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Office of Environmental Management

Office of Technology Development

VOCs in Non-Arid Soils Integrated Demonstration

Technology Summary

MASTER

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VOLATILE ORGANIC COMPOUNDS IN NON-ARID SOILS INTEGRATED DEMONSTRATION

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OFFICE OF TECHNOLOGY DEVELOPMENT OVERVIEW

The Department of Energy (DOE) established the Office of Technology Development (OTD;EM-50) as an element of Environmental Restoration and Waste Management (EM) in November, 1989 (see Figure A). The organizational structure of EM-50 is shown in Figure B.

EM manages remediation of all DOE sites, as well as wastes from current operations. The goal of the EM program is to minimize risks to human health and the environment, and to bring all DOE sites into compliance with Federal, state, and local regulations by 2019. EM-50 is charged with developing new technologies that are safer, faster, more effective and less expensive than current methods.

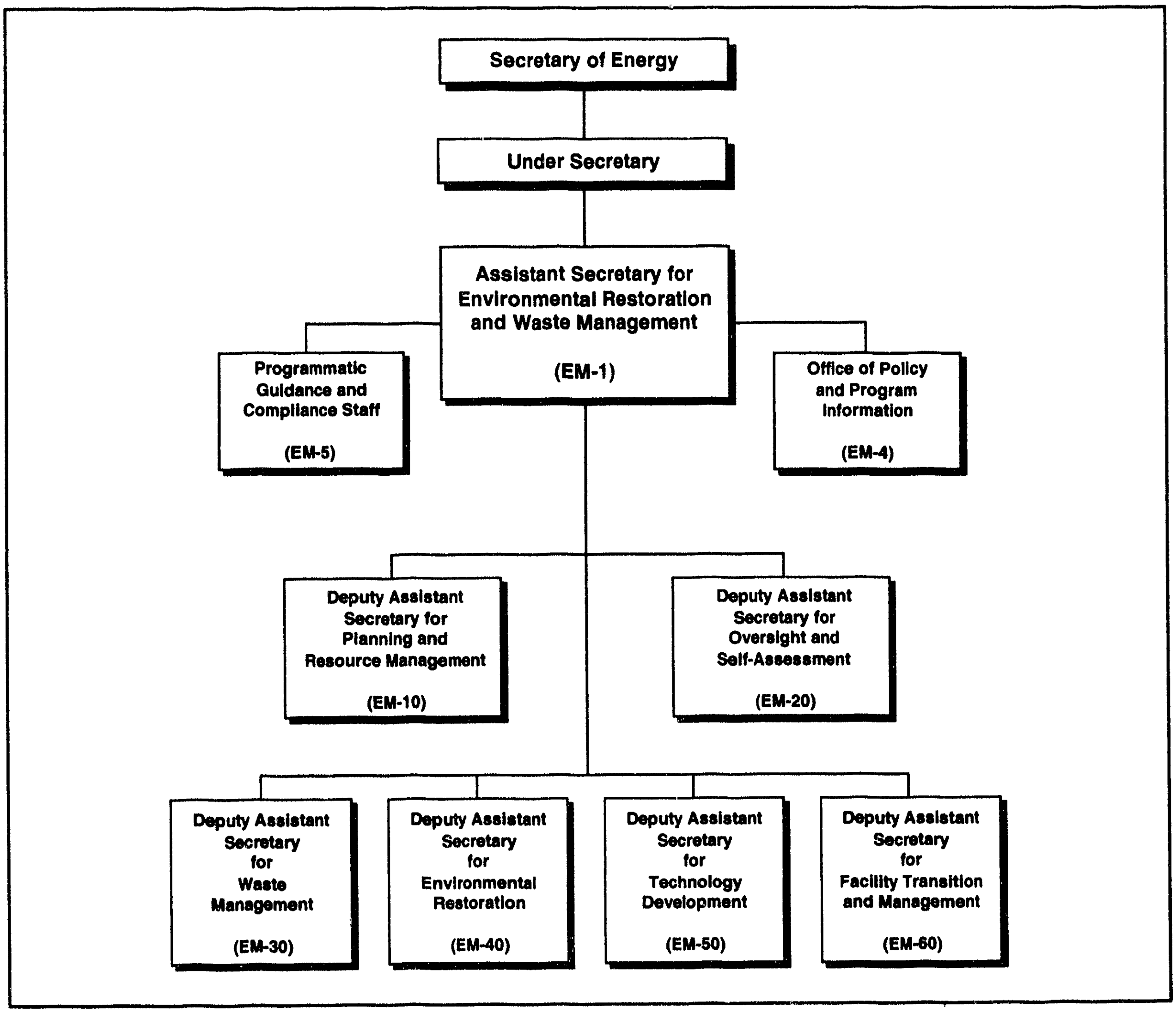

Figure A. DOE Organizational Structure as of June 1993.

In an effort to focus resources and address opportunities, EM-50 has developed **Integrated Programs (IPs)** and **Integrated Demonstrations (IDs).**

An *Integrated Program* focuses on technologies to solve a specific aspect of a waste management or environmental problem and it can be either unique to a site or common to many sites. An Integrated Program supports applied research to develop innovative technologies in key application areas organized around specific activities required in each stage of the remediation process (e.g., characterization, treatment, and disposal).

An *Integrated Demonstration* is a cost-effective mechanism that assembles a group of related and synergistic technologies to evaluate their performance individually or as a complete system in solving waste management and environmental problems from cradle to grave.

The Volatile Organic Compounds in Non-Arid Soils ID (the subject of this report) is part of EM-55, the Demonstration, Testing, and Evaluation (DT&E) Division.

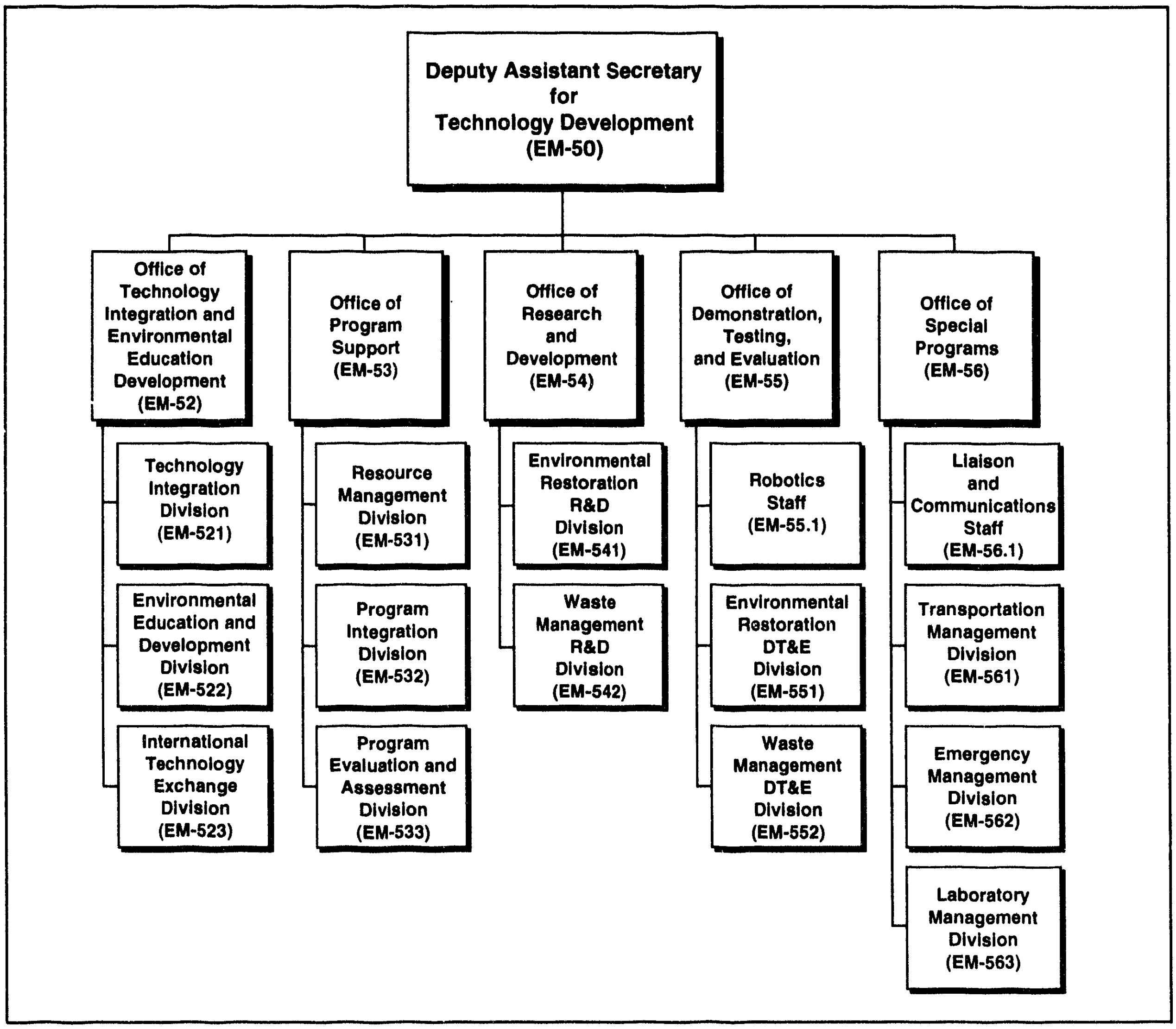

Figure B. Office of Technology Development Organizational Structure as of June 1993.

VOLATILE ORGANIC COMPOUNDS IN NON-ARID SOILS INTEGRATED DEMONSTRATION OVERVIEW

PURPOSE

The Volatile Organic Compounds (VOCs) in Non-Arid Soils Integrated Demonstration (ID) was initiated in 1989. Objectives for the ID were to test the integrated demonstration concept, demonstrate and evaluate innovative technologies/systems for the remediation of VOC contamination in soils and groundwater, and to transfer technologies and systems to internal and external customers for use in full-scale remediation programs. The demonstration brought together technologies from DOE laboratories, other government agencies, and industry for demonstration at a single test bed. This approach allowed additional validation of the various technologies through side by side comparisons. Specific goals for the technolgies are:

- Significant cost reduction for cleanup by minimization of excavation, transportation, and waste disposal;
- Reduction of the health impacts on workers and the public by minimization of exposure to wastes during the remedial process;
- Remediation of inaccessible areas such as deep subsurface or in, under, or around buildings;
- Supplement existing or baseline technologies to achieve regulatory compliance with the Clean Water Act (CWA), Clean Air Act (CAA), Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), and Resource Conservation and Recovery Act (RCRA).

The first step in the ID approach was to identify technology needs and data gaps. This required an interactive relationship with the customers, regulators, and stakeholders. The ID team then recommended technology and system solutions that would meet the needs and fill the data gaps. The technologic solutions entailed the modification of existing technologies/systems in addition to the development of new technologies and systems.

TECHNOLOGY NEEDS

More than 15 percent of the community drinking water supplies in the United States are contaminated with chlorinated hydrocarbons. The major organic contaminants at waste sites at DOE facilities are volatile chlorinated solvents that were used as cleaning and degreasing agents in the nuclear weapons component production process. The Savannah River Site (SRS) was chosen as the location for this ID as the result of having soil and groundwater contaminated with VOCs. The primary contaminants, trichlorethylene (TCE) and tetrachloroethylene (PCE), originated from an underground process sewer line servicing a metal fabrication facility at the M-Area. The soil and sediments at the SRS consist of interbedded sands, silts, and clays, with sands predominating. The groundwater table is at a depth of approximately 135 feet.

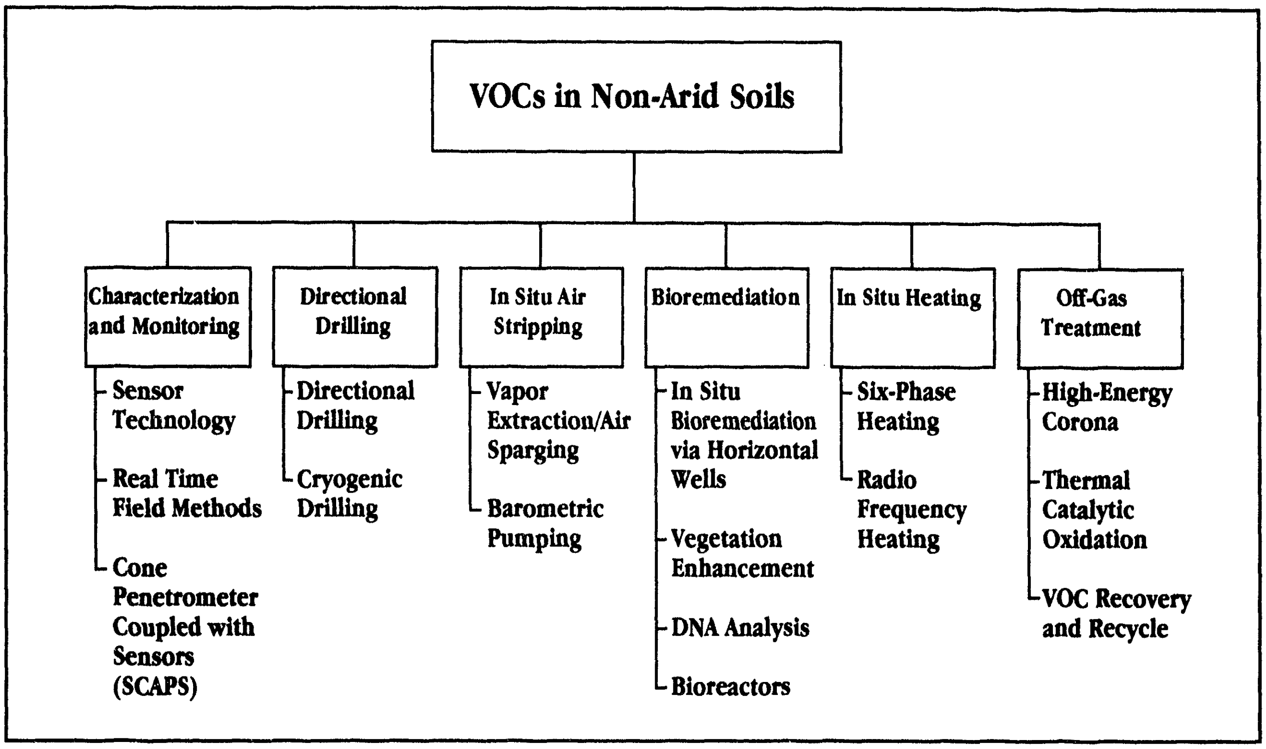

Figure C. Volatile Organic Compounds in Non-Arid Soils Integrated Demonstration Program Elements.

SOLUTIONS

The current baseline technologies for the remediation of VOC-contaminated soils and groundwater, primarily variations on pump-and-treat or excavation, are both inefficient and expensive. Pump-and-treat groundwater remediation, while proven as an effective method for hydraulic plume control and for removal of significant contaminant mass (300,000 pounds of VOCs have been removed at the site since 1984), is inadequate for cleaning up groundwater to drinking water standards. Existing characterization and monitoring methods are time consuming, expensive, and often inexact.

In addition to the need for innovative remediation systems, changes to the CAA (1990 revisions), precluded the atmospheric venting of gases recovered by a variety of extraction processes. This brought on the need for inexpensive and effective off-gas treatment technologies.

The VOCs in Non-Arid Soils ID was chartered with addressing the cited deficiencies by focusing on the demonstration, testing and evaluation of innovative methods for:

- in situ air stripping (sparging) using horizontal wells;
- thermally enhanced vapor extraction of VOCs from low permeability clay horizons in the unsaturated zone;
- in situ bioremediation of VOC contaminated sites;
- characterization of contaminated sites, and monitoring of contamination transport and effectiveness of remedial activities;

- treatment of off-gases from a variety of remedial activities.

Characterization and monitoring and remediation activities were directed toward VOC-contaminated sites; however, many of the demonstrated technologies and methodologies are readily applicable to other types of contaminants. The technologies evaluated as part of this ID are shown in Figure C, with more detailed summaries of their status appearing in the following pages.

ACCOMPLISHMENTS

The VOCs in Non-Arid Soils ID served as the model for the ID approach to remedial technology/system development. Major programmatic accomplishments for the ID are as follows:

- Established national criteria for implementation of the ID concept for development of innovative environmental remediation solutions.
- Transferred numerous technologies and systems to EM's Office of Environmental Restoration (EM-40), other government agencies, and industry. Outlined approach for ID closeout.

Some of the major technical accomplishments for the ID include the successful demonstration of the following:

- In situ air stripping coupled with horizontal wells to remediate sites through air injection and vacuum extraction;
- Crosshole geophysical tomography (both seismic and electrical resistivity) for mapping moisture content and lithologic properties of the contaminated media;
- In situ radio frequency (via horizontal wells), and ohmic heating (through vertical wells), to increase mobility of the contaminants, thereby speeding recovery and the remedial process;
- High-energy corona destruction of VOCs in the off-gas of vapor recovery wells;
- Application of a Brayton cycle heat pump to regenerate carbon adsorption media used to trap VOCs from the off-gas of recovery wells;
- In situ permeable flow sensors and the colloidal borescope to determine groundwater flow;
- Chemical sensors (fiber optic TCE, Halosnif, direct sampling) to rapidly quantify chlorinated solvent contamination in the subsurface;
- In situ bioremediation through methane/nutrient injection to enhance degradation of contaminants by methanotrophic bateria.

TECHNOLOGY IMPLEMENTATION/TRANSFER

An integral part of the ID process is the implementation of the demonstrated technology. The transfer of successful technologies to EM-40, other governmental agencies, and industry was accomplished using several mechanisms, including:

- outreach activities (tours, presentations, publications);

- licensing activities;

- direct information transfer to EM-40, other agencies, and industry;

- joint demonstrations with industry;

- training, including student programs; and

- technology commercialization plans.

Emphasis has been placed on industrial partnerships throughout this ID, whereby costs are shared with corporate partners and the resulting benefits are shared by DOE and these partners. Many of the technologies listed beforehand have been brought from the conceptual phase to operable, commercially-available technologies by this Integrated Demonstration.

Implementation of innovative remediation systems that have been demonstrated as part of this ID will potentially save DOE and other Federal agencies several hundred million dollars. Following successful demonstration of a new technology or system, their performance and cost-effectiveness are evaluated against that of existing baseline technologies. Application to industrial sector problems will add significantly to overall cost savings. For example, the cost analysis report (LA-UR-92-1927) that evaluates the cost and performance of the in situ air stripping system, relative to conventional cleanup technologies, such as soil vapor extraction and pump-and-treat for the removal of VOCs, has estimated that cleanup cost at applicable sites could be reduced by 50-60 percent. Assuming that the technology is suitable at 10 percent of DOE sites, this represents potential cost savings of over $140 million.

A number of innovative characterization technologies have been successfully transferred to the Savannah River Site (SRS) Environmental Restoration and have been used at other SRS waste sites. At least thirteen licenses for the in situ air stripping horizontal well patent have been granted to or filed by commercial vendors. Licenses for the Sandia National Laboratory (SNL) fluid flow sensor, Lawrence Livermore National Laboratory (LLNL) TCE sensor, and Pacific Northwestern Laboratory (PNL) Halosnif sensor, have been granted. The cone penetrometer fluorescence sensor has also recently been patented. The use of horizontal wells for environmental applications has flourished over the last year as a result of DOE's involvement in promoting this innovative technology.

FUTURE DIRECTIONS

As the ongoing work is completed, the integrated demonstration is being phased out. Technologies developed as part of the ID are being transferred to EM for use in remediation of sites within the DOE Complex. Corporate partners continue to implement the developed technologies on a commercial basis.

When this ID is completely closed out at the end of FY94, the emphasis will be shifted to other environmental problems of greater complexity, e.g., Dense Non-Aqueous Phase Liquids (DNAPLs). In addition, the ID test site may provide a unique opportunity to establish an education, training, and continued demonstration facility for testing of environmental characterization, monitoring, and remediation technologies by private industry and other interested parties.

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Characterization and Monitoring

Section 1.0

1.0 CHARACTERIZATION AND MONITORING

Characterization of contaminated sites and monitoring of changes in the site that occur through time, either as the result of contaminant migration or remedial actions, are time consuming, expensive, and often inexact. Because of the expense involved in gathering characterization and monitoring data, the amount of data gathered is often not adequate to provide a coherent evaluation of the spatial distribution of the contaminant. The characterization and monitoring subprogram seeks to develop methods that are less costly, provide results in "real time", and provide data not previously available for the more complete characterization of sites. This is accomplished through the development and demonstration of non-invasive or minimally-invasive technologies that allow characterization without the installation of monitoring wells.

One of the important advantages of gathering real-time characterization is that the characterization and remediation activities can be modified in response to these data, avoiding standby costs, and additional phases of unnecessary characterization. This allows a prompt definition of remedial alternatives and should ultimately result in the site being cleaned up earlier. The remedial alternatives can be focused because of the improved data, which will result in lower costs in the remedial process.

Innovative sensors, samplers and real-time analytical measurement technologies that have been developed include depth discrete water, sediment, and gas samplers (SEAMIST, arrayed sampler, membrane sampler, etc.); fiber optic sensors; groundwater flow sensors (thermal and microphotographic); real-time field analytical equipment (ITMS, Halosnif, PAWS); and seismic and resistivity crosshole tomography.

The mobile cone penetrometer, capable of rapidly penetrating the ground for collection of real-time geologic, geophysical, and geochemical data, has been demonstrated as a cost-effective subsurface characterization tool. Traditional methods to access the subsurface require drilling and boring operations, whereas this technology literally pushes the probe through the soil and subsurface sediments using high-pressure hydraulic rams. Grouting the hole provides a seal to eliminate a potential route for contaminant movement. The cone penetrometer can deploy state-of-the-art sampling and instrument devices, such as a basic screening detector for soil resistivity and a fiber-optic fluorometric sensor that detects petroleum hydrocarbons. New sensors, such as TCE and DNAPL Raman spectroscopic sensors, have been incorporated into the cone penetrometer for demonstration. This characterization technique can improve design of monitoring well networks. The cone penetrometer has been linked with vapor phase sampling systems, to provide concentration-depth profiles, leading to a better understanding of the subsurface.

1.1 CHEMICAL FIBER OPTIC SENSOR

TASK DESCRIPTION

The chemical fiber optic sensor is used to monitor in situ contaminant levels in soils (see Figure 1.1). The sensor can be placed in a cone penetrometer or isolated via packers in discretely screened intervals in monitoring wells.

The principle of detection for the sensor is a quantitative chemical reaction that forms visible light absorbing products on exposure to TCE. Absorption of light relative to reaction time is directly related to contaminant concentration. The measurement system has three major components: a pumping system, an electro-optic instrument that provides filtered light to the sensor and detects the returning transmission light, and the sensor.

TECHNOLOGY NEEDS

Current DOE policy requires characterization of sites where TCE has been discharged into the soil and groundwater. Contaminated samples are currently collected and analyzed by an outside laboratory. This is an expensive and time consuming process. An alternative is to use a sensor that can be put down monitoring or vadose zone wells or punched into the soil using a penetrometer type device. This allows measurements to be made continuously and at relatively low cost. In situ measurements can also be made at ambient temperatures using this method. An example of this type of sensor is the TCE chemical fiber optic sensor. This sensor is selective for TCE, and can detect this compound at levels below the Environmental Protection Agency (EPA) groundwater standards.

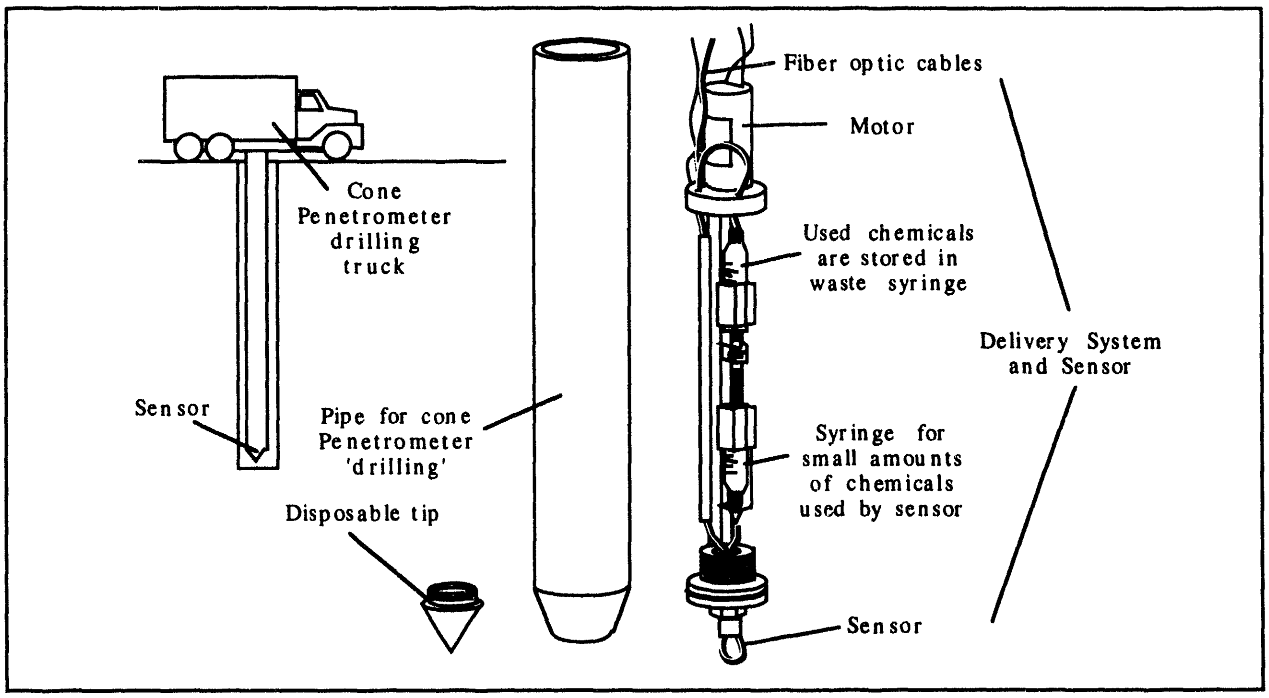

Figure 1.1. Chemical Fiber Optic Sensor.

ACCOMPLISHMENTS

The system has been successfully demonstrated and has been licensed to industry for monitoring use and other applications.

COLLABORATION/TECHNOLOGY TRANSFER

This technology was developed jointly by LLNL, Westinghouse Savannah River Co. and Burge and Associates. The technology is non-exclusively licensed to Burge and Associates and Purus, Inc. Other corporations have expressed interest in licensing the technology.

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1.2 COLLOIDAL BORESCOPE

TASK DESCRIPTION

This is an innovative technology used to determine groundwater flow and direction through observation of the movement of colloidal particles suspended in water. This instrument consists of a charge coupled device camera, an optical magnification lens, an illumination source, and a downhole compass in a watertight stainless steel housing (see Figure 1.2). The borescope is lowered into boreholes to determine the direction of depth-discrete groundwater flow within the borehole. After calibration, the instrument should be capable of yielding data that will provide the magnitude of the groundwater flow. The instrument is approximately 60 cm long, with a diameter of 4.4 cm. The electronic image is transmitted to the surface by a cable. The images are viewed on a high resolution monitor and recorded on VHS tape for further analysis. The magnified image corresponds to a 1.0 x 0.4 x 0.1 mm field of view. The flow of groundwater in the borehole is quantified by observation of the movement of colloidal particles suspended in the water. Flow direction is determined by comparison with the downhole compass, and velocity by timing the movement of particles across the field of view.

TECHNOLOGY NEEDS

The baseline technology is the standard technique used to measure hydraulic gradient to determine flow velocity. Four holes are usu-

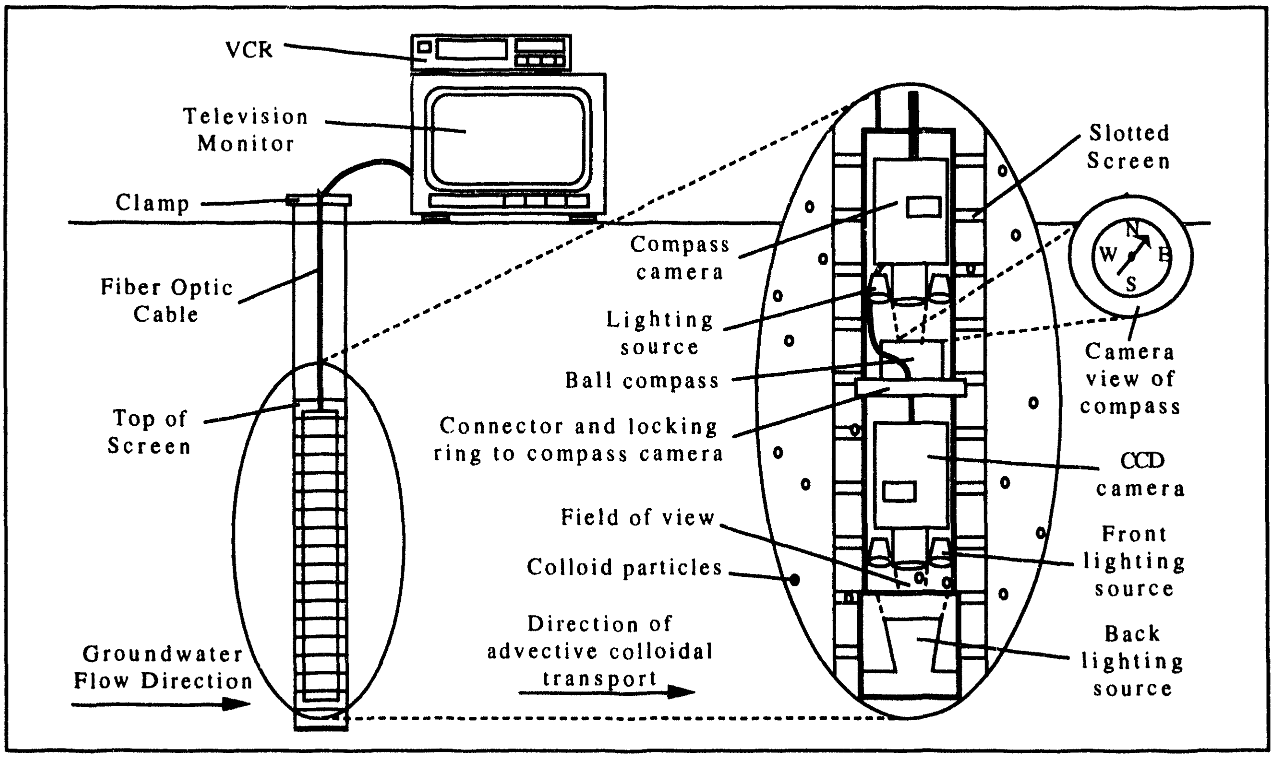

Figure 1.2. Colloidal Borescope.

ally required for a measurement using this standard technique as compared to one hole using the Colloidal Borescope. With the standard technique, information about the hydraulic conductivity of the medium is required and is generally determined using a pumping test in which large quantities of water are pumped from the well. Disposal of this purge water can be difficult and expensive. The standard technique measures a velocity that is averaged over a broad region, one whose dimensions are characterized by the separation of the boreholes.

The borescope is an in situ instrument capable of directly observing the movement of colloidal size particles within boreholes to quantify groundwater flow rate and direction. Current applications include: site characterization by determining preferential flow paths and fractures; assessing heterogeneities associated with porous media; establishing the existence of immiscible contaminant layers and their associated flow properties; assessing the efficiency of groundwater remediation programs by determining the effective radius of influence of groundwater extraction systems; and evaluating the effects of sampling on colloidal concentrations. Potential applications include providing physical observation capabilities necessary to develop and confirm new, more accurate theoretical models of porous media flow process, and assessing the effect of water sampling techniques on natural colloidal concentrations.

ACCOMPLISHMENTS

This instrument has been successfully tested, and proven as capable of determining the vertical and spatial distribution of local groundwater velocity, both in magnitude and direction. The instrument can assess local flow velocities up to 15 mm/sec. Results were corroborated by baseline technique (aquifer pumping test). Presently the rate of flow cannot be determined as a real-time measurement in the field, and work is on-going to develop this capability.

COLLABORATION/TECHNOLOGY TRANSFER

This technology was developed by Oak Ridge National Laboratory (ORNL) in partnership with R.J. Electronics. A prototype instrument was procured by Westinghouse Savannah River Company and is being used in environmental restoration activities on-site.

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1.3 IN SITU PERMEABLE FLOW SENSOR

TASK DESCRIPTION

This in situ flow sensor technology uses a thin cylinder heater buried vertically in the ground at the point where the groundwater flow is to be measured (see Figure 1.3). The temperature distribution over the surface of the cylinder will vary as a function of the magnitude and direction of the groundwater flow past the cylinder. In the absence of any flow past the device, the temperature on the surface of the probe will be independent of azimuth and symmetric about the vertical midpoint of the probe.

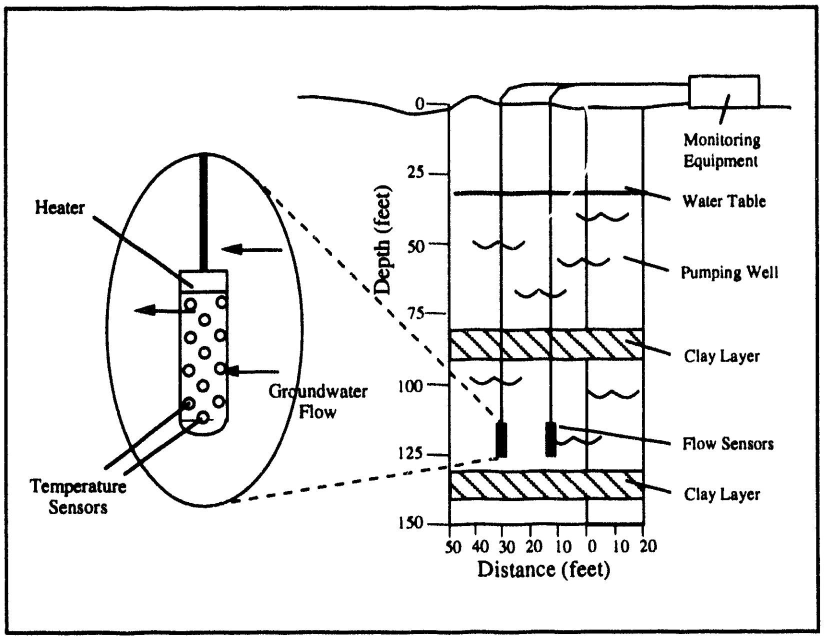

Figure 1.3. In Situ Permeable Flow Sensor.

Groundwater flow past the device perturbs the surface temperature distribution of the sensor, with the pattern and magnitude of the temperature variations reflecting the direction and magnitude of the groundwater flow velocity. In essence, relatively warm temperatures will be observed on the downstream side and relatively cool temperatures on the upstream side of the probe. If the groundwater flow has a vertical component then the temperature will no longer be symmetrical about the vertical midpoint. The magnitude and direction of the three-dimensional flow velocity vector are determined from the magnitude and the pattern of the temperature variations on the surface of the probe. The sensor should be sensitive to groundwater flows as low as a few meters per year.

TECHNOLOGY NEEDS

Because groundwater flow is perhaps the most important mechanism for the dispersal of many types of toxic wastes once they have been released to the subsurface, accurate information about the groundwater flow is critical to the characterization of waste sites, monitoring of the waste remediation activities and monitoring the post-closure performance of remediated waste sites.

The primary, currently accepted method of obtaining flow velocity information is to make water level measurements in screened boreholes to determine the hydraulic gradients in the subsurface. With hydraulic conductivity data the velocity field between the boreholes can be modelled. The shortcomings of this technique are:

- to obtain detailed knowledge of the hydraulic conductivity distribution in the subsurface, a pump test must be performed, and the extracted contaminated water must be disposed of as hazardous waste;

- a relatively large number of boreholes (four or more) are required to make one, three-dimensional flow velocity vector measurement; and

- the velocity determination is an average value characteristic of a broad region.

In contrast, in situ permeable flow sensors require only very crude estimates of the hydraulic conductivity, only a single hole needs to be drilled to measure the full three-dimensional groundwater flow velocity vector, and the flow velocity that is measured is characteristic of a region with scale lengths on the order of one meter.

ACCOMPLISHMENTS

This system has been successfully demonstrated and the technology has been licensed for use at other sites. Currently, temperature differences of about 0.010C can be measured. At this level, flow velocities as low as a few meters per year can be resolved. The probe design needs to be improved to assure long-term reliability of electronics and sensors in groundwater conditions. Currently, the lifetime of the sensors is on the order of one year.

COLLABORATION/TECHNOLOGY TRANSFER

This technology was developed by SNL. While the technology is not patented, SNL has applied for copyrights for the interpretation software used in the probe. A number of private companies have expressed interest in the probe and SIE, Inc., of Ft. Worth, Texas is engaged in discussions with plans to commercialize the technology.

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TASK DESCRIPTION

This technology utilizes seismic imaging to gain a better understanding of remediation system performance. Seismic images provide a means to image geologic conditions non intrusively. By placing the seismic source and receivers downhole (in boreholes) on the sides of the area to be imaged, travel distance is reduced; this preserves higher seismic frequencies resulting in better resolution. Seismic travel times are measured among a great number (over 300) of source and receiver locations in the two boreholes (see Figure 1.4). These travel times are then inverted into a two-dimensional velocity through a method known as tomography.

Shear wave and compressional wave sources were used. Both sources are pneumatic devices and operate on a compressed gas line from gas cylinders at the surface. The shear wave source is a controlled vibrator while the compressional wave source is an impulse source. Comparison of the velocity structures for the compressional and shear waves provides information about rock properties and fluid content.

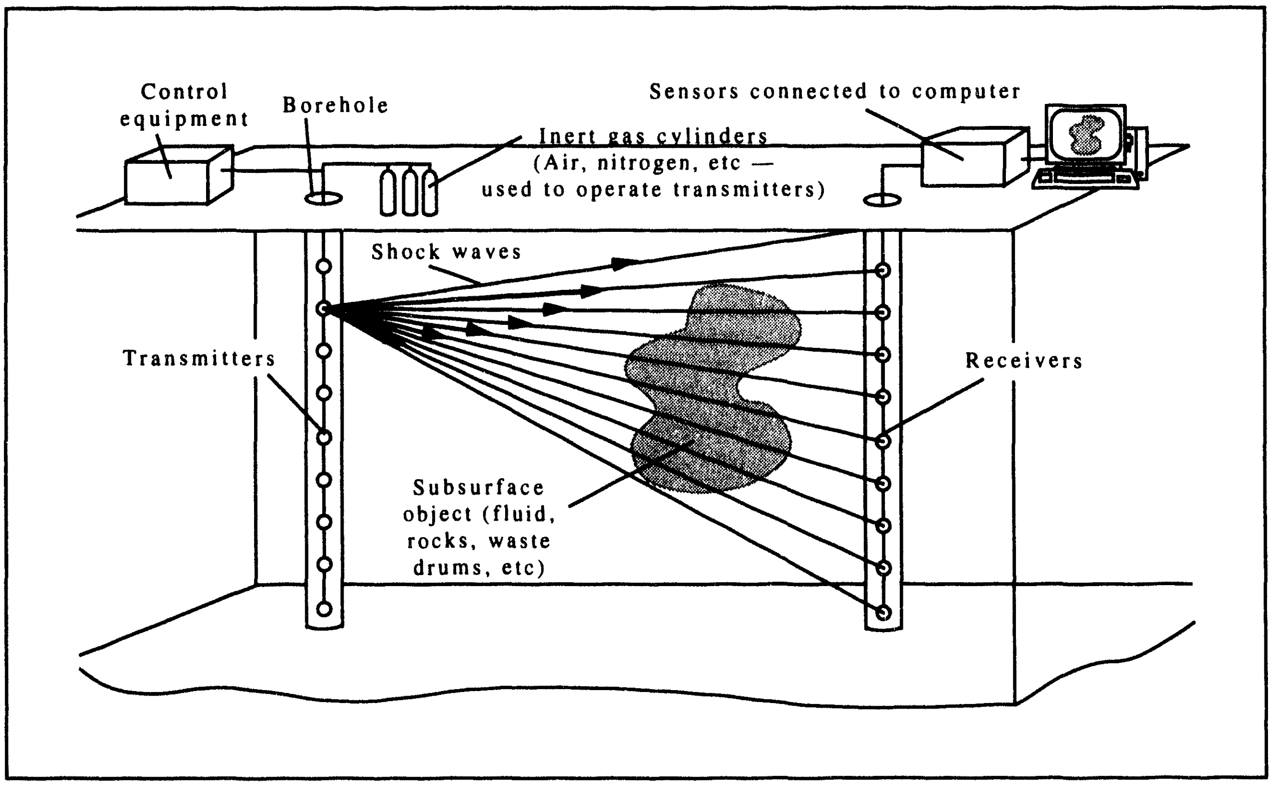

Figure 1.4. Crosswell Seismic Imaging.

TECHNOLOGY NEEDS

For all remediation technologies, a coherent image of the subsurface geology must be obtained to understand contaminant transport and to devise the proper remediation strategy. Much of this geologic input is presently derived from well log data, which may be scarce, especially in contaminated areas where drilling must be kept to a minimum. Seismic imaging provides a means to image the geologic conditions between boreholes non-intrusively. Some of this imaging can be done with surface seismic data. However, placing both the source and receivers downhole results in shorter travel paths, which preserves higher seismic frequencies resulting in better resolution.

For remediation processes where the properties of the subsurface are changed (e.g., air sparging, steam flooding, or in situ vitrification), comparison of seismic velocity images before, during, and after the process can provide needed information on where technology is being effective and to what degree the desired changes are being effected in the subsurface.

ACCOMPLISHMENTS

This technology has been successfully demonstrated at SRS. In addition to providing valuable data in the characterization of the geological conditions that existed prior to remedial activities, the method was also able to identify saturation changes associated with the in situ air stripping tests at the site. These changes in saturation ranged from a few percent up to 22 percent. The spatial resolution of the present system is approximately 1 m in size and saturation changes of about 5% can be seen.

The major technical challenges include: increasing the frequency and power output of the sources to increase resolution, improving the imaging and inversion codes to handle problems such as anisotropy, and decreasing the survey time through development of more rapid fielding sources and multi-station receiver strings. Times for fielding and interpretation should decrease significantly as the method develops further.

COLLABORATION/ TECHNOLOGY TRANSFER

This project is being performed by SNL in cooperation with Santerra Corporation. Santerra plans to develop the process for both environmental and oil and gas applications. A patent, "Advanced Downhole Periodic Seismic Generator", is co-owned by DOE, SNL, and Richard Hills.

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1.5 ELECTRICAL RESISTANCE TOMOGRAPHY

TASK DESCRIPTION

Electrical resistance tomography is used to create a 3-D visualization of in situ remediation processes, such as air stripping, bioremediation, and subsurface heating.

The task involves inducing an electrical current in the ground and measuring the potential distribution that results from the current flowing in the conductive subsurface. Pairs of electrodes are buried with some pairs acting as current source electrical dipoles and others acting as potential measuring dipoles (see Figure 1.5).

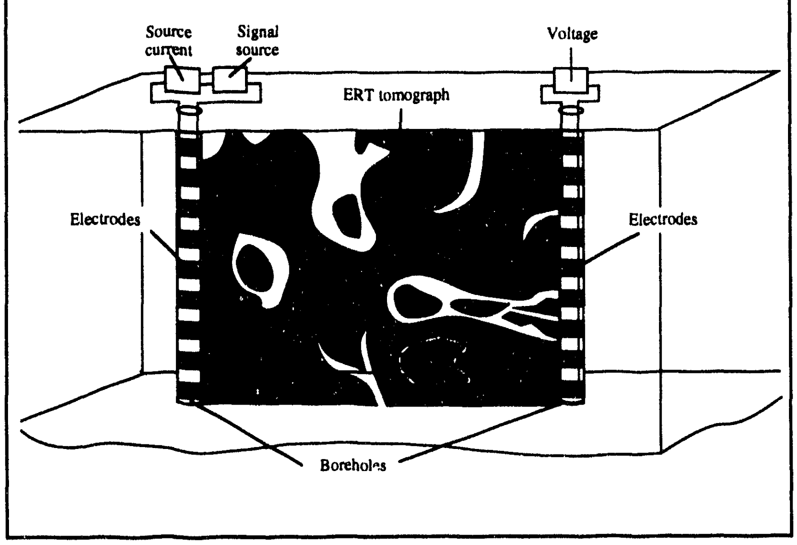

Figure 1.5. Electrical Resistance Tomography.

The resistivity distribution of the area in the vicinity of the borehole is then calculated. The current paths are dependent on the resistivity distribution within the geologic material in the vicinity of the borehole. The Electrical Resistance Tomography (ERT) inversion process involves solving both the forward and inverse resistivity problems.

The solution to the forward problem uses the finite element method to compute the potential electrical response in the soil due to the current source. The final products of the process are images (tomographs) showing the distribution of resistivity in the plane between the two boreholes used. By interconnecting a network of boreholes, a three dimensional representation of the area being investigated can be developed. By analyzing the resistivity images before, during, and after a remediation process, 3-D subsurface saturation changes can be inferred.

TECHNOLOGY NEEDS

Many remediation processes can interact with a contaminated area in ways that are difficult to predict; therefore, it is advantageous to be able to monitor this interaction so that the effectiveness of the remediation process can be assessed and process parameters can be modified to improve the effectiveness of the remedial process. There are no alternative methods currently available to image the fluid saturation distributions in two- and three-dimensional cross-sections of the subsurface. Point sampling of fluid saturation can be performed by acquiring core samples, and line measurements of fluid saturation along boreholes can be performed by using well-logging techniques.

Electrical resistance tomography is being developed as a tool to allow the 3-D visualization of underground processes such as those used in remediation. This technology, when used either separately or in conjunction with other geophysical, hydrologic, or geochemical methods, is a powerful tool in defining the initial conditions and the interactions between the remedial process and the contaminated environment.

At the Savannah River Site this technique has been effectively used to monitor the effectiveness of air permeation in the air injection and vacuum extraction tests.

ACCOMPLISHMENTS

This technique has been successfully tested at the Savannah River Site. The technique mapped changes in fluid saturation as the subsurface conditions were modified by the remedial process during air stripping. This technique has also been used to evaluate the effectiveness of the Radio Frequency Heating and Six-Phase Heating tests.

COLLABORATION/ TECHNOLOGY TRANSFER

Several companies are currently negotiating with LLNL to obtain licenses to use the technology and to cooperate in further development. British Petroleum has received a non-exclusive license to use the algorithm for the data inversion process.

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1.6 MICROBIAL MONITORING

TASK DESCRIPTION

This task involves the monitoring of microbial populations in soil and groundwater samples to evaluate the viability of in situ bioremediation. Microbial biomass is evaluated using measurements of colony forming units, Most Probable Number (MPN) techniques for methanotroph and methyltroph population, Phospholipid Fatty Acid (PLFA) analysis, and fluorescent antibody probes (FA). Microbial activity is assessed using acetate incorporation techniques and by measurement of TCE degradation in enrichments. DNA probes are used to enumerate specific groups of bacteria such as methanotrophs, toluene degraders, etc. Several new probes have been developed as part of this work.

TECHNOLOGY NEEDS

Many technologies designed to remediate sites contaminated with organic compounds either lead to an increase in the populations of bacteria that can degrade the compounds or increase in degradative populations as a secondary result of non-biological remediation (such as the biological benefits of venting-bioventing). This technology is needed to demonstrate the effectiveness of bioremediation and for demonstration of additional bioremediation benefits from other techniques. The various advanced monitoring techniques developed and applied as part of this task (DNA probe analysis, lipid analysis, activity and biomass measurements) all contribute to documenting the necessary changes in microbial populations. In addition, these techniques afford the opportunity to give feedback during the remediation operation so that procedures may be changed to increase the effectiveness of the remediation.

ACCOMPLISHMENTS

New DNA isolation and preservation methods were developed and used during the program (based on ion exchange resins) to allow for long term archiving of site DNA for future analysis. DNA probes were successfully used to detect the densities of specific functional groups important to the bioremediation process at the Savannah River Site. PLFA analyses were used to indicate the activity of the organisms present. FA tests provided key information about microbial community structure and function.

COLLABORATION/ TECHNOLOGY TRANSFER

This technology has been developed by Oak Ridge National Laboratory in conjunction with the University of Tennessee and the University of Minnesota. Presently there are no industrial partnerships involved in this task.

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Directional Drilling

Section 2.0

2.0 DIRECTIONAL DRILLING OVERVIEW

Directional drilling was developed by the petroleum and utility industries for resource recovery and utility and pipeline installation. Four directional drilling technologies were evaluated at the Savannah River Site for use in environmental restoration. These tests demonstrated the effectiveness of directionally drilled horizontal wells for air stripping, bioremediation and soil heating techniques (see Figure 2.0).

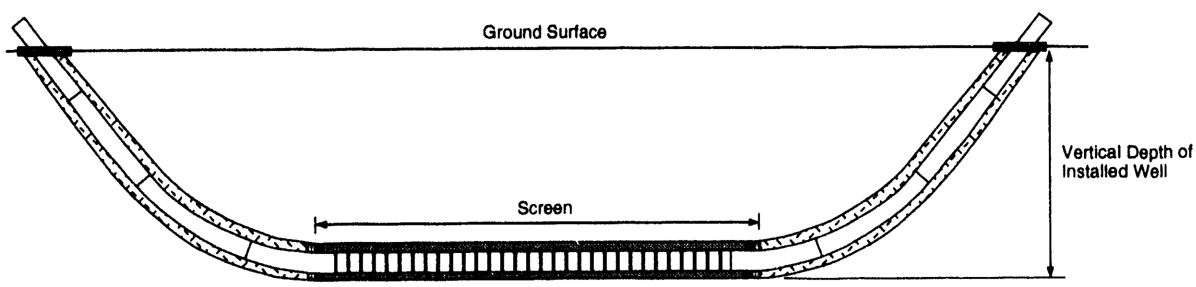

Figure 2.0. Continuous (Open) Horizontal Environmental Well Construction Diagram.

The four technologies that were tested as part of the ID are:

- Short Radius Drilling: This technology is a direct adaptation of petroleum industry methods and materials. Boreholes are deviated by downhole placement of a solid wedge to deflect the drill bit.

- Modified Petroleum Industry Drilling: This technology uses a standard petroleum industry drilling rig, but employs a steerable downhole motor, which allows greater flexibility to direct the borehole, and installs the casing during the drilling process.

- Utility Industry Compactional Drilling: This technology uses a set of hydraulic rams to drive the drill string, and a wedge shaped bit to direct the borehole.

- River Crossing Industry Drilling: This technology uses an inclined rotary drilling rig with a steerable hydraulic jet assembly. With this technology, a pilot well is installed and the final casing is installed through an overwash process.

The use of four different technologies to drill seven wells in the same area has provided a unique opportunity to assess the advantages of each technology, and develop criteria for matching technologies with specific site conditions.

Using directional drilling technology, a borehole can be placed horizontally through a contaminated zone to allow a greater volume to be remediated than could be achieved with vertically drilled wells. Directional drilling also allows for the remediation of areas generally inaccessible by vertical drilling technologies (such as beneath buildings, ponds, lagoons, or landfills). The entire lateral section of the horizontal well is screened to allow for a broader distribution of gas or liquid injection or extraction. The positioning of horizontal wells can be planned to conform to the distribution of subsurface contamination, optimizing the remediation system design by providing more surface area to contact the contaminant plume. Because most water-bearing formations are deposited in relatively thin but extensive zones, and their transmissivity in the horizontal direction normally exceeds their capability to transmit fluids vertically, horizontal wells provide more efficient fluid delivery and hence improve contaminant recovery.

Because the borehole in the horizontal section of directionally drilled wells is unstable, particularly in unconsolidated sediments, the borehole must be stabilized in some manner. The traditional methods for borehole stabilization are to use high density drilling fluid or to drive casing behind the drill bit as it advances. Because the drilling fluid used in drilling in contaminated sites must often be treated as hazardous waste, it is desirable to use drilling methods that do not require the use of fluids. Because of the curvature of the drilling assembly in directional drilling, casing driven after the drill bit can be damaged or ruined. To address these problems, cryogenic drilling is being developed in order to stabilize boreholes penetrating unconsolidated sediments. This technology freezes the moisture in the vicinity of the borehole to form an ice stabilized borehole while drilling is occurring.

2.1 DIRECTIONAL DRILLING TECHNOLOGIES

TASK DESCRIPTION

This task involves the adaptation of four petroleum and utility industries directional drilling methods for application to environmental restoration activities. The use of directional wells allows the remediation of areas not generally accessible by vertical drilling methodology and increases the efficiency of a variety of remediation, characterization, and monitoring activities.

In addition, it allows remediation activities to be performed without generating new contaminant pathways into unperturbed groundwater-bearing horizons. Tech-nologies that were also demonstrated and evaluated utilizing the seven horizontal wells that were installed during this task include in situ air stripping, bioenhancement for in situ bioremediation through injection of nutrients, and in situ radio frequency heating. They are described in separate sections. The four tested drilling technologies are:

- Short Radius Drilling (SRD). The basic equipment for this type of directional drilling is essentially the same as would be used for the installation of a vertical recovery or monitoring well. The borehole is drilled vertically using a non-steerable drill bit to the point where it needs to be deviated to achieve the desired configuration. At this point a wedge shaped block, referred to as a whipstock, is installed in the borehole such that it deflects the drill bit to the desired direction and inclination (see Figure 2.1a). The radius of curvature can be smaller than 150', but the relatively high cost encountered during the demonstration ($1255/foot) may hinder future application.

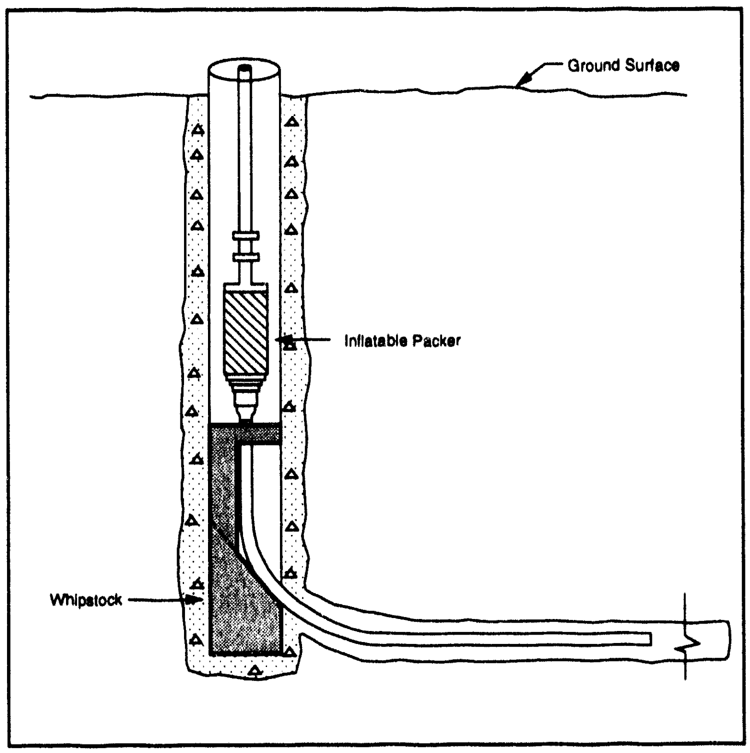

Figure 2.1a. Short Radius Environmental Horizontal Well (not to scale).

- Modified Petroleum Industry Drilling (MPID).The basic equipment for this type of directional drilling is essentially the same as would be used for the installation of a vertical well, except this system is modified to use a downhole motor assembly that can be inclined in order to deviate the borehole. The borehole is drilled vertically until it needs to be deviated to achieve the desired configuration. At this point the downhole motor assembly is inclined, through the use of eccentric stabilizers, to achieve the desired direction and inclination (see Figure 2.1b). While drilling two wells at the demonstration site, the MPID method was further modified to drilling in shallow, unconsolidated sediments.

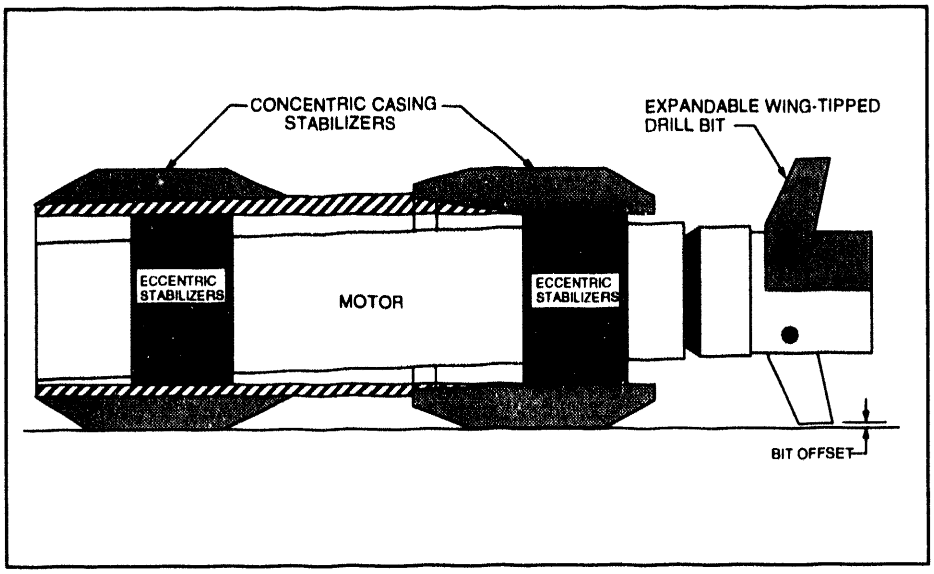

Figure 2.1b. Schematic of Down Hole Motor with Stabilizers Used in Modified Petroleum Industry Technology.

- Utility Industry Compactional Drilling (UICD). The basic equipment for this type of directional drilling is essentially the same as would be used for the installation of utility lines or pipelines. The borehole is advanced from an inclined platform using hydraulic rams and a wedge shaped bit. When the bit is rotated the borehole is advanced in a straight line. When the bit is advanced without rotation the borehole is deviated toward the untapered side of the bit. This technique allows the borehole to have multiple points of curvature and to be brought back to the surface after traversing the area through which the well is to be placed. Well casing is installed by pulling the casing back through the boring. The UICD method is advantageous in two respects: it generates a minimum of secondary waste, and requires a small amount of drilling fluids, minimizing the prospects for interference with soil vapor extraction.

- River Crossing Industry Drilling (RCID). The river crossing drilling technology demonstrated used a slant rig and a steerable hydraulic jet drill bit. The bit consists of an off-center jet through which mud is pumped. The jet of mud cuts through unconsolidated sediments and the bit advances in the direction the jet is pointed, or the drill string is rotated to advance in a straight line. A mud rotary bit can be used to advance through consolidated rock. Drilling proceeds by alternately advancing the drill string and then advancing a washover pipe over the drill string. When drilling is completed, the drill string is withdrawn leaving the washover pipe to provide a conduit to facilitate screen and casing installation. When the well is installed the washover pipe is removed. This technology allows drilling of long holes in a range of geologic conditions. In addition, borehole cave-in is much less of a problem with the use of the washover pipe.

TECHNOLOGY NEEDS

The major organic contaminant of waste sites at DOE facilities is chlorinated solvents. For instance, at the Savannah River Site, approximately 70 percent of the waste units are contaminated by VOCs.

In order to remediate these areas of VOC contamination, new drilling methods need to be developed that are more efficient, faster, and more cost effective than existing technologies.

The use of directional drilling technologies for environmental applications has significant advantages over remediation systems designed with conventional vertical wells. Specifically, the use of directionally drilled wells allows access to contaminated zones that are not otherwise accessible, and the amount of time to remediate sites can be reduced due to increase in extraction efficiencies when compared to vertical extraction wells. Additionally, directionally drilled wells can be used for fluid delivery, thereby expanding treatment options.

ACCOMPLISHMENTS

Four directional drilling systems have been successfully demonstrated at the Savannah River Site. The placement of horizontal boreholes was a requisite supporting technology for other demonstrations at the Savannah River Site. Using horizontal wells, significant improvements in remedial performance was achieved over baseline technologies in the air sparging/air stripping phases of this demonstration. Drilling costs of the MPID and UICD technologies were demonstrated to be generally on par with the corresponding costs incurred by industry for non-environmental well installation ($160-299/foot). The use of horizontal wells showed a five-fold increase in contaminant removal rate over that of vertical wells; further information is provided in Section 3.1.

COLLABORATION/ TECHNOLOGY TRANSFER

The horizontal drilling methods tested and modified in this demonstration were initially developed by the petroleum and utility industry. The application of the Short Radius and Modified Petroleum drilling technologies to the remediation of environmental contamination was carried out in partnership with Eastman Christensen Environmental. The application of the Utility Industry and River Crossing drilling technologies was carried out in partnership with Charles Machine Works and Cherrington Environmental Corporation, respectively. As a result of their successful demonstration, two new systems are currently commercially available for environmental applications, and over 30 environmental directional wells were installed by petroleum and chemical companies and by the Department of Defense (Tinker and Williams Air Force Bases).

Further utilization by the commercial sector is anticipated, as a result of information exchange in workshops hosted by the University of Wisconsin, Hanford, Wright-Patterson AFB, and the National Ground Water Association.

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2.2 CRYOGENIC DRILLING

TASK DESCRIPTION

This task provides a temporary method for stabilizing the borehole while drilling. Prevention of borehole collapse is an important consideration when drilling in unconsolidated sandy or gravelly sediments and in particular when drilling horizontal wells.

In cryogenic drilling, horizontal or vertical holes are drilled using super-cooled air as the drilling fluid, allowing holes to be stabilized by freezing a ring of soil around the borehole during the drilling process (see Figure 2.2). It results in a minimum alteration of the soil as well as minimization of surface wastes, due to the fact that liquid and volatile contaminants are frozen in place and the returns are limited to air and the volume of soil excavated from the hole. This method also precludes the need for the use of drilling liquids or hole stabilization additives.

TECHNOLOGY NEEDS

Many DOE and industrial sites are contaminated with toxic substances that have leaked into the near surface soils. In order to characterize and remediate these sites, boreholes must usually be drilled. One of the difficulties that arises in the drilling of near-surface boreholes in unconsolidated formations is the poor stability of the borehole. This can be an acute problem in drilling horizontal boreholes, which may be advantageous for economic reasons as well as necessary when surface obstacles prevent direct access. The problem is complicated further by the fact that it is desirable or required by environmental regulations, in some cases, that no drilling fluids be used to stabilize the boreholes.

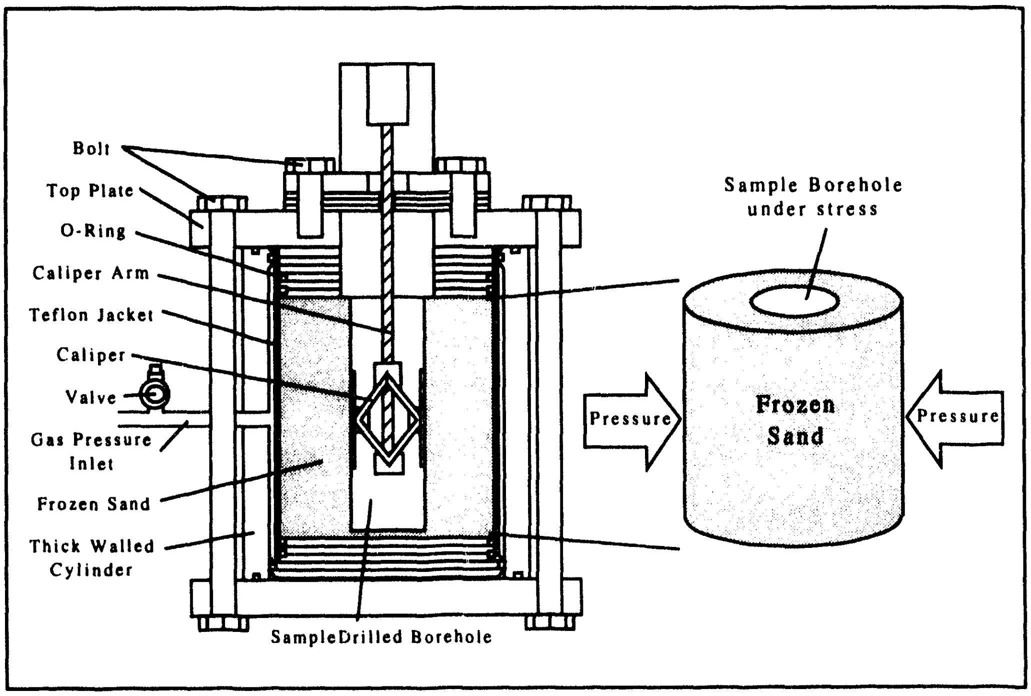

Figure 2.2. Frozen Borehole Test Apparatus.

ACCOMPLISHMENTS

This effort has focused on laboratory and bench-scale studies to evaluate the feasibility of future drilling demonstrations.

Because of the pending closeout of this ID, the demonstration of this technology is being pursued at other sites.

COLLABORATION/TECHNOLOGY TRANSFER

This technology is being developed by the University of California at Berkeley. There has to date been no collaboration with industry on this project, but a number of potential partners do exist.

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In Situ Air Stripping

Section 3.0

3.0 IN SITU AIR STRIPPING OVERVIEW

Remediation of contaminated soil and groundwater has traditionally meant the bulk removal of the contaminated media for treatment or controlled disposal. In situ air stripping focuses on the development of innovative solutions that can be used to replace the traditional pump-and-treat or excavation systems. Using air stripping, contaminants are extracted as vapor, reducing the treatment facilities needed to handle the large bulk of groundwater removed by pump-and-treat, and the energy requirements for pumping groundwater to the surface for treatment, and alleviating the potential need to dispose of the pumped groundwater.

In situ air stripping, as demonstrated at the Savannah River Site, is based on a simple mass transfer process using horizontal injection and vacuum extraction wells. Two subparallel horizontal wells are used: air is injected under pressure into the lower horizontal well (below the water table); air bubbles through the saturated zone, contacting dissolved, adsorbed, and/or separate phase contaminants, and into the vadose zone (the zone above the water table). Finally, the air and vapors are collected by the upper horizontal gas extraction well. During this process, contaminants are volatilized into the air stream and exit the subsurface through the upper horizontal well. The use of horizontal wells may provide better contact with contaminated subsurface strata than vertical wells.

3.1 VAPOR EXTRACTION/AIR SPARGING VIA HORIZONTAL WELLS

TASK DESCRIPTION

This task involves the injection or air via the deeper of a pair of horizontal wells and the recovery of displaced vapor through the second, more shallow well (see Figure 3.1). Utilizing this technique VOCs such as TCE, PCE, vinyl chloride, and Benzene, Toluene, and Xylene (BTEX) and their daughter products can be removed from the vadose zone. The horizontal wells that form the basis for this technology provide significant advantages over conventional air sparging and/or vacuum extraction with vertical wells or infiltration galleries.

The increased surface area treated by this method will allow more complete and more rapid removal of adsorbed VOCs and better recovery of the liberated vapor. Because of the larger surface area being treated the clogging of the formation, at or near the injection and recovery wells, is also minimized. The use of horizontal wells also allows remediation of relatively inaccessible areas such as beneath buildings, ponds or lagoons.

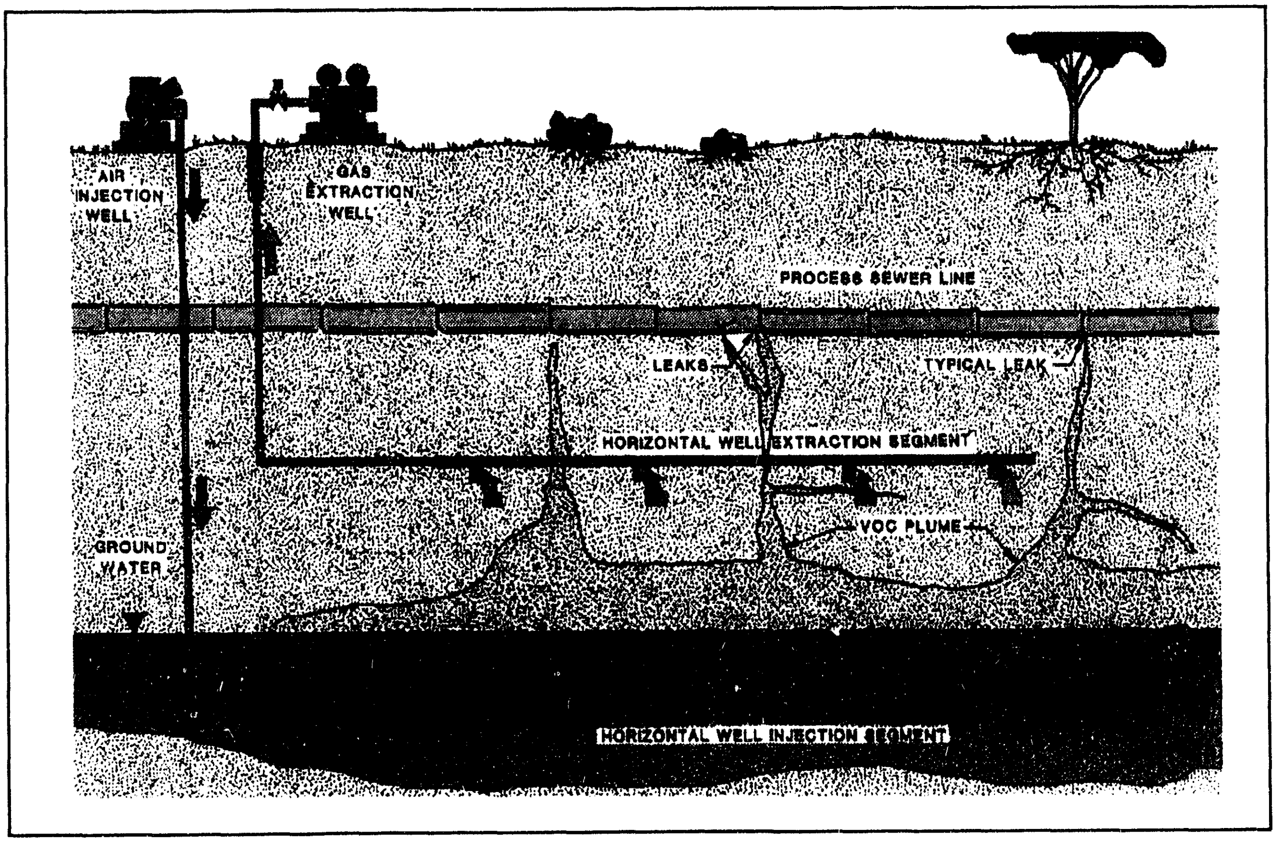

Figure 3.1. Schematic Diagram of Horizontal Well In Situ Air Stripping Concept.

TECHNOLOGY NEEDS

Air stripping via horizontal wells combines the functions of two baseline technologies: soil vapor extraction (SVE), targeting the vadose zone, and pump-and-treat, targeting the saturated zone. It is superior to the baseline technologies by virtue of eliminating the need for multiple vertical wells spread over several acres of land for extensive cleanup operations. It also significantly shortens the time required to complete cleanup operations. By actively injecting air (or other gas) to expel VOCs, it addresses a major limitation posed by the baseline technologies, where VOCs extraction declines over time due to diffusion-limited flow rates.

ACCOMPLISHMENTS

This technology has been successfully demonstrated at the Savannah River Site. Significant improvements in remedial performance were achieved over baseline technologies in the air sparging/air stripping phases of this demonstration. The use of horizontal wells showed a five-fold increase in contaminant removal rate over that of vertical wells. Over the 20 week test period, the horizontal wells removed 16,000 pounds of chlorinated solvents. This rate was equivalent to 11 pump-and-treat wells pumping at a rate of 500 gallons per minute. Analysis of groundwater samples from monitoring wells showed a significant drop of TCE and PCE concentrations in the groundwater after the completion of the demonstration. The use of horizontal wells for air sparging/vapor extraction at the Savannah River Site is predicted to result in a 40 percent cost savings compared to the use of conventional pump-and-treat technology.

COLLABORATION/ TECHNOLOGY TRANSFER

So far, thirteen license applications have been issued, and one full-scale system has been implemented in a commercial remediation site.

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3.2 BAROMETRIC PUMPING

TASK DESCRIPTION

The objective of the technology is to use the naturally induced pressure gradients between the surface and subsurface to create a flow path of contaminant laden air from the subsurface air in the vadose zone to the surface.

Barometric pumping is a subsurface technology that exploits the difference in air pressure between the surface and subsurface. If the two zones are connected by a well, air flow results. If the subsurface contains a volatile contaminant, this contaminant will be transported with the air flow to the surface. Since the driving force of this removal process (barometric pressure fluctuations) is provided naturally, the technology is inherently inexpensive. The key to this technology is to leverage the natural force to remediate contaminated areas by understanding the pressure relations between the surface and subsurface at a given site (see Figure 3.2).

This knowledge can be used to accurately install pathways (e.g. wells) to effect contaminant removal. The flow through these pathways can then be controlled using an intelligent valving system, or enhanced by wind or solar-powered pumping systems to optimize the performance of the technology.

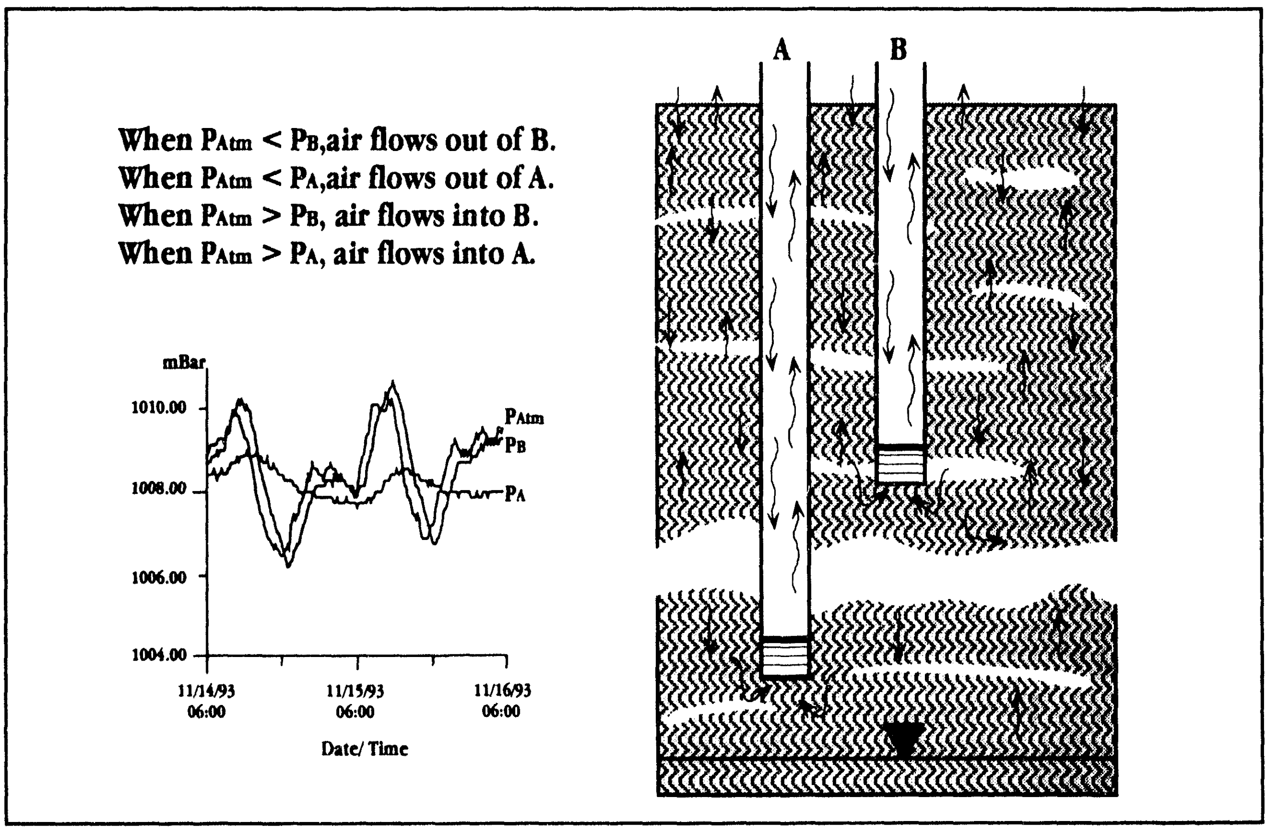

Figure 3.2. Barometric Pressure Fluctuations.

TECHNOLOGY NEEDS

One of the most significant problems affecting DOE sites is subsurface contamination by chlorinated solvents. These solvents tend to accumulate in the finer sediments of the unsaturated zone, where they serve as a continuing source of contamination to the water in the aquifers below. Barometric pumping technology is applicable to the removal of residual volatile contaminants in the unsaturated zone. In using the baseline technology (active soil vapor extraction) to remove contamination in the unsaturated zone, a point of diminishing returns is reached where a residual remains that is resistant to the active extraction process. At this point the baseline technology becomes progressively less cost-effective because of the expense of running the active extraction equipment (i.e., vacuum blowers) over a long period of time.

Barometric pumping technology is complementary to active vapor extraction. When the point of diminishing returns (because of mass transfer limitations) using active vapor extraction process is reached, the residual contaminant can be removed effectively and efficiently by tailoring the removal process to the physical and chemical limitations affecting the situation. The passive vapor extraction process using barometric pumping is a low-cost method to remove the recalcitrant residual contamination.

ACCOMPLISHMENTS

The system is operational in its most basic configuration. The dynamics of the process are being studied to optimize removal rate, to minimize plume dispersion, and to exploit the geology and geometry of given situations. Other barogradient-related technologies that are being investigated include:

- Plume control;
- low cost, low maintenance off-gas treatment; and
- passive bioenhancement.

COLLABORATION/ TECHNOLOGY TRANSFER

A CRADA has been established between Westinghouse Savannah River Company and JND Sterling, Inc., to enhance the natural barometric pumping using a solar pumping system. Other industry partners are expected because the cost of the technology is low. Collaborative efforts are also being planned with developers of off-gas treatment technologies at the University of Wisconsin. The lower flux rates of the barometric pumping process result in less stringent operational parameters required from the treatment technologies.

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Bioremediation

Section 4.0

4.0 BIOREMEDIATION OVERVIEW

This subprogram element focuses on the development of innovative solutions that can be used to enhance or replace the traditional pump-and-treat or excavation methods for remediation of contaminated soils and groundwater. In situ bioremediation technologies can destroy contaminants in place from both the vadose zone and groundwater. This approach utilizes the capability of indigenous microbial populations, once supplemented with injected nutrients, to decompose the VOCs into a mixture of innocuous constituents.

A promising technology for enhancement of remediation system performance is horizontal drilling, developed by the petroleum and utility industries and demonstrated at the Savannah River Site (see Section 2.0). The entire lateral section of a horizontal well is screened to allow for a broader distribution of injected nutrients. The use of horizontal wells provides more efficient nutrient delivery and hence improved contaminant destruction.

Another promising technology, applicable to the remediation of shallow contamination, is the selective planting of vegetation that enhances the native population of microbes that are capable of degrading VOCs into innocuous components. The identification of specific vegetation capable of stimulating VOC-degrading microbes and comparisons of the relative efficiencies of these plants in remediation, was carried out as part of the VOC in Non-Arid Soils ID.

Bioreactors afford a method for treatment of VOCs in groundwater that have been recovered by traditional pump-and-treat methodology. The VOCs in Non-Arid Soils ID includes development of operable bioreactors for such groundwater remediation. This work included process optimization in determining the most effective treatment rates and optimal nutrient levels for maximizing the microbial population.

4.1 IN SITU BIOREMEDIATION VIA HORIZONTAL WELLS

TASK DESCRIPTION

This task involves the stimulation of indigenous microorganisms to degrade TCE, PCE, vinyl chloride, and BTEX and their daughter products in situ by injection of air or a methane and nutrient mixture into the contaminated zone to facilitate in situ bioremediation (see Figure 4.1). The horizontal wells that form the basis for this technology provide significant advantages over conventional in situ bioremediation with vertical wells or infiltration galleries. This technology utilizes a pair of horizontal wells whereby air or an air/ methane/ nutrient mixture is injected into the formation via the deeper well and exhaust gases are recovered via the shallower well, and treated if necessary. The increased surface area being subjected to treatment by this method allows for better delivery of nutrients and better recovery of gases and water, as well as minimizing the effects of formation clogging and plugging due to microbial overgrowth.

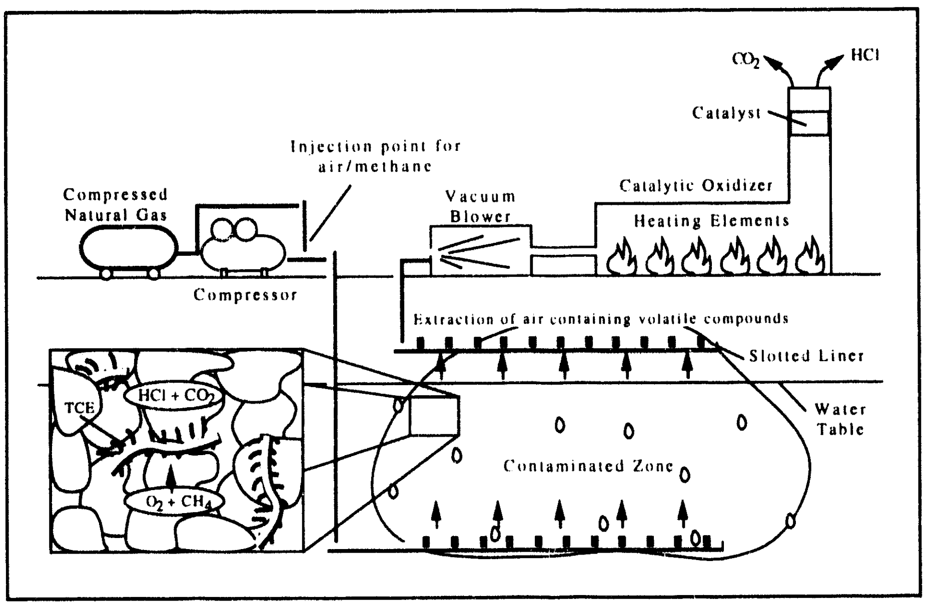

Figure 4.1. In Situ Bioremediation.

TECHNOLOGY NEEDS

In situ bioremediation coupled with air stripping is expected to significantly reduce the time required to complete the remediation because bioremediation provides a second simultaneous pathway for removal (destruction) of the VOCs. The stimulated indigeneous microorganisms are capable of accessing VOCs in the vadose and saturated zones that may be difficult to remove by air stripping alone. Because in situ bioremediation technology is based on biological destruction of the contaminants at the site, risks normally associated with handling, transporting, and treating contaminated residuals are avoided.

ACCOMPLISHMENTS

This technology has been successfully demonstrated at the Savannah River Site. Significant improvement in remedial performance was achieved over baseline technologies in both the air sparging/air stripping and bioenhancement phases of this demonstration. Evidence of successful biostimulation at the demonstration included:

- Complete consumption of the injected methane at the 1 percent injection level;
- Increased density of methanotrophic organisms by as much as five orders of magnitude;
- Decreases in the groundwater VOC concentrations in the same monitoring wells that showed increases in methanotrophic bacteria populations;
- Increased biomass, mineralization, and enzyme activities in groundwater from monitoring wells;
- Increased carbon dioxide concentrations in the extraction well and vadose zone piezometers; and
- Decreases in TCE and PCE concentrations in sediments collected after the initial methane injection campaign.

COLLABORATION/TECHNOLOGY TRANSFER

This technology was developed in partnership with ECOVA, Gas Research Institute, Auigas, Heritage Environmental and Groundwater Technologies. ECOVA is negotiating with the Japanese Research Institute to perform a similar demonstration in Japan.

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4.2 IN SITU BIOREMEDIATION OF ORGANIC CONTAMINATED SURFACE SOILS VIA VEGETATION ENHANCEMENT OF MICROBES IN THE RIZOSPHERE

TASK DESCRIPTION

Indigenous microorganisms are being stimulated to degrade TCE, PCE, and their daughter products in soils and groundwater by planting and cultivating specific types of trees and plants (see Figure 4.2). These bacteria and fungi associated with the roots of these plants fortuitously degrade contaminants in the soil. The stimulation of these microbes by the roots of the plants provides a solar nutrient source. Methanotrophic organisms have been demonstrated to degrade TCE completely to carbon dioxide and chloride.

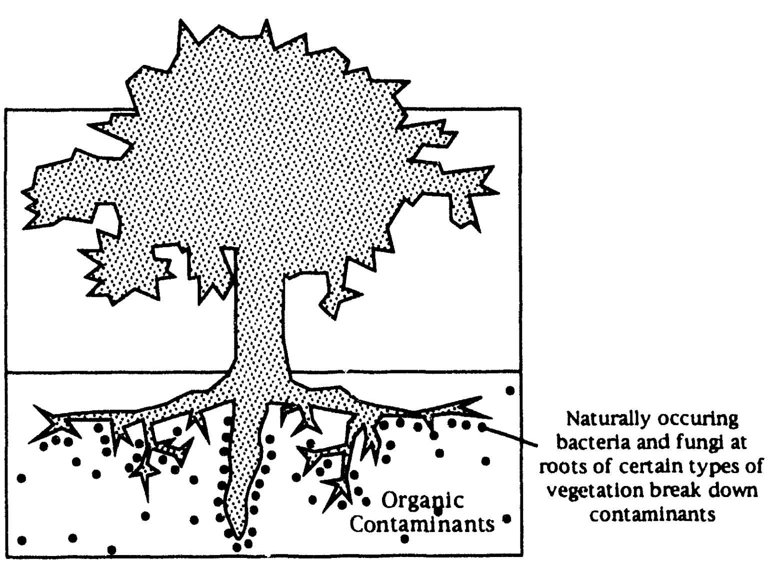

Figure 4.2. Vegetation Enhancement for Bioremediation.

TECHNOLOGY NEEDS

Utilizing the existing vegetation to encourage soil microorganisms to degrade TCE/PCE provides a method for remediating soils at minimal costs and reduced health risk. To date, studies have shown that TCE/PCE is not taken up by vegetation; nor are these compounds toxic to vegetation even at very high concentration.

ACCOMPLISHMENTS

To date, this technology was demonstrated at the SRS to double the rate of biodegradation of TCE and PCE in the soil. It was documented that the TCE and PCE were not taken up by the vegetation and that the microorganisms associated with the plant roots completely mineralize TCE and PCE to carbon dioxide and chloride.

COLLABORATION/TECHNOLOGY TRANSFER

This process is being developed jointly with the Gas Research Institute.

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4.3 DNA EXTRACTION FROM SEDIMENTS, DNA HYBRIDIZATION AND CULTURAL ENRICHMENT

TASK DESCRIPTION

This task involves both the assessment of the performance of bioremediation activities, correlation of DNA probe, and culture data (see Figure 4.3). The tasks involved are enrichment techniques to develop cultures better capable of degrading specific contaminants and testing a technique for the identification of the amount of DNA homologous to the gene being used as a DNA probe (where the gene is for an enzyme known or suspected to degrade TCE or PCE). For the enrichment task, plate count enumerations, from water and sediment samples, were performed for total heterotrophs on 10 percent peptone-tryptone-yeast extract-glucose agar. Selective enrichment for actinomycetes and fungi were carried out on actinomyces isolation agar and Rose-Bengal agar, and selected colonies were inoculated to headspace vials to determine if they could degrade TCE or PCE. Enrichments for other physiological groups were set up in headspace vials with appropriate electron donors, electron acceptors, and 0.1 micromole of TCE and PCE to enrich for methane-oxidizers, propane-oxidizers, ammonia-oxidizers, fermentors, Iron(III)/manganese(VI)-reducers, sulfur-reducers, and methanogens. Degradation of TCE and PCE was assayed by gas chromatography, with degradation of greater than 90 percent of the TCE and PCE relative to a sterile control constituting a positive result. For the DNA probe analysis task, there are

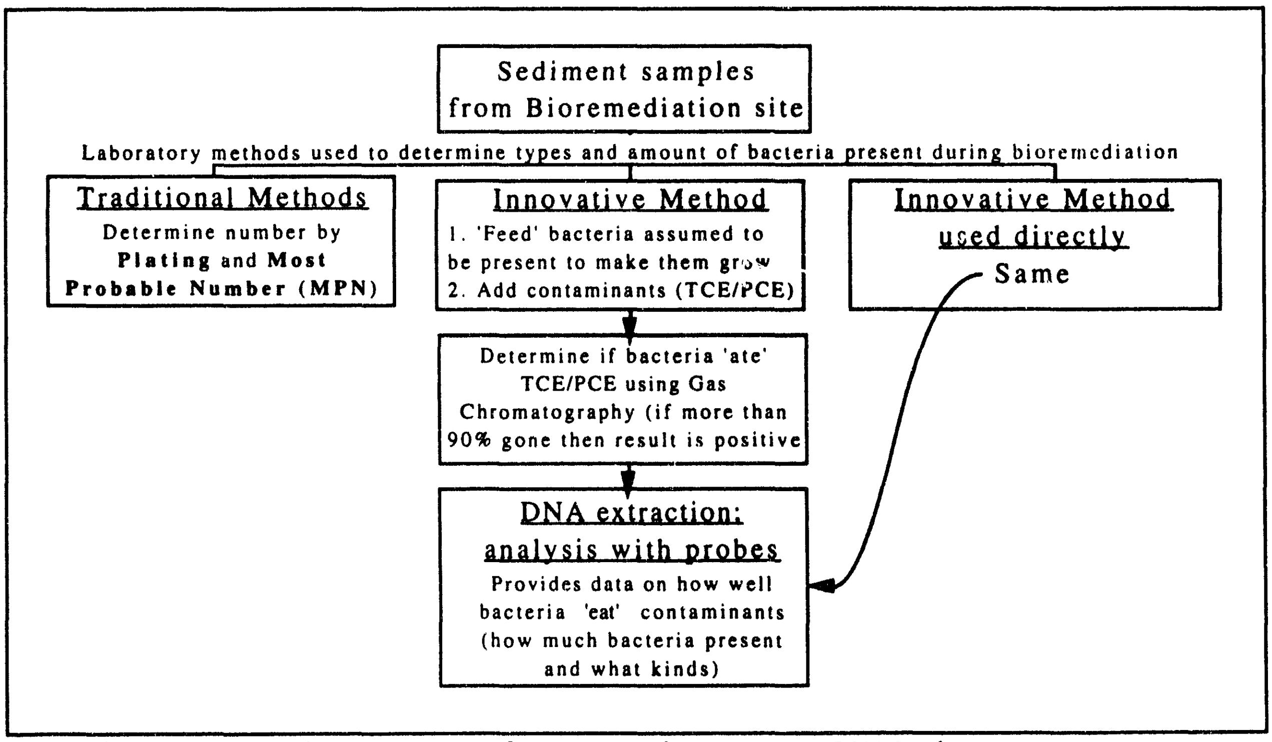

Figure 4.3. Organism Characterization for Bioremediation Using DNA Probes.

three cloned enzyme systems that are known to degrade TCE and PCE; these are soluble methane monooxygenase, toluene monooxygenase, and dioxygenases. Haloalkane dehalogenase and haloalkanoic acid dehalogenase do not degrade TCE or PCE, but may be able to degrade their metabolites. These enzymes are used to identify organisms that may be able to degrade TCE or PCE.

Community DNA is extracted directly from the initial sediment and water. DNA is denatured and bound to filter membranes for hybridization with probe DNA. Plasmid DNAs encoding the enzyme systems listed above are purified, and DNA encoding the enzymes are radiolabeled to produce probe DNA. The denatured community DNA and denatured probe DNA are allowed to hybridize to each other under conditions that allow complementary strands to bind to each other. The radioactive signal on the filter membrane is quantified to determine the number of microorganisms in the environmental sample and the enrichment culture that possess the genes specified by the DNA probe.

TECHNOLOGY NEEDS

With the use of bioremediation techniques, characterization of the microbial response to these techniques is needed to assess and demonstrate successful bioremediation. Classic enumeration and enrichment techniques are used to measure the density of certain physiological types of microorganisms likely to contain TCE or PCE degradative ability. These techniques measure only organisms that can grow in the laboratory. The techniques tested under this task allow the assessment of organisms that cannot grow under laboratory conditions, allowing a better assessment of the microbial community in bioremediation applications.

ACCOMPLISHMENTS

DNA probes have been demonstrated to directly detect specific functional groups of bacteria responsible for biodegradation of TCE in the soil. This technology has also demonstrated that cultural enrichment can be useful to detect bacteria capable of degrading TCE.

COLLABORATION/ TECHNOLOGY TRANSFER

The described techniques were in part already established. As part of this project, Washington State University developed and improved DNA extraction protocol.

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4.4 METHANOTROPHIC BIOREACTORS FOR BIOREMEDIATION OF CHLORINATED ORGANICS IN GROUNDWATER AND WASTEWATER

TASK DESCRIPTION

Indigenous microorganisms are being stimulated to degrade TCE, PCE and their daughter products in groundwater by pumping the contaminated water through a fermentor. The bacteria in the fermentor are attached to a substrate that allows them to adsorb and degrade the contaminants as they pass by (see Figure 4.4). The principal source of carbon and energy for the bacteria is methane; thus, methanotrophic organisms dominate in the optimum environment. Methanotrophs have been demonstrated to degrade TCE completely to carbon dioxide and chloride.

TECHNOLOGY NEEDS

The bioreactor technology provides a method for remediating groundwater not only as part of the remediation of contaminated sites, but also for the cleanup of waste water before discharge, and for destroying chlorinated solvents present in the raw water sources that are used for community supplies. Concerning waste abatement, this technology has been demonstrated for hydrocarbons other than TCE/PCE, e.g., toluene, xylene, and benzene. Cost analyses of methanotrophic bioreactors compared with air stripping that is combined with carbon adsorption of the air-stream and direct carbon adsorption from the water have suggested that for several TCE concentrations

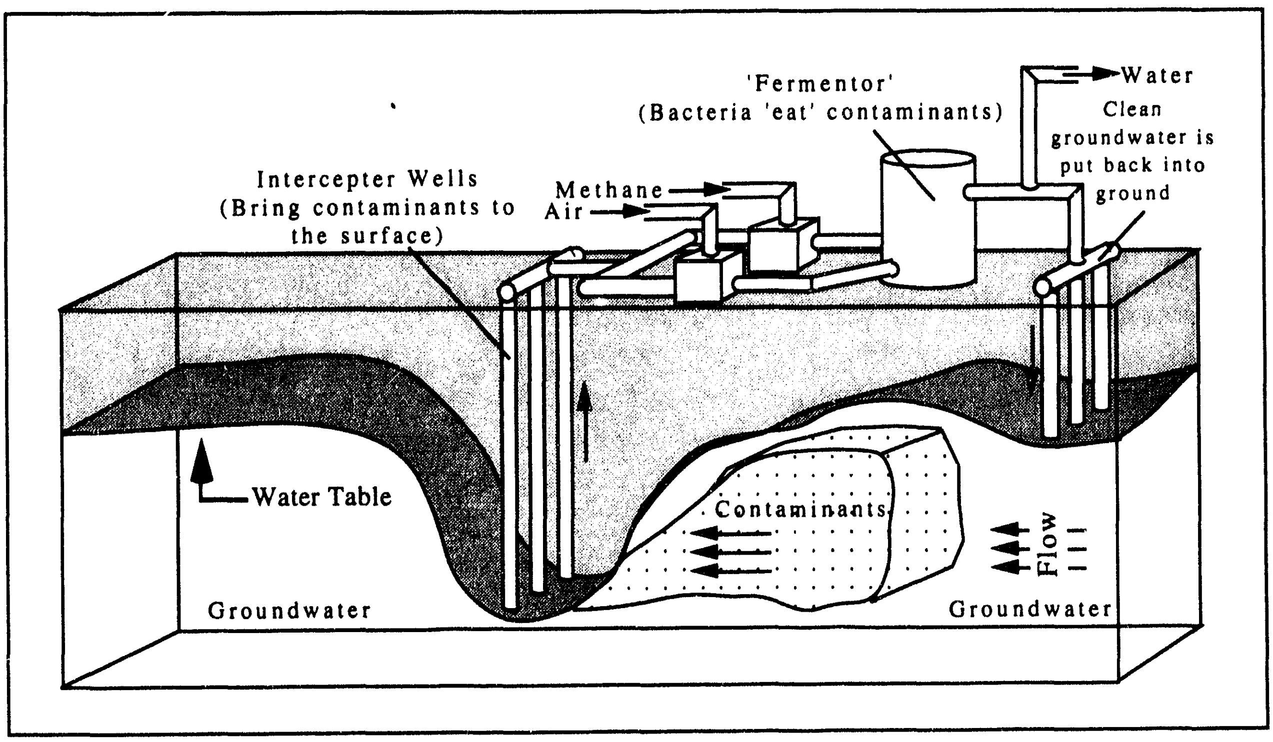

Figure 4.4. Above-Ground Methanotrophic Bioremediation.

and flow rates, the methanotrophic system would save 40-60% over conventional technologies. Similar savings are anticipated for in situ bioremediation of TCE alone or in combination with bioreactors.

ACCOMPLISHMENTS

This technology has been successfully demonstrated at pilot scale. These tests lasted more than one year and operated 24 hours a day with high reliability.

COLLABORATION/ TECHNOLOGY TRANSFER

Radian, Gas Research Institute, Michigan Biotechnical Institute, and Envirex are all partners in the development of this technology.

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In Situ Heating

Section 5.0

5.0 IN SITU HEATING OVERVIEW

Retrieval has traditionally meant the bulk removal of the contaminated media for treatment or controlled disposal. This subprogram element focuses on the development of methodologies that can be used to enhance the expulsion of contaminants or the destruction of contaminants in place from both the vadose zone and groundwater. Where fine-grained sediments strongly adsorb contaminants, expulsion can be enhanced by the application of heating methods.

Both radio frequency (RF) and electrical resistance (alternating current (AC)) heating are more effective in expelling VOCs from low permeability, clay-rich zones as compared to alternative forms of subsurface heating (e.g., hot air or steam injection). The electrical properties of the contaminated clay zones have been shown to preferentially capture the RF or AC energy, focusing the applied power precisely in the target zones. By selectively heating the clays to temperatures at or above 100°C, the release and transport of TCE and PCE will be enhanced as a result of several factors, including: (1) an increase in the contaminant vapor pressure and diffusivity; (2) an increase in the effective permeability with the release of water vapor and contaminant; and (3) enhanced removal from in situ steam stripping by the water vapor generated from heating to temperatures in excess of 100°C. Vapor released in the heated zone will be removed through a vacuum extraction well.

The radio frequency method tested at the ID entailed the placement of a RF transmitter in a horizontal well. The radio frequency is selected to excite molecules present and thereby produce heat. This heating volatilizes the VOCs, allowing their recovery via the screened portion of the same well.

Another system, recently demonstrated, involves in situ heating by the use of six-phase electrical current being applied to the soil using six vertically emplaced electrodes surrounding a single recovery well. The electrical current causes resistive heating of the soil column and the volatilization of VOCs, which can then be recovered via the central well.

5.1 SIX-PHASE SOIL HEATING

TASK DESCRIPTION

This task involves the enhancement of soil vapor extraction techniques by heating a clay-rich soil to increase the vapor pressure. This process is accomplished by placing six electrodes in a circle surrounding a central vent (see Figure 5.1). Six-phase Alternating Current (AC) is then applied to the electrodes, each electrode receiving a single phase. Each electrode is equipped with a separate transformer wired to provide each electrode with a separate AC phase. This ensures a more uniform distribution of electrical currents in the soil, so that additives that would normally be needed to make the soil electrically conductive are not required. Because the key to resistive heating is to maintain a small amount of moisture in the zone to conduct the electricity, splitting the current into six phases rather than the normal three phases prevents overheating and excessive drying around the electrodes. Resistive heating dissipates the electrical energy in the contaminated zone and vapor is withdrawn from the central vent as in conventional soil vapor extraction.

The six-phase heating process is quite rapid, on the order of weeks or months for many sites, and is expected to require minimal costs for on-site labor. Energy requirements are also low compared to incineration and other thermal treatment methods, as the need to heat soils past 100°C is avoided.

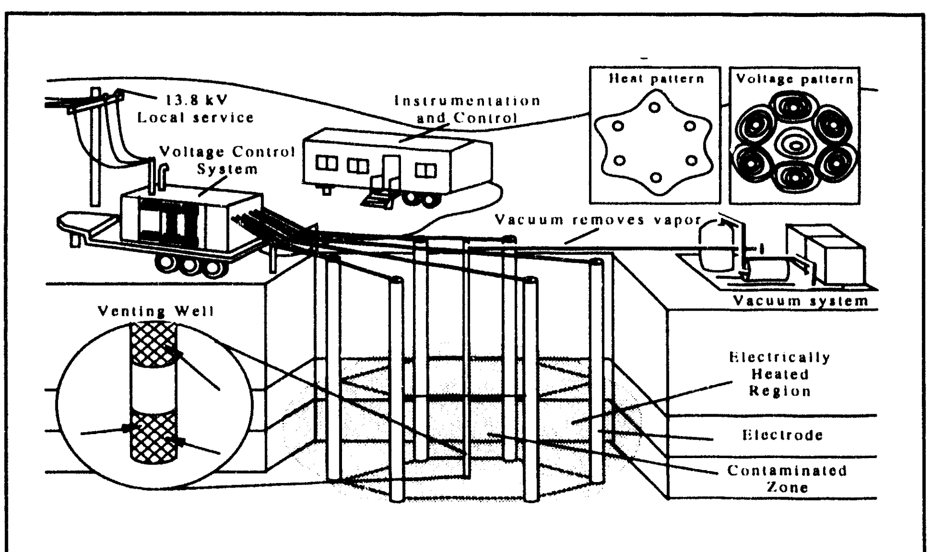

Figure 5.1. Six-Phase Soil Heating.

TECHNOLOGY NEEDS

Most DOE sites have been contaminated with volatile organic compounds, including chlorinated solvents like TCE and PCE, non-chlorinated solvents like methyl ethyl ketone (MEK), benzene and acetone, and fuels like gasoline. Techniques for retrieving these VOCs from soils are being developed and demonstrated at various Integrated Demonstrations. These techniques include in situ air sparging, dynamic stripping, radio frequency heating, electromagnetic heating and six-phase soil heating. All of these techniques remove VOCs as vapors from contaminated soils. The baseline technologies are soil vapor extraction within the vadose zone, and pump-and-treat for groundwater. These technologies are limited by the mobility of the contamination in the subsurface. Six-phase soil heating increases mobility and should result in faster and more complete removal of contamination from less permeable soils.

ACCOMPLISHMENTS

In FY92, a small-scale field test of six-phase soil heating was successfully performed at the in situ vitrification site in the 300-Area of Hanford, Washington. The test heated a 20-ft diameter cylinder of uncontaminated Hanford soil to a 10-ft depth. The test ran unattended, using a computer-based system. After 50 days of heating, soil at a 4 to 10 foot depth reached an equilibrium temperature of 76.5°C. A 1/10 pilot-scale test using TCE and PCE-contaminated soils representative of the M Area basin at the Savannah River Site was conducted in FY93, and resulted in 99.995% removal of both contaminants. The full-scale field test of this demonstration at the M Area is also complete.

COLLABORATION/ TECHNOLOGY TRANSFER

This technology was developed by Pacific Northwest Laboratory. Currently there are no industrial partnerships, but a number of industrial firms have expressed interest in licensing the technology.

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5.2 IN SITU RADIO FREQUENCY HEATING

TASK DESCRIPTION

This technology involves the use of radio frequency (RF) energy to heat vadose zone sediments through a dielectric heating mechanism in which the application of an electromagnetic field physically distorts the molecular structure of the material (see Figure 5.2). The physical distortion is transferred into mechanical and then into thermal energy. The frequencies applicable for heating earthen materials and mineral formations lie between .01 and 60 MHz. The most commonly used frequencies, 6.78 and 13.56 MHz, are those set aside for use by industrial, scientific and medical equipment. Because of its ability to penetrate and couple with the soil, RF heating is faster than convective or conductive heating modes.

The RF heating project is centered around the use of a dipole applicator developed and patented by KAI Technologies, Inc. The single wand applicator, approximately 20 feet in length, is constructed of flexible copper coaxial cable to facilitate the use of a horizontal well drilled to dissect and traverse a shallow clay lens located from 35 to 40 feet below the ground surface.

Computer modeling was performed to determine the output impedance history and temperature contours. The modeling was based on laboratory measurements of representative

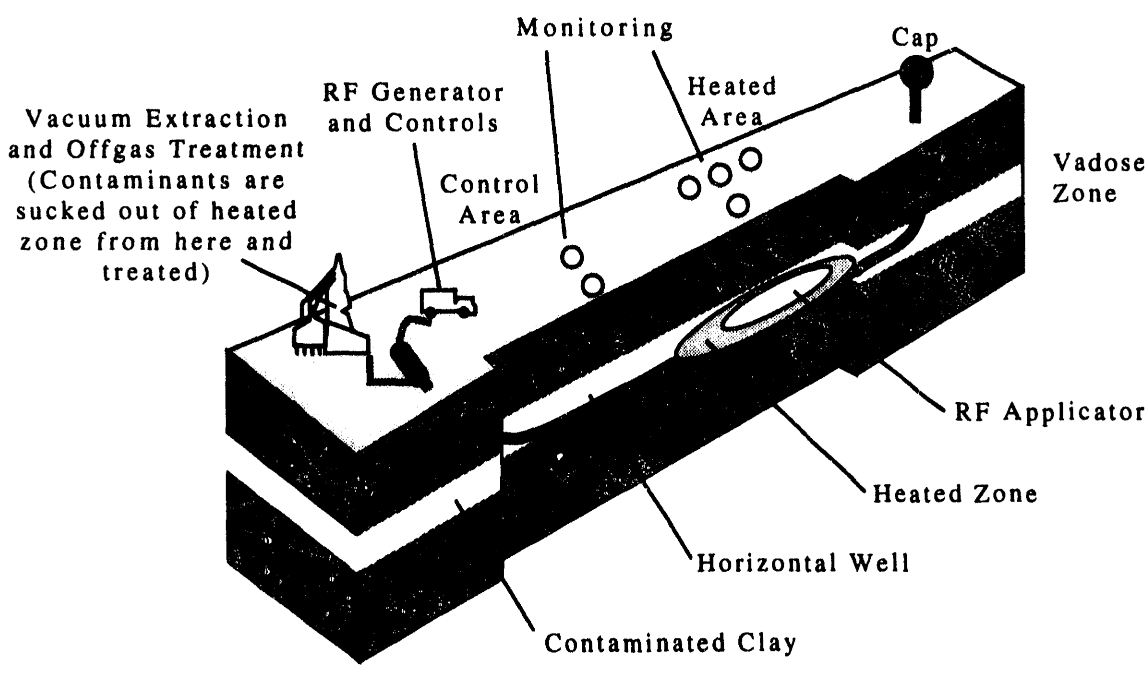

Figure 5.2. Radio Frequency Heating.

soils and assumes a homogeneous medium with no heat loss. The results predict that after 21 days a volume of approximately 1,000 cubic feet will be heated to a temperature in excess of 100°C.

The field test includes three separate operations: 1) a "cold" pump test to establish a baseline performance for the vacuum extraction system without heating; the duration of this test is approximately one week; 2) a heating phase with the RF hardware operation for approximately four weeks; and 3) a cool-down phase to monitor changes in off-gas venting as the subsurface temperature returns to ambient.

TECHNOLOGY NEEDS

Numerous sites across the country, both commercial and within the DOE Complex, have significant levels of organic contaminants within the unsaturated soil zone. Chlorinated volatile organic solvents can be held within this zone, especially in clays and organic materials. These zones slowly release the solvents and provide a long-term source for groundwater contamination. Despite the volatile nature of these contaminants, the clays severely limit the mass transfer rates of the material. With this mass transfer limitation, the use of soil vacuum extraction requires a long period of operation and the placement of numerous wells. By selectively heating the soils, the release of the solvents from the soil can be significantly enhanced.

ACCOMPLISHMENTS

The RF heating demonstration integrated RF application and vacuum extraction from a single, horizontal well. The horizontal well was drilled through a contaminated clay layer located between the M-Area and an adjacent seepage basin at the SRS. Off-gases drawn from the well were destroyed with a skid-mounted thermal-catalytic oxidation system.

During the 21-day demonstration period, approximately 11,000 kilowatt-hours of RF energy were successfully coupled to the subsurface clay layer, and heated a sediment volume of approximately 1500 cubic feet to greater than 600°C. Wellhead concentrations of VOCs increased during the heating phase, indicating an increase in liberation of VOCs from the soil; over 170 kg of VOCs were successfully extracted over the course of the demonstration. Two significant findings made during the test impeded the full assessment of the technology. First, a steam block formed downhole when temperature exceeded 100°C. This vapor block limited the achievable vacuum and, therefore, reduced the extractive rates. Second, the choice of casing material, and in particular, the temperature limits of the fiberglass screen, reduced the applicator power output. To control downhole temperatures at acceptable levels, the duty cycle of the applicator was lowered by 20%. In addition, liquid water infiltration into the well restricted the vapor flow from the well, and required modifications of the RF applicator control programming.

COLLABORATION/TECHNOLOGY TRANSFER

This technology was developed in partnership with KAI Technologies. Others have expressed interest in partnerships or licensing this technology.

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Off-Gas Treatment

Section 6.0

6.0 OFF-GAS TREATMENT OVERVIEW

The overall goal of this subprogram is to develop effective methods for the treatment of chlorinated volatile organic compounds (CVOCs) in the off-gases produced by air sparging and vacuum extraction of contaminants.

Atmospheric emissions of CVOCs at DOE facilities and throughout the United States will need to be abated in order to comply with the Clean Air Act Amendments of 1990. Current technologies for controlling atmospheric emissions of CVOCs include carbon adsorption, catalytic oxidation and incineration. Each of these control methods is best suited for particular conditions. For example, carbon adsorption is best suited for short-term, low mass flux applications, while incineration is best for long-term, high mass flux conditions. Catalytic oxidation works well for conditions between these two extremes. However, carbon adsorption is merely a transfer of the waste from one medium to another; incineration generates chlorinated products of incomplete combustion as well as NO_x, and the other oxidation technologies consume appreciable energy. Therefore, several technologies have emerged for providing decomposition of CVOCs into innocuous compounds, while at the same time potentially reducing operating costs.

The purpose of this testing program is to systematically evaluate emerging technologies for the abatement of atmospheric emissions of CVOCs. Classes of technologies and the outfits responsible for their development (in parenthesis) include: 1) free-radical oxidation processes, such as high-energy corona (PNL), cold plasma (LANL), Xenon Flashlamps (Purus), photocatalytic oxidation (NuTech and the University of Wisconsin), and ozone-enhanced oxidation process (Ultrox); 2) carbon regeneration processes, such as desorption and regeneration process (NuCon), and 3) catalytic oxidation (Johnson & Matthey's, Allied Signal). Although this report highlights the high-energy corona and VOC recycle/recovery, several other technologies are being demonstrated and data will be available towards the end of FY94.

6.1 HIGH-ENERGY CORONA

TASK DESCRIPTION

This thermal catalytic oxidation technology uses high-voltage electricity to destroy VOCs at room temperature. The equipment consists of a High-Energy Corona reactor in which the VOCs are destroyed, inlet and outlet piping containing process instrumentation (humidity, temperature, pressure, contaminant concentration, and mass flow rate), means for controlling inlet flow rates and inlet humidity, and a secondary scrubber for removing chloride and hypochlorite species when chlorinated organics like TCE and PCE are destroyed.

The reactor is a glass tube filled with glass beads through which the contaminated off-gas is passed (see Figure 6.1). Each reactor is 2 in. in diameter, 4 ft. long and weighs less than 20 lb. A high-voltage electrode is placed along the centerline of the reactor, and a grounded metal screen is attached to the outer glass surface of the reactor. A high-voltage power supply connected across the electrodes provides 0 to 50 mA of 60 Hz electricity at 30 kV. The electrode current and power are varied depending upon the type and concentration of contaminant being treated. Each reactor can process up to five standard cubic feet per minute.

TECHNOLOGY NEEDS

Most DOE sites and many industrial sites have been contaminated with VOCs, including chlorinated solvents like TCE and PCE, non-chlorinated solvents like methyl, ethyl ketone (MEK), benzene and acetone, and fuels like gasoline. Techniques for retrieving these VOCs from soils are being developed and demonstrated. The vapors recovered by these techniques must, in most cases, be treated (collected or destroyed) prior to releasing the cleaned soil off-gas to the atmosphere. The High-Energy Corona is one of a number of approaches DOE is testing to effect this removal or destruction.

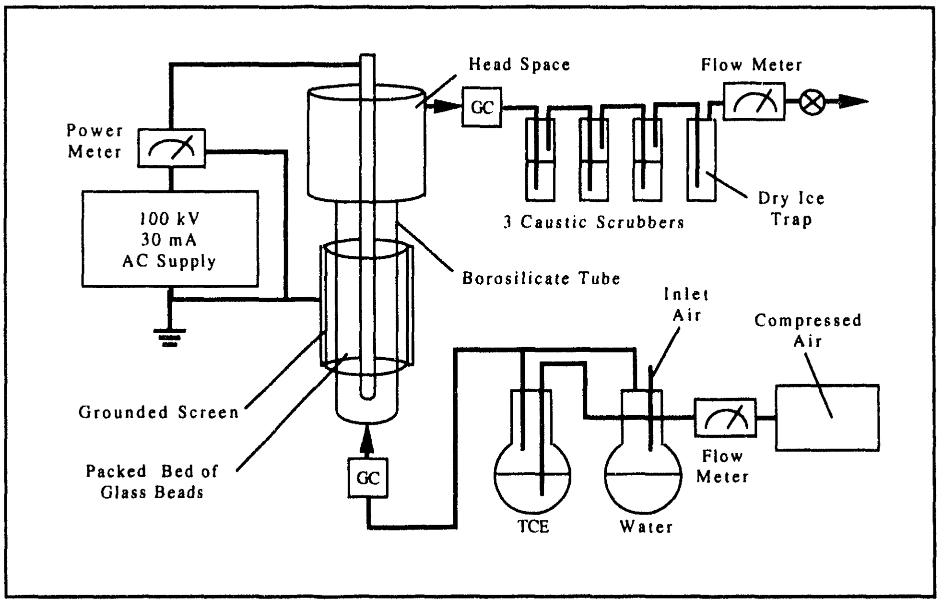

Figure 6.1. Low-Temperature Plasma Reactor.

ACCOMPLISHMENTS

This technology has successfully demonstrated 99% destruction of TCE at inlet concentrations to 2000 ppmv, and flow rates up to 5 scfm. This was accomplished without generating detectable chlorinated organic byproducts, phosgene and ozone, and with total NOx around 1 ppm. A number of configurations and flows were tested to determine the optimum operating conditions. Energy costs were demonstrated to be low, typically less than 7 kW-hr/lb TCE destroyed. This technology won the prestigious R&D 100 award in 1993.

COLLABORATION/ TECHNOLOGY TRANSFER

This technology was developed by Pacific Northwest Laboratory. Currently three US firms have expressed an interest in forming partnerships for the commercialization of this technology.

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6.2 VOLATILE ORGANIC COMPOUND RECYCLE/RECOVERY

TASK DESCRIPTION

This process consists of activated carbon adsorbers located at each extraction well, plus a truck-mounted Brayton cycle heat pump (BCHP) to regenerate the adsorbers on a periodic basis (see Figure 6.2). The VOC-laden air from the well is passed through the carbon bed, adsorbing the VOCs. When the carbon bed becomes saturated, hot nitrogen from the regenerator is used to desorb the VOCs. The nitrogen is then passed through a chiller, is compressed, and is then cooled in a recuperator, where 50 to 80 percent of the organics are removed.The partially depleted nitrogen stream is then expanded through a turbine, lowering the temperature down to minus 101°C, to condense the remaining VOCs. The now clean nitrogen passes through the recuperator to cool the incoming VOC-laden nitrogen.

TECHNOLOGY NEEDS

Many DOE sites as well as private industrial sites have soil and/or groundwater that are contaminated with organic compounds. These sites will have to undergo remediation in the future. One method of remediation is vapor vacuum extraction, but air quality regulations requires that the exhaust be free of organic vapors before they are vented to the atmo-

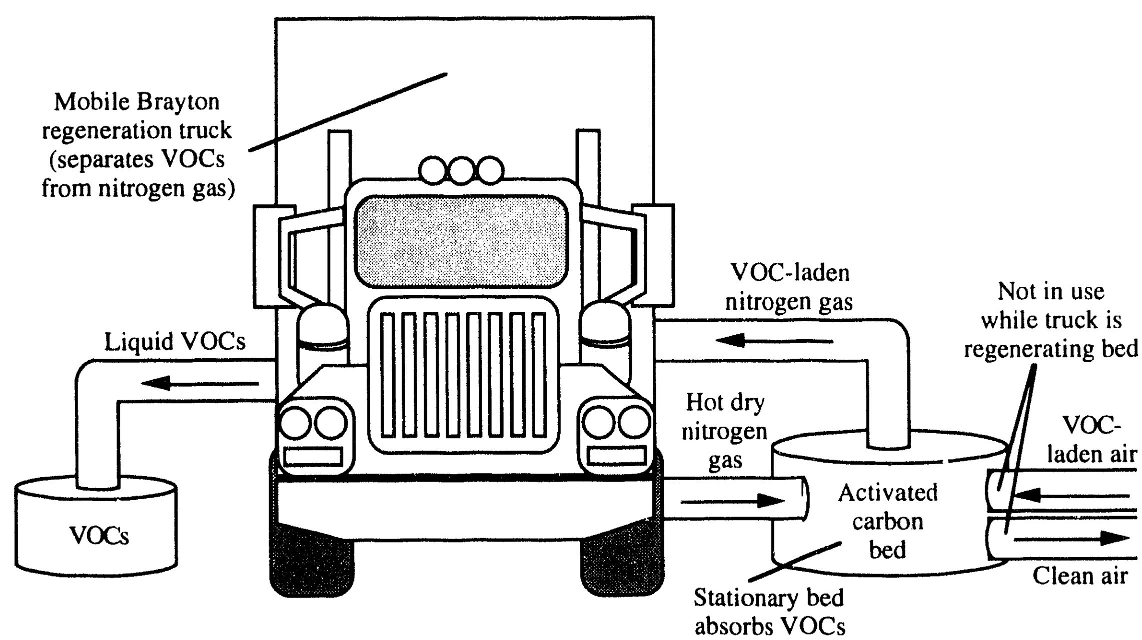

Figure 6.2. Volatile Organic Compound Recovery and Recycle.

sphere. Therefore, a method of organic vapor recovery or destruction will be required before vapor vacuum extraction can be used. The BCHP technology provides a lower cost alternative to carbon canisters, which must be shipped to a regenerating facility or disposed of as hazardous waste.

ACCOMPLISHMENTS

This technology was field tested at the Savannah River Site and successfully recovered solvents from the off-gas generated by the vacuum extraction process. Before this process can be used in a long- term application, a use or user for the recovered solvents must be identified. For the test application the solvents will be disposed of after testing.

COLLABORATION/ TECHNOLOGY TRANSFER

The BCHP technology is being developed in collaboration with NUCON International, Inc. Numerous other companies have indicated interest in the BCHP technology.

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How to Get Involved

Section 7.0

7.0 HOW TO GET INVOLVED

WORKING WITH THE DOE OFFICE OF ENVIRONMENTAL RESTORATION AND WASTE MANAGEMENT

DOE provides a range of programs and services to assist universities, industry, and other private-sector organizations and individuals interested in developing or applying environmental technologies. Working with DOE Operations Offices and management and operating contractors, EM uses conventional and innovative mechanisms to identify, integrate, develop, and adapt promising emerging technologies. These mechanisms include contracting and collaborative arrangements, procurement provisions, licensing of technology, consulting arrangements, reimbursable work for industry, and special consideration for small business.

Cooperative Research and Development Agreements (CRADAs)

EM will facilitate the development of subcontracts, R&D contracts, and cooperative agreements to work collaboratively with the private sector.

EM uses CRADAs as an incentive for collaborative R&D. CRADAs are agreements between a DOE R&D laboratory and any non-Federal source to conduct cooperative R&D that is consistent with the laboratory's mission. The partner may provide funds, facilities, people, or other resources. DOE provides the CRADA partner access to facilities and expertise; however, no Federal funds are provided to external participants. Rights to inventions and other intellectual property are negotiated between the laboratory and participant, and certain data that are generated may be protected for up to 5 years.

Consortia will also be considered for situations where several companies will be combining their resources to address a common technical problem. Leveraging of funds to implement a consortium can offer a synergism to overall program effectiveness.

Procurement Mechanisms

DOE EM has developed an environmental management technology development acquisition policy and strategy that uses phased procurements to span the RDDT&E continuum from applied R&D concept feasibility through full-scale remediation. DOE EM phased procurements make provisions for unsolicited proposals, but formal solicitations are the preferred responses. The principle contractual mechanisms used by EM for industrial and academic response include Research Opportunity Announcements (ROAs) and Program R&D Announcements (PRDAs).

EM uses the ROA to solicit advanced research and technologies for a broad range of cleanup needs. The ROA supports applied research ranging from concept feasibility through full-scale demonstration. In addition, the ROA is open continuously for a full year following the date of issue and includes a partial procurement set aside for small businesses. Typically, ROAs are published annually in the Federal Register and the Commerce Business Daily, and multiple awards are made.

PRDAs are program announcements used to solicit a broad mix of R&D and DT&E proposals. Typically, a PRDA is used to solicit proposals for a wide-range of technical solutions to specific EM problem areas. PRDAs may be used to solicit proposals for contracts, grants, or cooperative agreements. Multiple awards, which may have dissimilar approaches or concepts, are generally made. Numerous PRDAs may be issued each year.

In addition to PRDAs and ROAs, EM uses financial assistance awards when the technology is developed for public purpose. Financial assistance awards are solicited through publication in the Federal Register. These announcements are called Program Rules. A Program Rule can either be a one-time solicitation or an open-ended, general solicitation with annual or more frequent announcements concerning specific funding availability and desired R&D agreements. The Program Rule can also be used to award both grants and cooperative agreements.

EM awards grants and cooperative agreements if fifty-one percent or more of the overall value of the effort is related to a public interest goal. Such goals include possible non-DOE or other Federal agency participation and use, advancement of present and future U.S. capabilities in domestic and international environmental cleanup markets, technology transfer, advancement of scientific knowledge, and education and training of individuals and business entities to advance U.S. remediation capabilities.

Licensing of Technology

DOE contractor-operated laboratories can license DOE/EM-developed technology and software to which they elect to take title. In other situations where DOE owns title to the resultant inventions, DOE's Office of General Counsel will do the licensing. Licensing activities are done within existing DOE intellectual property provisions.

Technical Personnel Exchange Assignments

Personnel exchanges provide opportunities for industrial and laboratory scientists to work together at various sites on environmental restoration and waste management technical problems of mutual interest. Industry is expected to contribute substantial cost-sharing for these personnel exchanges. To encourage such collaboration, the rights to any resulting patents go to the private sector company. These exchanges, which can last from 3 to 6 months, are opportunities for the laboratories and industry to better understand the differing operating cultures, and are an ideal mechanism for transferring technical skills and knowledge.

Consulting Arrangements

Laboratory scientists and engineers are available to consult in their areas of technical expertise. Most contractors operating laboratories have consulting provisions. Laboratory employees who wish to consult can sign non-disclosure agreements, and are encouraged to do so.

Reimbursable Work for Industry

DOE laboratories are available to perform work for industry, or other Federal agencies, as long as the work pertains to the mission of a respective laboratory and does not compete with the private sector.

The special technical capabilities and unique facilities at DOE laboratories are an incentive for the private sector to use DOE's facilities and contractors expertise in this reimbursable work for industry mode. An advanced class patent waiver gives ownership of any inventions resulting from the research to the participating private sector company.

EM Small Business Technology Integration Program

The EM Small Business Technology Integration Program (SB-TIP) seeks the participation of small businesses in the EM Research, Development, Demonstration, Testing and Evaluation programs. Through workshops and frequent communication, the EM SB-TIP provides information on opportunities for funding and collaborative efforts relative to advancing technologies for DOE environmental restoration and waste management applications.

EM SB-TIP has established a special EM procurement set aside for small firms (500 employees or less) to be used for applied research projects, through its ROA. The program also serves as the EM liaison to the DOE Small Business Innovation Research (SBIR) Program Office, and interfaces with other DOE small business offices, as well.

CONTACT

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EM-523
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EM Central Point of Contact

The EM Central Point of Contact is designed to provide ready access to prospective research and business opportunities in waste management, environmental restoration, and decontamination and decommissioning activities, as well as information on EM-50 IPs and IDs. The EM Central Point of Contact can identify links between industry technologies and program needs, and provides potential partners with a connection to an extensive complex-wide network of DOE Headquarters and field program contacts.

The EM Central Point of Contact is the best single source of information for private-sector technology developers looking to collaborate with EM scientists and engineers. It provides a real-time information referral service to expedite and monitor private-sector interaction with EM.

To reach the EM Central Point of Contact, call 1-800-845-2096 during normal business hours (Eastern time).

Office of Research and Technology Applications

The Office of Research and Technology Applications (ORTAs) serves as a technology transfer agents at the Federal laboratories, and provide an internal coordination in the laboratory for technology transfer and an external point of contact for industry and universities. To fulfill this dual purpose, ORTAs license patents and coordinate technology transfer activities for the laboratory's scientific departments. They [illegible]ilitate one-on-one interactions between the laboratory's scientific personnel and te[illegible] recipients and provide information on laboratory technologies with potential ap[illegible]ns in private industry for state and local governments.

For more information about these programs and services, please contact:

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Technology Integration Division
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Acronyms

Section 8.0

8.0 ACRONYMS

AC	Alternating Current
BCHP	Brayton Cycle Heat Pump
BTEX	Benzene, Toluene, and Xylene
CAA	Clean Air Act
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CRADA	Cooperative Research and Development Agreement
CVOCs	Chlorinated Volatile Compounds
CWA	Clean Water Act
DNAPLs	Dense Non-Aqueous Phase Liquids
DoD	Department of Defense
DOE	Department of Energy
EM	Environmental Restoration and Waste Management
EPA	Environmental Protection Agency
ER	Electrical Resistance
ERT	Electrical Resistance Tomography
FA	Fluorescent Antibody
ID	Integrated Demonstrations
IP	Integrated Program
LLNL	Lawrence Livermore National Laboratory
MEK	Methyl Ethyl Ketone
MPID	Modified Petroleum Industry Drilling
ORTAs	Office of Research and Technology Applications
ORNL	Oak Ridge National Laboratory

OTD	Office of Technology Development
PCE	Tetrachloroethylene
PLFA	Phospholipid Fatty Acid
PNL	Pacific Northwestern Laboratory
PRDA	Program Research and Development Announcement
RCID	River Crossing Industry Drilling
RCRA	Resource Conservation and Recovery Act
RDDT&E	Research, Development, Demonstration, Testing, and Evaluation
RF	Radio Frequency
ROA	Research Opportunity Announcement
SBIR	Small Business Innovation Research
SB-TIP	Small Business Technology Integration Program
SNL	Sandia National Laboratory
SRD	Short Radius Drilling
SRS	Savannah River Site
TCE	Trichlorethylene
UICD	Utility Industry Compactional Drilling
VOCN	Volatile Organic Compounds in Non-Arid Soils
VOCs	Volatile Organic Compounds