioning and microfiltration process for site remediation has significant technical advantages and economic benefits.

- It allows contaminants to come into direct contact with metal precipitates and powdered adsorbent and ion-exchange materials; it uses natural impurities like iron and calcium effectively.
-

-
- The combined processes of precipitation, coprecipitation, adsorption, ion exchange, and cross-flow microfiltration effectively remove contaminants into a concentrated suspension while generating quality effluent appropriate for discharge.
 - The very large surface area provided by the powdered ion-exchange/adsorbent materials results in high contaminant removal efficiencies and fast kinetics.
 - The process uses low-cost waste by-products from the production of ion-exchange/adsorbent materials.
 - Because cross-flow microfiltration and an air backwash system are used, the process is suitable for continuous operation.
 - The process can be readily turned on and off without a long transient time.
 - The system's modular construction makes it portable and allows a wide range of flow rates.
 - The process can easily handle suspensions that are difficult to dewater.

Waste Applicability

Frequently, treating contaminated groundwater requires several types of processing to reduce the concentrations of heavy metals (including many radionuclides) to acceptable levels. The process discussed here is sufficiently generic to permit treatment of waste solutions containing a variety of radioactive and hazardous species. Depending on the nature of the site application, the technology can be used alone or in conjunction with other technologies. For example, the proposed technology is not sufficient for applications involving soil decontamination; a soil washing technology would be needed at the front end to provide an adequate soil leachate feed to this process. Similarly, if the waste solution to be treated contains high concentrations (several hundred parts per million) of volatile organics, the waste influent must be pretreated by using established technologies such as air-stripping or in-situ decontamination using a horizontal-well technology.

Although such pretreatment technologies would remove the bulk of the organics, some contaminants would remain, perhaps in the range of tens of parts per million or lower. The residual organics would enter this three-part, ex-situ process for further treatment, where the organics would be removed, along with radionuclides and other heavy metals.

Status

A simplified, single-stage version of the process was successfully implemented to treat groundwater and surface water contaminated with strontium-90 at the Chalk River Laboratories (CRL) site in Chalk River, Ontario, Canada.

This technology will undergo additional trials at CRL that will include more detailed and complete analyses of its capacities to remediate radioactive and chemically hazardous waste solutions and groundwaters. The successful application at CRL, which was carried out with modular equipment, clearly demonstrated that this technology can be used to purify both groundwater and soil washing solutions in a cost-effective and efficient manner. The probability of continued success is high, even for new applications, because inexpensive bench-scale tests can be conducted in advance to establish the chemistry control.

Potential Commercial Applications

The technology can be applied in four major areas:

1. Selective removal of a wide range of dissolved toxic metals and radionuclides and trace organics from groundwater;
2. Treatment of aqueous solvent solutions that were contacted with waste oils to extract radioactive and toxic species;
3. Removal of radionuclides, heavy metals, and organics from a leachate solution (in conjunction with soil leaching); and
4. Selective removal of dissolved radioactive species (e.g., uranium), heavy metals (e.g., lead), and trace levels of organics (e.g., trichloroethylene), from treatment ponds or other waste water sources.

Baseline Technology

The use of cross-flow microfiltration and air backwash make the process more compact than conventional systems. In addition, the system's modular construction makes it more portable and easier to modify for higher throughput requirements.

Intellectual Property Rights

A patent application has been submitted for the basic process technology. The patent owner is the U.S. Department of Energy. Atomic Energy of Canada Limited holds an irrevocable, worldwide license for the process technology with the right to sublicense.

<i>Project</i>	Design, Manufacture, and Evaluation of a Hydraulically Installed, Multisampling Lysimeter
<i>Report No.</i>	DOE/CH-9203
<i>Organization</i>	Bladon International, Inc.

Description

Chemical spills, underground storage tank leaks, and improper burial of contaminants can cause extensive groundwater contamination. Determining the extent of underground pollution and the potential for groundwater contamination requires monitoring in the vadose zone, the section between ground level and the groundwater table. Where there is no major water flow in the vadose zone, conventional monitoring wells will not function as designed.

The primary objective of this experimental program was to develop a modular suction lysimeter (with multisampling ports) that can be inserted into the area of interest in the vadose zone without using a predrilled hole and without incurring exorbitant costs. The resulting multisampling lysimeter is installed in much the same way as a cone penetrometer. Liquid in the vadose zone is drawn into the lysimeter through a porous section by applying a vacuum to extraction tubes. The samples are transported to collection vessels at the surface through the extraction tubes.

Technical Performance Data

The lysimeter, procured from Timco Manufacturing, Inc., is comprised of a stainless steel ram point and body, one or more ceramic porous sections, and one or more extraction tubes. The stainless steel ram point is used for hydraulic or mechanical installation, which eliminates the need to drill a borehole, thereby reducing the expense and the risk of cross-contamination.

An important characteristic of any lysimeter is the strength, integrity, and uniformity of pore size of the porous section. Bubble pressure tests were used to identify uniformity of pore size, air entry pressure, cracks, and leaks. The porous sections tested in the prototype lysimeters were aluminum oxide, from Timco and from Ferro Corp., and nickel, from the Institute of Gas Technology Fuel Cell Group. Both the Timco and Ferro porous sections performed well, but the Timco product tended to be brittle and susceptible to cracking. The Ferro material was able to withstand severe impact without cracking. The porous nickel outperformed the ceramic materials in pore plugging tests and demonstrated the ability to retrieve soil pore liquids from unsaturated soils.

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The effect of hydraulically inserting the lysimeter was investigated by comparing the operation of a specifically designed and constructed lysimeter that had been manually driven into the soil with the operation of an identical lysimeter that had been installed by using the standard procedure of predrilling a hole. Next, a prototype of a new lysimeter, which could be hydraulically installed at the desired depth without drilling, was constructed and evaluated. On the basis of test results, another modified lysimeter was designed, constructed, and evaluated. The lysimeter developed in this project, known as the Bladon instrument, represents a practical means of developing a three-dimensional profile of soil contamination at a reasonable cost.

The hydraulically installed suction lysimeter was evaluated by visual inspection and by tests of bubble pressure, pore plugging, and soil moisture operating range. Visual inspections were conducted throughout the project to identify gross defects such as cracks, nonuniformity, and incorrect assembly.

Representative sampling tests were performed to determine whether the concentration of organic compounds extracted by the suction lysimeter was representative of the organic concentration in the original solution. The tests confirmed that the lysimeter data were representative of the original solution.

Waste Applicability

The equipment can provide screening-level and decision-quality samples for remediation, control, and verification of contaminants in soils, sediments, and groundwater. Contaminants that can be monitored include PCBs, heavy metals, organics, inorganics, radionuclides, and mixed waste. Both liquids and VOCs can be retrieved from the vadose zone. The lysimeter is an effective tool for conducting a three-dimensional profile of soil contaminant plumes and their movement. The device can be used to deliver microbes, nutrients, and a source of oxygen for in-situ bioremediation.

Conclusions

On the basis of the tests of pore plugging and soil moisture operating range, the modified lysimeter with the Timco porous ceramic section was selected for further testing. Future development work will focus on improving the pore size distribution and the strength of the porous ceramic sections. The use of porous nickel will eliminate the need for seals and will enhance the structural integrity of the lysimeter. Prototype porous nickel modules have been developed in the laboratory and now need to be verified in field applications.

Potential Commercial Applications

The modified lysimeter could easily be used with the electric cone penetrometer (ECPT) developed by Applied Research Associates, Inc. (ARA). The ECPT is one element of ARA's approach to integrating surface and subsurface site exploration. The multisampling lysimeter can be readily linked with physical and chemical sensors for on-site screening of contaminants.

Baseline Technology

Current subsurface characterization methods for dispersed contaminants primarily involve a time-consuming, expensive process of drilling wells, taking samples, sending these samples to laboratories, and waiting for results. Drilling is very expensive, and creates conduits through which contamination can spread, often producing invalid results.

Accurate determination of the spatial distribution, movement, and concentrations of contaminants is essential to the assessment of remediation needs and for the design of remediation measures. A special need exists for three-dimensional subsurface characterization technologies.

The hydraulically installed lysimeter is easier to install than standard cup lysimeters and is more rugged. Also, compared with standard methods of installation involving drilling, it is expected that using hydraulically installed, multisampling lysimeters would reduce the cost of subsurface characterization by 80 percent or more and reduce the work requirements for sampling and analysis by about 89 percent.

Intellectual Property Rights

No patent applications have been submitted.

<i>Project</i>	Development of a Combined Soil-Wash/In-Furnace Vitrification System for Soil Remediation at DOE Sites
<i>Report No.</i>	DOE/CH-9204
<i>Organization</i>	GTS Duratek

Description

Successful remediation technologies for contaminated soils and sludges must effectively stabilize hazardous and radioactive contaminants into solid, immobile waste that is highly resistant to aqueous corrosion or other degradation. The ideal stabilization technology concentrates and immobilizes all contaminants and renders them chemically nonreactive. This study demonstrated the potential value of a remediation approach in which multiple technologies (soil washing, thermal desorption, and vitrification) are integrated and multiple waste streams are blended. The project focused on the potential roles of vitrification and soil washing.

For the site at Weldon Spring, Missouri, raffinate sludges were used in a direct vitrification study to investigate their use as fluxing agents in glass formulations. Several sludge samples were extensively characterized to obtain the data on chemical composition and physical properties needed to apply the treatment technologies. Various blends of soil/sludge and chemical additives were used in a composition study based on crucible melts of 400 g each. The glasses produced were then characterized to obtain data on key process parameters and waste form performance parameters. Viscosity and conductivity were measured. Leach resistance was evaluated with two separate testing methods: the U.S. Environmental Protection Agency's toxicity characteristic leachate procedure (TCLP) for inorganics and the more aggressive Savannah River product consistency test (PCT).

The use of a slurry feed was also tested for several blends, which were treated in a small-scale Duramelter continuous joule-heated vitrification system.

Storm sewer sediments from the Y-12 site at Oak Ridge, Tennessee, were used to study a treatment combining soil washing and vitrification. The material was subjected to physical and chemical characterization to provide the data needed to design the soil washing study. The contaminated fraction from the soil washing process contained an unexpectedly large amount of highly volatile mercury, which posed problems for subsequent stabilization by vitrification. As an alternative approach, a sample of the contaminated fraction was treated by thermal desorption to remove the mercury before vitrification. Finally, vitrification tests similar to those performed at the Weldon Spring site were conducted.

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Technical Performance Data

Testing showed that both mercury and uranium could be removed from the Oak Ridge soil by chemical extraction, reducing the volume of that waste stream by 80 percent. For the contaminant-rich minority fraction, thermal desorption was used to separate the mercury from the uranium. Vitrification tests demonstrated that glasses having a high waste loading could be produced from both the radioactive stream at Oak Ridge and the wastes at Weldon Spring. Both the TCLP and the PCT showed that these glasses had very good leach resistance. The glasses also showed viscosities and electrical conductivities in the range suitable for joule-heated ceramic melter processing. A system that combined soil washing, thermal desorption, and vitrification produced clean soil (about 90 percent of the input waste stream), nonradioactive mercury, and a glass waste form. The estimated processing costs for such a system are in the range of \$260 to \$400 per cubic yard.

Waste Applicability

Vitrification technologies are best suited to inorganic waste streams, particularly those with low metal content. The approach is applicable to radioactive wastes, hazardous wastes, and mixed wastes. The following criteria for waste content are provided as a general guide:

- Metals: less than 10 wt% on a dry basis;
- Organics: less than 10 wt% on a dry basis; and
- Solids: greater than 10 wt%.

These limits can be greatly extended in a multitechnology integrated system, however. For example, wastes with a high mercury content can be handled by pretreating by thermal desorption, and high organic wastes can be treated by incineration followed by vitrification of the resulting ash. Limited amounts of metals and organics can be consumed directly in a vitrification process, but at intermediate to high levels, introducing an additional unit operation for pretreatment may be the most cost-effective approach.

Status

These innovations have been incorporated in the Minimum Additive Waste Stabilization (MAWS) System for laboratory development and on-site demonstration at Fernald. The objective of this program is to demonstrate that by blending multiple waste streams and applying multiple technologies, the need for additives in the stabilization process can be minimized. The program relies on the integration of soil washing, ion

exchange, and vitrification technologies, each of which substantially reduces waste volume. The result is an integrated process, centered on stabilization by vitrification, which minimizes both waste volume and the overall cost of treatment and disposal of multiple waste streams.

The MAWS project began at Fernald in June 1992, and as of mid-December 1993, all systems installed (Duramelter vitrification system, GTS Duratek ion exchange system, and Lockheed TRUclean soil washing system) have been tested extensively with nonradioactive surrogate feed materials with very encouraging results. It is expected that the radioactive soil washing demonstration will be underway before the end of 1993, as will vitrification testing with fluoride-containing surrogate feeds. Radioactive vitrification demonstrations should commence in early 1994, pending the results of the earlier tests.

Potential Commercial Applications

This basic technology has many potential commercial applications. Examples include treatment of contaminated soils and sludges at commercial sites; treatment of incinerator ashes from municipal, medical, and other wastes; destruction of asbestos from commercial asbestos removal activities; and treatment of a variety of low-level radioactive wastes from nuclear power plants.

Baseline Technology

Researchers working on the problem of high-level nuclear waste have concluded that vitrification provides one of the safest means of stabilizing hazardous materials over the long term. Like other multitechnology approaches to treating blended waste streams, vitrification results in a low-volume, stable "enhanced" waste form. Compared to the waste forms produced by alternative technologies, such as stabilization by cementation, the enhanced waste form produced by vitrification has much greater leach-resistance and a much smaller volume. Vitrification is often perceived as more expensive than the alternatives, but because it greatly reduces waste volume, it is actually less expensive overall.

Intellectual Property Rights

GTS Duratek holds intellectual property rights in a number of areas, including the Duramelter vitrification system, off-gas scrubber design, and a variety of ion-exchange media. The soil washing technology and thermal desorption technology used for the present study are owned by Westinghouse Electric Corporation.

<i>Project</i>	Fiber Optic Raman Spectrograph for In-Situ Environmental Monitoring
<i>Report No.</i>	DOE/CH-9205
<i>Organization</i>	EIC Laboratories, Inc.

Description

The objective of this project was to develop a powerful, field-size Raman spectrograph that can be used with a fiber optic sampling probe. The prototype spectrograph is 10 times more powerful than conventional Raman instruments, but one-tenth their size. The new spectrograph features an optical throughput more than 10 times greater than that of existing Raman spectrographs. The new spectrograph has a unique design that combines compactness and high light-collection efficiency without sacrificing resolution. This combination is impossible to achieve in traditional spectrographs having linear dispersion and reflective optics.

New in-situ screening methods — such as this fiber optic Raman spectrograph technique — are key to reducing the cost of site characterization and remediation.

Technical Performance Data

System development entailed the fabrication of a "breadboard" version of a spectrograph/monochromator that has high resolution and also covers the entire Raman spectral range. Because this prototype has fewer optical elements than conventional research units, its throughput is up to 10 times greater. It is capable of evaluating contaminants at both very high and very low (parts per billion) concentrations.

The key to the spectrograph's design is a high-efficiency diffraction grating, which gives it both high resolution and a large spectral range, all in a very compact package. Used in this configuration, the multiple diffracted orders overlap spatially. Therefore, a secondary dual dispersive element, in this case two prisms, is used in an orthogonal direction to separate the orders.

The system components include a commercially available 52.65 groove/mm echelle grating, which is operated at an incident angle of 63.4 degrees. The secondary dispersion element is a dual prism system that allows the Raman spectrum ($200\text{--}4,000\text{ cm}^{-1}$) to be obtained in about 14 orders. A commercial software package by Photometrics and Galactic Industries is employed for manipulating and storing spectral information and maintaining a spectral database, which can be used with spectral matching algorithms.

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Waste Applicability

The new spectrograph can be deployed to environmental restoration sites for immediate chemical characterization of a variety of samples (e.g., soil, groundwater, storage tank contents, waste spills). The increased efficiency of site characterization offered by this technology will greatly increase the rate at which hazardous regions can be isolated or selected for remediation.

Using this new technology, Raman probes can be introduced into underground storage tanks containing unknown contents. The concentrated wastes in such tanks tend to be heterogeneous and cannot be characterized without multiple samples. The fiber optic Raman techniques will allow highly specific chemical characterization and mapping within the containers. Further, high-sensitivity Raman probes can be introduced into wells for in-situ sampling and characterization of groundwater. The instrument developed during this effort should provide a useful, general means for environmental analysis.

Status

EIC Laboratories, Inc., and Oak Ridge National Laboratories established a Collaborative Research Agreement to exchange the technology and facilities necessary to develop and test this new fiber optic Raman spectroscopy. EIC expanded the program to fabricate fiber optic probes for testing at the Los Alamos mock-up waste storage tank. A later demonstration is planned for the Hanford Site.

EIC also established agreements with contractors involved in soil and groundwater mapping to provide further means for deploying the spectroscopic probes.

Potential Commercial Applications

The final product should be a commercial, field-portable fiber optic Raman system. Eventually, this approach could be employed with penetrometers for more complete and cost-effective site mapping than is possible with drilled and excavated wells.

Baseline Technology

Raman spectroscopy is a relatively insensitive analytical method unless it is "enhanced." With conventional tools, it is very difficult, for example, to measure spectra at concentrations below 100 ppm. This new technology of surface enhanced Raman spectroscopy is practical for low-level analysis and has been proven in the laboratory at the parts per billion level. At present, no such instrument exists outside the laboratory.

Intellectual Property Rights

EIC maintains commercial rights worldwide to its spectrograph, fiber optic probes, and "enhanced" Raman technologies. The company provides customized Raman instruments and services to industry and government for process control and environmental characterization.

<i>Project</i>	Electrokinetic Treatment of Contaminated Soils, Sludges, and Lagoons
<i>Report No.</i>	DOE/CH-9206
<i>Organization</i>	Electro-Petroleum, Inc.

Description

This laboratory project was performed to determine the feasibility of decontaminating soil without excavation by using electrokinetic processes — specifically electroosmosis, electromigration, and electrophoresis. The investigation took place in two phases. In the first, a number of electrokinetic tests lasting between 24 and 48 hours each were conducted on various clay and clay-sand soil types contaminated with metals (e.g., Cd, Hg, Pb, Ni, Zn), surrogate radionuclides (e.g., Co, Cs, Sr, U), and organic compounds prevalent at DOE sites. To prepare the soil slurries used in these tests, an aqueous solution of the contaminants was mixed with the soil, then the mixture was consolidated to a known density and placed in sample tubes. Samples were placed in an electrokinetic test apparatus and monitored for voltage, current, and inflow and outflow of liquid through the soil. After the tests, soil samples were analyzed for contaminants.

In the second phase, the electrokinetic process was enhanced by physical methods (e.g., application of heat and high-frequency, low-amplitude seismic waves) and chemical methods (e.g., pH control, injection of complexing agents).

Technical Performance Data

The electrokinetic apparatus designed specifically for this work featured the following components:

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- A sample tube accommodating three graphite electrodes through which voltage was measured during the experiment,
- Porous elements at either end of the tube to hold the soil in place without impeding the water flow,
- Graphite rod electrodes and electrode chambers,
- Gas expulsion ports to release gas created by electrode reactions,
- Glass burettes to measure inflow at the anode chamber and outflow at the cathode chamber, and
- Dedicated power supplies capable of providing either constant voltage (0-30 V) or constant current (0-1,500 mA).

The soil consolidation equipment fabricated for this project consisted of a metal frame supporting a pneumatic cylinder. Pressurized air entered at

the top of the cylinder and forced a piston and plate assembly to exert vertical pressure on a column of slurry. During this consolidation, fluid drained through the bottom of the sample and through the porous elements. To permit fluid drainage from the top as well, the piston plate also contained porous elements.

The laboratory results showed that electrokinetic processes could remove up to 99 percent of the metal from contaminated soil; also, contaminants were observed to move through soil with a permeability as low as 10^{-8} cm/s. The effectiveness of the electrokinetic processes was highly dependent on the interaction between the soil and the contaminants and on transient electrochemical effects.

For metals, removal efficiencies depended more on metal type and pH than on electroosmotic flow. When ionic concentrations were high, as for zinc, the direction of osmotic flow sometimes reversed, and significant removal of metal occurred at both electrodes. In addition, the basic conditions near the cathode caused most of the metals to precipitate in the soil near it; pH adjustment was effective in controlling this precipitation.

For organic contaminants, electroosmotic transport was most effective when the contaminants were undissociated and poorly adsorbed. Addition of a surfactant improved transport of chlorobenzene and hexachlorobenzene but had less effect on transport of trichloroethylene and phenol. The application of heat resulted in a promising improvement in the removal of trichloroethylene. However, low-amplitude, high-frequency shear waves had no appreciable effect on transport under the test conditions used in this study.

Waste Applicability

The electrokinetic processes investigated in this project could be applied to sites with plutonium and uranium in soils or with volatile organic compounds in arid soils. Other potential applications include containing contaminant transport and removing chromate from mixed-waste land fills. The other metals tested (Cd, Hg, Pb, Ni, Zn, Co, Cs, Sr) are typical of contaminants at both DOE and industrial sites.

Soil composition and buffering capacity may affect metal extraction by electrokinetics. In natural soils, it may be necessary to use secondary treatment or enhancement methods in conjunction with electrokinetics to extract metals into the aqueous phase. In mixed waste cases, metals may migrate preferentially, affected partly by the soil exchange and retention capacity. Therefore, site-specific engineering will be required for successful application of this technology.

Status

Laboratory studies have been performed to better understand electrokinetic phenomena as they relate to in-situ soil decontamination for contaminants of interest to DOE (metals, radionuclides, and organic compounds). Electro-Petroleum, Inc., is prepared to demonstrate the electrokinetic process in the field.

Potential Commercial Applications

The electrokinetic process is applicable to a broad range of actual site conditions. It could be used in parallel with a surfactant flush, pump, and treat scheme. Also, the electrokinetics process has been demonstrated in the field for other activities such as site dewatering, water collection, and oil recovery. It is one of the few processes for treating contaminated soils that does not require excavation and/or a large area for operating equipment. Electrokinetics can be integrated with other processes as a pretreatment step for contaminants in a relatively small volume of soil or pumpable water.

Baseline Technology

Standard equipment was not available, so two new pieces of equipment were developed for this project: an electrokinetic test apparatus and a slurry consolidation machine.

Intellectual Property Rights

Electro-Petroleum, Inc., holds several patents relating to the field application of the technology. The results of the laboratory program are documented in DOE report DOE/CH-9206.

<i>Project</i>	Biodegradation of Chlorinated Hydrocarbons in a Vapor-Phase Reactor
<i>Report No.</i>	DOE/CH-9207
<i>Organization</i>	Envirogen, Inc.

Description

The objective of this project was to evaluate (at bench scale) the feasibility of using degradative microorganisms in a vapor-phase reactor to destroy trichloroethylene (TCE) and other volatile organic compounds (VOCs) as they are stripped from contaminated soils or groundwater. Because many states do not permit conventional remediation methods such as air stripping and vapor extraction to be used without secondary treatment systems for gaseous emissions, VOCs removed from aquifers or soils must be captured or destroyed rather than being released directly into the air.

A design for a biological vapor-phase reactor was developed based on a modified gas-lift loop design. The reactor tank contains the biocatalyst as a cell suspension in a nutrient broth. The contaminated air is fed into the reactor as a stream of small bubbles from the bottom of the riser. The gases circulate through the reactor and come into contact with the biocatalysts, where degradation occurs. Treated gases exit through a port in the top of the reactor. This biological vapor-phase reactor is a cost-effective alternative for bringing air-stripping and vapor-extraction technologies into compliance with regulations on TCE and other VOC emissions.

Technical Performance Data

Two bench-scale gas-lift loop reactors were constructed, with volumes of 3.5 and 7.0 L. The reactors operated equally well with either of two biocatalysts: *Pseudomonas cepacia* and *Pseudomonas mendocina*. After proper operating conditions were established for the reactor/biocatalyst combination, both microorganisms could degrade 95 percent of inlet TCE at air flow rates of up to 3 percent of the total reactor volume per minute. TCE concentrations between 300 and 3,000 µg/L were degraded with 95 percent or better efficiency.

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The reactor can be operated continuously for at least 14 days and up to 33 days, averaging 92 percent destruction of TCE. TCE removal efficiencies can be increased to greater than 99 percent (clearly exceeding state regulatory requirements) by adding a small canister of granulated carbon to scrub the last traces of TCE from the air. The biocatalysts are relatively insensitive to system shocks, such as large "spikes" of TCE (in excess of 5-10 mg/L) in the inlet air. After exposure to several transient

high TCE concentration events over a period of nine days, reactor performance could be restored to removal efficiencies of 90 percent or greater.

Waste Applicability

This technology effectively removes VOCs and TCE from an air stream after they have been volatilized from contaminated groundwater and soils.

Status

A bench-scale vapor-phase reactor for TCE destruction was successfully demonstrated. It offers potential cost savings and reduced environmental risks compared to current alternative remediation methods. Envirogen has built a demonstration-scale vapor-phase bioreactor at its own expense. This pilot scale system has performed satisfactorily in a field demonstration.

Potential Commercial Applications

The vapor-phase biodegradation system can be used alone for treating VOCs emitted from point sources. It can also be attached to existing air stripping or vapor extraction systems, replacing more expensive and/or less efficient secondary vapor removal methods such as carbon adsorption or catalytic oxidation for treating off-gases. No ancillary technologies are necessary to utilize this system in these applications.

Baseline Technology

It had been demonstrated that TCE-degrading microorganisms were effective in remediating contaminated solids (soils) and liquids (groundwater), but the development of an effective vapor-phase system had not been reported. Compared to in-situ systems for activating indigenous methanotropic bacteria, this technology uses the cosubstrate (phenol or toluene) 15 to 150 times more effectively. An economic analysis showed that this biological treatment system would cost about 50 percent less to operate than conventional carbon adsorption technology.

Intellectual Property Rights

A patent is pending on this technology.

<i>Project</i>	Composting of Soils/Sediments and Sludges Containing Toxic Organics, Including High-Energy Explosives
<i>Report No.</i>	DOE/CH-9208
<i>Organization</i>	IIT Research Institute

Description

The objective of this project was to evaluate composting as a remediation technique for explosives found in the soils at the U.S. Department of Energy's Pantex Plant near Amarillo, Texas. Composting is a biological process that utilizes the unique ability of thermophilic microorganisms to degrade toxic organics (e.g., high-energy explosives) in soils, sediments, and sludges. To perform the remediation, soils containing the toxic organics are mixed with composting materials. The composting materials typically consist of a nutrient source, such as animal manure, food processing wastes, or fresh grass clippings, and a bulking agent, such as waste hay, cornstalks, or wood chips. The nutrient source must be a readily degradable organic with a favorable carbon/nitrogen ratio (approximately 30:1). The nutrient source supplies the energy and carbon needed to fuel the high microbial activity required to reach thermophilic conditions. The bulking agents provide air voids that permit aeration of the nutrient mass. The hazardous waste/compost material mixture is assembled into piles or windrows, where it is aerated and mixed to promote high microbial activity. Heat resulting from the microbial activity raises the temperature of the compost into the upper thermophilic range (60-70°C). Under the thermophilic conditions, hazardous organic materials are rapidly degraded.

Suspected contaminated sites within the Pantex Plant were sampled and analyzed for explosives, other organics, and inorganic wastes. Soils in drainage ditches and playas at the Pantex Plant were found to be contaminated with low levels of explosives, including RDX, HMX, PETN, and TATB.¹ Additional sites previously used for solvent disposal were heavily contaminated with solvents and transformation products of solvents, as well as with explosives and byproducts of explosives.

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Technical Performance Data

During the program, both laboratory and pilot-scale experiments were conducted. The laboratory experiments, conducted as shown in the first

¹ RDX: hexahydro-1,3,5-trinitro-1,3,5-triazine; HMX: octahydro-1,3,5,7-tetranitro-1,3,5,7-tetraazocine; PETN: pentaerythritoltetranitrate; TATB: triamino-trinitrobenzene.

figure, showed that composting rapidly degraded the explosives in the Pantex soils. The order of removal effectiveness was PETN > RDX ≥ HMX > TATB. RDX and HMX were mineralized in the composts, as was PETN, to a lesser extent. No persistent degradates from any of the explosives were formed during composting. Degradation of the solvents by composting was also evident. However, a significant portion of the volatile solvents were volatilized from the compost.

The pilot-scale experiments (see second figure) resulted in even more rapid degradation of RDX, HMX, and PETN. After 18 days, these explosives were nondetectable in the compost extracts. About 32-39 percent of the TATB was still present after 42 days, but it is anticipated that the rate of TATB degradation can be improved in larger composts. Also, seeding the larger composts with acclimated microorganisms could improve the TATB degradation rate. The compost volumes in the pilot-scale experiments were reduced by about 70 percent during six weeks of composting. When the compost residue was mixed with soil and used to grow rye and soybeans, healthy foliage was obtained, indicating that there were no phytotoxic effects from the compost residue.

Waste Applicability

Composting can be used to treat soils, sediments, and sludges that are contaminated with high-energy explosives (e.g., RDX, HMX, PETN, TATB). Soil loading rates up to 40 percent (weight basis) can be employed with rapid destruction of waste. Somewhat higher loading rates (50-60 percent) may be possible. The concentration of explosives in most of the Pantex soils is relatively low (≤2,000 ppm). Previous experience has shown that concentrations of explosives as much as two orders of magnitude higher can be successfully decontaminated by composting, although remediation time increased with increases in explosives concentrations.

Status

Laboratory and pilot-scale testing have demonstrated that composting is an effective method for remediating the explosives-contaminated soil at Pantex. The process could be optimized in a field demonstration or in the early stages of implementing full-scale cleanup.

Potential Commercial Applications

On the basis of data obtained from the pilot-scale studies, a demonstration plant was designed, and costs were estimated. Using four windrows, this demonstration plant would treat 55 cubic yards of explosives-contaminated soil. Capital costs would be about \$188,000, and operating costs would be about \$285,000. Permitting costs are estimated to be \$124,000.

Baseline Technology

Explosives-contaminated soils are often incinerated, but while incineration can process the soils rapidly, it pollutes the air and leaves behind an unfertile, amorphous soil residue that must be landfilled. Moreover, public opinion runs high against incineration. In contrast, composting takes longer, but the residue is a very fertile soil. Composting (\$226/ton) also costs less than incineration (\$272/ton).

Given the poor public opinion of incineration, it should be used only when absolutely necessary — when the explosives are entering the groundwater and faster remediation is needed. But if the explosives are in a stable environment, composting may be the preferred method.

Intellectual Property Rights

Proprietary information pertaining to this project cannot be disclosed outside the federal government without the express permission of IIT Research Institute.

Laboratory-Scale Composting Design

Schematic of Compost Setup

<i>Project</i>	Combined Air Stripper/Membrane Vapor Separation Systems
<i>Report No.</i>	DOE/CH-9209
<i>Organization</i>	Membrane Technology and Research, Inc.

Description

The objective of this project was to build and operate a system that combines air stripping and membrane vapor separation technologies. The combined system removes volatile organic compounds (VOCs) from the stripper air-vent stream without generating a waste stream. It is much smaller than a carbon adsorption system, and it does not have the problems associated with regeneration of spent activated carbon.

Technical Performance Data

The overall flow diagram of the combined air stripper/membrane vapor separation system is shown in the figure. In the air stripper, air and water are brought into constant contact by countercurrent flow, and the air leaving the top of the column is laden with VOCs in the vapor phase.

This air stream is fed into a three-stage membrane separation system. The VOCs are drawn through a membrane by a vacuum pump, and the resulting vapor stream is then cooled and condensed. The final volume of liquid is very small: a 100,000 gpd water stream at a VOC concentration of 1 ppmw produces only 0.84 pound of VOCs per day. The system constructed in this project treats 15-125 gpm of VOC-contaminated water. The stripper air flow rate varies from 46 to 70 scfm.

Waste Applicability

Because the costs of the system are determined by the flow rate of air to be treated (and thus by the flow rate of water through the system), rather than by the VOC content of the air, the technology is especially suited for treating streams with relatively concentrated VOCs.

The performance of the system was evaluated with four VOCs that are common groundwater contaminants: trichloroethylene, carbon tetrachloride, 1,2-dichloroethane, and chloroform. VOC removal efficiencies ranged from 12 to 96 percent. The system removed dichloroethane least efficiently (12-29 percent) and carbon tetrachloride most efficiently (60-96 percent). Most removal efficiencies were in the range of 80-90 percent. In 30 out of 37 experiments, VOC removal of 90 percent or more was achieved. A removal efficiency of 99 percent could be achieved with a taller air stripping tower (the current tower is 3 m high; a tower of 6-10 m is required for optimum performance). The level of removal is

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determined by the Henry's law coefficient of the VOC, as is the case for conventional air stripping operations. Also, the membrane recovery process is more efficient at higher VOC concentrations.

The economic benefits of this new system are considerable. Estimates indicate that the cost of treating air stripper emissions by membrane technology will be about \$15 per pound of VOCs recovered, which is less than one-third the cost of carbon-adsorption treatment. The cost of the membrane vapor separation treatment is estimated to be about 60 cents per 1,000 gallons of treated groundwater for a contaminant level of 1-5 ppm or higher.

Waste Applicability

The combined air stripper/membrane vapor separation system can be tailored to treat a variety of wastes, from contaminated groundwater containing a few parts per million of VOCs, to industrial process waters containing organic solvents at the high parts per million/low percent level.

Status

The combined air stripper/membrane vapor separation concept has been successfully demonstrated in pilot-scale experiments, and it is ready to be evaluated in the field.

Potential Commercial Applications

This new technology can be used in two ways: (1) a complete combined system can be installed at the start of a remediation project, or (2) membrane vapor separation systems can be added to existing air strippers that are producing effluent air streams that do not comply with air-quality regulations.

Baseline Technology

Air stripping is the least expensive way to remove VOCs from polluted groundwater. However, increasingly stringent air pollution regulations require the capture or destruction of the VOCs in the stripper air-vent stream before they are discharged from the stream into the atmosphere. Carbon adsorption is commonly used to capture the VOCs in the air-stripper emissions, but this process produces a secondary waste of spent carbon and costs at least \$50 per pound of VOC. The amount of organic compound discharged from an air stripper is small, so off-site regeneration is the most efficient method of handling the spent carbon.

Intellectual Property Rights

Membrane Technology and Research, Inc., has retained the rights to this technology. A patent application covering combinations of air strippers and membrane separation systems, including those investigated under this program, has been allowed.

Flow Diagram of the Combined Air Stripper/Membrane Vapor Separation System to Remove VOCs from Contaminated Groundwater

<i>Project</i>	Predicted Performance of Systems for Bulk Soil Assay, Barrel Inspection, and Decommissioning
<i>Report No.</i>	DOE/CH-9210
<i>Organization</i>	Nuclear Diagnostic Systems, Inc.

Description

The focus of this project was predicting the detection performance of a new neutron diagnostic probe technology. The technology (developed by Nuclear Diagnostic Systems, Inc.; Lorton, VA) can be used to detect and identify pollutants, uranium and transuranics (TRU), and gamma-ray emitters. The new element in this diagnostic technology is a sealed tube neutron generator (STNG), which includes a unique integral alpha particle detector. This detector allows the associated particle time-of-flight (APTOF) method to be used to define the neutron beam.

The technology can operate in three modes: inelastic-gamma ray imaging and spectroscopy (IGRIS), capture-gamma ray spectroscopy (CGRS), and passive detection. IGRIS and CGRS studies can be done simultaneously.

Conceptual designs incorporating the STNG were developed for systems for bulk soil assay, barrel inspections, and decommissioning surveys. These three systems show great potential for environmental restoration. Laboratory studies were performed using CGRS, IGRIS, and passive detection to determine the minimum detectable levels for layered and mixed targets of known composition. The performance of the proposed assay and inspection systems was estimated from the laboratory results.

The designs for the proposed bulk soil assay and barrel inspection system are similar: the STNG rests in a borated polyethylene shield and 6-in. by 6-in. by 18-in. NaI scintillators are positioned in an array behind the material being evaluated. In the barrel inspection system, the detectors are split to flank a 55-gallon barrel. In these systems, the relative positions of the STNG and gamma-ray detector were changed from the laboratory system to reduce the background activity. This change is expected to reduce the minimum detectable levels for CGRS by a factor of five. The decommissioning system is simply an IGRIS system designed to noninvasively detect a few grams of pollutants deposited in pipes, valves, etc., in measurement times of about 1,000 seconds.

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Technical Performance Data

Minimum detectable levels were obtained from known samples by passive measurement, CGRS, and IGRIS (as appropriate) for the following contaminants: arsenic, cadmium, cesium-137, chlorine, chromium,

cobalt-60, lead, mercury, nickel, uranium-235 and -238, and zinc. Predicted values for the proposed system were then calculated; the table presents selected values.

The estimated cost of operation is estimated to be \$800/day for the bulk soil assay or barrel inspection system and \$400/day for the decommissioning system.

Waste Applicability

The proposed bulk soil assay system could be used for assay of excavated waste and highly polluted soil. The proposed barrel inspection system could be used to verify the contents of containers of radioactive waste received at DOE disposal sites, to assay the contents of 55-gallon barrels of radioactive waste now stored at DOE facilities, and to assay the contents of barrels and other containers excavated from waste sites.

Examples of Predicted Minimum Detectable Levels for Proposed Systems

Element/ Isotope	Mode	Minimum Detectable Level	
		Homogeneous Target	Target in One Voxel
Bulk Soil Assay System			
Cs-137	Passive	0.0078 pCi/g	2.5 nCi ^a
U-235	CGRS	11 ppm	3 g ^a
Cr	IGRIS	232 ppm	3 g ^a
Barrel Inspection System			
Cs-137	Passive	0.0091 pCi/g	1.8 nCi ^b
U-235	CGRS	13 ppm	2.5 g ^b
Cr	IGRIS	270 ppm	2.2 g ^b

^a Weight of voxel: 0.5 kg.

^b Weight of voxel: 0.3 kg.

Status

The next step in the development of this technology would be assembling and bench-testing each of the prototype systems.

Potential Commercial Applications

Neutron diagnostic probe systems have been investigated through the proof-of-concept stage for applications such as detection of corrodents in steam turbine blades, on-line bulk coal assay, uranium borehole logging, identification of chemical ordnance, and identification of chemical explosives. Other possible applications of neutron diagnostic probes include detection of drugs in cargo containers, inspection of nuclear warheads for treaty verification, inspection of meat and animals, and in vivo medical applications to measure protein, fat, and water content. Although all nuclear diagnostic probes utilize the same principles of physics, the design of a specific system is highly dependent on the application.

Baseline Technology

The proposed barrel inspection system complements rather than competes with the active and passive neutron detection systems developed to assay uranium and transuranics for nuclear safeguards application. The proposed system detects elements other than uranium and transuranics and has better sensitivity than safeguards equipment for uranium and transuranics in a low gamma radiation background. However, the proposed system is not adequate for assaying uranium and transuranics in a high gamma radiation background (the design goal of most safeguards equipment).

Intellectual Property Rights

The detailed design of the STNG and the source code for the software that is generic to all IGRIS systems is proprietary to Nuclear Diagnostic Systems, Inc. All results of other research and development have been published and are in the public domain.

Project	The High Resolution Shear Wave Seismic Reflection Technique
Report No.	DOE/CH-9218
Organization	Paul C. Rizzo Associates, Inc.

Description

A literature review and model study confirmed the soundness of the proposed theoretical and practical basis for identifying aquifer systems using both compressional wave (P-wave) and shear wave (S-wave) reflections. This was the initial task of the project. The development and testing of the technology are described in a separate summary.

Several characteristics of P- and S-waves make them potentially useful for characterizing shallow groundwater conditions. (1) P-wave velocities are severely affected if an unconsolidated sediment is saturated with water. The opposite is true of S-wave velocities. (2) The ratio of P-wave to S-wave velocity (V_p/V_s) can be an indicator of lithology. (3) S-waves are much more susceptible to the effects of anisotropy than are P-waves, and this information can be useful in identifying lithology and/or predominant fracture trends. Useful information regarding S-wave sources, noise suppression, and recording procedures was identified for incorporation into future field studies.

Knowledge of S-wave velocities represents a powerful tool for assessing the fluid characteristics of subsurface layers, especially when combined with knowledge of P-wave velocities. Material properties (and lateral changes in material properties, such as a change from clay to sand) can be inferred from a careful, comparative evaluation of P-wave and S-wave records.

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Research Conclusions

In the few studies of S-wave reflection conducted before the 1970s, the results were discouraging. Recent results, however, show the principle to be sound. A critical result of this information search was the conclusion that if groundwater regimes are to be characterized, both P- and S-wave reflection data are required. The first step in subsurface characterization would be correlating the P- and S-wave reflections. Velocity analysis would then yield interval velocities corresponding to discrete layers that could be identified for both sections.

The S-wave reflection technique initially achieved credibility when the Continental Oil Company (CONOCO) Shear Wave Group reported some excellent data from research using horizontal vibrators as sources. That and other studies indicated that S-wave reflections may be useful for subsurface characterization for several reasons: they are largely free of

amplitude anomalies caused by pore fluid in rock; the V_p/V_s ratio is helpful in determining lithology, porosity, and fracturing; S-waves may provide better resolution than P-waves; and S-waves may be helpful in identifying anisotropy.

In this review of the literature, including several case studies, the following issues were identified for consideration in the field evaluations.

- **Variety of sources:** A variety of sources can be used, the most common being a wooden plank, sometimes with spikes and sometimes with a heavy weight on top. The plank is struck at both ends with a sledgehammer. Explosive sources do not work well.
- **Ground surface effects:** The ground surface has an important effect on S-wave data acquisition: Love waves can hinder accurate S-wave data acquisition, though when tests are conducted over high-velocity surfaces, the problem is not as severe. However, testing over high-velocity surfaces can lead to erroneous depth interpretations.
- **Refraction surveys:** The correction for surface statics is a significant problem for S-wave data. P- and S-wave refraction surveys should accompany reflection surveys to characterize near-surface velocities.
- **Common reflectors:** The use of P- and S-waves together requires that common reflectors be identified from each data set.
- **SH-waves vs. P-SV converted waves:** SH-waves appear to be more useful than P-SV converted waves for assessing relatively shallow targets.
- **Shallow data:** When very shallow data are to be obtained, a large signal bandwidth and careful one- and two-dimensional filtering are required. The dynamic resolution of the analog/digital converter should be high.

Site Applicability

A review of the case histories indicated that it would be best to begin field studies at a site having unconsolidated soil without excessive structural complexities. The review also showed that rock sites and complex sites should be avoided in the early stages of field investigations. However, future research at such sites could prove worthwhile.

Status

This information search established the suitability of the technique, and the appropriate apparatus was developed for field-testing (described in a separate summary).

Baseline Technology

The high resolution S-wave reflection technique will serve as a much-needed geotechnical tool. Currently, S-wave reflections are routinely used by geotechnical engineers in the Far East to define subsurface conditions at soft sediment sites. P-waves are usually not obtained. When the goal of a survey is to characterize groundwater, however, both P- and S-wave data will have to be analyzed.

Project	High Resolution Shear Wave Reflection Surveying for Hydrogeological Investigations
Report No.	DOE/CH-9211
Organization	Paul C. Rizzo Associates, Inc.

Description

The main objective of this research was to develop the technology necessary to make high resolution shear wave (S-wave) profiling a useful tool in conducting shallow groundwater investigations. A literature review conducted as part of the initial task of this project was published separately and is presented here as a separate summary. This method offers the potential for greatly enhancing the data that can be extracted from the subsurface, in particular regarding the fluid characteristics of subsurface layers. The use of S-waves in a high resolution seismic reflection survey increases subsurface resolution in soil environments. The increased resolution may permit detection of confined and unconfined aquifers from the ground surface. By using this method, detailed information on stratigraphic and aquifer conditions can be obtained with minimal use of boreholes. Data obtained by S-wave surveying will improve the level of confidence in site characterization, reduce the risk associated with characterization activities (because the methodology is noninvasive), and reduce the cost for site characterization by limiting the number of borings required.

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Technical Performance Data

The methodology was tested at Cooke Crossroads, South Carolina. The site had low-velocity sediments without excessive structural complexities. A simplified survey was conducted in which different sources were tested, and separate compressional (P-wave) and S-wave profiles were obtained. Recordings were made by using off-the-shelf equipment commonly used for engineering geophysical applications (Bison 9024 seismograph, Toshiba T-5200 computer for permanent data storage, Oyo two-component SMC-70 series geophones). Later, a comprehensive survey was conducted to define the maximum amount of subsurface information obtainable with S- and P-wave seismic reflection techniques.

A professional geophysical data processing service converted the seismic reflection field data into zero-offset reflection seismograms. This comprehensive processing was compared to the limited processing available in the field through personal-computer-based software.

The correlations between lithology and P- and S-wave reflections made it possible to determine hydrogeological conditions at the site. In general, where a confined aquifer is sufficiently thick, S-waves appear to be useful in mapping it. A saturated sand aquifer in unconsolidated sediments would likely be a good target for an S-wave reflection survey. Where the understanding of groundwater flow depends on mapping of thin clay layers functioning as aquitards or thin sand layers functioning as aquifers, S-wave reflections offer significant possibilities for nonintrusive characterization.

Several general observations resulted from the field testing. Sufficient data quality was obtained with two-component, separate SH- and P-wave recordings. It is essential to obtain P- and S-wave velocity data from a borehole to establish correlations between P- and S-wave profiles. A steel cylinder appeared to be the most effective source, although other site conditions might require a different source. Field processing of data is useful but cannot replace professional processing.

Waste Applicability

This research will have potential application whenever subsurface geologic characterization is a concern in an environmental investigation. Implementation of the results can reduce health and environmental risks, lower costs, strengthen operations, and ultimately improve regulatory compliance. Additional experience will clarify the geological characteristics for which S-wave reflections are most useful.

Status

Additional research is needed to define the best means to obtain subsurface control for relating the separate P- and S-wave reflections; this control is the major requirement for defining where aquifers are present. The high resolution S-wave reflection technique has been successfully demonstrated at the Cooke Crossroads site, where the technology has surpassed expectations. It would now be appropriate to extend this research to a site with a more complicated sedimentary geology.

Potential Commercial Applications

S-wave reflection adds one more tool to the site characterization tool bag. In combination with conventional P-wave reflection measurements, the S-wave reflection technique has the potential to directly detect where confined and unconfined aquifers are present. The information obtained can be complementary to other techniques. Although additional research would be desirable, the technique has been commercially applied. In one application, Quaternary faults with less than 5 feet of vertical offset were

mapped in Southern California. The method has been successfully applied to locate abandoned coal mine workings in Illinois and to locate a limestone cave with open-channel containment flow in Kentucky.

Baseline Technology

The research demonstrated that a combined P- and S-wave survey could be used to infer aquifer conditions, but the interpretation process is complex. Perhaps the most significant result of the survey was the resolution obtained: when S-waves are used in a coastal plain environment, the resolution obtainable is more than double that obtainable from conventional reflection technology, which already offers a higher resolution than any other surface method.

Intellectual Property Rights

As the research essentially involved the development of the technique using off-the-shelf hardware and software, the developers are not pursuing any patents for the technology.

Project	Remediation of Groundwater Containing Radionuclides and Heavy Metal Using Ion Exchange and the AlgaSORB® Biosorbent System
Report No.	DOE/CH-9212
Organization	Science Applications International Corporation

Description

The goal of this project was to determine the effectiveness of the AlgaSORB®/ion exchange treatment process for removing low concentrations of heavy metal ions (including many radionuclides) from contaminated groundwater and for producing effluents of acceptable quality for discharge back into the aquifer.

AlgaSORB® is an immobilized algal biomass that has high affinity for heavy metal ions. Such biologically derived resins represent an advancement in the "state of the art" of ion exchange. Groundwater contaminated with heavy metals is passed through columns containing the resin, which adsorbs the metal ions. The metals are then stripped from the resin, producing a highly concentrated waste stream.

The AlgaSORB® resins, along with commercial ion exchange resins used for metal ion removal, were tested on contaminated groundwaters collected from three sites: Hanford, Oak Ridge, and Savannah River.

The selected adsorbent resins were screened and tested for their efficiency in binding metal ions. The most promising advanced to full-fledged column studies. The groundwater samples were then pumped into columns at various flow rates. Effluents were collected in four bed-volume fractions and analyzed for metal ion content. Different loading and stripping flow rates were tested to optimize binding and stripping protocols. Finally, adsorbents were recycled (i.e., loaded and stripped over several cycles) to measure any signs of diminished capacity.

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Technical Performance Data

Samples were collected from two wells at Hanford. One well contained 50-300 ppb of uranium; the second well contained 200-400 ppb of chromium. The goal was to reduce the uranium concentration to below 10 ppb and the chromium concentration to below 50 ppb. Samples from wells at Oak Ridge and Savannah River had mercury levels at 10-50 ppb and 4 ppb, respectively. The goal was to reduce mercury levels to below 2 ppb.

The results showed that using AlgaSORB® resin AZ-316P at 20 bed volumes per hour should produce effluents containing less than 50 ppb of chromium for at least 1,000 bed volumes of contaminated water. For uranium-contaminated groundwater, one cubic foot of the resin should treat at least 23,000 gal at 10 bed volumes per hour, producing effluents

containing less than 10 ppb uranium. The stripping process requires passage in sequence of five bed volumes of 3M NaOH, three bed volumes of water, five bed volumes of 2M HCl, and five bed volumes of water. The bed is then ready for reuse. In some cases, such as when high-activity radionuclides are present, recycling of the bed may not be appropriate, and a single-use application may be designed in which bed materials are sent for processing into a final waste form.

Although the results from the Oak Ridge samples were compromised somewhat by growth of microorganisms and loss of mercury, the data strongly suggest that binding and stripping performance is satisfactory (for AlgaSORB® resin AZ-601, influent flow rates of 10 bed volumes per hour, and stripping with 1M thiourea in 0.1M HCl). Microbial growth would probably not be a problem on-site, however. Waters tested in these studies were collected several weeks before column studies began, providing ample time for microorganism growth.

AlgaSORB® resin AZ-601 performed very well in removing mercury from the Savannah River samples; stripping cycles were equally successful. Since waters were spiked with mercury, however, on-site studies will be needed to verify laboratory results.

Waste Applicability

This treatment is appropriate for groundwaters containing heavy metal ions. If the groundwaters contain a mix of heavy metal and organic contaminants, however, the AlgaSORB®/ion exchange process should be used in conjunction with a treatment process that more fully treats the waters. AlgaSORB® preparations are very selective in binding heavy metal ions, to the exclusion of organic contaminants.

Status

The AlgaSORB®/ion exchange technology was tested with four different groundwaters from three different sites. The results show that groundwater can be treated with this technology to provide effluents that satisfy drinking water limits for heavy metals.

Potential Commercial Applications

Systems capable of handling flow rates from as low as 1 gpm to several hundred gallons per minute have been manufactured and installed. Scaleup of this technology at DOE sites appears feasible.

Though it is difficult to extrapolate costs from tests in this project, researchers estimate that capital costs for a model system (for a single metal) with a capacity of 600 gpm would range from \$1 million to more than \$3 million, excluding costs for site preparation, pretreatment,

installation, etc. The operating cost per thousand gallons treated would range from \$0.25 to \$5.00.

Baseline Technology

Current methods for removing contaminants from groundwater include conventional precipitation, advanced precipitation, evaporation, and reverse osmosis. The method described here reduces chemical costs and reduces operator involvement (thus lowering staffing requirements). Furthermore, the process does not produce hazardous sludge, and in many cases the byproducts are recyclable.

Intellectual Property Rights

The patent on the AlgaSORB® material is held by Bio-Recovery Systems, Inc., Las Cruces, NM, which develops systems and equipment using the material for government and industry applications.

Project	Development of the SEAMIST™ Concept for Site Characterization and Monitoring
Report No.	DOE/CH-9213
Organization	Science and Engineering Associates

Description

In every DOE site where contamination threatens the water table, the transport path of contaminants is through the unsaturated layer, or vadose zone. Construction of monitor wells to characterize the nature and extent of vadose zone contamination at these sites is expensive, but with optimum use of boreholes it is possible to reduce the total number of drilled wells in site characterization and monitoring projects.

The SEAMIST™ (Science and Engineering Associates Membrane Instrumentation and Sampling Technique) system is designed to increase the quantity and quality of data retrieved from these monitor wells. SEAMIST™ is a borehole liner and instrument emplacement technique with a wide range of applications in groundwater monitoring and site characterization. The system deploys an impermeable tubular membrane into a borehole by inversion under pneumatic pressure. The membrane supports the borehole wall and seals once it is emplaced, acting as a low pressure liner. Instruments and sampling devices mounted on the membrane's surface are pressed against the borehole wall to maintain contact with the geologic media.

This project developed the SEAMIST™ system explicitly for multilevel sampling of gas and pore fluid in the vadose zone for specific DOE monitoring circumstances.

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Technical Performance Data

The mechanical emplacement system was tested at the directional boring test range at Sandia National Laboratories, where two horizontal boreholes were instrumented and/or lined. As a test of the integrated SEAMIST™ sampling system, gas and liquid samples were collected for permeability measurements from a borehole under an existing radioactive waste landfill at Los Alamos National Laboratory.

These field tests demonstrated system performance in horizontal holes as long as 230 ft. Subsequent demonstrations were successful in vertical boreholes down to 130 ft. The systems have been deployed in boreholes with diameters ranging from 1-3/4 in. to 10 in. The membrane moves easily around corners and small obstructions in the borehole.

The utility of the SEAMIST™ system lies in its rapid emplacement and in the high degree of spatial resolution attained in its sampling systems. Sampling instruments can be installed for use in most boreholes in less than 30 minutes, and absorbent collectors can be stationed at virtually any spacing. These collectors can collect pore liquid at very low moisture contents, where the only competitive technique would be soil sampling. Absorbent collector materials were shown in laboratory tests to wick water samples at matrix potentials as high as 15 bars. The SEAMIST™ system allows repeated sampling in the same borehole over time to monitor contaminant movement. When the borehole is no longer needed, the membrane can be removed easily, without leaving behind residual material.

Waste Applicability

SEAMIST™ shows a great deal of promise for use in in-situ instrument emplacement, emplacement of selective contaminant sampling devices, and transport of logging tools and cameras.

Status

System development and subsequent field tests have demonstrated the ability of SEAMIST™ to conduct liquid and vapor sampling and permeability measurements with high spatial resolution. The equipment designs have been tested and field proven.

Potential Commercial Applications

In April 1993, the SEAMIST™ borehole instrumentation technology was sold to Eastman Cherrington Environmental, headquartered in Houston, Texas. Eastman Cherrington will be manufacturing and fielding the SEAMIST™ technology.

SEAMIST™ can be used as a vehicle for other monitoring instruments. In particular, the in-situ fiber optic and electrochemical sensor systems under development in other DOE Office of Technology Development programs can be readily deployed with a SEAMIST™ system by mounting the fibers on the membrane's outer surface.

Baseline Technology

SEAMIST™ is a new technology that replaces ex-situ analysis of soil samples. This method provides better accuracy, higher spatial resolution, and less risk of contamination.

Intellectual Property Rights

The patent and trademark are owned by Eastman Cherrington Environmental, Houston, Texas; patent number 5176207.

<i>Project</i>	Chromate Reduction and Heavy Metal Fixation in Soil
<i>Report No.</i>	DOE/CH-9214
<i>Organization</i>	Sizemore Technical Services, Inc. (now EET, Inc.)

Description

The primary objective of this project was to investigate a novel approach for remediating heavy metal contamination in soil: iron and destabilized silica are used in situ for chromate reduction and heavy metal fixation (Cr, Pb, Zn, Cu, Cd, Ni). Secondary objectives included (1) determining whether the reduction reaction goes to completeness in a soil environment, (2) determining whether a silica treatment will further reduce the solubility of heavy metals when they are exposed to leaching fluids of increasing acidity, and (3) screening the chemical parameters for this process in a soil pH range of 7 to 9.

In this remediation approach, developed by Sizemore Technical Services, Inc. (now EET, Inc.), Fe II reduces Cr VI to Cr III; the Cr III and Fe III thus formed are precipitated at soil pH as $\text{Cr}(\text{OH})_3$ and $\text{Fe}(\text{OH})_3$. In this precipitation step, other metals are coprecipitated and adsorbed on the hydroxides. In the absence of Cr VI or another oxidized species, Fe III must be substituted for Fe II. The silica treatment serves two purposes: it reduces metal solubility, and it lowers the soil permeability. Thus, this process reduces the leaching of metals because it lowers both the flow rate and the concentration, which together determine the metal leaching rate.

The chemicals used with this treatment pose no health or environmental risks. Health risks are much lower than those associated with other chemicals currently used for chromate reduction, such as sulfite in an acidic medium. Iron sulfate treatment is odorless, noncorrosive, and nontoxic.

The experimental approach comprised the following six research areas:

1. Chemical and physical characterization of three soils.
2. Measurement of soil-metal isotherms.
3. Determination of the hydraulic coefficients (K_h) of untreated and silica-treated soils.
4. In-situ chromate reduction with ferrous salt at soil pH.
5. Metal fixation through treatment with iron and a destabilized aqueous sodium silicate solution. Both acid gels and zeolite gels (sodium silica solutions destabilized with sodium aluminate) were tested. Zeolite gels retain more of the alkalinity of sodium silicate, so they offer more stability in acidic environments.

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6. Estimation of the combined protection against leaching in acid conditions that is achieved by chemical fixation and reduction of soil permeability.

Technical Performance Data

The quantitative results obtained in the study are illustrated by the following data.

- The metal retentions after iron-silica treatment in column leaching experiments were as follows:

Pb	>99%
Cr	98-99%
Zn	98%
Cd	96%
Ni	95%
Cu	81%

- The hydraulic conductivity after treatment was on the order of 10^{-7} to 10^{-6} cm/sec (original virgin soil: 10^{-2} cm/sec).

Since the leaching rate [$\text{mg}/(\text{m}^2 \text{ sec})$] is the product of leachate concentration [mg/L] and leachate flow rate [$\text{L}/(\text{m}^2 \text{ sec})$], the lowering of the leachate concentration by a factor of 10^2 , combined with the simultaneous lowering of the soil permeability by a factor of about 10^4 , should lead to a reduction of the leaching rate in treated soils by a factor of about 10^6 .

Waste Applicability

In-situ chromate reduction and metal fixation are needed to prevent the migration of contaminants, to isolate volumes through impermeable barriers, and to provide permanent containment. The contaminants comprise organics, inorganics, and radionuclides.

Status

Because in-situ Cr VI reduction with Fe II was successful, this project is now ready for field evaluation for soils containing up to 400 ppm Cr VI. At higher Cr VI concentrations, treatment in combination with soil washing may be preferable.

Metal fixation was successful at concentrations up to 100 ppm per metal using 6,000 ppm Fe III and zeolite gel. The equipment for in-situ soil mixing with simultaneous addition of liquids has been developed and is currently in use. However, more work in gel refinement and

performance is needed. An extraction pH not greater than 8.5-9.0 is desirable. Above this pH, increased levels of lead in the leachate and increased solubility of silica were observed.

Potential Commercial Applications

The results discussed above suggest that in-situ silica gel treatment of soils could be used to perform the following functions:

- Reduce the mobilization of contaminants in subsurface groundwaters by sorption onto the silica gel and/or hydrous metal oxide [specifically, Fe(III) hydroxide] precipitates.
- Reduce the permeability of the soil by introducing a gel into the connected pores in the soil, thereby providing a barrier to groundwater movement.

The chemicals used are applied as aqueous solutions with good soil penetration properties. The chemicals can be added in situ by direct injection or in conjunction with in-situ soil mixing. The technique should be especially applicable to remediating the fringes around more heavily polluted cores. In such fringes, the pollution gradually decreases while the volume of soil to be treated increases exponentially with the distance from the core. The chemical cost to treat 1 yd³ is estimated to be around \$5.

Baseline Technology

The iron sulfate proposed for chromate reduction is widely used as a fertilizer. Silica gels have been applied for over a century for mechanical and hydrological soil stabilization projects and are considered environmentally safe. Silica solutions, unlike portland cement slurries used for soil stabilization, contain no particles that can be filtered out by soil.

Intellectual Property Rights

EET, Inc., and the inventor have applied for a patent.

<i>Project</i>	Assessment of Subsurface VOCs Using a Chemical Microsensor Array
<i>Report No.</i>	DOE/CH-9215
<i>Organization</i>	University of Michigan

Description

At many DOE sites, soil and groundwater have been contaminated with volatile organic compounds (VOCs). In site assessment, chemical analyses are needed to identify and quantify the VOC contamination. This project demonstrated that arrays of microfabricated surface-acoustic-wave (SAW) chemical sensors could be used to rapidly assess VOC contamination in subsurface media. These sensor arrays could be incorporated in small, inexpensive instruments for continuous selective measurement of VOC concentrations. Such instruments would considerably improve the quality and quantity of analytical data used to guide assessment and restoration efforts at contaminated sites.

SAW devices function by generating mechanical (acoustic) waves along the surface of a piezoelectric quartz substrate. The devices respond with high sensitivity to changes in surface mass, and, as a result, they can be used for a wide range of potential organic vapor analytes. Sensitivity to and selectivity for VOCs are achieved by coating the SAW device with a polymer or high-boiling liquid into which the vapor will reversibly partition: vapor sorption increases the mass of the surface coating and causes a proportional shift in the oscillation frequency.

The response of a given coated sensor depends on the volatility of the vapor and the strength of the coating vapor solubility interactions. An array of SAW sensors, each with a different coating, will provide a response pattern characteristic of a particular vapor or class of vapors. With proper design, a simple array can identify and quantify a wide range of vapors.

Technical Performance Data

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The instrument developed and investigated has an array of four SAW sensors that operate at a frequency of 158 MHz and an internal, four-channel frequency counter. The instrument consumes approximately 2 W of electrical power. The work emphasized six compounds (chloroform, trichloroethylene, benzene, m-xylene, isooctane, and hexane) that represent three classes of organic compounds (chlorinated hydrocarbons, aromatic hydrocarbons, and saturated aliphatics). Fifteen coatings capable of rapidly and reversibly absorbing organic vapors were tested. From experimental data involving exposures to nearly 100 test atmospheres of individual

vapors and binary vapor mixtures, correct identifications were obtained in 91 percent of the cases, and concentrations were accurately determined.

A pattern-recognition procedure was developed that uses sensor response patterns to identify both individual vapors and the components of vapor mixtures. This method, extended disjoint principal components regression (EDPCR), takes advantage of the integration of the qualitative and quantitative aspects of the sensor responses. With EDPCR, vapors were correctly identified more often (an average of 95 percent of the time in single and binary vapor mixtures), and vapors could be distinguished both within and between the three chemical classes.

Detection limits vary significantly depending on the vapor being considered, the coatings employed on the sensor array, and the operating temperature. However, for many VOCs, the limits of detection are in the range of 20 to 500 $\mu\text{g/L}$ (or about 5 to 125 ppm). Recent improvements in SAW sensor design could reduce the detection limits by an order of magnitude.

This technology has a number of advantages: ruggedness, low power requirements, expected low cost of manufacture (approximately \$1,000 for a four-sensor array), and the capability for continuous unattended operation.

Waste Applicability

SAW microsensor arrays can identify and quantify VOCs of the types typically found at contaminated DOE sites. Furthermore, sensor responses are linear and additive over a wide concentration range, making them suitable for identifying vapor mixtures.

Status

In laboratory demonstrations, relatively simple and rapid measurements provided compound-specific concentrations of VOCs. A field-deployable instrument would require mechanisms for active transport of vapors and for regulating the effects of humidity. In addition, a data processing module would be needed to perform pattern recognition. The required components are commercially available.

Potential Commercial Applications

The results obtained in this project support the use of SAW sensor instrumentation for applications such as headspace analysis, soil gas monitoring, and vacuum extraction process monitoring. It may also be possible to develop a battery-powered version for use in wells and pipes and for screening waste drums or performing compatibility analyses.

Baseline Technology

The analysis of VOCs in soil and groundwater at contaminated DOE sites is currently impeded by the high cost and limited sensing capabilities of field monitoring instrumentation. Small, inexpensive, continuous monitoring instruments are needed to allow the collection and analysis of greater numbers of samples and to improve the quality of data used to guide remediation efforts. Several instrumental methods have been explored for monitoring VOCs in soil and groundwater. Unfortunately, their application is limited by their sensing capabilities, expense, and/or complexity. Several SAW array designs are commercially available, but their applicability to subsurface VOC monitoring has not been well investigated.

Intellectual Property Rights

No information was available.

5 IMPLEMENTATION OF R&D RESULTS

Selection and placement of these R&D contracts represented a major milestone, but the true measure of success is either the movement of the technology toward the demonstration, testing, and evaluation phase of technology development or the direct application of the technology to DOE environmental restoration problems at the completion of the project. Several of the successful projects have progressed into integrated demonstrations and other demonstration activities at DOE sites, as summarized in Table 3.

Implementation of these R&D results in environmental restoration activities is the ultimate goal of the program. Science and Engineering Associates (SEA) has implemented systems at three DOE sites. At Lawrence Livermore National Laboratory, a SEA Membrane Instrumentation and Sampling Technique (SEAMIST™) system collects water samples using passive adsorbent samplers. The laboratory analyzes them for tritium as part of their groundwater monitoring program. Two systems have been delivered to the Hanford Site near Richland, Washington, for use in their soil gas monitoring program. The systems will be used to pack off the hole to permit the gas in the hole to be sampled for carbon tetrachloride. Finally, the SEAMIST™ system has been implemented at the Waste Isolation Pilot Plant in New Mexico to map brine infiltration and measure flowrates. In July 1993, the SEAMIST™ borehole instrumentation technology was sold to Eastman Cherrington Environmental, headquartered in Houston, Texas. SEA will continue to support Eastman Cherrington as it develops its SEAMIST™ manufacturing and field application capabilities.

The VOC-Arid Integrated Demonstration contracted with Applied Research Associates, Inc. (ARA), to conduct a series of field tests of ARA's electric cone penetrometer test (ECPT) technology (February 1992 to November 1993). These tests were carried out in several phases and at various locations at the Hanford Site. They successfully demonstrated the ability of the ECPT to characterize soil contamination. ARA's ECPT was shown to be potentially cost-effective in characterizing the Hanford Site for several reasons: it is minimally invasive, it generates minimal waste, it is faster and less costly than drilling, and it permits real-time data processing.

GTS Duratek has completed Phase I of a program to develop and implement, through on-site field demonstration, a combined vitrification, soil washing, and water treatment system for mixed and low-level radioactive waste streams at Fernald, Ohio. The minimum additive waste stabilization (MAWS) program is an outgrowth of the work performed under the initial DOE/ANL private sector contracting initiative that combined soil washing and in-furnace vitrification for treating low-level radioactive wastes. GTS Duratek and their subcontractors (Lockheed and Catholic University of America) have successfully demonstrated the synergistic integration of blending waste streams, reducing volume, and producing a durable, leach-resistant glass waste form.

TABLE 3 Transition from R&D to Demonstration for FY 1990 Private Sector R&D Contractors (as of October 29, 1993)^a

Company/PI Phone No.	Technology Description	DOE Host Site	Contact/ Organization ^b	Potential Applications	Status of Transition
AECL Leo Buckley (613) 584-3311	Chemical condition- ing/microfiltration of radionuclides from water	Nonspecific (METC PRDA)	C. Zeh (METC)	Soil treatment to remove radionuclides	Ongoing
ARA Jimmie Bratton (505) 881-8074	Geophysical characterization software and penetrometer	UST ID (WHC)	D. Meyers	Tank characterization	Demo completed
		VOC Arid Sites ID	D. Meyers	Site characterization	Demo completed
		Hanford	B. Cassem	Penetrometer tests	Three projects (completed)
		VOC Humid Sites ID	D. Kaback (SRS) and M. Erickson (ANL)	Stratigraphic characterization	Completed
		VOC Humid Sites ID	J. Rossabi (SRS) and M. Erickson (ANL)	Integration of Raman probe for DNAPL characteriza- tion (collaboration with EIC)	Completed
		Expedited Site Characterization	C. Purdy (DOE)	Site characterization	Ongoing
Duratek Ian Pegg (202) 319-6700	Vitrification (ex-situ)	Fernald	R. Gimple (FERMCO)	Raffinate sludge vitrification	Completed
		Fernald	M. Shupe (DOE), G. Ordaz, and D. Kozlowski	Minimum additive waste stabilization (MAWS) program	Phase I completed; Phase II underway

TABLE 3 (Cont.)

Company/PI Phone No.	Technology Description	DOE Host Site	Contact/ Organization ^b	Potential Applications	Status of Transition
EIC Michael Carrabba (617) 769-9450	Downhole Raman spectroscopy	UST ID (WHC)	R. Gilcrest	Tank waste characterization	Sensors integrated with LLNL spectrometer; completed
		ORNL	J. Hass	Field test of new probe	Cooperative agreement in place
		VOC Humid Sites ID	J. Rossabi (SRS)	Integration with ECPT for DNAPL characterization (collaboration with ARA)	Completed
		Nonspecific (METC PRDA)	C. Zeh (METC)	Adapt for in-situ characterization	Ongoing
EPI/Lehigh J. Kenneth Wittle (215) 687-9070	Electrokinetics	SNL (MWL ID)	J. Phelan	Cr contamination	Ongoing
Membrane Technology & Research Hans Wijmans (415) 328-2228	Membrane separation of VOCs	Nonspecific (Idaho PRDA)	S. Webber (DOE)	Pervaporation separation of VOCs from groundwater	Ongoing
		Nonspecific (METC PRDA)	C. Zeh (METC)	Protective clothing from pemselective membranes	Ongoing
Rizzo ^c Bill Johnson (now at D'Appolonia Environmental Services, Inc.) (412) 856-9440	High-resolution geophysical survey (S&P waves)	SRS	J. Rossabi and M. Erickson (ANL)	DNAPL characterization	Completed

TABLE 3 (Cont.)

Company/PI Phone No.	Technology Description	DOE Host Site	Contact/ Organization ^b	Potential Applications	Status of Transition
SEA Carl Keller (now at Eastman Cherrington Environmental) (505) 983-3199	Membrane insertion (vadose zone)	LLNL	B. Mellon	Tritium in groundwater, leachate monitoring	Technology transferred, demonstration completed
	Sampling	Hanford	V. Rohay	Soil gas monitoring	Equipment delivered
		MWL ID (SNL)	J. Stormont	Lining horiz. wells & sensor emplacement	Completed
		SRS	D. Kaback	VOC ID participation	Completed
		Nonspecific (METC PRDA)	C. Zeh (METC)	Detect radioactive contami- nation inside pipes	Ongoing
		SRS	J. Rossabi/ M. Erickson (ANL)	DNAPL characterization	Completed

^a The following acronyms and abbreviations are used in this table: ANL = Argonne National Laboratory; ARA = Applied Research Associates, Inc.; DNAPL = dense nonaqueous phase liquids; ECPT = electric cone penetrometer testing; EPI = Electro-Petroleum, Inc.; FERMCO = Fernald Environmental Remediation Management Corp.; ID = Integrated Demonstration Site; LANL = Los Alamos National Laboratory; LLNL = Lawrence Livermore National Laboratory; METC = Morgantown Energy Technology Center; MMES = Martin Marietta Energy Systems; MWL = mixed-waste landfill; ORNL = Oak Ridge National Laboratory; PRDA = Programmatic Research and Development Announcement; RFP = Rocky Flats Plant; SAIC = Science Applications International Corp.; SEA = Science and Engineering Associates; SNL = Sandia National Laboratories; SRS = Savannah River Site; TTP = technical task plan; UST = underground storage tank; VOC = volatile organic compound; WHC = Westinghouse Hanford Company; WSRC = Westinghouse Savannah River Company.

^b Unless otherwise noted, the contact person is with the host site organization.

^c Demonstrations conducted by Bay Geophysical Associates, Inc., Traverse City, MI; contact: John Clark, (616) 941-7660.

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