DEPARTMENT OF ENERGY • UNITED STATES OF AMERICA

SUBSURFACE CONTAMINANTS FOCUS AREA

Technology Summary
August 1996

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SUBSURFACE CONTAMINANTS FOCUS AREA TECHNOLOGY SUMMARY

TABLE OF CONTENTS

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FIGURES

INTRODUCTION

The Office of Environmental Management (EM) is responsible for cleaning up the legacy of radioactive and chemically hazardous waste at contaminated sites and facilities throughout the U.S. Department of Energy (DOE) nuclear weapons complex, preventing further environmental contamination, and instituting responsible environmental management. Initial efforts to achieve this mission resulted in the establishment of environmental restoration and waste management programs. However, as EM began to execute its responsibilities, decision makers became aware that the complexity and magnitude of this mission could not be achieved efficiently, affordably, safely, or reasonably with existing technology.

Once the need for advanced cleanup technologies became evident, EM established an aggressive, innovative program of applied research and technology development. The Office of Technology Development (OTD) was established in November 1989 to advance new and improved environmental restoration and waste management technologies that would reduce risks to workers, the public, and the environment; reduce cleanup costs; and devise methods to correct cleanup problems that currently have no solutions.

In 1996, OTD added two new responsibilities—management of a Congressionally mandated environmental science program and development of risk policy, requirements, and guidance. OTD was renamed the Office of Science and Technology (OST).

THE EM ORGANIZATION

OST is one of seven Deputy Assistant Secretarial Offices within EM. Each Deputy Assistant Secretarial Office is discussed here, with the exception of OST (EM-50), addressed in detail later in this Introduction.

Office of the Assistant Secretary for Environmental Management (EM-1)
The Office of the Assistant Secretary for Environmental Management provides centralized direction for waste management operations, environmental restoration, and related applied research and development programs and activities within DOE. The Office of the Assistant Secretary develops EM program policy and guidance for the assessment and cleanup of inactive waste sites and facilities, and waste management operations; develops and implements an applied waste research and development program to provide innovative environmental technologies to yield permanent disposal solutions at reduced costs; and oversees the transition of contaminated facilities from various departmental programs to environmental restoration. The Assistant Secretary provides guidance to all DOE Operations Offices. Organizational relationships are shown in Figure A.

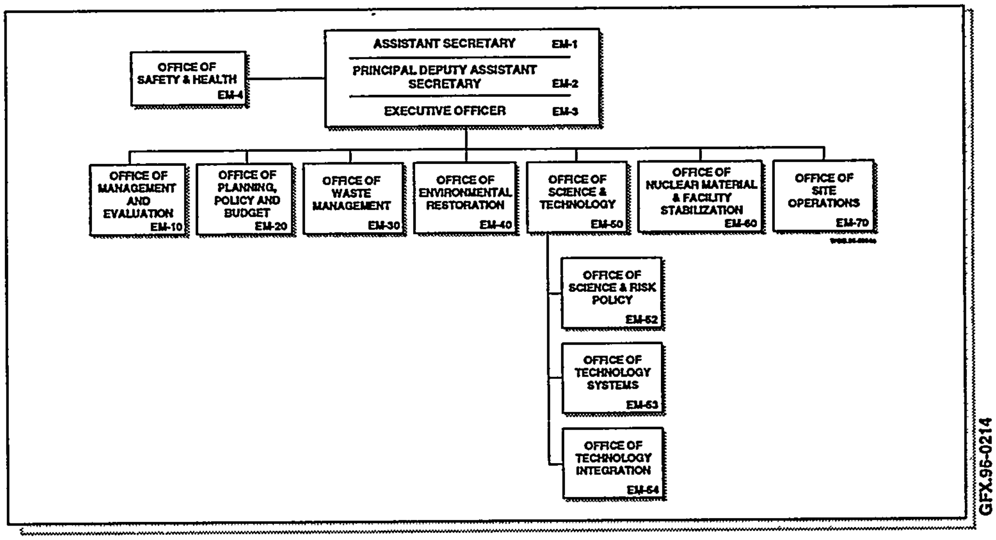

Figure A. Office of Environmental Management Organization Chart.

The Office of Management and Evaluation (EM-10)

The Deputy Assistant Secretary for Management and Evaluation serves as the Assistant Secretary's principal advisor on all administrative functions and activities for EM line offices. Responsibilities include personnel administration; training and career development; total quality management; organization and manpower management; cost and performance management; space and logistics management; acquisition, procurement, and contracts management; general administrative support services; and automated data processing, automated office support systems, and information resources management.

The Office of Planning, Policy, and Budget (EM-20)

The Office of Planning, Policy, and Budget analyzes and provides support on policy and planning issues associated with environmental compliance and cleanup activities, waste management, nuclear materials and facilities stabilization, overall budget and priority setting analyses, nuclear nonproliferation policy practices, and the ultimate disposition of surplus materials and facilities. This Office is also responsible for the review, coordination, and integration of inter-site, interagency and international planning activities related to these issues. The Office coordinates policy and procedural issues associated with the external regulation of the environmental restoration, waste management, and nuclear materials and facility stabilization programs.

The Office of Waste Management (EM-30)

The Office of Waste Management provides an effective and efficient system that minimizes, treats, stores, and disposes of DOE waste as soon as possible in order to protect people and the environment from the hazards of those wastes. The Office carries out program planning and budgeting, evaluation and intervention, and representation functions associated with management of radioactive high-level, transuranic, and low-level waste; hazardous and sanitary waste; and mixed waste.

The Office of Environmental Restoration (EM-40)
The Office of Environmental Restoration remediates departmental sites and facilities to protect human health and the environment from the risks posed by inactive and surplus DOE facilities and restores contaminated areas for future beneficial use. This Office provides program direction for and management of environmental restoration activities involving inactive sites and facilities, including the decontamination of surplus facilities.

The Office of Nuclear Material and Facility Stabilization (EM-60)
The Nuclear Material and Facility Stabilization program mission is to protect people and the environment from the hazards of nuclear materials and to deactivate surplus facilities in a cost-effective manner. The Office provides program planning and budgeting, evaluation and intervention, and representation functions associated with the stabilization of nuclear materials and the deactivation of surplus facilities.

The Office of Site Operations (EM-70)
Acting to eliminate barriers and ensure that field concerns are recognized in major EM decisions, the Office of Site Operations acts as a focal point and champion for the Operations Offices and field sites, serving as facilitator, coordinator and ombudsman for crosscutting issues and topics raised by the various EM elements. The Office of Site Operations provides Headquarters policy direction for landlord planning and budgeting and sets policy and guidance to improve the effectiveness of crosscutting environment, transportation management, and waste minimization activities.

The Office of Science and Technology (EM-50)

OST manages and directs focused, solution-oriented national technology development programs to support EM by using a systems approach to reduce waste management life-cycle costs and risks to people and the environment. OST programs involve research, development, demonstration, testing, and evaluation of innovative technologies and technology systems that meet end-user needs for regulatory compliance. Activities include coordination with other stakeholders and the private sector, as well as collaboration with international organizations. In 1994, the EM program identified five major problem areas on which to focus its technology development activities (later two were combined), and implemented Focus Areas to address these problems. In addition, some needs were identified that were common to all the Focus Areas, and three Crosscutting Programs were created to address them.

OST programs establish, manage, and direct targeted, long-term research programs to bridge the gap between broad fundamental research that has wide-ranging application and needs-driven applied technology development research. OST expects to produce technologies to answer the needs of its major customers within EM for innovative science and technology through

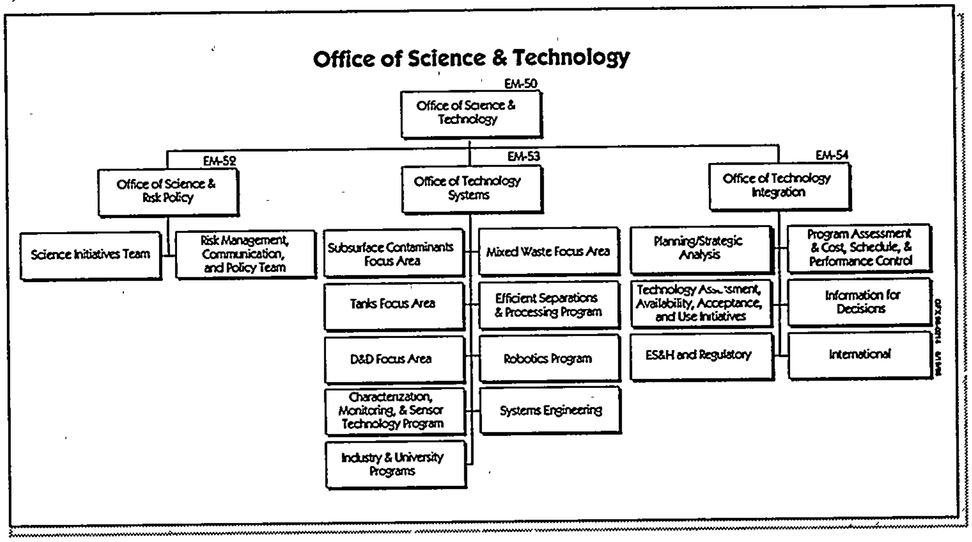

Figure B. Organization Chart of the Office of Science and Technology.

integration of basic research programs, applied research programs (Focus Areas and Crosscutting Programs), industry partnerships, and technology transfer activities.

Three offices comprise OST: the Office of Science and Risk Policy, the Office of Technology Systems, and the Office of Technology Integration. The organization for OST is shown in Figure B.

Office of Science and Risk Policy (EM-52)

The Office of Science and Risk Policy manages EM's Science Program and the formulation of risk policy. The mission of this office includes the development of a targeted, long-term basic research agenda for environmental problems so that "transformational" or breakthrough approaches can lead to significant reduction in the costs and risks associated with the EM Program. This Office also bridges the gap between broad fundamental research that has wide-ranging applicability, such as that performed in DOE's Office of Energy Research, and needs-driven applied technology development that is conducted in EM's Office of Technology Systems. This Office was designed to focus the country's science infrastructure on critical national environmental management problems.

The Science Program draws on information from its DOE customers to identify necessary basic research. The Science Program concentrates its efforts on the characterization of DOE's wastes and contaminants, interactions of radioactive elements with biosystems in various natural media and waste forms, extraction and separation of radioactive and hazardous chemical contaminants, prediction and measurement of contaminant movement in DOE facilities' environments, and formulation of scientific bases for the risks associated with DOE-based contaminants.

Risk policy activities within this Office involve the development of policies, procedures, and guidance to ensure that EM activities in preventing risks to the public, workers, and the environment are within prescribed, acceptable levels. Risk evaluation methods and event and consequence analyses provide DOE with a basis for assessing both the risk and any actions being considered to reduce that risk. The Office of Science and Risk Policy ensures that advances in risk evaluation methods are integrated into coherent decision-making processes regarding risk acceptability. Decision-making processes must meet DOE missions while protecting public health, worker health and safety, ecosystem viability, and cultural and national resources.

Office of Technology Systems (EM-53)

OST programs involve research, development, demonstration, testing, and evaluation activities designed to produce innovative technologies and technology systems to meet national needs for regulatory compliance, lower life-cycle costs, and reduced risks to the environment. To optimize resources, OST has streamlined technology management activities into a single focus team for each major problem area. To ensure programs are based upon user needs, these teams include representatives from user offices within EM. There are four major problem areas upon which technology development activities are focused.

- Mixed Waste Characterization, Treatment, and Disposal
- Radioactive Tank Waste Remediation
- Subsurface Contaminants
- Decontamination and Decommissioning

Mixed Waste Characterization, Treatment, and Disposal Focus Area

DOE stores 167,000 cubic meters of mixed low-level and transuranic waste from over 1,400 mixed radioactive and hazardous waste streams at 38 sites. The Mixed Waste Characterization, Treatment, and Disposal Focus Area provides an integrated, multi-organizational, national team to develop treatment systems for the department's inventory of mixed radioactive and hazardous waste and to dispose of these low-level and transuranic waste streams in a manner that fulfill regulatory requirements.

This Focus Area plans to demonstrate three technologies to treat at least 90 percent of DOE's stored mixed waste inventory by the end of FY97. The outcome will be waste forms that are reduced in volume, as compared to the volume of stored mixed waste, and meet regulatory requirements for safe, permanent disposal. Technology development is being conducted in the areas of thermal and nonthermal treatment emissions, nonintrusive drum characterization, material handling, and final waste forms.

Radioactive Tank Waste Remediation Focus Area

The Radioactive Tank Waste Remediation Focus Area develops technologies to safely and efficiently remediate over 300 underground storage tanks that have been used to process and store more than 90 million gallons of high-level radioactive and chemical mixed waste. Technologies are needed to characterize, retrieve, and treat the waste before radioactive components are immobilized. All this must be done in a safe working environment. Emphasis is placed on in situ or remotely handled processes and waste volume minimization.

Research and development of technologies in this area is aimed at enabling tank farm closure using safe and cost-efficient solutions that are acceptable to the public and that fulfill Federal Facility Compliance Act requirements of site regulatory agreements.

Subsurface Contaminants Focus Area

The Subsurface Contaminants Focus Area is developing technologies to address environmental problems associated with hazardous and radioactive contaminants in soil and groundwater that exist throughout the DOE complex, including radionuclides, heavy metals, and dense, nonaqueous phase liquids. More than 5,700 known DOE groundwater plumes have contaminated over 600 billion gallons of water and 50 million cubic meters of soil. Migration of these plumes threatens local and regional water sources, and in some cases has already adversely impacted off-site resources. In addition, the Subsurface Contaminants Focus Area is responsible for supplying technologies for the remediation of numerous landfills at DOE facilities. These landfills are estimated to contain over 3 million cubic meters of radioactive and hazardous buried waste, some of which has migrated to the surrounding soils and groundwater. Technology developed within this specialty area will provide effective methods to contain contaminant plumes and new or alternative technologies for remediating contaminated soils and groundwater. Emphasis is placed on the development of in situ technologies to minimize waste disposal costs and potential worker exposure by treating plumes in place. While addressing contaminant plumes emanating from DOE landfills, the Subsurface Contaminants Focus Area is also working to develop new or alternative technologies for the in situ stabilization and nonintrusive characterization of these disposal sites.

Decontamination and Decommissioning Focus Area

The Decontamination and Decommissioning Focus Area is developing technologies to solve the department's challenge of deactivating 7,000 contaminated buildings and decommissioning 700 contaminated buildings. It is also responsible for decontaminating the metal and concrete within those buildings and disposing of 180,000 metric tons of scrap metal. Technology development for decontamination and decommissioning focuses on large-scale demonstrations, each of which incorporates improved technologies identified as responsive to high-priority needs. All technologies will be considered for eventual deployment, and side-by-side comparisons of improved technologies are being performed using existing commercial technologies as baselines.

CROSSCUTTING PROGRAMS

In addition to work directed to specific Focus Areas, EM is engaged in research and development programs that cut across these problem areas. Technologies from these Crosscutting Programs may be used within two or more of the Focus Areas to help meet program goals. These programs complement and facilitate technology development in the Focus Areas as shown in Figure C. The Crosscutting Programs are:

- Characterization, Monitoring, and Sensor Technologies,
- Efficient Separations and Processing, and
- Robotics Technology Development Program.

Characterization, Monitoring, and Sensor Technologies Crosscutting Program

DOE is required to characterize more than 3,700 contaminated sites, 1.5 million barrels of stored waste, 385,000 m^3 of high-level waste in tanks, and from 1,700 to 7,000 facilities before remediation, treatment, and facility transitioning commence. Monitoring technologies are needed to ensure worker safety and effective cleanup during remediation, treatment, and site closure.

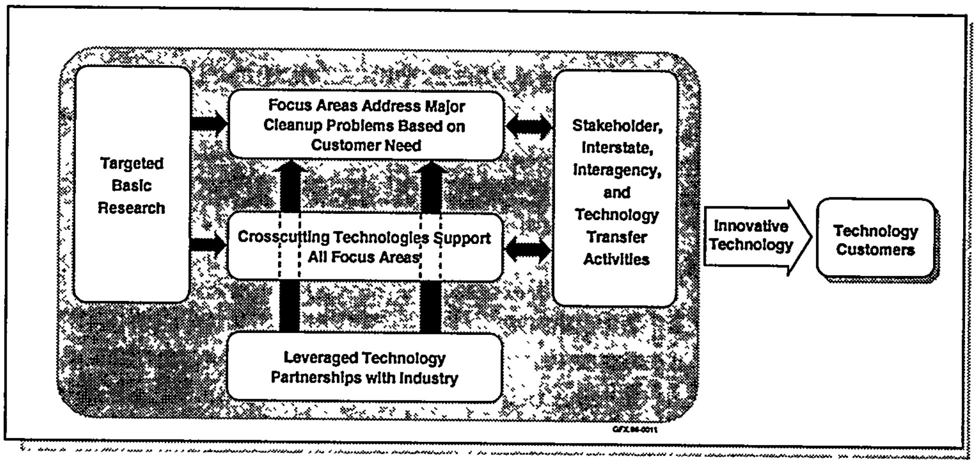

Figure C. Relationships between Focus Areas and Crosscutting Programs.

Efficient Separations and Processing Crosscutting Program

Separations and selected treatment processes are needed to treat and immobilize a broad range of radioactive wastes. In some cases, treatment technologies do not exist; in others, improvements are needed to reduce costs and secondary waste volumes and to improve waste form quality. This Crosscutting Program concentrates efforts on specific high-priority needs as defined by the Focus Areas, then evaluates and adapts the technologies for other applicable Focus Areas.

This program is working to meet Federal Facilities Compliance Act milestones and other regulatory requirements, and to develop separations and treatment technologies that minimize risk, the volume of waste requiring deep, geological disposal, and secondary waste volumes.

Robotics Technology Development Crosscutting Program

Existing technologies are often inadequate to meet EM's mission needs both at a reasonable cost and under conditions that promote adequate worker safety. Robotic systems reduce worker exposure to the absolute minimum while providing proven, cost-effective, and, in some cases, the only acceptable approach to problems.

Robotics remote systems development work occurs in three areas. Remote systems for decontamination and dismantlement of facilities will reduce or eliminate extensive worker radiation protection requirements and increase productivity. Robotic systems for characterization and retrieval of stored tank waste will allow work to proceed within the radiation fields in the waste storage area. Automated chemical/radiological analysis systems are estimated to provide a cost benefit of $10.5 billion from FY96 through FY00.

Industry and University Programs

Industry and University programs provide to the Focus Areas and the Crosscutting Programs the capability to involve private industry, universities, and other interested parties in their program through direct procurement with DOE. The public-private partnerships that are established encourage the enhancement and commercialization of technologies developed by the private sector through pilot- and field-scale demonstration at DOE sites. The integration of industry, academia, and the DOE laboratories allows all aspects of the technology to be evaluated, including worker safety and health, commercial potential, and technical merit.

Industry and University activities support more than 100 agreements with the private sector. These agreements include the Small Business Innovative Research (SBIR) program, international activities, stakeholder activities, worker safety and health activities, and commercialization initiatives, as well as the direct support to the Focus Areas. For information on how to participate in these programs, see the "DOE Business Opportunities" section at the end of this book.

Office of Technology Integration (EM-54)

The Office of Technology Integration addresses issues that affect the involvement of critical external entities such as production/waste sites, users, the public, tribes, regulators, and commercial parties. The office is involved in the assessment, acceptability, availability, and use of improved technical solutions by providing uniform guidance, tools, and initiatives to support the Office of Technology Systems. This office also sponsors efforts to encourage and promote the involvement of affected parties' in regulatory issues.

In addition, the Office of Technology Integration sponsors domestic and international technology transfer programs within OST and coordinates planning and cost-benefit analyses with other EM organizations.

Subsurface Contaminants Focus Area Overview

The U.S. Department of Energy (DOE) Subsurface Contaminants Focus Area is developing technologies to address environmental problems associated with hazardous and radioactive contaminants in soil and groundwater that exist throughout the DOE complex, including radionuclides; heavy metals; and dense non-aqueous phase liquids (DNAPLs). More than 5,700 known DOE groundwater plumes have contaminated over 600 billion gallons of water and 200 million cubic meters of soil. Migration of these plumes threatens local and regional water sources, and in some cases has already adversely impacted off-site resources. In addition, the Subsurface Contaminants Focus Area is responsible for supplying technologies for the remediation of numerous landfills at DOE facilities. These landfills are estimated to contain over 3 million cubic meters of radioactive and hazardous buried waste, some of which has migrated to the surrounding soils and groundwater. Technology developed within this specialty area will provide effective methods to contain contaminant plumes and new or alternative technologies for remediating contaminated soils and groundwater. Emphasis is placed on the development of in situ technologies to minimize waste disposal costs and potential worker exposure by treating plumes in place. While addressing contaminant plumes emanating from DOE landfills, the Subsurface Contaminants Focus Area is also working to develop new or alternative technologies for the in situ stabilization, and nonintrusive characterization of these disposal sites.

Extent of the Subsurface Problem at DOE Sites

The problem faced by the Subsurface Contaminants Focus Area is daunting. More than 5,700 known DOE groundwater plumes have contaminated over 600 billion gallons of water and 200 million cubic meters of soil. Migration of these plumes threatens local and regional water sources, and in some cases has already adversely impacted off-site resources. In addition, DOE landfills are estimated to contain over 3 million cubic meters of buried waste. This waste is in the form of containers that have degraded with time and have now contaminated the surrounding environment with transuranic (TRU), low-level, or hazardous wastes. Currently available cleanup technologies are inadequate or unacceptable due to excessive costs, increased risks, long schedules, or the production of secondary waste streams. The mission of the Subsurface Contaminants Focus Area is to develop and transfer to private industry effective alternative technologies that can overcome these issues. This mission is critical to allowing DOE to meet its legally enforceable remediation requirements.

The Subsurface Contaminants Focus Area consolidates and integrates all research and development activities pertaining to the remediation of contaminated soils and groundwater, including landfills and buried waste, that are currently in progress within the Office of Environmental Management (EM). This consolidation and integration provides the basis for rigorous, systematic, and effective management of the technology development process. The Subsurface Contaminants Focus Area works closely with the Site Technology Coordination Groups to identify specific environmental problems as they relate to technology needs for soils and ground remediation, including landfills and buried waste. This coordination includes creation of remediation schedules and the formulation of associated plans. Focus Area activities also allow for the evaluation of existing and newly developed technologies to determine their effectiveness for resolving today's remediation problems.

The Subsurface Contaminants Focus Area establishes technical and programmatic goals by identifying specific technology gaps. This determination is based on detailed global analyses of available technology and EM requirements. The Focus Area also coordinates collaborative efforts with other federal agencies.

The Subsurface Contaminants Focus Area has established a directed research, development, demonstration, testing, and evaluation program that integrates all activities from basic research to implementation. All the activities under this Focus Area are based on enhanced communication, cooperation, and collaboration between technology developers, customers (problem holders), stakeholders, and regulators.

A guiding principle for the Focus Area is product deployment. The Subsurface Contaminants Focus Area is committed to using the best minds and technology available to address the technological challenges facing the DOE in the remediation of soil and groundwater. Therefore, the Focus Area continues to increase the participation of universities, the private sector, and regulators in the technology development process. In particular, the emphasis is on getting all parties (customers, stakeholders, universities, private sector, and regulators) involved in technology development efforts to participate as early in the developmental process as possible. Early involvement is likely to increase the potential for effective technologies to be successfully demonstrated, implemented, and commercialized.

The Subsurface Contaminants Focus Area is structured into four technology areas (see Figure D.). This structure enables the Focus Area to meet the remediation and management needs associated with buried waste sources and their contaminant plumes across the DOE complex. These four

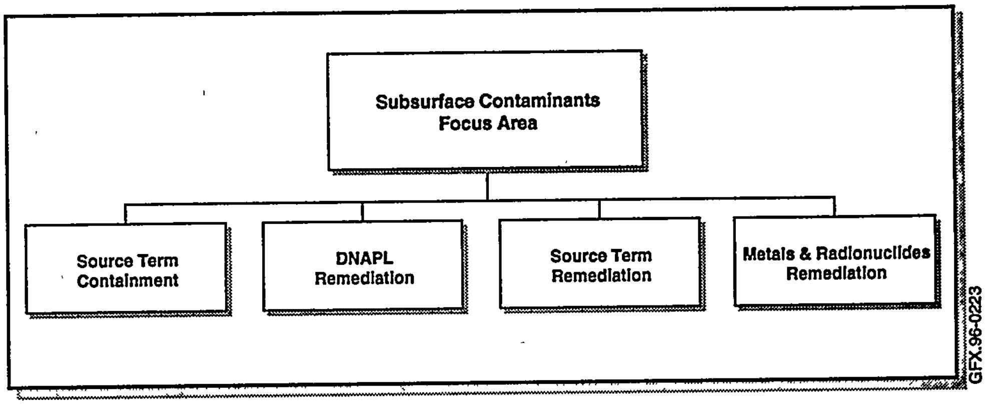

Figure D. Subsurface Contaminants Focus Area Breakdown Structure.

"Deployment Sectors" address needs in the following specific categories: (1) Source Term Containment, (2) DNAPL Remediation, (3) Source Term Remediation, and (4) Metals and Radionuclides Remediation.

Source Term Containment

Containment is the restriction or confinement of buried waste to a limited area to prevent its migration or leaching beyond its confined domain. This is typically achieved by: (1) installation of surface caps or covers, (2) placement of impermeable engineered subsurface (vertical or horizontal) barriers and systems, and (3) permeable barriers that stop only contaminants while allowing uncontaminated material to pass through. The barrier materials are chosen on the basis of their long-term durability, inertness to acids and bases, resistance to corrosion, and water impermeability. Placement of barriers around the waste is determined on the basis of site and waste characterization data. Containment may serve as an interim action to reduce or prevent contaminant migration pending future remedial decisions and actions or as a long-term measure for use as final remediation action.

Surface Caps. Surface caps are constructed of synthetic and/or natural geological materials like clay. They control erosion, deep percolation, and biological intrusion. The spectrum of designs vary from very simple soil barriers that have optimum configurations, plant cover, and surface slope, to more complex multilayered cover profiles, incorporating engineered barriers that inhibit downward movement of soil moisture. Few existing designs have actually been constructed in the field and monitored in a way that allows a complete evaluation of performance characteristics. Those few that have been field tested have only been evaluated under very specific climate and environmental conditions. The Subsurface Contaminants Focus Area will take the initiative and lead efforts to develop and monitor field-tested, climate-specific migration barrier cover systems that can serve as the sole containment technology or as a component of an integrated barrier system that incorporates other barrier concepts, along with cover, to contain wastes.

Subsurface Barriers. Waste containment may also include emplacement of subsurface barriers (vertical and horizontal) to control water infiltration and contaminant release. The barriers are usually composed of grouting materials such as concrete, soil-bentonite, or cement-bentonite slurry material. The current state of the art for emplacement of barriers in near-surface soils lies primarily with vertically emplaced barriers. Subsurface horizontal to subhorizontal barriers that retard mass movement are not currently employed. New technology initiatives are geared toward the development of superplastic grouts, chemical-based materials, and soil cement of significantly superior mechanical, electrical, and durability properties.

Subsurface migration of heavy metal and radionuclide contamination can be minimized by physical and chemical subsurface barriers. Physical barriers that can intercept migrating contaminants must be capable of demonstrating compatible treatment technologies that can permanently reduce the mobility or toxicity of the contaminants or demonstrate that the barrier will survive the length of time that the contaminants remain mobile or toxic. A reactive barrier is an innovative containment technology to prevent the migration of contaminants in a groundwater plume while allowing water to pass through a treatment barrier. The reactive barrier may be used in conjunction with an impermeable wall when the transverse extent of the plume is broad, in order to direct the contaminated plume toward the reactive barrier that serves as a permeable window through the hydraulic barrier. Chemical treatment zones that physically stabilize contaminants must be capable of insuring adequate capacity for the design life of the installation.

For both physical and chemical barriers, emplacement technologies are needed to efficiently install materials in the subsurface soils. Limitations on installation methods may severely impact the commercial application of physical and chemical barriers. Demonstrations involving the installation and performance evaluation of containment and stabilization zones are needed for sites with similar subsurface properties as actual environmental restoration target sites.

In support of containment activities, a wide range of remediation monitoring technologies are also under development. These technologies are necessary to verify subsurface activity. Many types of monitors are being developed by DOE as part of containment and treatment systems: monitors for system performance and failure prediction, air borne release of contaminants detection, and digface monitoring of contaminants of concern and for parameter measurement (i.e., temperature, flow rates, and particle size).

DNAPL Remediation

A U.S. Environmental Protection Agency report released in 1993 stated that in more than 60 percent of the sites where organic contamination has occurred, the likely source was DNAPL. Remediation of DNAPL is one of the greatest challenges confronting the environmental industry. Experts agree that, of all types of contaminated sites in need of remediation, the type where success is least likely includes the presence of DNAPL in any kind of geology.

Because DNAPLs are the long-term solvent source at many DOE installations, efficient DNAPL remediation strategies represent the most significant potential cost savings for solvent contaminated sites. Through the Subsurface Contaminants Focus Area, the DOE will identify and develop characterization and remediation methods that target the unique character and expected distribution of DNAPLs. The DNAPL deployment sector is currently investigating various tracer and geophysical methods to locate DNAPL plumes and to determine the extent of their migration from a potential source. Treatment/remediation technologies for DNAPLs include thermal destruction (soil heating and hot fluid injection); air, water, surfactant, and cosolvent flushing techniques to enhance removal efficiencies; in situ treatment; and destruction technologies involving chemical treatment and bioremediation. Secondary waste treatment technologies for the recovery/reuse/recycle of DNAPLs, surfactants, and cosolvents are also under investigation within this deployment sector.

Source Term Remediation

Retrieval. Retrieval involves the excavation of waste or contaminated soil for ex situ off-site treatment or disposal. When treatment occurs on site, the treated soil which is considered decontaminated may be backfilled in lieu of off-site disposal. Retrieval operations can be divided in two categories: (1) full-scale retrieval, and (2) hot-spot or selective retrieval.

- **Full-Scale Retrieval**. Conventional drilling and excavation equipment are typically used for this purpose. However, remote-operated equipment is being developed and demonstrated for retrieval of waste, in particular, radioactive and/or mixed waste. The new technologies include: remote excavation systems, full-scale remote retrieval, waste conveyance using innovative end effectors, and contaminated material excavation handling and retrieval systems.

- **Hot-Spot Retrieval**. Alternatives to conventional hot-spot retrieval techniques, such as drilling and excavation, are currently being developed. Selective retrieval dual robotic arms are being developed to support the system concept of hot-spot retrieval. Technology development in support of this concept includes cooperative telerobotic retrieval.

Ex Situ Treatment. Ex situ treatment involves exhuming, packaging, and transporting waste to a treatment facility. Treated waste may then be disposed of on site or off site. The ex situ processing may include four interrelated processes: pretreatment, primary treatment, secondary treatment, and process controls or verifications. The processes are employed for the immobilization, detoxification, volume reduction, and/or stabilization of retrieved buried waste and contaminated soils.

Pretreatment techniques are used to minimize the amount of waste to be treated and to optimize the primary treatment of the waste. Pretreatments may include: cryofracture; conventional shredding; thermal technologies, such as desorption; or sorting of retrieved waste into waste types (soils, metals, and combustibles) using advanced assaying methods.

Pretreatment and primary treatment technologies require additional ancillary systems. These techniques include feed systems, offgas systems, process diagnostics, and secondary waste stream treatment. The technologies comprising these systems may need to be evaluated. These technologies include nonthermal plasma, dry high efficiency particulate air filters, various combinations of existing offgas systems, and secondary waste recycled into the primary treatment. Some primary treatment technologies may be used to treat secondary waste and help reduce the amount of secondary waste.

In Situ Treatment. Stabilization of waste in situ involves altering its physical, chemical, and toxicological properties and rendering it immobile and incapable of leaching under the most stringent conditions. Grouting the waste or soil matrix to reduce water and contaminant migration through the waste matrix will stabilize the waste. Another example of the stabilization process is in situ vitrification which uses high temperatures to chemically incorporate waste into a glass matrix while destroying organics.

Metals and Radionuclides Remediation

The volume of soil contaminated with radionuclides and/or heavy metals within the DOE complex is estimated to be in excess of 200 million cubic meters. The current baseline technology for the remediation of these soils is excavation, containerization, transportation, and final disposal at a permitted land disposal facility. The major cost involved with this scenario is for the disposal facility. At the Nevada Test Site, the cost of "storage" is approximately $10 per cubic foot while storage at a Nuclear Regulatory Commission licensed facility is greater than $400 per cubic foot. Development of in situ treatment technologies or effective volume reduction technologies will provide DOE with a significant cost savings in "storage" fees alone.

Many heavy metal and radionuclide contaminants exist in the liquid or solid phases and have become distributed throughout the soil matrix. The Subsurface Contaminants Focus Area seeks in situ extraction and immobilization technologies that will utilize physical or chemical processes to remove contaminants from the soil matrix without removing or excavating the soils. The objective of these technologies is to reduce or eliminate the potential for contaminants to migrate from existing locations. Traditional extraction by aquifer pumping needs to be augmented by other physical or chemical means to separate and extract contaminants from the soil.

Stabilization and containment technologies must demonstrate effective reduction or elimination of contaminants through surface disposal and/or leaching, serve as a barrier to inhibit contaminant migration, not preclude subsequent treatment, minimize the generation of secondary waste, and be verifiable. Technologies that can service the unsaturated zone to transport contaminants to collection zones for removal may also have merit as long as adequate containment of the treatment zone can be demonstrated.

In situ treatment technologies are being sought that would modify the chemical structure of the contaminant to reduce its toxicity and/or mobility. Technologies in this area must demonstrate permanent solutions in which long-term contaminant release to groundwater, surface soil, or air is reduced to acceptable levels. Technologies under consideration in this area include transforming inorganic waste forms using chemical, electric, and/or biotechnical methods. Technologies that modify contaminant oxidation states and reduce solubility are directly related to this effort.

Future Plans of the Subsurface Contaminants Focus Area

In Fiscal Year 1997, the Subsurface Contaminants Focus Area will shift a number of technologies and ex situ waste treatment activities to the Mixed Waste Focus Area. Activities for site and waste characterization will be managed by the Characterization, Monitoring, and Sensor Technology Crosscutting Program. The following activities will remain with the Subsurface Contaminants Focus Area: (1) containment and stabilization performance monitoring; (2) verification; and (3) containment or treatment and control of groundwater, soils vegetation, and in situ treatment.

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1.0 ORGANICS PRODUCT LINE

The Subsurface Contaminants Focus Area is developing technologies to better remediate soil and groundwater contaminated with organic compounds. Organic contamination problems are often categorized according to whether the contaminant is lighter or denser than water. Organic compounds that float on water include gasoline, jet fuel, and diesel fuel. These are found as environmental contaminants in many locations throughout the United States, including some U.S. Department of Energy (DOE) facilities. Chlorinated organic compounds are often heavier than water and are primarily found as contaminants at industrial sites, including most DOE laboratories and production facilities.

Technology has developed to the point where there are a number of commercially available remediation options for most problems involving fuel hydrocarbons. For this reason, DOE has reduced funding of research and development efforts that involve light non-aqueous phase liquids and dissolved organic compounds. As a result, the Organics Product Line will be discontinued after FY96. However, some of the Organics Product Line projects will continue in FY97 as part of the dense non-aqueous phase liquids (DNAPLs) Product Line.

DNAPLs, such as trichloroethylene (TCE) and perchloroethylene (PCE), are common industrial solvents that were used and disposed of at many DOE sites. Chemically, these differ from fuel hydrocarbons mainly by having chlorine attached to their molecules and by being more toxic or carcinogenic. DOE will continue to develop methods to remediate DNAPL contamination. (See Section 2.0, DNAPLs Product Line.)

The Organics Product Line is concentrating on in situ remediation systems that provide alternatives to pump and treat. Technology development activities for the Organics Product Line are subdivided into several technology groups, which are further subdivided into subgroups and systems of technologies that progressively address more specialized components of organic contamination problems. These subdivisions are summarized as follows:

Characterization. There is a need to better characterize site conditions and evaluate the effectiveness of remediation activities. Development and demonstration of improved instrumentation for subsurface fluid flow measurements are included in this group. In general, characterization technologies for the Organics Product Line are addressed by the Characterization, Monitoring, and Sensor Technology Crosscutting Program and the Morgantown Energy Technology Center Industrial Partnership Program.

In Situ Treatment and Remediation. This group of technologies consists of the following three subgroups:

- Enhanced extraction from groundwater
- Treatment and stabilization
- Passive treatment

Offgas Treatment. Some of the enhanced extraction technologies generate secondary waste streams which require treatment or disposal. Work is being directed at treating offgas from remediation systems that remove organic contaminants from the subsurface.

For FY96, most Organics Product Line projects are in the field demonstration stage. As the Product Line is phased out, it is important to gather field performance data for these projects and publish final evaluation reports so that the DOE investment in the Organics Product Line will not be lost.

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1.1 SUBSURFACE FLUID FLOW SENSORS

TECHNOLOGY NEED

The flow of fluids, both water and air, through the subsurface is perhaps the most important mechanism for the dispersal of most types of toxic waste once they have been released into the ground. Therefore, accurate information on fluid movements is critical to the characterization of waste sites, waste remediation process monitoring, and the post-closure performance monitoring of remediated waste sites.

TECHNOLOGY DESCRIPTION

Groundwater and soil gas flow sensors are a new technology for measuring directly the full 3-dimensional fluid flow velocity vector at essentially a single point in porous media. Each probe consists of a rod approximately 30 inches long by 2 inches in diameter, fabricated of low thermal conductivity polyurethane foam (see Figure 1.1-1). Deployed on the surface of the rod are a thin-film, flex circuit style heater and an array of 30 temperature sensors (thermistors). The probe is buried in the ground at the point where the flow is to be monitored. When the heater is activated, a temporally and spatially uniform heat flux from the probe is established. In the absence of any flow past the probe, the temperature distribution observed on the surface of the probe is independent of azimuthal position of the probe and symmetric about the

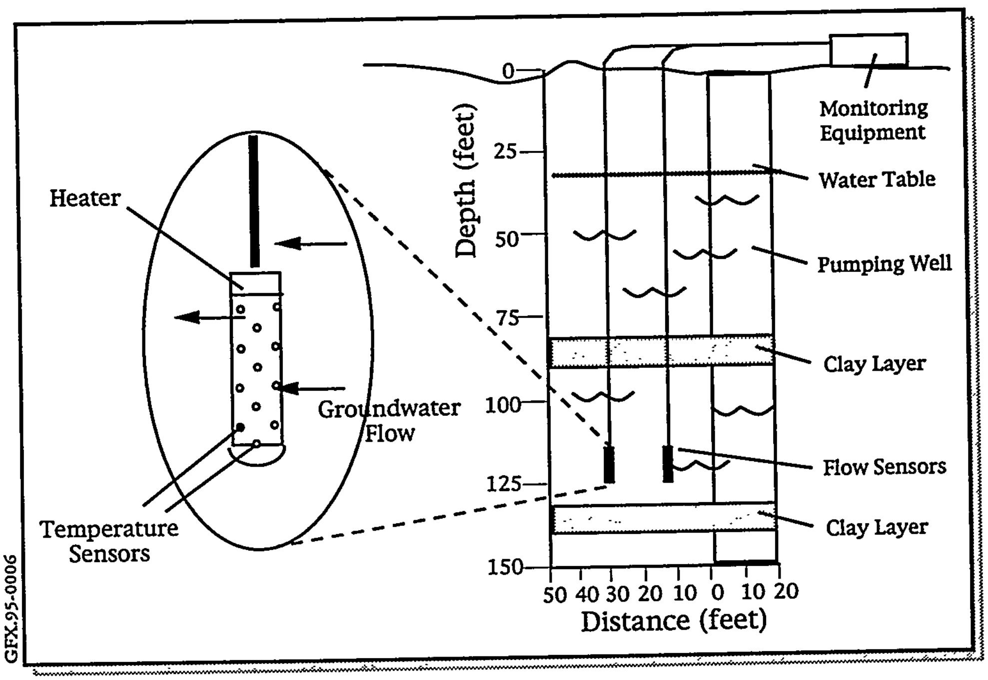

Figure 1.1-1. In Situ Permeable Flow Sensor.

vertical midpoint of the probe. If there is significant groundwater flow past the instrument, then the temperature distribution on the surface of the tool is perturbed as some of the heat emanating from the probe is advected around the tool by the moving fluid. The downstream side of the probe will be relatively warm compared to the upstream side. The direction and magnitude of the full 3-dimensional flow velocity vector can be deduced from the measured temperature distribution on the surface of the probe. In water-saturated sediments the probes are capable of accurately measuring groundwater flow velocities in the range of approximately 5×10^{-6} to 5×10^{-3} cm/s. Because the heat capacity of a given volume of air is much less than that of the same volume of water, the probes can measure air flow velocity in dry sediments in the range of 1×10^{-3} to 1 cm/s. Changes in flow about one order of magnitude smaller than this can be resolved.

A critical aspect of obtaining reliable data from the flow sensors is the method of deployment. In order to avoid negative impacts on the flow velocity caused by the presence of a borehole, well screen, and gravel pack, the flow sensors must be buried directly in the ground, in intimate contact with the formation. This limits the range of applicability of the technology to sites where the sediments are unconsolidated. The probe is installed in a borehole at the desired monitoring location. The borehole can either be backfilled with appropriate media, or soil can be allowed to collapse around the probe. Although this deployment strategy means that the relatively inexpensive probes cannot be recovered once deployed, they can be monitored remotely on a continuous basis for long periods of time (months to years).

Benefits

The benefits of this approach include:

- The flow sensor provides measurements of hydraulic conductivity and only requires a single borehole to measure a full 3-dimensional flow velocity.
- Unlike conventional aquifer testing, the flow sensor does not perturb the aquifer flow conditions or create a secondary waste which cannot be reinjected.
- The soil-gas sensor provides a means to determine the dynamics and zone-of-influence of both passive and active remediation efforts in the unsaturated zone.

Collaboration/Technology Transfer

Development of the In Situ Permeable Flow Sensor used in groundwater flow applications is essentially complete. The technology has been demonstrated several times, including deployments at Savannah River, Hanford, the Weeks Island Louisiana Strategic Petroleum Reserve Site, and Edwards Air Force Base. The technology has been licensed to SIE, Inc., of Fort Worth, Texas, for commercialization, and another company is currently seeking a license. Application of the technology to measure air flow in the vadose zone is still under development but should be available for demonstration very soon. Potential licensees are currently being identified.

Accomplishments

Recent accomplishments for this project include:

- Successfully monitored In-Well Vapor Stripping Experiments at Edwards Air Force Base using in situ permeable flow sensors
- Developed and field tested the Subsurface Gas Flow Meter at Sandia National Laboratories

TTP Information

Subsurface Fluid Flow Sensors technology development activities are funded under the following technical task plan (TTP):

TTP No. AL26PL21, Task 1, "In Situ Permeable Flow Sensor and Subsurface Gas Flow Meter"

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1.2 THERMAL ENHANCED VAPOR EXTRACTION SYSTEM

TECHNOLOGY NEED

Concentrated organic sources of environmental contamination are difficult to remediate by conventional vacuum vapor extraction due to the low mass removal rates at ambient temperatures. Especially difficult are those chemicals that have low vapor pressures at ambient temperatures or are found in low permeability soils. Thermal enhancement technologies are most suitable for these low permeability soils or chemical contaminant mixtures with low vapor pressures at environmental temperatures.

TECHNOLOGY DESCRIPTION

The objective of the Thermal Enhanced Vapor Extraction System (TEVES) demonstration is to assess the cost and performance of two soil heating technologies, combined with vacuum vapor extraction, for the removal of containerized and free-liquid chemical wastes in and below an unlined landfill disposal cell. Having achieved this objective, the results of this demonstration can now be used by environmental restoration programs to determine the utility of this technology for application at other sites with high concentrations of organic chemicals in soils.

The value of thermal enhancement technologies is to increase the mass removal rate of soil contamination due to increased vapor pressure and in situ steam stripping. In addition, the aggressive nature of these technologies decreases the diffusion limitation problem of conventional advective transport by evaporating existing soil water. This action opens up new air flow paths and drives contaminants from dead end soil pore spaces. The increased mass removal rate decreases the total remediation time relative to ambient vacuum vapor extraction and decreases total remediation costs.

The TEVES technology uses the Illinois Institute of Technology Research Institute (Chicago, Illinois) tri-plate array configuration of electrodes. This is optimized for efficient radio frequency (RF) energy input into the soil, but can also be used for powerline frequency energy (60 Hz AC). (See Figure 1.2-1.) The center row electrodes are connected as the excitor (energy input) source. The two exterior rows are the ground/guard electrodes which restrict the input energy to the treatment zone. Two dual-purpose vacuum vapor extraction wells/electrodes are installed as part of the excitor array. A standard vacuum extraction blower is used to remove the heated soil contaminants. The offgas treatment system used in the TEVES demonstration consists of a conventional thermal catalytic oxidation system; however, the large amount of water vapor extracted with the contaminants required an innovative approach. An air-to-air heat exchanger is used to moderate the water vapor extracted from the treatment zone. A temperature controller that cycles the heat exchanger fan is used to limit the exit temperature, hence the water vapor mass, as needed. The condensate collected from the heat exchanger is cycled through a flat plate air stripper with the contaminated air passing into the thermal catalytic oxidizer. The treated water then passes through a carbon polishing step prior to collection in a tank.

The AC heating system relies on the conductive path of soil water to heat the treatment zone. Additional water is added to the top of each excitor row electrode to maintain electrical conductivity. When the temperature of the treatment zone neared 100°C, the resistive heating energy input becomes constrained because the conductive paths of water were being evaporated. At this point, continuing with the resistive heating mode is not effective so switching to the RF heating mode is appropriate.

RF heating uses high energy radiowaves (2-20 MHz) to heat the soil. The RF energy is transmitted through the soil without relying solely on the soil water as the conductive path. Energy deposition is a function of the frequency applied and the dielectric properties of the soil medium. Frequency selection is based on tradeoffs of wave penetration depth and the dielectric constant of the soil profile. Lower frequencies penetrate further but carry less energy. A matching network is used to match the output of the RF source to the changing impedance of the soil as water and contaminants are removed and

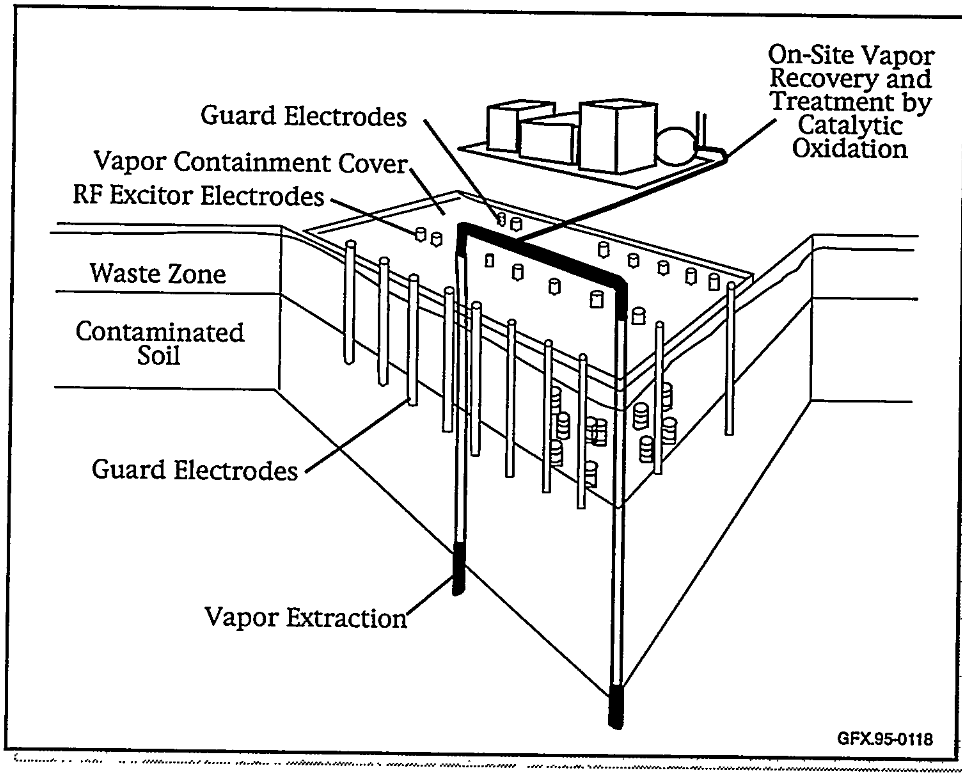

Figure 1.2-1. Thermal Enhanced Vapor Extraction System.

soil temperature rises. Soil heating can continue up to 250°C or greater, depending on the total energy input.

Benefits

The benefits of this technology are:

- This technology can remove relatively low volatility soil contamination without excavation, ex situ treatment, or lengthy vacuum extraction at ambient temperatures.
- Either AC heating or RF heating can be used, with the selection criteria being soil type and chemical contaminant mixture.
- Costs for implementation of this technology are superior to excavation/ treatment and long-term operation of conventional vacuum extraction technology.

Collaboration/Technology Transfer

This project involves collaboration with the Illinois Institute of Technology Research Institute, Science and Engineering Associates, Groundwater Technologies, Inc., and Sandia National Laboratories.

Accomplishments

Recent accomplishments for this project include:

- The project completed the demonstration of the TEVES technology at the Chemical Waste Landfill at Sandia National Laboratories, New Mexico. Figure 1.2-2 shows the cracking and subsidence of soils on the surface of the heated zone following treatment. Regulatory support for this demonstration was through a Resource Conservation and Recovery Act Research, Development and Demonstration Permit and a local air emissions permit.
- The AC heating period used 45,000 kW-hr of energy to bring the soil temperature up to an

Figure 1.2-2. Post-test Soil Cracks and Subsidence from TEVES Demonstration.

average of 80°C over 33 days. Contaminant removal rates increased by 200 to 300 percent, with peak levels up to 1,000 percent.

- The RF heating period used 30,000 kW-hr of energy to bring the soil temperature up to an average of 105°C over 30 days. Contaminant removal rates increases were similar to the AC heating period.
- Implementation costs for this thermal enhanced configuration are about $150/yd[3].

TTP Information

Thermal Enhanced Vapor Extraction System activities are funded under the following TTP:

TTP No. AL26PL21, Task 2, "TEVES Performance Reporting"

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1.3 In-Well Vapor Stripping

Technology Need

Many DOE sites have aquifers where groundwater is contaminated with volatile organic compounds (VOCs) such as carbon tetrachloride, chloroform, and TCE. The current baseline technology for cleaning up sites with VOCs in the groundwater is "pump and treat," a technology that is generally ineffective at achieving current regulatory cleanup levels. The baseline technology also requires the treatment and disposal of large amounts of water at the surface, which may increase risks to workers and require additional permitting and high capital costs for equipment. Furthermore, if the water contains tritium or other non-volatile contaminants, as is the situation at many DOE sites, surface storage and disposal of the water may be a major problem. Through In-Well Vapor Stripping, however, risk reduction can be achieved by removing VOCs from the aquifer without having to handle contaminated water at the surface. The system converts a groundwater contamination problem into a vapor stream, which can be treated easily at the surface (see Figure 1.3-1).

Technology Description

The objective of this project is to demonstrate the In-Well Vapor Stripping system at Edwards Air Force Base (AFB), California, and evaluate: 1) the system's effectiveness at removing VOC contamination, 2) its ability to bring concentrations to or below regulatory limits, and 3) the size of its zone of influence as determined through field results and computer simulations.

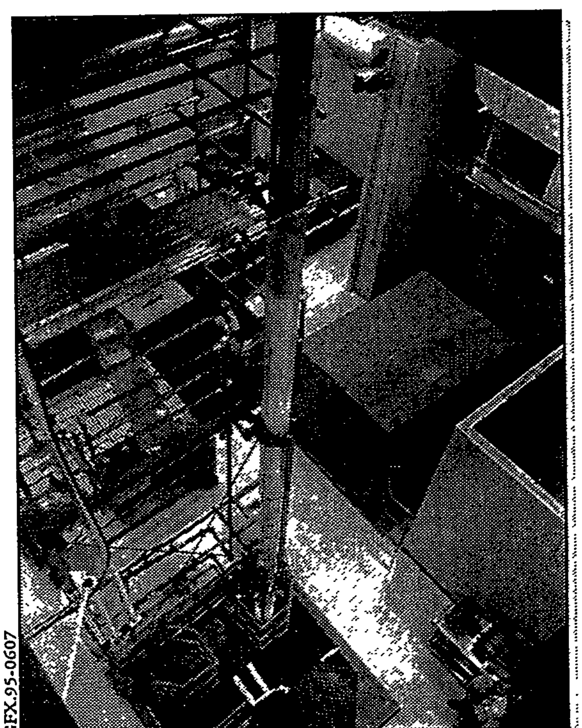

Figure 1.3-1. In-Well Vapor Stripping Down Hole Equipment.

The In-Well Vapor Stripping method extracts VOCs dissolved in groundwater by aerating the water column in a well. VOCs enter the gas phase and are pulled to the surface for treatment. Aeration also lifts the water within the well. Clean water exits the well above the water table, where it is then allowed to infiltrate through the ground. By simultaneously extracting groundwater and re-introducing this water above the water table, a circulation cell is created in the subsurface that systematically removes VOCs.

BENEFITS

The benefits of this approach include:

- The In-Well Vapor Stripping system is an in situ method that can continuously remove VOCs from groundwater without pumping the water to the surface or removing the water from the ground.
- It avoids handling contaminated water above the surface and disposing or storing partially treated water.
- There is no need for an above-ground air-stripping tower or storage tanks to contain the water that is free of VOCs, but that may have other contaminants such as tritium.
- Compared to the baseline pump and treat method, where reinjection of tritiated water was permitted, the In-Well Vapor Stripping System would not require the expense of drilling injection wells.
- The method has the further advantage of enabling recirculation of chemical aids to groundwater remediations, such as surfactants and catalysts.
- Finally, it also has the advantage that a single well can be used for extraction of soil vapors and for groundwater remediation. The baseline technology would require separate pump and treat wells and soil vapor extraction wells. The In-Well Vapor Stripping System is more economical and more efficient than pump and treat and soil vapor extraction.

COLLABORATION/TECHNOLOGY TRANSFER

In-Well Vapor Stripping is currently being developed in cooperation with NoVOCs, Inc. In September 1994, EG&G Environmental, Inc. purchased NoVOCs, Inc. and initiated an aggressive program for commercialization. EG&G Environmental is installing the technology directly as well as licensing other contractors to install systems. Stanford University owns the patent for this technology.

Accomplishments

Recent accomplishments for this project include:

- Performed a series of full-scale laboratory tests at the Hanford site to verify the concept and design of the prototype system; the tests were used to refine operating parameters, design specifications, and air stripping efficiency
- Built the treatment system and monitoring network for the field demonstration at Edwards AFB
- Demonstrated In-Well Vapor Stripping at Edwards AFB; this installation is the first demonstration of In-Well Vapor Stripping in the United States; TCE has been successfully removed from groundwater

TTP Information

In-Well Vapor Stripping activities are funded under the following TTPs:

TTP No. RL36PL21, Task 5, "In-Well Vapor Stripping Demonstration Operation"

TTP No. SR06PL21, Task 1, "IAG-EPA In-Well Vapor Stripping"

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1.4 AIR SPARGING OPTIMIZATION MODEL

TECHNOLOGY NEED

Air sparging is an effective technology used for removal of volatile contaminants (see Figure 1.4-1). However, optimization of existing applications and initial evaluation of the applicability of air sparging for cleanup are often addressed insufficiently. There is a need for models that can provide decision support both for new applications and for optimization of current sparging activities. This need exists within DOE and the air-sparging industry as a whole.

This project is developing a user-friendly, personal computer-based tool for planning, optimizing, applying, and monitoring field applications of air sparging technology. This decision tool uses site- and contaminant-specific data to determine the applicability of air sparging for a particular remediation scenario.

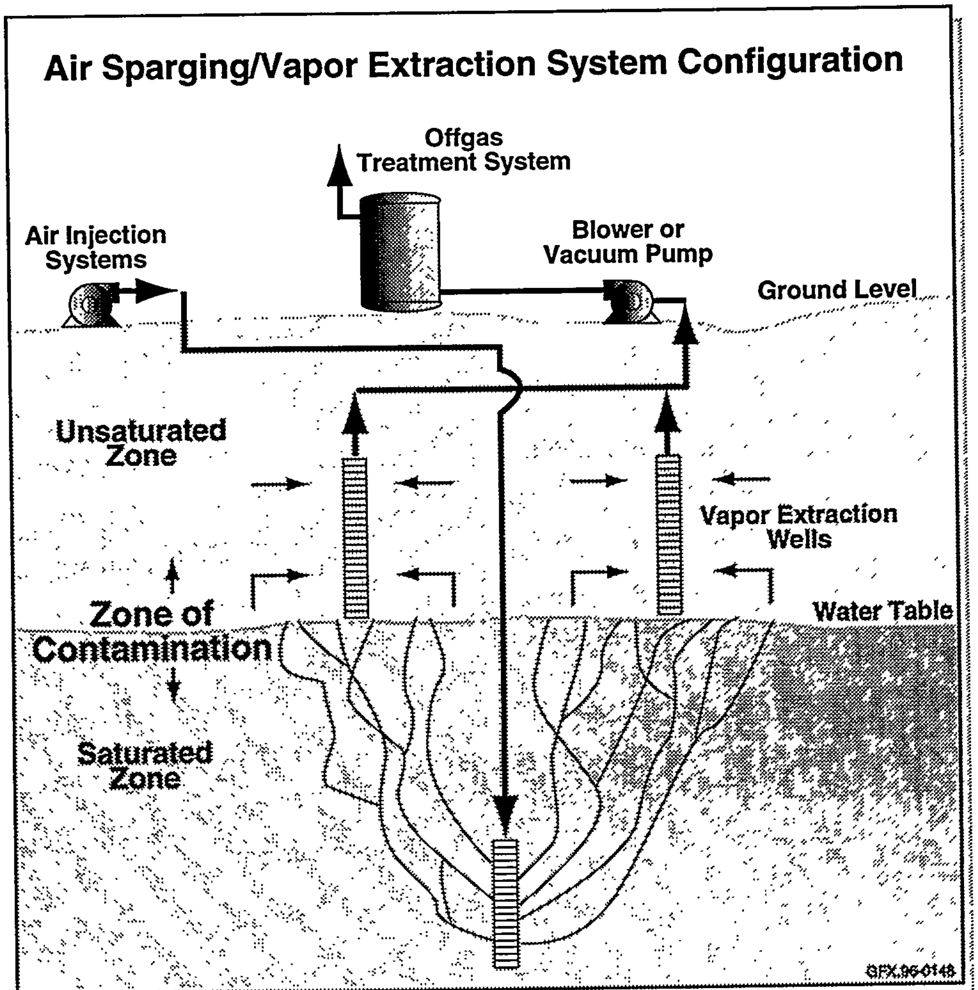

Figure 1.4-1. Application of Air Sparging Concept with Vapor Extraction for Cleanup of Petroleum Hydrocarbon Contamination.

In addition, this tool can be used to analyze operating data from existing air sparging systems and evaluate the performance of the systems based on such factors as removal effectiveness and operating efficiency.

The tool is complete and ready for distribution. It is calibrated and tested against existing data from air sparging remediation efforts. Supporting documentation, including user manuals and a full description of features, is transferred with the tool.

BENEFITS

The benefits of developing an optimization decision tool for use in air sparging are:

- Rapid and accurate decision-making with respect to determining appropriateness of air sparging technology to a specific remediation scenario; the tool will advise field practitioners of the applicability of air sparging
- Shorter learning curve for the application of air sparging technology by relatively inexperienced remediation personnel
- An overall faster and less expensive remediation effort

COLLABORATION/TECHNOLOGY TRANSFER

The project was initiated with the development of a review team by Parsons Engineering Science (ES). The team included well-known individuals experienced and knowledgeable in the area of air sparging technology. ES also assembled the computerization base. This collaborative effort was accomplished in conjunction with MSE-TA, Inc., the Subsurface Contaminants Focus Area organization, and DOE's Office of Environmental Management (EM-50).

Technology transfer is being accomplished by submitting professional presentations and papers to conferences where air sparging is an included technology. Additional technology transfer efforts are under development.

The copyright and licensing issues related to this effort are in progress. Distribution through licensing will be handled by the Energy Science and Technology Software Center in Oak Ridge, Tennessee.

ACCOMPLISHMENTS

Recent accomplishments of this project include:

- A literature review for applicable or relevant existing models was completed.

- Alpha and beta versions of the tool were developed and reviewed using existing air sparging industry data.
- The final tool was completed and is in preparation for distribution.

TTP Information

Air Sparging Optimization Model activities are funded under the following TTP:

TTP No. PE16PL21, "Air Sparging Optimization Tool"

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Bibliography of Key Publications

None at this time.

1.5 In Situ Treatment of Mixed Contaminants in Groundwater

Technology Need

Many DOE sites have groundwater contaminated with hazardous substances (e.g. VOCs) and radionuclides. Sites with mixed contaminants pose special treatment problems. For instance, treatment of VOC-contaminated groundwater above ground may be inefficient and costly, creating mixed or radioactive waste. Likewise, permits to reinject partially treated groundwater or to discharge treated water to surface waters may be difficult or impossible to obtain, especially for water containing radionuclides. Consequently, a method of treating mixed contaminants in situ is needed to expedite treatment and improve cost-effectiveness.

Technology Description

The overall goal of this task is to package one or more treatment process units for in situ remediation of VOCs and radionuclides in groundwater as modular components in vertical or horizontal recirculation wells.

Specific subtasks include:

1. Evaluation of horizontal wells for inducing groundwater recirculation (see Figure 1.5-1)
2. Evaluation of porous filter pipe instead of conventional well casing (see Figure 1.5-2)
3. Determining appropriate maintenance and operating parameters for an installation using porous filter pipe
4. Demonstration of a treatment system that simultaneously removes radionuclides and destroys chlorinated VOCs

Recirculation wells are an emerging technology for treating groundwater and soil air. These specially designed wells pump water or soil air through a screened interval and transfer it back into the aquifer through a separate interval. Treatment occurs below ground within the well casing, which may reduce expenses of utilities and maintenance. Below-ground treatment also eases obtaining regulatory approval, both for treatment and recirculation. Previously, only air stripping has been a treatment strategy. In this project, treatment will be performed with palladium-catalyzed zero-valence iron.

Palladized iron reduces TCE to harmless gases, i.e., ethane and ethene. Catalysis increases reaction rates by one to two orders of magnitude over that

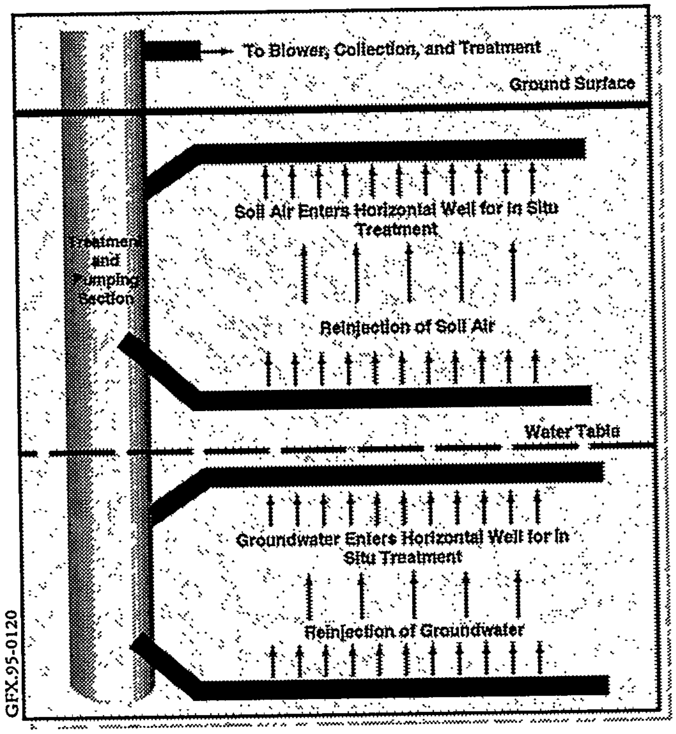

Figure 1.5-1. Recirculation Wells for Subsurface Groundwater and Soil Air Remediation.

with iron alone, which renders the technology suitable for forced flow applications. Research at Oak Ridge National Laboratory (ORNL) and elsewhere has demonstrated that iron is also an effective sorbent for Tc-99. The treatment approach to be used consists of an initial column of iron which will remove the Tc-99, followed by a series of canisters containing palladized iron. The expectation is that the Tc-99 will be removed in the first column and that the VOCs will be destroyed as they pass through the palladized iron. The result will be that small quantities of Tc-99 laden iron, without a hazardous waste component, will be all that remain for final treatment or disposal.

BENEFITS

The benefits of this approach are:

- Beginning in 1992, research at Oak Ridge determined the environmental restoration potential of recirculation systems and their applicability to problems across the DOE complex. Current work will extend recirculation technology to many additional sites. The novel combination of reagent and catalyst, palladized iron, may have applications throughout the DOE complex and industry as a whole.

Figure 1.5-2. Microporous Pipe Used in Construction of Recirculation Wells.

- Successful development of this in situ technology will result in significant cost savings by decreasing treatment time, easing permitting, and decreasing utility costs.
- Successful completion of this task will directly benefit the Portsmouth Gaseous Diffusion Plant, since it will provide an effective treatment of mixed contamination in the groundwater plume present under the X-701B sites. This plume is over 0.5 mile long and contains high levels of TCE and technetium-99. In addition, Portsmouth plans to use the approach at several other contaminated locations.
- The work will benefit the Hanford site by providing alternate treatment modules that can remediate groundwater contaminated with carbon tetrachloride and other VOCs.

COLLABORATION/TECHNOLOGY TRANSFER

Previous work included collaboration with Virginia Polytechnic Institute and State University. Collaboration with other DOE facilities, both at the laboratory and field level, will continue. For example, prior experience in horizontal well design at the Savannah River Site (SRS) was considered, as was research with vertical recirculation and in situ treatment of radionuclides at Hanford. Research on the ability of zero-valence metals to dechlorinate TCE and absorb technetium-99 being conducted at Portsmouth, Paducah, and Oak Ridge was evaluated and contributed to the decision to use palladized iron in the full-scale field test. Research Corporation Technologies (RCT), the holder of the patent for palladized iron, is providing the palladized iron and the complete treatment system at no cost to DOE.

RCT is a technology transfer company and will widely disseminate the results of the testing. Researchers at the University of Arizona are co-developers of palladized iron and will also participate in the project.

ACCOMPLISHMENTS

Major recent accomplishments for this project include:

- The project developed a well-characterized clean test site; this test area is now suitable for additional tests such as evaluating contaminant recovery using horizontal recirculation, comparing recirculation efficiency of various fluids, and comparing groundwater tracers.
- Two horizontal wells were installed using porous, flexible, filter pipe instead of conventional well casing.
- The Portsmouth Environmental Restoration program selected the X-701B contaminated site for the full-scale demonstration. This will be the first full-scale test of palladized iron.

TTP Information

In Situ Treatment of Mixed Contaminants in Groundwater activities are funded under the following TTP:

TTP No. OR16PL21, Task 1, "Recirculating Well Treatment of TCE and Technetium in Groundwater"

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1.6 Remediation Technology Development Forum on In Situ Bioremediation of Chlorinated Solvents

Technology Need

Chlorinated solvents such as TCE and PCE have been produced and used for many years by industry and the federal government during routine operations. The used solvents were then disposed of in a variety of ways that have resulted in site contamination and the migration of the chemicals into groundwater. It is estimated that the DOE alone has over 2,500 plumes of chlorocarbon contamination on its sites. To date, over 50 Records of Decision have identified remediation needs for chlorinated solvents in groundwater. Although processes such as pump and treat and vapor vacuum extraction have been developed for treating chlorocarbon-contaminated groundwater, they are largely inefficient and very costly. The need to establish and validate more cost-effective alternatives to these processes is widely recognized by problem holders as well as remediation contractors.

Technology Description

The Remediation Technology Development Forum (RTDF) Bioremediation subgroup is conducting efforts to demonstrate, validate, and establish implementation protocols for three bioremediation technologies for the in situ cleanup of chlorinated organic contaminants. The three technologies being developed within this program are:

- Accelerated anaerobic biodegradation, which involves the addition of nutrients to the subsurface to enhance in situ biodegradation (see Figure 1.6-1)
- Intrinsic remediation, which enables the prediction of the fate and transport of contaminants in the subsurface as a function of biotic and abiotic effects
- Cometabolic bioventing for vadose zone remediation by microbes which utilize a co-substrate such as toluene, phenol, or gasoline, resulting in the degradation of chlorinated solvents

The associated activities are multidisciplinary in design, and include the efforts of hydrogeologists, microbiologists, geochemists, and engineers. These technology protocols are initially being developed in conjunction with field studies at Dover Air Force Base and with others working on similar technology development efforts. The modification and validation of the protocols developed by the RTDF will occur at a second site which has yet to be identified. Validation will occur by demonstrating the utility of the protocols and their

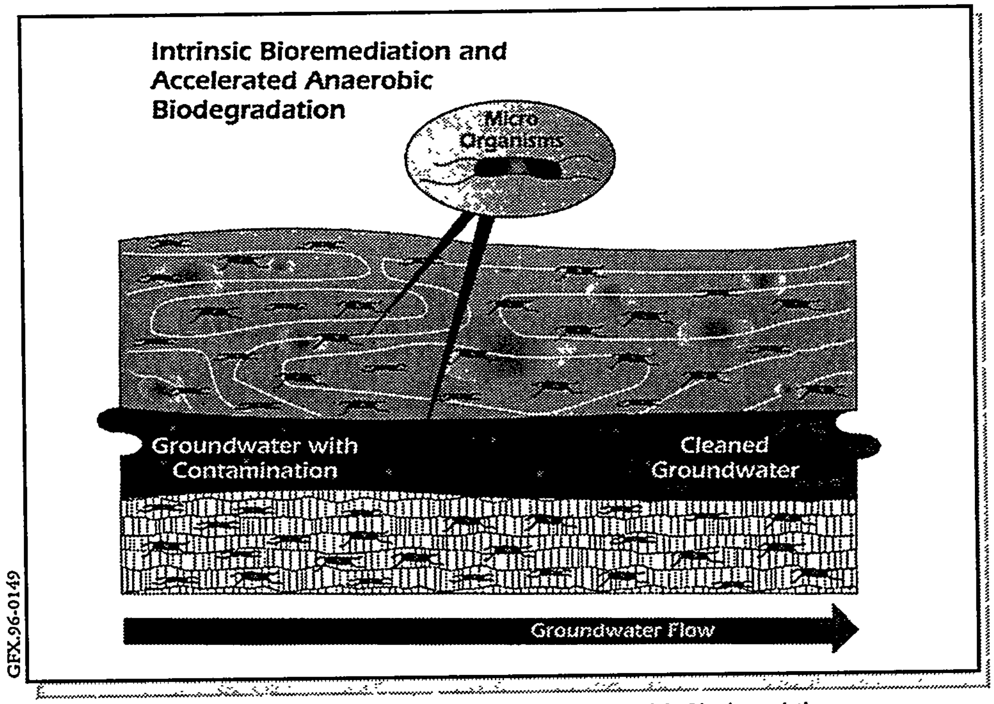

Figure 1.6-1. Intrinsic Bioremediation and Accelerated Anaerobic Biodegradation.

ability to predict the remediation potential at a site. Regulators and stakeholders are involved in this process to ensure acceptance of the final protocols. Specific DOE tasks which are being conducted in support of this effort include:

- Participation on the RTDF Steering Committee
- Evaluation of the Differential Soil Bioreactor as a tool for predicting and optimizing in situ biodegradation
- Microbial characterization support using phospholipid fatty acid analysis and specific enzyme probes
- Development of a personal computer-based model for describing and predicting in situ biodegradation
- Evaluation of the Fed-Batch Bioreactor as a tool for predicting and optimizing in situ biodegradation
- Funding for field activities including sampling, well drilling, cone penetrometer activities, and geoprobe site characterization

Benefits

The benefits of this approach are:

- Biotechnology development has recently been pursued to treat wastes in situ due to its potential cost-effectiveness. During the past several years, DuPont has determined that in situ anaerobic biodegradation processes can be enhanced by careful addition of nutrients and control of groundwater flow. Their studies have estimated that bioremediation processes may be able to save at least 50 percent of the costs associated with traditional treatments.

- General Electric, Dow, DOE, the U.S. Air Force, and the U.S. Environmental Protection Agency (EPA) have attempted to better understand the natural degradation of contaminants in the subsurface and the microbial role to provide a reliable risk assessment tool such that 'natural remediation' could be allowed to proceed at sites where effective control of contaminant migration is occurring. They estimate that this assessment, monitoring, and degradation process will save 75 percent of the costs of conventional active treatments.

Collaboration/Technology Transfer

The RTDF Bioremediation Working Group is composed of a consortium of participants currently consisting of DOE, EPA, U.S. Air Force, Ciba, Dow, DuPont, General Electric, ICI, Monsanto, and Zeneca. Each partner in the consortium brings the expertise as well as the resources necessary to conduct the studies, evaluate the effectiveness of the technologies, and produce the protocols needed for technology implementation. DuPont brings considerable expertise and field experience with anaerobic degradation. Dow, General Electric, ICI, Monsanto, Ciba, Zeneca, and the DOE bring to the team bioremediation expertise and unique laboratory and modeling experience. The EPA and the U.S. Air Force's Armstrong Laboratory bring their knowledge and field experience in designing and testing bioventing systems. Regulators and site managers have been involved in the development of these field studies at Dover AFB from the onset. In addition, the Western Governors Association and the Interstate Technology and Regulatory Cooperation Bioremediation Subgroup are aware of these efforts and will provide assistance during the development and validation of the technology protocols.

Accomplishments

Recent accomplishments of this project include:

- Chose Dover AFB as the initial site for technology protocol development
- Completed extensive geological and hydrological characterization at Dover AFB, including a calibrated flow model
- Initiated laboratory biodegradation studies in batch, column, fed batch, and differential soil bioreactors

- Identified three proposed technologies as the remediation methods of choice in the Record of Decision for the specific operable units at Dover AFB
- Completed preliminary microbial characterization of the groundwater and sediments at the site
- Initiated field borehole studies at the site
- Contacted the Western Governors Association and the Interstate Technology and Regulatory Cooperation Bioremediation Work Group; they have become involved in the program

Technical Task Plan Information

RTDF on In-Situ Bioremediation of Chlorinated Solvents activities are funded under the following TTPs:

TTP No. ID76PL21, Task 2, "RTDF Industrial Coordination"

TTP No. ID76PL21, Task 3, "Differential Soil Bioreactor"

TTP No. OR16PL21, Task 2, "Monitoring for RTDF Projects"

TTP No. RL36PL21, Task 4, "Technical Support to the RTDF"

TTP No. SR06PL21, Task 2, "RTDF Bioremediation Industry Consortium"

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1.7 In Situ Bioremediation

Technology Need

Chlorinated solvent contamination is widespread across the DOE complex. Many contaminant plumes present difficult cleanup problems because of the presence of non-aqueous phase contaminants and the complex geology of the aquifer. Pump and treat is the current baseline treatment for groundwater, but it has significant limitations due to poor extraction efficiency and the high expense of above-ground treatment. In situ bioremediation is being developed to stimulate the growth of naturally occurring organisms that can degrade and detoxify chlorinated solvent contamination in place in soils and groundwater.

Technology Description

Although bioremediation is broadly applicable and versatile, several key technical issues have prevented widespread use of bioremediation for organic and inorganic groundwater contaminants in heterogeneous subsurface environments. These issues include development of 1) an effective means to create and, in particular, control an area of active biodegradation in the aquifer, and 2) adequate tools for applying rigorous scale-up procedures and for *a priori* determination of successful operating and monitoring strategies.

To address these issues, a design tool was developed based on focused application of predictive computer simulations that integrate all of the primary phenomena associated with in situ bioremediation. The tool has been used successfully to design and operate a field test at Hanford and other locations. The computer-based tool was used to aid in selecting the appropriate system design and to determine optimal operating strategies. In addition, simulators proved to be valuable during remediation operations to determine appropriate changes to the operating strategy as the bioremediation process progressed. This is particularly important since in situ bioremediation is not a steady-state process.

A specific bioremediation process targeted at carbon tetrachloride and nitrate remediation was field tested at the Hanford Site (see Figure 1.7-1). The in situ design methodology used to successfully conduct this field test may be applied to many other contaminant species. Use of the design tool was evaluated during operation of the field test to determine the most efficient method to transition from initial site characterization data to a full-scale in situ bioremediation system. This technology is currently being applied to field test in situ anaerobic bioremediation of other chlorinated solvents and to design full-scale in situ remediation systems.

In situ bioremediation, as applied in this project, is based on the principal of biostimulation, supplying nutrients to indigenous microbes to stimulate their metabolic activity and subsequent degradation of contaminants. Typically, a network of injection and extraction wells are used to recirculate groundwater into which amendments are added for distribution within the aquifer. The objective is to create a microbially active zone that maximizes contaminant destruction within the aquifer while controlling the distribution of microbial growth. It is important to minimize growth near the wells and provide a large zone of influence around each injection well.

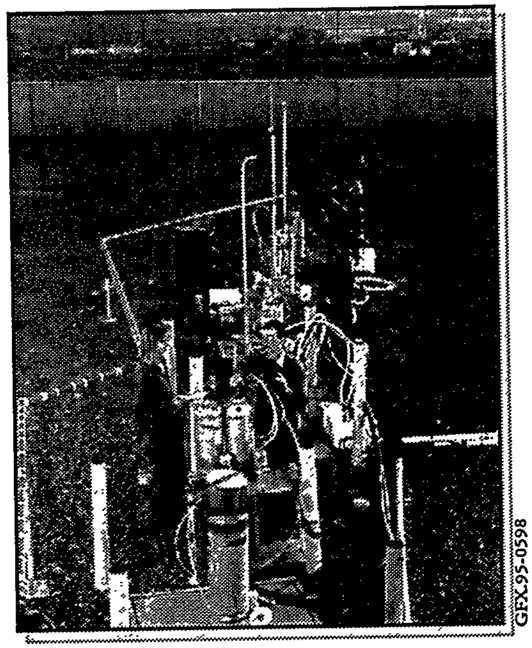

Figure 1.7-1. In Situ Anaerobic Bioremediation at Hanford Reservation.

BENEFITS

Present estimates indicate that this technology can remediate carbon tetrachloride at the Hanford test site in about half the time and with half the cost of conventional pump and treat methods (based on a mass removal destruction basis). In situ bioremediation is expected to have even greater advantages at sites with a greater portion of sorbed contaminant. For these sites (where contaminants are held up in adsorptive soils) or for less permeable silts, sediments, and clays, in situ bioremediation can be used to destroy the organics in place. In situ bioremediation will also be used to reduce the mass transport limitations associated with organic adsorption/desorption to sediments and dissolution into the groundwater that limits pump and treat technologies.

The time and cost of cleanup may be substantially reduced if bioremediation is employed alone, or in conjunction with other bulk-contaminant removal technologies. In situ bioremediation provides on-site destruction of the contaminant, converting the hazardous compounds to non-hazardous products. This technology may also be deployed to reduce the further spread of contamination. Other advantages include: 1) decreased worker exposure to chemical contaminants, 2) no off-site contaminant transport or handling with the corresponding liability, and 3) a high likelihood for stakeholder acceptance because remediation is through a natural process.

Collaboration/Technology Transfer

There is no one specific design, apparatus, or prescribed mixture of amendments that is associated with this technology. Rather, this technology and its application are site and contaminant specific. Therefore, the product from this project with the most commercial value is an integrated design tool for in situ bioremediation. This design tool can be transferred for use across the DOE complex, to Department of Defense installations, and to industrial sites. Industrial partnerships have been established with major full-service engineering and remediation companies including OHM Remediation Services and Montgomery Watson. These partnerships will serve as a mechanism for additional validation of the design tool and for technology transfer.

Accomplishments

Recent accomplishments of this project include:

- Completed field testing of in situ bioremediation for carbon tetrachloride and nitrate at Hanford in January 1996
- Controlled performance of the field test so that destruction of carbon tetrachloride occurred at a rate predicted by laboratory experiments and no chloroform was produced as a byproduct
- Controlled the distribution of the microbial growth within the aquifer during the field test to avoid plugging of the aquifer near the injection well area
- Developed and used a design tool during the field test; the tool is available and is being used in collaboration with industrial partners for applications at other contaminated sites, including demonstration of In-Well Vapor Stripping at Kelly Air Force Base

TTP Information

In Situ Bioremediation activities are funded under the following TTPs:

TTP No. RL06PL21, "Complete Field Demonstration of In Situ Bioremediation"

TTP No. RL36PL21, Task 1, "Engineering System for In Situ Bioprocessing"

TTP No. RL36PL21, Task 2, "Design and Evaluation Technologies — Engineering Simulator"

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1.8 PASSIVE SOIL-VAPOR EXTRACTION (BAROMETRIC PUMPING)

TECHNOLOGY NEED

Chlorinated solvents in the subsurface are one of the most significant environmental problems at DOE sites. These solvents tend to accumulate in finer sediments of the unsaturated zone, where they serve as a continuing source of contamination to aquifers below. There are over 50 sites within the DOE complex where the soil is contaminated with VOCs. Passive Soil-Vapor Extraction (PSVE) technology can remove volatile contaminants from the unsaturated zone, and thereby inhibit their downward migration.

The baseline technology, active soil vapor extraction, removes VOC contamination from the unsaturated zone but becomes progressively less cost-effective as VOC concentrations decrease. PSVE technology is a low-cost complement to active vapor extraction. PSVE can remove residual contamination effectively and efficiently without the need for main-powered vacuum pumps and blowers.

TECHNOLOGY DESCRIPTION

PSVE technology takes advantage of natural pressure gradients to cause the flow of contaminant-laden subsurface air from the vadose zone to the surface (see Figure 1.8-1). These gradients are caused by changes in atmospheric pressure which fluctuate diurnally and with the movement of large air masses.

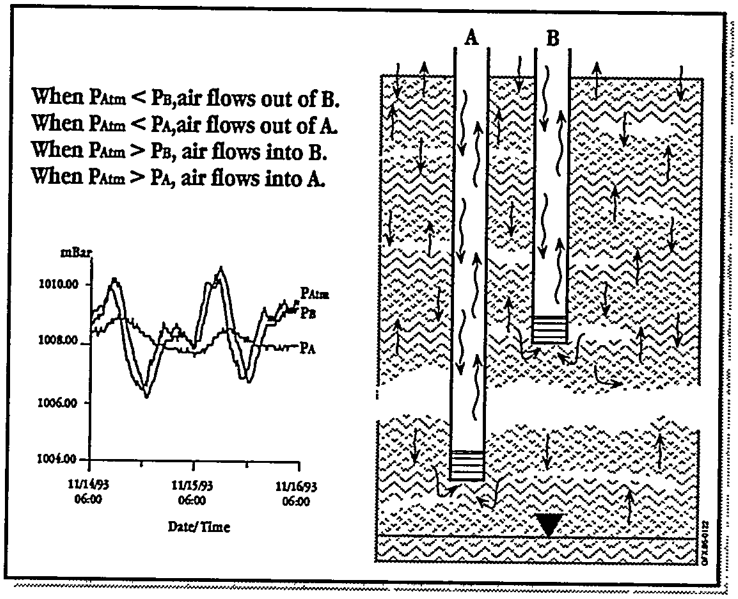

Figure 1.8-1. Barometric Pressure Fluctuations.

When atmospheric pressure increases, permeation into the soil occurs, opposed by the viscosity of air as it passes through small openings to pressurize soil pores. Then, after surface pressure drops, the pressurized pores act as a reservoir of compressed air that tries to flow to the surface. Under natural conditions, there may be considerable renewal of air in pores near the surface, but only the pressure changes, with little air flow, in deeper pores.

Application of PSVE involves the creation and utilization of pathways, such as wells and pipe collection networks, to produce a directed air flow in response to natural pressure changes. Because the driving force for flow is free, the technology is inherently inexpensive. Flow through these pathways can be controlled by solar-powered, microprocessor-operated valving systems or by wind- or solar-powered pumping systems to optimize and economize the performance of the PSVE. One ingenious system uses a passive one-way valve similar to that in a child's snorkel. There are two different types of PSVE:

Wellhead PSVE. A well with a screened (open) interval above the water table allows air flow into the deeper vadose zone. Controls to enhance system operations include: 1) one-way valves which allow air to escape from the well, but force fresh air to sweep through the soil and exit through the well, 2) monitors to determine the contaminant concentration in the escaping air, and 3) a stripper or absorber to remove contaminants from the escaping air stream (see Figure 1.8-2). Passive borehole remediation consists of installing granulated activated carbon (GAC) canisters or other non-powered treatment systems on open wellheads to capture the contaminants as they flow from boreholes.

Surface PSVE. If there is no well present, air cycles in and out of the soil surface. Surface modification for enhanced flux is a method of changing or controlling the air entry. Examples include paving, tilling, plastic sheeting covers, aerodynamic barriers, and other surface effects. Combining these surface modifications with collection pipe networks can cause contaminated air to move laterally to a collection point to enable the contaminant to be stripped from the air, similar to the wellhead systems.

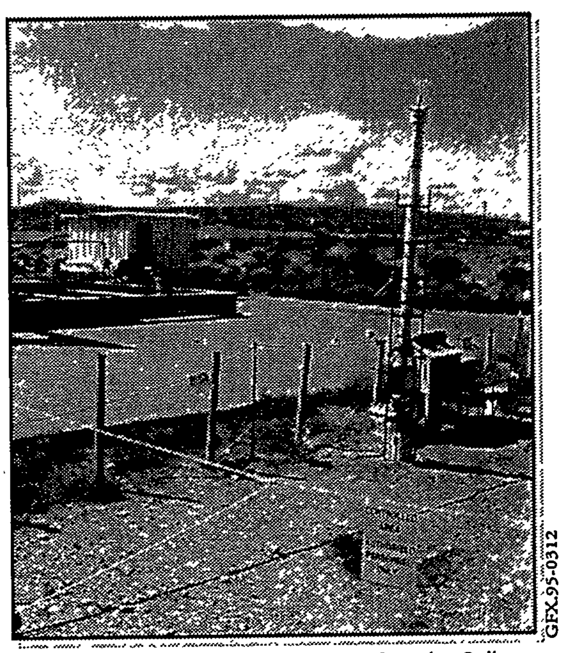

Figure 1.8-2. Field Demonstration of Passive Soil Vapor Extraction.

BENEFITS

Soil vapor flux enhancement by PSVE has the following benefits:

- It provides high performance in applications as a polishing tool after conventional active VOC extraction technologies have reached inefficiency and as a tool at the margins of subsurface plumes.
- It offers large cost savings in capital investment, maintenance, and cost of operations compared to the conventional active VOC extraction methods.
- It will work for any contaminant vapor in the vadose zone (above the water table).

COLLABORATION/TECHNOLOGY TRANSFER

The PSVE Working Group represents collaborations among IT-Hanford, EPA Region 10, Idaho National Engineering Laboratory (INEL), Lawrence Livermore National Laboratory (LLNL), Los Alamos National Laboratory (LANL), Pacific Northwest National Laboratory (PNNL), Westinghouse Savannah River Company (WSRC), and Science and Engineering Associates, Inc.

A Cooperative Research and Development Agreement (CRADA) has been established between WSRC and JND Sterling, Inc., to enhance the natural PSVE using a solar pumping system. Efforts are underway to develop a commercialization plan.

ACCOMPLISHMENTS

Recent accomplishments for this project include:

- The dynamics of the process have been studied to optimize removal rate, minimize plume dispersion, and use the geology and geometry of each situation. Other related technology developments are plume control, offgas treatment, and active extraction and bioremediation.
- PSVE systems were demonstrated at three separate DOE facilities representing different site conditions: Hanford, INEL, and Savannah River Site (SRS). The Hanford demonstration was successful in showing that high volumes of soil gas (average flow rate of 5 cfm) could be extracted for treatment using perforated pipe under plastic sheeting.
- With regulatory approval, wells equipped with one-way valves are being used to complete remediation of a leaky underground storage tank site in Idaho.

TTP Information

Passive Soil-Vapor Extraction (Barometric Pumping) activities are funded under the following TTPs:

TTP No. AL16PL21, Task 2, "Barometric Pumping"

TTP No. ID76PL21, Task 1, "Passive Venting"

TTP No. RL36PL21, Task 3, "Characterization and Evaluation Methods for Passive Control of Soil VOCs"

TTP No. SF26PL21, Task 1, "Enhanced Passive Soil Vapor Extraction"

TTP No. SR16PL21, Task 1, "Passive Control of VOCs Using Valved Well Heads"

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1.9 TUNABLE HYBRID PLASMA

TECHNOLOGY NEED

It has been estimated that there are 300,000-400,000 sites in the United States where soil and groundwater may be chemically contaminated. Some surface and groundwater supplies are known to be contaminated with chlorohydrocarbon concentrations up to 1 mg/liter, and trihalomethane levels in some areas exceed the federal standard of 0.1 mg/liter. In the past, VOCs were dumped in the ground at a number of locations, including most DOE facilities. Prevention of the spread of contamination and remediation of these sites often requires vacuum extraction of the VOCs in dilute concentrations. The baseline treatment technologies for gaseous effluents are GAC adsorption (with off-site regeneration and/or disposal) and thermal and catalytic incineration. A more cost-effective, environmentally attractive technology is needed to treat these streams as well as offgas from industrial sites and from air stripping of water.

TECHNOLOGY DESCRIPTION

The objective of the Tunable Hybrid Plasma (THP) system is to provide low-cost, environmentally attractive treatment of dilute concentrations of VOCs in air streams (see Figures 1.9-1 and 1.9-2). This system uses commercially established technologies and contains three main components. The first component is a steady-state, moderate energy electron beam (100-300 keV) which produces a low temperature plasma in the waste air stream. This creates a destructive process which converts toxic substances into non-toxic chemicals

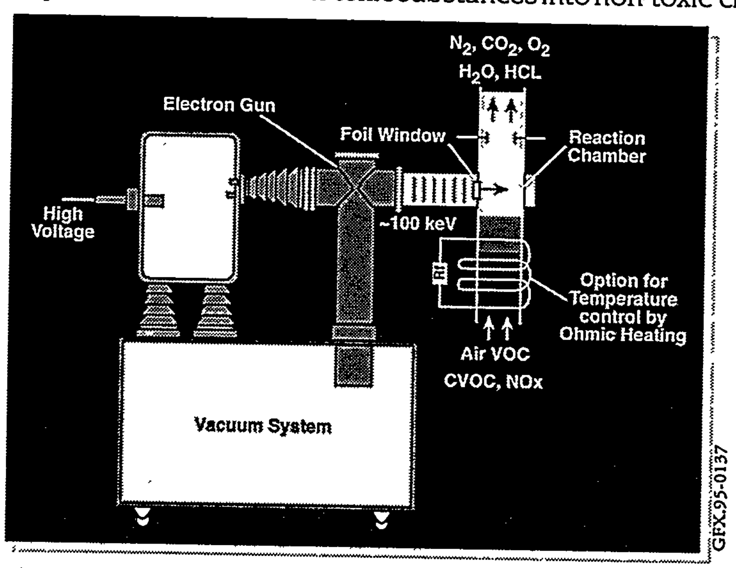

Figure 1.9-1. Tunable Hybrid Plasma Concept.

through their interaction with the electrons and radicals in the plasma. The second component is an aqueous scrubber to neutralize the halogenated byproducts. The third component is a gas analysis system with a PC-based control system which creates a feedback control loop and can be controlled remotely via a modem. This feature eliminates the need for operators during long-duration runs, thereby reducing labor costs. Also, this feature allows the system to work at varying inlet concentrations with a maximum efficiency of the electron beam generator.

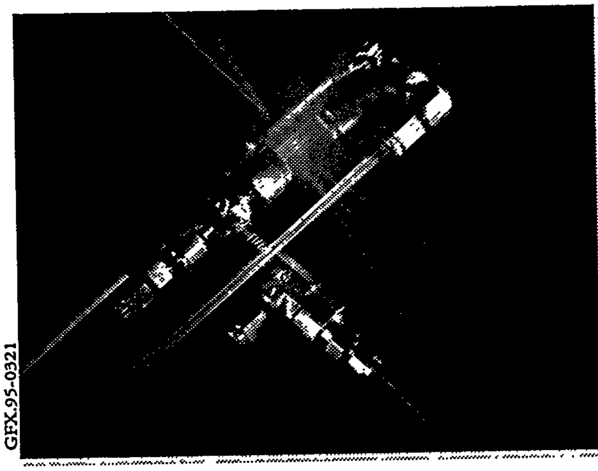
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Figure 1.9-2. Offgas Treatment Using Tunable Hybrid Plasma.

BENEFITS

The advantages of THP technology include:

- On-site destruction of toxic substances in gas streams at varying concentrations with high destruction efficiency, without production of undesirable substances produced by incomplete combustion
- Relatively low cost; capability for high throughput operation
- Reduction of end products to solid salts and carbon dioxide
- Minimum pre- and post-treatment requirements
- Entirely automated operations that can be controlled remotely, minimizing human presence at high-level contaminated sites
- No need for regenerables (such as catalysts or GAC) or fuel
- The costs for THP treatment are generally significantly lower than the costs for use of GAC and are also quite competitive with costs for thermal incineration and catalytic oxidation; cost projections for the THP system are approximately 50 cents/pound for TCE and several dollars per pound for carbon tetrachloride (CCl_4) and trichloroethane (TCA).

Collaboration/Technology Transfer

Massachusetts Institute of Technology is collaborating with Tecogen/Thermo Power Corporation on the evaluation of the THP technology, and PNNL is providing services in kind.

THP technology will reach its final pre-commercialization stage after a pilot field test. This test will provide results which will be used to design a commercial scale unit. This test will also allow the identification of possible changes needed for industrial units.

Accomplishments

Recent accomplishments for this project include:

- The field test of the THP field unit at the Hanford Site was completed. CCl_4 that was vacuum extracted from the ground was reduced from 200 ppm in the inlet stream to less than 0.1 ppm. Chlorine was converted to salt (NaCl).
- Several compounds (e.g., TCA, TCE, CCl_4, toluene) were studied with the THP laboratory device, and the energy expense of each was determined.
- A commercial cost evaluation of the THP system was performed, including a comparison with GAC, thermal incineration, and catalytic oxidation.

TTP Information

Tunable Hybrid Plasma activities are funded under the following TTP:

TTP No. RL36PL21, Task 6, "Tunable Hybrid Plasma"

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2.0 DNAPLs Product Line

The dense non-aqueous phase liquids (DNAPLs) Product Line is developing cost-effective technologies to remediate sites contaminated with DNAPLs. The primary objective of the DNAPLs Product Line is to develop a needs-driven program for the benefit of the Environmental Management problem holders (e.g. Environment Restoration) throughout the DOE complex. The program focuses on matching existing technologies as well as developing or improving new technologies to address DNAPL characterization, containment, treatment, and remediation needs.

In a 1995-96 survey conducted by the Subsurface Contaminants Focus Area, 15 DOE facilities representing a variety of hydrogeologic settings had suspected or confirmed contamination by DNAPLs. The most commonly reported DNAPL compounds include trichloroethylene (TCE), perchloroethylene (PCE), and carbon tetrachloride (CCl_4). Many other volatile organic compounds (VOCs) [e.g. dichloroethylene (DCE), dichloroethane, trichloroethane (TCA), etc.] as well as polychlorinated biphenyls (PCBs) are also common co-contaminants. The most frequent occurrence of DNAPLs is in unconsolidated sediments ranging to a depth of about 100 feet. Occurrences at greater depths and/or in fractured media, while very important, are less common among DOE sites. Many sites have DNAPL contamination in both the vadose and saturated zones. In the eastern part of the country, where shallow water tables predominate, DNAPLs in the saturated zone are of primary concern. In contrast, at DOE sites in the arid, western part of the United States, DNAPLs in the thick vadose zone are important, although associated groundwater contamination at some of these sites is of significant concern.

Nationwide, the DNAPL problem is recognized as one of the most difficult environmental challenges to be addressed. First, because of the toxicity of most chlorinated solvents, their unique physical properties (high density and interfacial tension), and their poorly understood migration pathways in the subsurface, it is very difficult to determine the location and distribution of DNAPL source areas with any degree of certainty at most sites. Second, due to the limited solubility of DNAPL compounds in water, DNAPL sources (especially those below the water table) are capable of contaminating enormous quantities of groundwater and can continue to be a source of contamination for many decades. Thirdly, because of the physical properties of DNAPLs, currently available treatment and remediation technologies are generally incapable of completely removing contamination from the source area. Incomplete removal means that the residual DNAPL will continue to be a long-term source of groundwater contamination. Mass recovery methods generate secondary waste that must be addressed. In situ destruction technologies (chemical oxidation, bioremediation) have certain advantages over mass removal methods, but are in relatively early stages of development.

For all of these reasons, an alternative strategy being considered by many sites is the use of permeable/reactive or impermeable barriers to contain DNAPL sources and to prevent further contamination of groundwater, while the search continues for reliable and cost-effective remediation and treatment processes to address the problem.

Technology development activities for the DNAPL Product Line are subdivided into several technology groups, which are further subdivided into subgroups and systems of technologies that address progressively more specialized components of DNAPL problems. These subdivisions are summarized as follows:

Characterization. There are three major subgroups under Characterization which include: 1) geologic/stratigraphic characterization, 2) location and distribution of DNAPLs, and 3) monitoring to support containment and treatment/remediation activities. Development and demonstration of a variety of geophysical, geochemical, and DNAPL compound-sensing tools are included in this group. In general, characterization technologies for the DNAPLs Product Line are addressed by the Characterization, Monitoring, and Sensor Technology Crosscutting Program and by the Morgantown Energy Technology Center Industrial Partnership Program. The DNAPLs Product Line works closely with these other programs to demonstrate new characterization technologies at DOE sites.

Treatment/Remediation. The treatment/remediation subgroups include: enhanced mass removal (thermal, fracture enhancing, and flushing technologies), in situ destruction (chemical oxidation and bioremediation), and passive treatment (permeable, reactive barriers for DNAPL source containment).

Secondary Waste Treatment. Some of the enhanced removal technologies under development involve the use of surfactants or co-solvents to improve efficiency. A major consideration in the viability of this approach is how cost-effectively the contaminant and surfactant or co-solvent can be separated from the waste stream and disposed of (contaminant) or recycled (surfactant, co-solvent). The Subsurface Contaminants Focus Area works with the Efficient Separations and Processing Crosscutting Program to address these activities.

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2.1 DEMONSTRATION OF INNOVATIVE DNAPL CHARACTERIZATION TECHNOLOGIES

TECHNOLOGY NEED

Residual industrial solvents, primarily DNAPLs, are currently the most significant barrier to successful completion of most large groundwater and soil cleanup efforts. Characterization of DNAPLs above and below the water table is a key component of developing a comprehensive remediation strategy. Traditional sampling approaches are not appropriate for this objective. Above the water table, residual DNAPL will reside in intergranular pores, held by capillary forces. Below the water table, DNAPLs behave in a complex fashion, moving downward as an immiscible phase and accumulating in highly concentrated discrete layers. Because of the physical and chemical characteristics of DNAPLs, characterization and remediation methods that minimize unnecessary waste generation are prudent. Finally, precise delineation of DNAPL areas will facilitate the design of appropriate remediation strategies and help to keep cleanup costs from escalating.

TECHNOLOGY DESCRIPTION

The central thrust of the characterization task includes detecting DNAPL directly, minimizing invasiveness by emphasizing small scale tests, and generating data to optimize cleanup activities. Because of these design concepts, the proposed technologies are required to target the thin, highly discrete DNAPL zones typical of most sites. In support of DNAPL characterization, ResonantSonic℠ drilling technology has been demonstrated to access these DNAPL zones with no investigation-derived waste (see Figure 2.1-1). The DNAPL characterization tools include spectral gamma logging of natural radionuclides in existing monitoring wells, small-scale single well alcohol injection extraction tests, small-scale partitioning tracer tests above the water

Figure 2.1-1. Angled Well Installed into a DNAPL Zone at the Savannah River Site Using ResonantSonic℠ Technology.

table, and related methods (e.g., geophysics and high resolution video in existing monitoring wells). These technologies will complement tools currently used or proposed by industry, the U.S. Environmental Protection Agency (EPA), and the U.S. Department of Defense [(DOD) e.g., surface geophysics and large scale differential tracer tests]. The theory of spectral gamma logging, as well as information about the small-scale single well alcohol tests and the vadose zone partitioning tracer tests, are discussed below as examples of the characterization approach.

Spectral Gamma Logging. The basis of the spectral gamma technique is fractionation of natural radioactivity because of the high partition coefficient of radon into DNAPL. Task investigators first observed this phenomenon of elevated radon measurements during a solvent recycle test. Below the water table, where DNAPL occurs in sands just above clay layers, the spectral gamma signal will indicate a clear doublet. The clay zone gamma signal will show the presence of primarily K with U and Th parents in equilibrium with radon daughters. The overlying DNAPL zone will show less K, indicating decreased amounts of clay in the sand unit, with elevated U and Th series gamma signals strongly shifted to radon daughters. A similar scenario has been described for DNAPL above the water table. The theoretical basis of the work was confirmed: hypothetical spectral gamma signatures for DNAPL above and below the water table were generated. The spectral gamma logging technique provides detailed information about DNAPL location without additional drilling and with minimal investigation-derived waste.

Small-Scale Single Well Alcohol Test. As with spectral gamma logging, the scale of the other characterization technologies in this program has been reduced far below current industry practice. For example, the single well alcohol injection extraction test in this program uses existing wells and less than 55 gallons of injection volume. The injected fluid, a solution of low molecular weight alcohol that can solubilize DNAPL without mobilizing it, permeates a small cylinder around the test well. When the solution is re-extracted, a large increase in the concentration of DNAPL components is an unequivocal indicator of the presence of residual DNAPL. The test provides clear confirmation of DNAPL without having to drill additional holes.

Vadose Zone Partitioning Tracer Tests. The deployment of the differential partitioning tracer test in the vadose zone is difficult because most of the DNAPL above the water table at the test site at Savannah River Site testing area (SRS) is trapped in clay layers. This is true for many sites across the country. Thus, an alternative interpretation is proposed to evaluate DNAPL quantity and mass transfer into the sand zones. Since most of the remediation airflow during soil cleanup is in the sand zones, the differential tracer tests are useful in estimating cleanup time.

BENEFITS

A coordinated package of innovative DNAPL characterization tools is being deployed. Each technology is carefully designed to:

- Minimize secondary waste
- Eliminate undesirable gravitational movement of DNAPL
- Minimize investigation-derived waste
- Mitigate similar types of collateral environmental damage inherent in addressing this complex environmental need

By emphasizing safety and small-scale direct DNAPL detection, the technologies provide the most accurate possible information about the precise intervals where DNAPL occurs, leading to optimized remediation design. The technologies in this task reduce waste and improve the precision of delineating DNAPL zones.

COLLABORATION/TECHNOLOGY TRANSFER

This work is a collaboration between various federal agencies, universities and private industry. Principal partners include: Clemson University, the U.S. Geological Survey (USGS), ARA, Fugro, Water Development Corporation, R J Electronics, Oak Ridge National Laboratory (ORNL), and Argonne National Laboratory (ANL). Additional collaboration has been obtained from Intera, University of Texas, EPA, the U.S. Air Force, and others.

ACCOMPLISHMENTS

Recent accomplishments of this project include:

Spectral Gamma Logging

- The theoretical basis of the work was confirmed, and hypothetical spectral gamma signatures for DNAPL above and below the water table were generated.
- A spectral gamma logger was fabricated and deployed in a control (non-DNAPL) well. The control well data provided counting statistics for the overall study. Based on these results, each well will require about 15 hours to log (at 30 minutes to count each elevation). Confirmation of the theory with field data, by deployment in wells installed through known DNAPL zones, will be completed in April 1996.

Single Well Alcohol Injection Extraction Test

- The test plans are complete, equipment fabrication is ongoing, and the underground injection control permit has been prepared.
- In coordination with remediation tasks, the Oleofilter has been procured to assist in handling investigation derived waste.

Vadose Zone Partitioning Tracer Tests

- Preliminary vadose zone partitioning tracer tests have been completed. Based on these results, laboratory column studies and additional field tests are scheduled.
- Improved small-scale access continues, using the cone penetrometer (and related tools) for deployment of DNAPL characterization.
- Other studies are being completed, including 3D digital imaging of contaminant and geological data, geophysical tests by the USGS, and high resolution video studies.

TTP Information

Demonstration of Innovative DNAPL Characterization Technologies activities are funded under the following technical task plan (TTP):

TTP No. SR16PL31, Task 1, "Characterization and Monitoring of DNAPLs"

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2.2 EVALUATION OF CRITICAL MOBILIZATION PARAMETERS

TECHNOLOGY NEED

Several existing DNAPL contamination remediation technologies can lead to a reduction of the capillary forces responsible for the stability of DNAPL pools in the subsurface. These technologies may increase the mobility of DNAPL as a separate fluid phase and result in the spread of contamination into previously uncontaminated regions. Due to regulatory, environmental, and human health concerns, data are required to provide design limits which will reliably define conditions where separate phase mobilization is likely to occur.

TECHNOLOGY DESCRIPTION

Alcohol and surfactants can increase DNAPL solubility in water, enhancing its recoverability by pump and treat methods and resulting in a decrease in remediation time. These technologies, however, also reduce the capillary force which increases the potential for further migration of the DNAPL, now in solution. If the capillary force is reduced too far, residual DNAPL can begin to flow, potentially magnifying a contamination problem. This program is designed to provide greater understanding of the processes associated with enhanced DNAPL remediation by surfactant dissolution and to provide guidance for site-specific system design which will minimize the risk of remobilizing DNAPL.

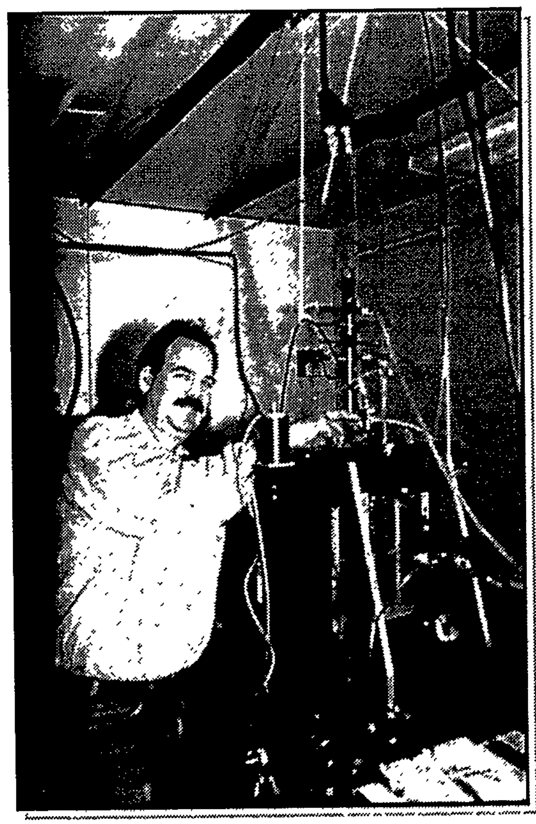

Figure 2.2-1. Soil Columns Mounted at Cornell University's Synchrotron Facility.

High energy synchrotron X-rays are used to non-destructively monitor DNAPL saturation in experimental porous media (see Figure 2.2-1). The large X-ray flux allows relatively rapid monitoring of changes in DNAPL saturation which are characteristic of separate phase flow. Surfactant concentration and the resultant capillary force is determined in situ using a tracer (e.g., iodine). The white X-ray spectrum emanating from the synchrotron allows tracer concentration and DNAPL saturation to be determined by taking measurements at two different X-ray energies. The test determines the capillary force conditions at which discrete DNAPL blobs trapped in porous media of different grain size, grain size distribution, and porosity become mobile. These data provide guidance to minimize the risk of initiating undesirable separate phase DNAPL flow during an enhanced remediation.

Additional experiments employing gamma rays (i.e., gamma-gamma geophysical logging) are used to measure DNAPL solubilization rates into various surfactant solutions as a function of porous media characteristics. All such experiments must infer the mass transfer rate by assuming a relationship between the DNAPL-water interfacial area and DNAPL saturation. Current experiments are designed to directly measure the solubilization rate of DNAPL components. This information provides input parameters for computer models and data to validate the model's performance.

A pore-scale computer model has been developed to simulate several aspects of surfactant enhanced DNAPL remediation, including miscible surfactant-transport, initiation of DNAPL flow under the reduced capillary force, and DNAPL dissolution into passing water. The model has accurately described laboratory experiment results and it provides key information for the determination of critical interfacial tension.

BENEFITS

Successful completion of the tasks under this project will provide methods for determining site-specific design criteria that can be used to enhance DNAPL remediation, while minimizing the risk of spreading DNAPL contamination.

COLLABORATION/TECHNOLOGY TRANSFER

This task includes active participation from Cornell High Energy Synchrotron Source (CHESS), Krüss USA, Princeton University, University of South Carolina, and Westinghouse Savannah River Company.

ACCOMPLISHMENTS

The project has accomplished the following results:

- Completed evaluation of several surfactants for use in experiments
- Completed several dissolution kinetics experiments

- Developed new pore-scale computer model incorporating realistic geometrical conditions based on random packing of spherical grains
- Successfully completed initial experiments at CHESS demonstrating experimental technique of using X-rays to monitor DNAPL saturation

TTP Information

Demonstration of Innovative DNAPL Characterization Technologies activities are funded under the following TTP:

TTP No. SR16PL31, Task 2, "Evaluation of DNAPL Mobilization Potential"

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2.3 DEMONSTRATION OF INNOVATIVE DNAPL REMEDIATION TECHNOLOGIES

TECHNOLOGY NEED

Residual industrial solvents, primarily DNAPLs, are currently the most significant barrier to successful completion of most large groundwater and soil cleanup efforts. DNAPLs are generally mixtures of these solvents, are relatively toxic, and sometimes contain co-contaminants such as PCBs. The presence and slow dissolution of DNAPLs stabilize nearby groundwater concentrations at levels far above regulatory limits. Groundwater pump and treat technology successfully removes dissolved contaminants; but at sites with DNAPL, cleanup periods of several hundred years are now forecast. The most widely proposed options for improving DNAPL cleanup involve using additives such as surfactants or cosolvents to speed up the bulk solvent removal process by either solubilization or mobilization.

For solubilization, the goal is to increase effective aqueous solubility to allow the DNAPL to dissolve faster for collection by a groundwater pump and treat system. For mobilization, the goal is to decrease interfacial tension, allowing the bulk solvent phase to move to a collection point. Each of these existing approaches has significant problems. Solubilization, while faster than simply pumping groundwater, is slow and additives must be reliably recycled for the process to be economical. Mobilization is much faster, but there are legitimate environmental and regulatory concerns about mobilizing the DNAPL, which will gravitationally migrate rapidly down and away from the site if the collection system is not 100 percent effective. Creative alternatives that minimize waste generation and maximize safety are needed.

TECHNOLOGY DESCRIPTION

The central themes emphasized in developing environmentally responsible remediation methods include: minimizing excess waste, improving remediation safety and speed, and emphasizing life-cycle impacts. Demonstrations of remedial technologies at the Savannah River Site provide an ideal test bed for evaluating new, emerging, and commercially available technologies, because of the well characterized nature of the site and available logistical support. Cleanup methods that have been or are being evaluated by this task include on-site batch destruction, hydrophobic surface-based collection systems, solvent recycle techniques, pilot studies on a density balancing mobilization approach, and field implementation of a commercial in situ destruction process. As discussed on the following pages, these diverse remediation technologies provide alternative advantages.

Recycling/Destruction of Recovered DNAPLs. Recycling and/or on site destruction of collected DNAPLs represent a significant potential improvement in DNAPL management strategy. Several proposed DNAPL remediation technologies generate a separate phase liquid (typically at a low rate). In some cases this material is potentially usable and in others it may contain co-contaminants (e.g., PCBs) and require responsible destruction. This subtask examines on-site destruction technologies. The primary destruction technology tested is nascent hydrogen dechlorination. The process, applied to DNAPLs, has been studied by DOE-Savannah River Technology Center and chemists from SRK Environmental. In some cases, recycle technologies are particularly environmentally sound because they reduce energy costs associated with destruction. Direct recycle of solvents will provide a feedstock for users/industry and generally reduce the need for new/additional solvent production. To efficiently collect DNAPLs, two technologies are being studied: hydrophobic lances and Oleofilters. Both technologies are based on preferential wetting of hydrophobic surfaces, followed by DNAPL draining to a collection point (see Figure 2.3-1). These methods rely on preferential interfacial tension relationships for energy and will allow collection and separation of DNAPL at an extremely low cost.

Alcohol Flushing. Scoping studies of a new design paradigm have been proposed by Clemson University, resulting in improved speed and safety in cleaning up groundwater zones contaminated with DNAPLs. A preconditioning step is used, where a low molecular weight alcohol solution is flushed

Figure 2.3-1. An Oleofilter Using a Hydrophobic Surface to Passively Separate DNAPLs from Groundwater.

through the site. While this increases DNAPL solubility, it does not mobilize the pool. Following this step, a mobilizing cosolvent alcohol is added to allow collection of the bulk DNAPL pool. The unique feature of this approach is that the preconditioning step allows use of a much higher molecular weight cosolvent in the second step. The cosolvent partitions into DNAPL and reduces its density. The result is that the pool is mobilized with a density about equal to water. This allows rapid and reliable collection using standard pump and treat wells.

Chemical Oxidation. A Cooperative Research and Development Agreement (CRADA) has been implemented with GeoCleanse International to deploy an in situ destruction technology. The proprietary method, an aggressive oxidation reaction based on Fenton's chemistry, has been successfully applied to oils and gasoline and is now proposed for DNAPL.

BENEFITS

A coordinated package of innovative DNAPL remediation tools is being deployed. All remediation tools proposed in this project are potentially useable by government or public entities with DNAPL cleanup needs. Each technology is carefully designed to:

- Minimize secondary waste
- Eliminate undesired gravitational movement of DNAPL
- Minimize investigation-derived waste
- Mitigate collateral environmental damage

COLLABORATION/TECHNOLOGY TRANSFER

This work is a collaboration between various federal agencies, universities and private industry. Principal partners include: Clemson University, GeoCleanse International, APROTEC, ORNL, and ANL. Through the national Subsurface Contaminants Focus Area technical support efforts, additional collaboration has been obtained from Intera, University of Texas, EPA, U.S. Air Force, and others.

ACCOMPLISHMENTS

Recent accomplishments of this project include:

- **On-Site Destruction**. Initial bench-scale experiments started with pure DNAPL and examined destruction of chlorinated solvents and PCB co-contaminants. The character of residual matter in these experiments was examined to determine if it had any commercial value. Various conditions in the study generated destruction efficiencies of >99 percent for TCE and PCE and >90 percent for PCBs. Residual matter was comprised of water and zinc acetate salt. Contacts with local industry indicate a possible market for accepting the zinc acetate residual as a feedstock.

- **Hydrophobic Surfaces.** An Oleofilter was purchased and modified for testing DNAPLs. This device, originally demonstrated in the EPA Superfund Innovative Technology Evaluation (SITE) program for light oils, is based on a proprietary hydrophobic ceramic surface. The Oleofilter was installed at a known DNAPL site (i.e., adjacent to the M-Area Settling Basin at the Savannah River Site).
- **Chemical Oxidation.** A CRADA with GeoCleanse International was placed for a field demonstration of in situ oxidation of a known DNAPL target in an aquifer.
- **Alcohol Flushing.** The density balancing mobilization technology was demonstrated in the laboratories at Clemson University; cosolvents were applied that resulted in floating a TCE pool in a test tube.

TTP Information

Demonstration of Innovative DNAPL Remediation Technologies activities are funded under the following TTP:

TTP No. SR16PL31, Task 3, "Evaluation/Demonstration of DNAPL Remediation Technology"

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2.4 SIX-PHASE SOIL HEATING MULTIPLE ARRAY DEMONSTRATION

TECHNOLOGY NEED

VOC-contaminated sites are common in the DOE complex, DOD sites, and private industry sites. The total volume of VOC-contaminated soil requiring treatment within the DOE complex alone is over 37 million cubic meters. Contaminants at these sites include chlorinated solvents such as TCE and PCE; nonchlorinated solvents such as methyl ethyl ketone, benzene, and acetone; and fuels such as gasoline.

Techniques for efficiently removing VOCs from soils are needed. The baseline technologies, soil vapor extraction (SVE) within the vadose zone and pump and treat for groundwater, are limited by the mobility of the contamination in the subsurface. Six-Phase Soil Heating (SPSH) increases mobility and should result in faster and more complete removal of contamination from less permeable soils.

TECHNOLOGY DESCRIPTION

Six-Phase Soil Heating is a method to increase the removal of volatile and semi-volatile contaminants from soils (see Figure 2.4-1). To implement the technology, electrodes are placed in the ground and a voltage is applied. Electrical current conducts through the soil, heating the soil resistively. This

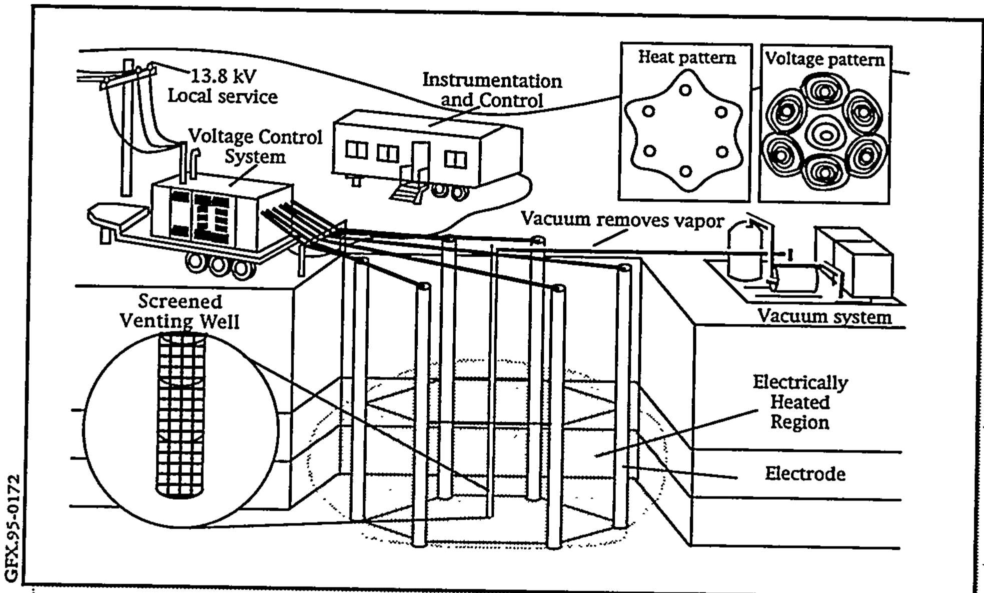

Figure 2.4-1. Six-Phase Soil Heating.

heating volatilizes contaminants and water (to produce steam) in the soil, effectively steam-stripping contaminants in situ. The volatilized contaminants and steam are then removed by soil venting and treated aboveground.

SPSH is applicable to sites contaminated by VOC and semi-volatile organic compound contaminants. Although SPSH is effective in all soils, it is most cost-competitive where soils are tight, where SVE and in situ bioremediation methods are not effective, or where contamination is deep and excavation is not practical.

A demonstration of a simultaneously heated multiple array SPSH approach is being funded at Hanford in FY96 to increase cost-effectiveness at large sites within the DOE complex and elsewhere. This method of operations will reduce operating time and costs substantially compared to sequential application of singly heated arrays. In addition, this demonstration will provide industrial partners the opportunity to participate in SPSH operations, enabling them to become familiar with the technology and thereby facilitate technology transfer.

BENEFITS

The benefits of this approach include:

- SPSH is applicable to sites where contaminants are not very volatile or are present as a non-aqueous phase liquid (NAPL), and where soils are impermeable or heterogeneous.
- Low permeability zones are targeted by heating, forcing out contaminants that can only be removed by diffusion (over long periods of time) with SVE.
- SPSH reduces VOC removal time to a few weeks for a typical site, whereas SVE would require years for remediation. This can significantly decrease costs over SVE (from 2 to 10 times).
- Excavation and ex situ soil treatment is typically much more expensive to implement than SPSH, especially at deep sites. Estimates indicate that SPSH is between 20 and 30 percent of the cost of excavation, with either on-site treatment or disposal of the excavated waste off-site.
- The in situ nature of this treatment minimizes potential exposure to humans and the environment. Ex situ options like excavation require repeated worker handling of the contaminated soil and increased opportunity for volatilization of contaminants, leading to off-site contamination.
- The secondary offgas stream generated as part of the SPSH process can be treated easily using conventional offgas treatment technologies such as catalytic oxidation, thermal oxidation, condensation, and granular activated carbon (GAC).

Collaboration/Technology Transfer

SPSH will be transferred through training and support to industrial partners who will implement the technology to help clean up sites. Pacific Northwest National Laboratory (PNNL) is currently working with two such partners to implement SPSH at sites in Chicago and Boston. After training and operations assistance from PNNL, the partners will seek out other opportunities to deploy SPSH under licensing agreements with PNNL.

SPSH is currently available through several environmental remediation providers. TerraVac is currently partnering with PNNL to remediate a privately owned site in Chicago, Illinois. PNNL is also pursuing licensing agreements with several potential industrial partners with extensive environmental cleanup experience.

SPSH is protected by a set of United States and Canadian patents as well as a set of United States and foreign patent applications.

Accomplishments

Recent accomplishments for this project include:

Field Demonstration. A field demonstration of SPSH was performed in FY94 at DOE's Savannah River Site. The test site consisted of a subsurface clay layer, contaminated with PCE and TCE. Approximately 1,000 m^3 were treated during this demonstration with the following results:

- 99.7 percent removal of PCE was observed based on pre- and post-test soil samples.
- After seven days of heating, soil temperatures uniformly increased to 100°C.
- Power was applied to the soil for approximately 25 days, at an average level of 200 kW per hour for the whole remediation system.
- 70,000 liters of moisture were removed during venting.

Process Improvements and Cost Reductions. Over the past two years significant improvements have been made in the SPSH design to increase cost effectiveness of the technology. These include:

- Introduced low cost electrodes, constructed from off-the-shelf materials with minimal assembly
- Automated operations allowing remote computer control and data analysis of on-site monitoring is not required

- Development of surface applications including collection of contaminants from a surface plenum
- Preliminary investigation of SPSH in the saturated zone for removal of DNAPL contamination
- Resolution of grounding issues to allow heating near buildings and other occupied areas

TTP Information

Six-Phase Soil Heating (SPSH) Multiple Array Demonstration activities are funded under the following TTP:

TTP No. RL36PL3, Task 1, "Six-Phase Soil Heating Multiple Array Demonstration"

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2.5 Remediation of DNAPLs in Low Permeability Soils

Technology Need

DNAPLs such as TCE and PCE contribute to major environmental problems across the DOE complex and the industrialized world. In addition, low permeability soil and geologic media (LPM) represent site conditions that are common and very problematic for environmental restoration. Approximately 40 percent of the underground petroleum tanks around the world are located in close proximity to low permeability soils. DNAPL compound behavior in LPM is often complex and highly uncertain, which makes risk assessment difficult and in situ remediation extremely challenging. In the vadose zone, DNAPL compounds can continually volatilize into the soil air or leach into percolating water. In the saturated zone, DNAPLs can dissolve slowly and contaminate flowing groundwater. As a result, LPM contaminated by DNAPL compounds can represent a long-term source of potential adverse effects to air and water quality and public health.

In situ remediation by conventional SVE or groundwater pump and treat approaches has been attempted, but with limited success. Efforts to develop more effective in situ technologies have occurred over the past few years. As described below, the adaptation and enhancement of relatively simple emerging technologies to achieve effective in situ treatment of DNAPLs in LPM represents an attractive alternative to the development of more exotic methods.

Technology Description

In this project, in situ remediation technologies are being evaluated for both source control and mass removal of DNAPL compounds in LPM. This effort is focused on chlorinated solvents (e.g., TCE and PCE) in the vadose and saturated zones of LPM, including massive LPM deposits, and fine-grained layers in otherwise permeable strata (see Figure 2.5-1). The technologies selected for testing include two coupled facets: 1) subsurface manipulation of LPM through soil fracturing and lance permeation, and 2) in situ treatment of the DNAPL compounds through enhanced mass transfer and destruction. These technology approaches were chosen based on their relative simplicity and low cost, and their potential for effective performance. Their attributes support the potential for rapid and widespread application at relatively simple, small sites as well as at more complex, larger sites. In addition to research and demonstration of treatment technologies, efforts are being expended to

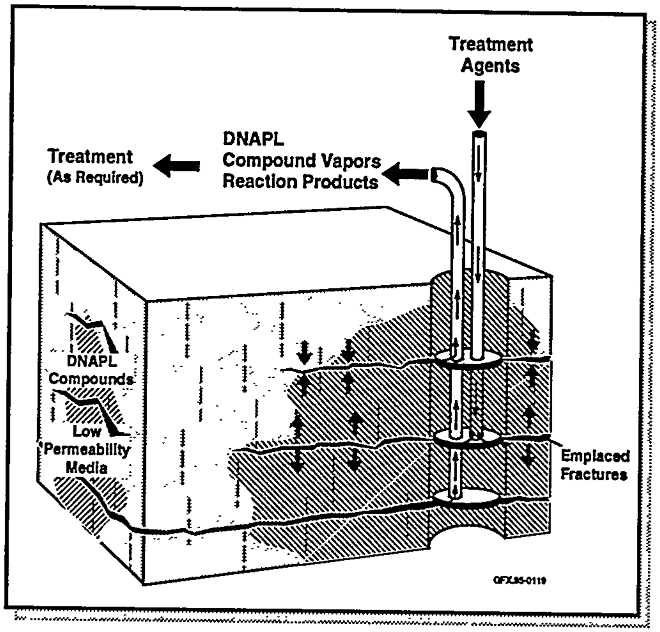

Figure 2.5-1. Source Control and Mass Removal of DNAPL Compounds in Low Permeability Media.

understand the processes that influence DNAPL migration and in situ treatment in LPM and the methods for assessing the operation and performance of the remediation technologies.

This project is interdisciplinary and multi-institutional and comprises a series of interrelated tasks including:

- A field test of hydraulic fracturing
- A field test of enhanced vapor extraction for non-aqueous phase liquid (NAPL) removal
- A field test of hydraulic and pneumatic control and hot fluid injection via hydrofractures
- A field comparison of multiple point injection and permeation dispersal of reactants
- A field-scale comparative test of in situ technologies at a contaminated DOE site
- Experimental analyses of the mobility of residual NAPLs versus varying degrees of mass removal
- Preparation of 16 DNAPL focus papers and reports

Field testing activities have occurred at three locations: Sarnia, Ontario Province, Canada; Aber Road outside Cincinnati, Ohio; and the DOE Portsmouth Gaseous Diffusion site near Piketon, Ohio.

BENEFITS

As a result of this project, there have been advancements in the operation and performance of in situ treatment technologies for DNAPLs in LPM. These advancements and others yet to come will define the need for and benefit gained by in situ treatment. It will also broaden the applicability and cost effectiveness of such methods.

The project accomplishments are being achieved through the leveraging of resources from DOE EM-50 and EM-40 as well as the American Petroleum Institute (API). Moreover, the interaction between multiple institutions and sites will foster rapid and widespread technology transfer.

COLLABORATION/TECHNOLOGY TRANSFER

This research and demonstration project was initiated by DOE in collaboration with the API in late 1993. At that time, API already had just initiated a project focused on light non-aqueous phase liquids (LNAPLs) in low permeability soils. Meanwhile, DOE was confronting widespread problems with DNAPL compounds in low permeability soils. A Memorandum of Understanding was developed between DOE and API to foster cooperation and share research information. API retained direction and control of the ongoing LNAPL work while DOE initiated and maintained control of the DNAPL work. This project has included active participation by six universities and six private industries. Synergistic linkages have been made with DOE sites (e.g., Portsmouth) to gain co-funding as well as facilitate the rapid transfer of promising results into full-scale implementation within DOE's environmental restoration programs.

ACCOMPLISHMENTS

Recent accomplishments for this project include:

- Sixteen state-of-the-art focus papers were prepared on DNAPL transport, risk, and remediation, including separation and transfer processes (e.g., vapor extraction and subsurface mobilization), destruction processes (e.g., chemical and biological degradation), thermal enhancement (e.g., hot air, steam injection, electromagnetic heating, and resistance heating), and enabling technologies (e.g., hydraulic and pneumatic fracturing and mixing).
- In collaboration with Oregon Graduate Institute (OGI) under API sponsorship, an evaluation was conducted of enhanced vapor extraction for NAPL removal during 1993 to 1995. The results indicated relatively low mass removal efficiency in the clay till (e.g., about 40 to 50 percent) at the controlled release test cell at Sarnia, Canada.

- In collaboration with the Portsmouth Gaseous Diffusion site and Hayward Baker Environmental, a demonstration was completed during November 1994 to evaluate multipoint injection and permeation dispersal of different agents (e.g., hydrogen peroxide, colloidal iron, compressed air, etc.). Permeation dispersal of reagents indicated that volumes of different fluids introduced into the LPM deposit could dramatically impact subsurface properties (e.g., raising Eh to >800 mV or elevating pH to >10).

- In collaboration with the University of Cincinnati and FRx, Inc., field tests at the Cincinnati and Portsmouth sites were initiated during 1995 to evaluate heat and mass transfer enhancements achieved by hydropneumatic control, in-well hot fluid generation, and injection into propped fractures.

- Planning for a field demonstration was initiated in collaboration with DOE and Lockheed Martin Energy Systems for full-scale field testing of multiple technologies directed at a DNAPL in an LPM land treatment site at Portsmouth.

- In collaboration with the Colorado School of Mines and OGI, work was initiated to evaluate the mobility of residual contamination after varying degrees of mass removal were achieved through experimental work with intact cores under controlled laboratory conditions. This effort was continued through field testing in concert with the comparative field demonstration.

TTP Information

Remediation of DNAPLs in Low Permeability Soils activities are funded under the following TTP:

TTP No. OR16PL31, Task 1, "Remediation of DNAPL in Low Permeability Media"

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2.6 IN SITU CHEMICAL OXIDATION OF SOILS

TECHNOLOGY NEED

Soil and sediment contamination has been identified and documented throughout the DOE complex. Many sites are contaminated with VOCs at soil concentrations that range from trace levels to concentrations so high that the presence of DNAPLs is suspected. Two commonly reported VOCs (occurring at > 50 percent of DOE facilities) are TCE and tetrachloroethylene (PCE). These VOCs and many other chlorinated organic compounds are known or suspected carcinogens that must be removed, destroyed, or immobilized in place in order to meet regulatory cleanup requirements.

TECHNOLOGY DESCRIPTION

The goal of this research is to develop and demonstrate an in situ treatment process to degrade VOCs in soil (see Figure 2.6-1). As currently envisioned, chemical oxidant solutions will be introduced to contaminated soil using a variety of reagent-injecting or soil-mixing apparatus. The oxidant solution interacts with soil contaminants and degrades them to innocuous end products. The two chemical oxidant solutions being evaluated include hydrogen peroxide (H_2O_2) and potassium permanganate ($KMnO_4$). Potassium permanganate is a strong, non-specific oxidant and is believed to degrade organic contaminants by direct oxidation. Hydrogen peroxide is catalyzed by iron (Fe II) to produce hydroxyl radicals (OH•), which are known to be very strong, non-specific oxidizers capable of destroying many organic compounds, including the VOCs of interest to DOE. The iron catalyst for this process can be either the iron native to the soil being treated or supplemental iron added as iron sulfate ($FeSO_4$) solution during oxidant injection.

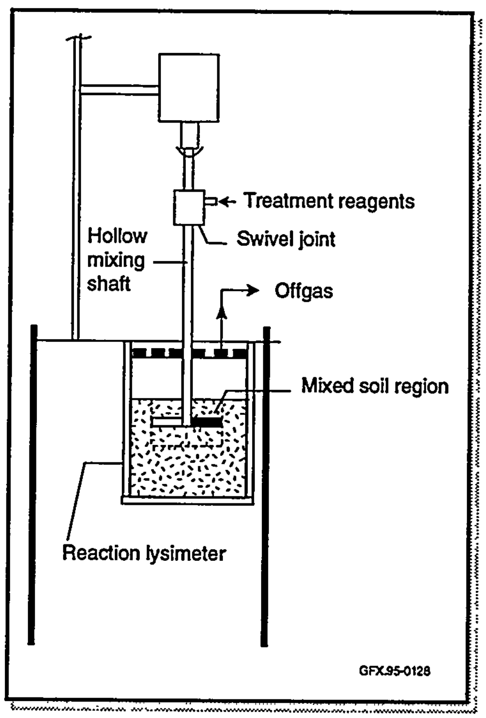

Figure 2.6-1. In Situ Chemical Oxidation Process.

Laboratory batch experiments have been completed that compared $KMnO_4$ and H_2O_2 as soil contaminant oxidants and evaluated the effect of contaminant, soil, and oxidant conditions on treatment efficiency. For soils with low total organic carbon (TOC) levels, $KMnO_4$ appears to be the most effective soil contaminant oxidant (>99 percent TCE removal, >90 percent PCE removal). In low TOC soil, H_2O_2 treatment levels are lower than $KMnO_4$ but are improved significantly by the addition of $FeSO_4$ (85 percent TCE removal, 65 percent PCE removal). For high TOC soils, $KMnO_4$ reacts with both soil organic matter and organic contaminants and is depleted more rapidly, often before contaminant destruction is completed. Conversely, H_2O_2 is not depleted as rapidly in high TOC soils and appears to be the more effective oxidant in VOC-contaminated high TOC soils. The effect of oxidant addition on soil properties has also been evaluated and no negative effects were observed.

Current project activities include laboratory evaluation of oxidant delivery, batch studies to evaluate PCB treatment by chemical oxidation, and field demonstration of deep soil mixing with $KMnO_4$ injection. The field demonstration is scheduled for FY96 at a site containing a tight clay soil contaminated with TCE and DCE. Long term project plans include the evaluation of alternative delivery methods and additional field demonstrations at other DOE sites, including at least one site with high permeability soils.

BENEFITS

In situ chemical oxidation offers several advantages over other in situ or ex situ remediation technologies. In addition to the benefits associated with most in situ treatment processes (less worker exposure to hazardous compounds, reduced cost, and applicability to remote sites), in situ chemical oxidation uses inexpensive, readily available reagents; is easily controlled; and is applicable to a wide variety of contaminants. Perhaps the greatest advantages of this process are the rapid treatment time and the ability of the process to treat highly contaminated soils. VOC degradation with chemical oxidation is usually completed in a matter of hours compared to the much longer treatment times required for stripping/extraction processes (days) or biological treatment (months to years). Also, pretreatment with in situ chemical oxidation may enhance bioremediation by partially degrading larger, more recalcitrant compounds and by reducing contaminant levels to within the range amenable to biotreatment.

COLLABORATION/TECHNOLOGY TRANSFER

A field demonstration of this technology is planned for the DOE Kansas City Plant. Primary funding for this demonstration is provided by the Kansas City Plant Environmental Restoration Program. In addition, researchers at the University of Tennessee, Knoxville, evaluated the effect of in situ chemical oxidation on metal mobility in soil.

Accomplishments

Recent accomplishments for this project include:

- The laboratory evaluation of the TOC effect on chemical oxidation treatment efficiency using $KMnO_4$ and H_2O_2 was completed.
- The treatability study was completed in preparation for a full scale demonstration at the Kansas City Plant.
- Soil from six DOE sites was collected, characterized, then used in studies evaluating the chemical oxidation treatment rate and the effect of treatment on soil properties.

TTP Information

In Situ Chemical Oxidation of Soils activities are funded under the following TTP:

TTP No. OR16PL31, Task 2, "In Situ Chemical Oxidation of Soils"

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2.7 ADSORPTION/DESORPTION RELATIVE TO APPLYING BIOREMEDIATION TO ORGANICS

TECHNOLOGY NEED

In situ technologies are needed to treat organic contaminants that are commonly sorbed and become less mobile in the subsurface environment. Organic contaminants sorb onto organic materials and soil particles by natural chemical (adsorptive) and physical (absorptive) processes. Sorbed contaminants represent a technical challenge because they are harder to remediate in situ than contaminants which are dissolved in groundwater. Sorbed contaminants must be treated to achieve site cleanup because these contaminants may later desorb, resulting in a potential environmental and health risk. Results from this study have the potential to greatly increase the efficiency of in situ bioremediation at hazardous waste sites through the selective stimulation of indigenous microorganisms, by the introduction of contaminant degrading bacteria, and by desorption of contaminants and enhanced bioavailability following surfactant addition.

TECHNOLOGY DESCRIPTION

The purpose of this investigation is to develop and demonstrate technologies that will accelerate the rates of in situ biological remediation of soil containing sorbed contaminants (see Figure 2.7-1). This work involves two related

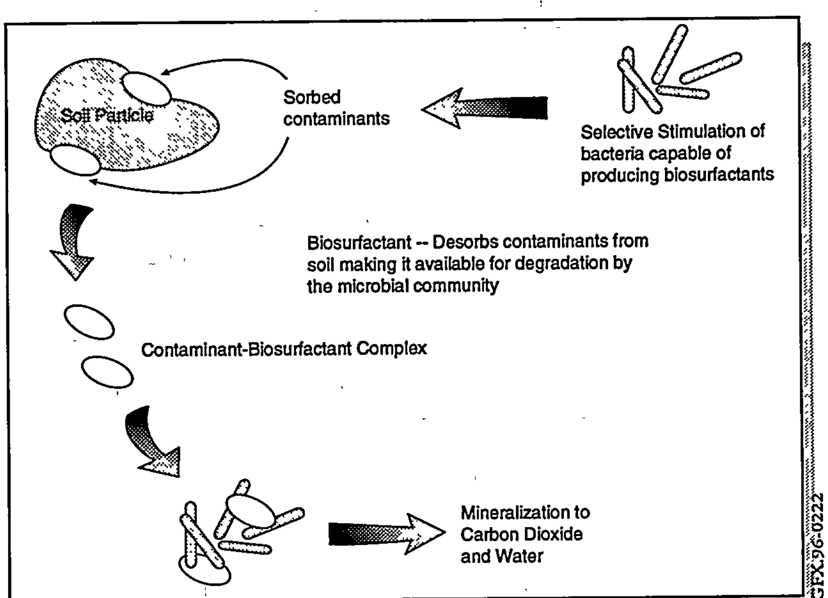

Figure 2.7-1. Biosurfactants for DNAPL Remediation.

approaches for increasing contaminant biodegradation: 1) the addition of bacteria capable of degrading TCE in the subsurface, and 2) the use of a nutrient/surfactant mixture to facilitate contaminant desorption and degradation. Both of these approaches to enhance biodegradation of TCE within a tight clay are being evaluated at a DOE field site. This work involves the use of commercially available nutrients, surfactants and biosurfactant mixtures that facilitate solubilization of contaminants, making them available for bacterial degradation. To monitor biodegradation, bacterial biosensors are used to directly measure the physiological activity of the contaminant-degrading microorganisms and the changes that occur in contaminant bioavailability when biosurfactants, surfactants, and other compounds are added. This information is coupled with traditional analytical techniques, such as gas chromatography, which measures the final contaminant concentrations in order to optimize and effectively monitor the remediation process.

The bacterium being used is a well characterized microbe (B. *cepacia* G4) that is found nearly ubiquitously. Studies have shown that it generates an enzyme which enhances TCE degradation. Furthermore, cultivating this bacterium in the laboratory and then introducing it into the subsurface at a contaminated site, which is the approach used by this investigation, appears to be much more efficient than in situ biostimulation of indigenous bacteria.

The integration of a nutrient/surfactant mixture with a TCE degrading consortia will be evaluated in a field demonstration. This simple nutrient solution will feed the TCE degrading bacteria before injection. An operating system consisting of storage tanks, pumps, and the associated instrumentation will be used to add the bacteria and nutrient mixture to the subsurface. This solution will be dispersed throughout the treatment zone by a traditional pump and treat system, a multipoint injection system, or deep soil mixing.

Benefits

The benefits of this approach are:

- This project offers an in situ remediation alternative that is less expensive and more cost-effective than the pump and treat method.
- Sorbed contaminants can extend treatment times for remediation activities that utilize pump and treat approaches.
- Although developed for TCE degradation, aspects of this project are applicable to bioremediation of other types of contaminants.

- The successful completion of this project will result in an environmentally safe process that destroys the contaminant in the subsurface where it is contained, thereby eliminating the risk of exposure to cleanup personnel and others through air contamination or transfer of contaminated adsorbents to a landfill.
- Because neither contaminated water nor sludge will be pumped above-ground, there is minimal risk of reduced air quality from volatile vaporization.
- None of the materials required for operation are expected to cause the operating system equipment to deteriorate.

Collaboration/Technology Transfer

This project represents a joint effort of ORNL, the University of West Florida, and Rem-Tec. ORNL is conducting the overall effort. The laboratory work characterizing the TCE degrading organisms is being performed by the University of West Florida, using a research team with extensive experience working with TCE degrading bacteria. The Rem-Tec Company is providing the nutrient/surfactant mixture for the laboratory experiments as an in-kind contribution.

Accomplishments

Recent accomplishments for this project include:

- A sensitive colloid tracer was developed to monitor bacterial transport during in situ field activities. This tracer has been tested in the laboratory and has undergone a small-scale evaluation. Lockheed Martin Energy Systems has elected to file a patent for this tracer.
- A small field scale analysis was performed in Portsmouth, Ohio, to ensure the distribution of bacteria into a clay matrix using the multi-point injection system. To evaluate the potential for enhanced distribution, the colloid tracer was injected with both water and the nutrient surfactant mixture.
- Several adhesion-deficient TCE degrading bacteria were identified in Fiscal Year 1995 (FY95) under a subcontract to Envirogen.
- Laboratory experiments were performed to characterize the interaction between surfactants and chlorinated solvents in soils from DOE's Kansas City Plant in preparation for a field demonstration in late FY96.

- Soil slurry studies were conducted using TCE-degrading organisms, which were introduced into nutrient/surfactant/contaminant mixtures. Conditions for optimization of the TCE degradation process were identified during these studies.

TTP Information

Adsorption/Desorption Relative to Applying Bioremediation to Organics activities are funded under the following TTP:

TTP No. OR16PL31, Task 3, "Adsorption/Desorption Bioremediation of DNAPLs"

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2.8 DNAPL Remediation by Electro-Osmosis

Technology Need

Contamination of low-permeability soil with DNAPLs has been identified as a serious environmental problem at a number of DOE and commercial facilities throughout the United States. At the DOE sites, the most commonly reported DNAPLs are chlorinated solvents such as TCE and PCE. These compounds are known or suspected carcinogens and could pose a serious health hazard to the general population through exposure to contaminated soils and groundwater. Low-permeability soils are particularly difficult to remediate because contaminants slowly diffuse into the matrix of the soil over a long period of time where their recovery or access to reactive agents is difficult. Slow leaching of DNAPL compounds from the soil result in a long-term source of contamination to groundwater.

Removal of DNAPLs from low-permeability media is a long-term and expensive process. Conventional technologies such as pump and treat or soil vapor extraction have been attempted but are very inefficient at removing diffusion-controlled contamination. Consequently, there is a need for technologies that can effectively mobilize DNAPL compounds in low-permeability media and make them available for removal or in situ destruction. In situ destruction processes are preferred because they tend to reduce worker exposure and avoid generation of a secondary waste stream, thereby reducing overall remediation costs.

Technology Description

In 1994, a consortium consisting of Monsanto Company, E.I. duPont de Nemours & Company, Inc., and General Electric (GE) was formed to explore the benefits of developing electro-osmosis as a method of mobilizing VOC contaminants in low-permeability media. With participation from DOE and EPA, the consortium combined resources to accelerate the development of the LASAGNA™ technology.

The LASAGNA™ process, so named for its layered structure of electrodes and treatment zones, is an integrated in situ treatment technology in which established geotechnical methods are used to install treatment zones and electrodes directly into low permeability soil (see Figure 2.8-1). Power is then applied to the electrodes and electro-osmosis is used to move the contaminants dissolved in groundwater through the treatment zones where they are either adsorbed or destroyed in situ. A number of chemical and biological methods can be used in the treatment zones to remove the contaminants

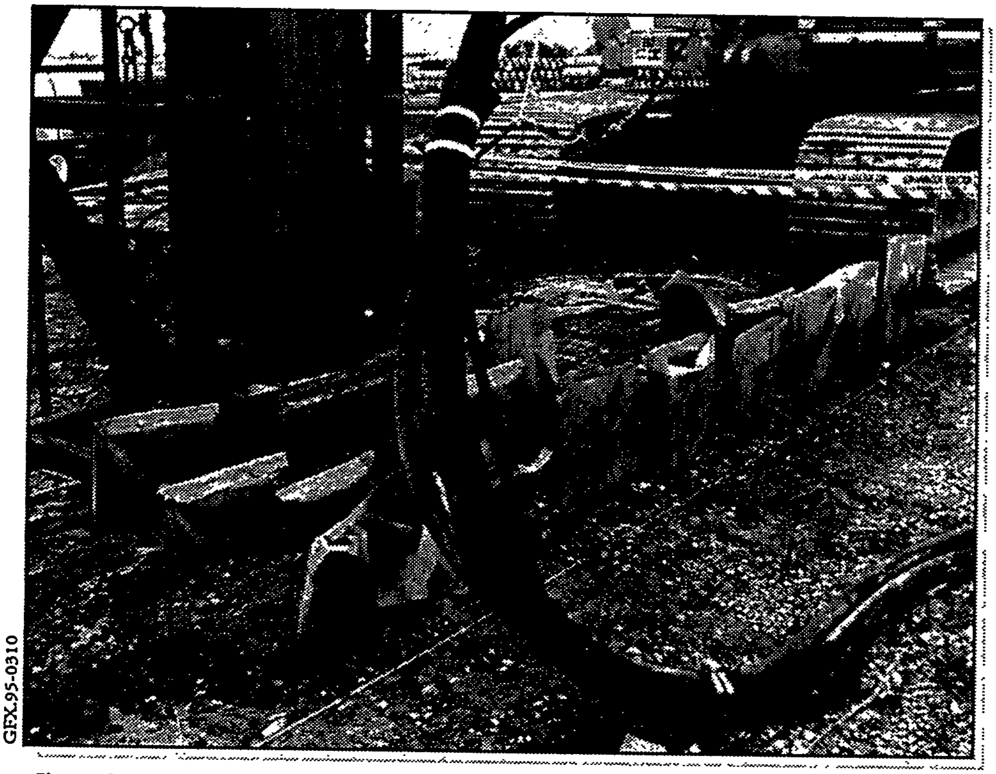
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Figure 2.8-1. Electro-Osmosis Demonstration at Paducah Gaseous Diffusion Plant.

depending upon the nature of the contaminant and site specific conditions. The electrodes and treatment zones can be installed in either a vertical or horizontal orientation depending on the installation methods chosen.

A demonstration site has been chosen at the Paducah Gaseous Diffusion Plant (PGDP) to test the next phase of the LASAGNA™ process. In 1995, LASAGNA™ technology was employed at this site in a vertical configuration in a small field test cell. The demonstration proved that electro-osmosis is capable of causing the migration of TCE at reasonable rates through the clay-rich soil to treatment zones where the contaminants were fully captured by activated carbon treatment media. A second, larger-scale demonstration is planned for the summer and fall of 1996 in which treatment zones composed of iron filings will be used. This treatment material should result in the complete destruction of the TCE. Pending successful performance of this demonstration, EM-40 at Paducah has agreed to use this refined LASAGNA™ process for the complete cleanup of the solid waste management unit surrounding the demonstration site.

BENEFITS

It is believed that the LASAGNA™ process can effectively remediate hard-to-treat, low-permeability soils at a very low cost compared to pump and treat and soil vapor extraction technologies which are inefficient when applied to this type of media. Costs for applying baseline technologies are in the range of $500 per cubic yard. The target cost for the LASAGNA™ technology is approximately $50 per cubic yard for a one acre site. This technology also goes beyond the conventional treatment systems by remediating the contamination in situ and avoiding generation of secondary wastes that will require treatment, storage, or disposal.

COLLABORATION/TECHNOLOGY TRANSFER

Since 1994, the consortium of Monsanto, duPont and GE, has been heavily involved in the development of the LASAGNA™ process to address DNAPL contamination in low-permeability soils at their own sites. Research for this project has been carried out at the laboratories of each of the members of the consortium. The EPA, specifically the Remediation Technology Development Forum (RTDF), has also been involved in the early stages of development along with the University of Cincinnati. DOE is providing the site for the demonstration as well as most of the funding for the project. Approximately 20 percent of the costs of the project will be co-funded by the consortium members. After the demonstration and first application at Paducah, the LASAGNA™ technology is expected to be included in the Rapid Commercialization Initiative process, so that the technology could be used to remedy contaminated sites throughout the United States.

The term LASAGNA™ has been trademarked by Monsanto. P.H. Brodsky and S.V. Ho hold the patent (i.e., U.S. Patent No. 5,398,756 entitled, "In Situ Remediation of Contaminated Soils," March 1995).

ACCOMPLISHMENTS

Recent accomplishment for this project include:

- The pilot-scale Phase I demonstration of the LASAGNA™ Project at the PGDP was successfully completed in FY95.
- Results obtained at the end of Phase I showed that the remediation technology is very effective (up to 99 percent reduction of TCE levels) and cost-efficient (approximately $50/yd³).
- A contract was signed with Monsanto to start Phase II of the LASAGNA™ Project for the complete remediation of a contaminated site at the PGDP.

TTP Information

DNAPL Remediation by Electro-Osmosis (LASAGNA™) activities are funded under the following TTP:

TTP No. OR16PL31, Task 4, "DNAPL Remediation by Electro-Osmosis (LASAGNA™)"

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2.9 In Situ Bioremediation of Chlorinated Solvent DNAPLs

Technology Need

Chlorinated solvents such as TCE and PCE have been produced and used for many years by industry and the federal government during routine operations. The used solvents were then disposed of in a variety of ways that have resulted in site contamination and the migration of the chemicals into groundwater. It is estimated that the DOE alone has over 2,500 plumes of chlorocarbon contamination on its sites and many of these sites also have free phase solvents (i.e., DNAPLs). Newly developed, in situ thermal and soil washing technologies show promise in remediating chlorinated solvent DNAPL contaminated aquifers. However, even under the best conditions, removal technologies leave a small amount of residual contamination. Over time, this material will leach out into the main flow paths of an aquifer and contaminate the groundwater (Grubb and Sitar, 1994). Hence, companion technologies are needed for long-term plume management. In situ bioremediation, using highly efficient metabolisms such as direct dehalogenating or iron reducing bacteria, is one potential follow-on technology that could provide effective long-term containment of DNAPL plumes (see Figure 2.9-1).

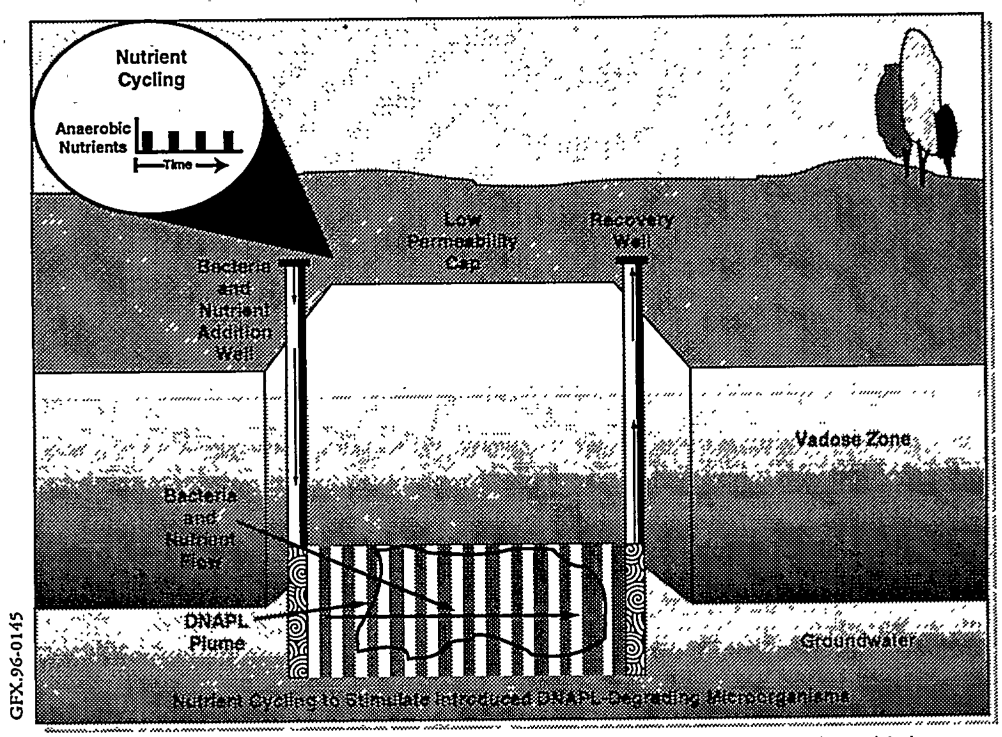

Figure 2.9-1. Treatment Strategy for In Situ Anaerobic Bioremediation of Chlorinated Solvent DNAPLs in Groundwater.

The goal of this project is to evaluate the cost of using metabolisms for long-term DNAPL plume management. Microbial and engineering design information is being developed to compare the cost of using in situ bioremediation to the cost of using the current baseline process for destroying residual DNAPL contamination that remains after applying a removal technology. PCE and TCE will be used as model solvents in this work. Future activities will focus on conducting field demonstrations if this technology shows significant cost savings over the baseline.

Three microbial systems are being considered in this work: direct dechlorinating bacteria (DDB), iron reducing bacteria (IRB), and a conventional anaerobic co-metabolism. Both the DDB and IRB have shown the potential for highly efficient dehalogenation and represent a best case scenario for system evaluation. In contrast, conventional anaerobic co-metabolism is much less efficient and will provide a worst case estimate for processing costs. The cost estimate will be developed using data from an actual DNAPL contaminated site as a basis. Previously published methods will be applied (Skeen et al., 1993). Experimentally measured microbial kinetics for three processes will be evaluated separately in existing reactive flow and transport simulators to determine injection/extraction well and nutrient requirements. Installation, operation, and maintenance costs will then be estimated according to guidelines established by the American Association of Cost Engineers. Simulations of both DDB and anaerobic co-metabolism will be based on periodic nutrient injection and groundwater recirculation to facilitate biological dehalogenation. Simulations of the IRB system will rely on nutrient injection to develop a subsurface region where ferric iron is reduced to ferrous iron. Dehalogenation will then be mediated by abiotic electron transfer by ferrous iron.

The five functional objectives for FY96 are to:

- Measure anaerobic microbial growth, substrate consumption, and contaminant destruction kinetics for DDB
- Measure anaerobic microbial growth and substrate consumption kinetics for IRB
- Determine kinetic rate equations for chloroethylene dehalogenation by reduced iron sediments
- Prepare a cost analysis for in situ DNAPL destruction using simulations based on metabolisms studied in the first three objectives above
- Demonstrate, in flow cell tests, that biological activity is capable of destroying PCE near a DNAPL source

Benefits

There are currently no field-ready in situ treatment technologies for the destruction of chlorinated solvent DNAPLs in groundwater. Pump and treat technologies can remove significant amounts of contaminants when locations of DNAPL pools are known. However, locating these materials in the subsurface is virtually impossible. In addition, groundwater pumping often results in very slow contaminant removal due to low solubilities and sorption characteristics of chlorinated solvents.

Newly developed in situ thermal soil washing technologies show promise in remediating DNAPL contaminated aquifers. However, even under the best conditions, these technologies still may not be able to achieve mandated cleanup objectives and consideration should be given to combining these techniques with treatment methods suitable for long-term plume management (Grubb and Sitar, 1994). In situ bioremediation has the potential to provide cost-effective long-term plume management. In addition, developing kinetic models will aid in understanding interactions between reacting chemical species as well as in formulating nutrient feeding strategies to be implemented in accelerated in situ bioremediation.

Collaboration/Technology Transfer

This project is a collaboration between PNNL and Washington State University. Transfer of this technology will take place through OHM, Parsons Engineering Science, and Montgomery Watson, PNNL's industrial partners in commercializing advanced in situ bioremediation technologies.

Accomplishments

PNNL completed a test plan for FY96 experiments and a cost study. This document contains a detailed description of all the tests that will be conducted along with the associated analytical and microbial procedures.

TTP Information

In Situ Bioremediation of Chlorinated Solvent DNAPLs activities are funded under the following TTP:

TTP No. RL36PL31, Task 2, "In Situ Bioremediation of Chlorinated Solvent DNAPLs"

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2.10 DNAPL Plume Remediation Project

Technology Need

DNAPLs now contaminate many subsurface groundwater plumes within the complex of DOE facilities. Several remediation technologies are now being used to remediate these contaminants. However, it has been shown that remediation is not always practical, and containment technologies are needed to prevent the contaminant plume from migrating and/or becoming a source of downgradient contamination. Also, some remedial technologies currently being used (i.e., surfactant flushing and soil vapor extraction) have their own disadvantages. A major disadvantage of subsurface surfactant flushing of DNAPLs is the inability to efficiently separate, recover, and recycle the surfactant solution once it has been extracted from the subsurface. A major disadvantage of soil vapor extraction is the inability to efficiently separate, recover, and possibly recycle chlorinated volatile organic compounds (Cl-VOCs) from the vapor stream once they have been extracted from the subsurface. The three tasks of this project target each of these technological problems.

Technology Description

This project is managed by the Western Environmental Technology Office (WETO) in Butte, Montana. It was initiated in FY96 in order to support the continuing efforts of the Subsurface Contaminants Focus Area to remediate DNAPL contaminated groundwater within the DOE complex. Three separate tasks comprise this project.

Task 1: Containment of DNAPL Sources will identify and/or develop innovative permeable, reactive containment technologies to prevent DNAPL sources from continuing to be long-term sources of groundwater contamination (see Figure 2.10-1).

Task 2: Recovery/Recycling of Surfactant Solutions will identify and/or develop innovative technologies for the separation, recovery, and recycling of surfactants from subsurface mass removal technologies, such as surfactant flushing.

Task 3: Ex Situ Recovery/Recycling of Chlorinated Compounds will develop improvements for efficient Cl-VOC separation and recovery from vapor streams associated with SVE remedial actions.

Initial activities for this project include engineering systems analyses in which available technologies and those under development are evaluated relative to DOE needs. Technical areas warranting development will be identified for future work.

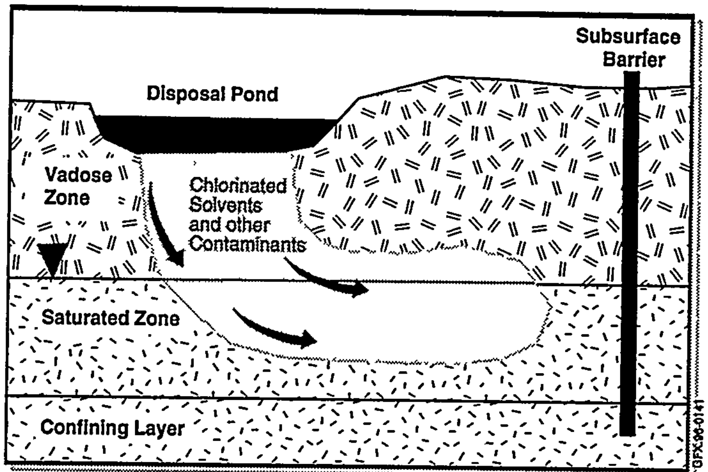

Figure 2.10-1. Containment of DNAPLs Using a Subsurface Barrier.

BENEFITS

The technologies identified and demonstrated through this DNAPL remediation project will result in more effective and efficient subsurface barriers with lower groundwater remediation costs. Furthermore, the technologies will generate smaller quantities of waste materials requiring storage, treatment, and/or transportation and disposal. Significant benefits will be realized when recovered surfactants and solvents can be reused or marketed for secondary uses.

Information gained from these activities will be mutually beneficial and directly applicable to multiple interested parties, including DOE, technology providers, environmental problem holders, environmental regulators, private sector remediation industries, DOD, Department of the Interior, EPA, and other federal and state agencies. These benefits will be realized by providing the end users with the technical and economic proofs they require to select and implement the subject technology.

Technology development activities will include demonstrations to provide hard field data to private sector technology investors, including financial investors, banking institutions, venture capitalists, and other commercial interests. These interests require proof of technical and economic performance to calculate cost savings and returns on investment (i.e., a "market pull").

These efforts should realize cheaper, faster, and more effective cleanup of environmental problems in the United States and internationally, by providing proven alternatives to interested parties. Improved interactions via partnerships among private sector interests, government, and academia will ensure that new technologies are pulled to the marketplace, thus improving U.S. industrial competitiveness.

Collaboration/Technology Transfer

Project personnel will utilize established means for transferring technological information, including presentations to the Subsurface Contaminants Focus Area management; publishing reports and data; and presentations to workshops, conferences, symposia, seminars, and other formal meetings. Execution of project tasks will require direct contact with technology providers, problem holders, regulators, and other stakeholders. In particular, development activities associated with recycling/recovery of Cl-VOC from effluent vapor streams will be coordinated with the Savannah River Technology Center.

With coordination of the Subsurface Contaminants Focus Area management, the project will support educational programs; participate in the development and presentation of short courses related to project technologies; and participate in existing government and private sector technology information exchange systems. The purpose of supporting and participating in these existing efforts is to maximize the project's technology transfer effectiveness at the least cost.

Accomplishments

Recent accomplishments for this project include:

- Technical teams have been formed to address each of the 3 tasks within this project.
- Technical experts have been identified for inclusion in a technical support group.
- Subcontracting efforts have been initiated.

TTP Information

WETO Plume DNAPLS Product Line Projects activities are funded under the following TTPs:

TTP No. PE16PL31, Task 1, "Containment of DNAPL Sources"

TTP No. PE16PL31, Task 2, "Recovery/Recycling of Surfactant Solutions"

TTP No. PE16PL31, Task 3, "Ex Situ Recovery/Recycling of Chlorinated Compounds"

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None at this time.

3.0 METALS AND RADIONUCLIDES PRODUCT LINE

The Metals and Radionuclides Product Line is developing cost-effective technologies to remediate soil and groundwater that are contaminated with metals and radionuclides. Assessments of problems faced by operable unit managers have been collected by product team staff. These contamination problems range from very large-scale soil and aquifer volumes to limited discrete zones that traditional baseline restoration methods are challenged to remediate. For example, groundwater restoration of uranium contamination at Fernald is possible, albeit as a very long and costly project. As another example, Sr^{90} emanation from disposal cribs at Hanford are migrating into the Columbia River. This is a continuing threat that will be very costly to remediate with traditional pump and treat methods. For each problem, an evaluation was performed to determine how to improve the cost or performance of the baseline method by adding innovative technology or by completely replacing the baseline method.

Each supplemental or replacement technology must be supported by the knowledge of the complex chemical interactions that metal and radionuclide contaminants have with the aquifer and soil systems. Some radionuclides, such as Cs^{137} and Pu^{238}, commonly interact very strongly with soil particles, so that they are essentially immobile in soils. Though immobilization aids containment, these strong bonds pose a significant challenge when separations technologies attempt to reduce the volumes of soil necessary for final disposal. These interactions are also complicated by the ability of some metals and radionuclides to be chemically altered, adsorbed onto mobile colloids, or complexed with co-contaminants, thus changing their mobility and toxicity. Chromate, for example, is very mobile and toxic but can be permanently changed to an essentially immobile and significantly less toxic form.

Cleanup standards for radionuclides also pose a significant challenge for restoration strategies. Some radionuclides such as tritium and strontium have short half-lives, indicating that on-site containment could allow radioactive decay to eliminate the contamination problem without a large investment in excavation or treatment. Other radionuclides have long half-lives, requiring more stringent regulations.

Technology development solutions to the metal and radionuclide problems of the DOE Environmental Restoration Program have been organized into three main groups: characterization, in situ treatment/remediation, and secondary waste treatment. These groups are established to compete new technologies against the two leading baseline restoration methods: retrieve/transport/dispose and pump and treat.

Characterization. Characterization technologies that are approaching the deployment stage of development are incorporated into the Subsurface Contaminants Focus Area. This strategy has enabled the product deployment team to ensure a complete transfer. Systems in this group included radionuclide contaminant detection technology and a sampling optimization technology valued by the ER end-users.

In Situ Treatment/Remediation. The technologies used in these systems involve physical, chemical, and biological means of extracting or treating contamination to produce forms with less risk to human health and the environment. These technologies are organized into three subgroups: enhanced removal, treatment stabilization, and passive treatment. In the enhanced removal subgroup, technologies will selectively remove metal and radionuclide contamination from the soil without the use of bulk excavation methods. The treatment/stabilization subgroup uses either a liquid or a gas chemical reagent as a flooding agent to react with soil and aquifer contamination and render contaminants into less toxic forms. Liquid phase reagents are used for aquifer contamination, and gas phase materials are used for unsaturated soils. For the passive treatment subgroup, groundwater is guided to a treatment zone containing media that will selectively remove the contaminants and let clean groundwater to continue to flow to the aquifer.

Secondary Waste Treatment. Some Environmental Restoration (ER) problem holders will continue to use pump and treat technologies as a primary remediation method or as a hydraulic containment system. Innovative treatment systems are being developed that are more selective in removing target contaminants and produce smaller volumes of secondary waste. In this subgroup, new selective polymer separations materials and a magnetic separator system are being explored.

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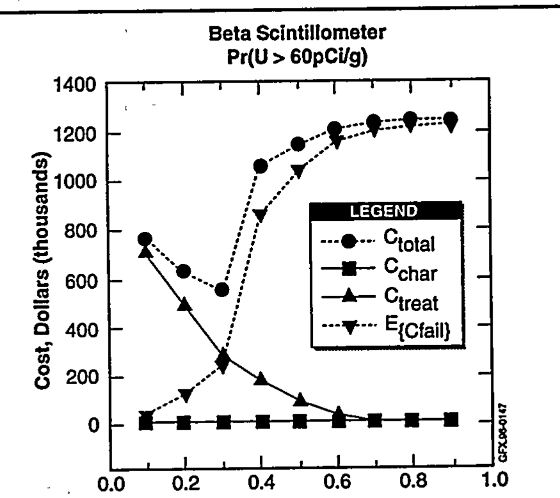
3.1 Smart Sampling

Technology Need

Decisions to achieve environmental remediation are made in a complex context comprising site data, laws and regulations, cost and funding issues, and available technologies. Decision makers need to consider and evaluate many of these factors simultaneously. Smart Sampling integrates sampling and characterization with programmatic, economic, and legal performance objectives to assist in this evaluation. This process provides real time analysis for decision makers and field personnel and allows for the evaluation of sampling strategies versus cost and performance objectives. Using easy-to-understand graphics and simple economic functions, the Smart Sampling process helps program managers and stakeholders to visualize the characterization and sampling data coming from a specific site.

Technology Description

Smart Sampling is divided into three integrated technical product lines: 1) information management and visualization, 2) advanced geostatistical applications, and 3) economic risk-based decision analysis. This process has two functional lines: technology development and technology deployment. Smart Sampling uses geostatistical simulation to generate maps or 3-dimensional pictures that display the likelihood of exceeding design or performance criteria at a specific site as a function of currently available information, such as the likelihood of exceeding a regulatory action level for a particular contaminant. Emphasis is on integrating the ability to perform Smart Sampling with existing hardware and software systems at individual sites.



With an action level of 60pCi/gm, there is a cost minimum when cleanup is taken to the point where the probability of exceeding the action level is reduced to 0.3. (C_{total} = total cost; C_{char} = characterization cost; C_{treat} = remediation cost; $E_{\{Cfail\}}$ = likely cost resulting from failure to meet cleanup standard)

Figure 3.1-1. Total Cost Function and Component Costs for the Fernald Detector Test Site.

For example, Figure 3.1-1 shows that with an action level of 60 pCi/gm, there is a cost minimum when cleanup is taken to the point where the probability of exceeding the action level is reduced to 0.3. The numbers underlying the visual representation are used as input to an economic objective function that calculates the economic worth of additional samples versus other design alternatives like treatment or removal.

Benefits

Benefits to date include:

- Highly leveraged basic and applied research dollars (40:1)
- An order-of-magnitude decrease in information management and analysis times
- Technically defensible, state-of-the-art site sampling and decision strategies
- Documentable and defensible basis for programmatic decisions and negotiations with the regulatory and stakeholder communities

Collaboration/Technology Transfer

The project is vertically integrated with industry and the university community. Basic research is supported by over 30 industry partners through the Stanford Center for Reservoir Forecasting. A separate environmental institute is currently being formed. Applied research, proof-of-concept, public domain software development, and maintenance are supported by industry and federal dollars through programs at the Colorado School of Mines and the University of New Mexico. Licensing arrangements are being developed. Inquiries from several hundred companies indicate that a dozen or so would likely enter into a licensing agreement. Adoption of Smart Sampling is under evaluation by the Ohio Environmental Protection Agency, the Nuclear Regulatory Commission, and the U.S. Army. The project is working through the Cooperative Monitoring Center to apply Smart Sampling overseas on issues of environmental security. Discussions have been started with the United States Department of Agriculture (USDA) on potential applications to precision farming.

Accomplishments

Recent accomplishments of this project include:

- The project attained full-scale usage of the technique at Fernald.
- Technology transfer activities are underway at Mound, Sandia, Weldon Spring, Fernald, and Ohio EPA.

TTP Information

Smart Sampling activities are funded under the following technical task plan (TTP):

TTP No. AL26PL41, Task 3, "Smart Sampling"

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3.2 TRITIUM ANALYSIS SYSTEM

TECHNOLOGY NEED

Tritium is one of the most widespread and mobile radioactive contaminants in the DOE complex. Tritium-contaminated plumes extend for several miles at Hanford, Savannah River Site (SRS), Idaho National Engineering Laboratory (INEL), Nevada Test Site, and Lawrence Livermore National Laboratory Site 300. Tritium in effluent from nuclear reactors is a large concern to the nuclear power industry. Due to its molecular structure, tritium behaves the same as the normal hydrogen ion because of its ionic formation. As a result of this chemical similarity, tritium can replace a hydrogen ion present in water to form tritiated water. Tritium can only be separated from other non-radioactive isotopes of hydrogen by very sophisticated and elaborate techniques that are not amenable for contaminated water cleanup.

Tritium in environmental samples is currently measured in analytical laboratories which typically have analysis turnaround times of several weeks to months. The Tritium Analysis System (TAS) under development (see Figure 3.2-1) represents an environmental breakthrough by providing a portable, real-time tritium analysis instrument which can be used to determine the nature and extent of tritium contaminated waters and to continuously monitor surface and groundwater quality. Real-time determination of the presence of

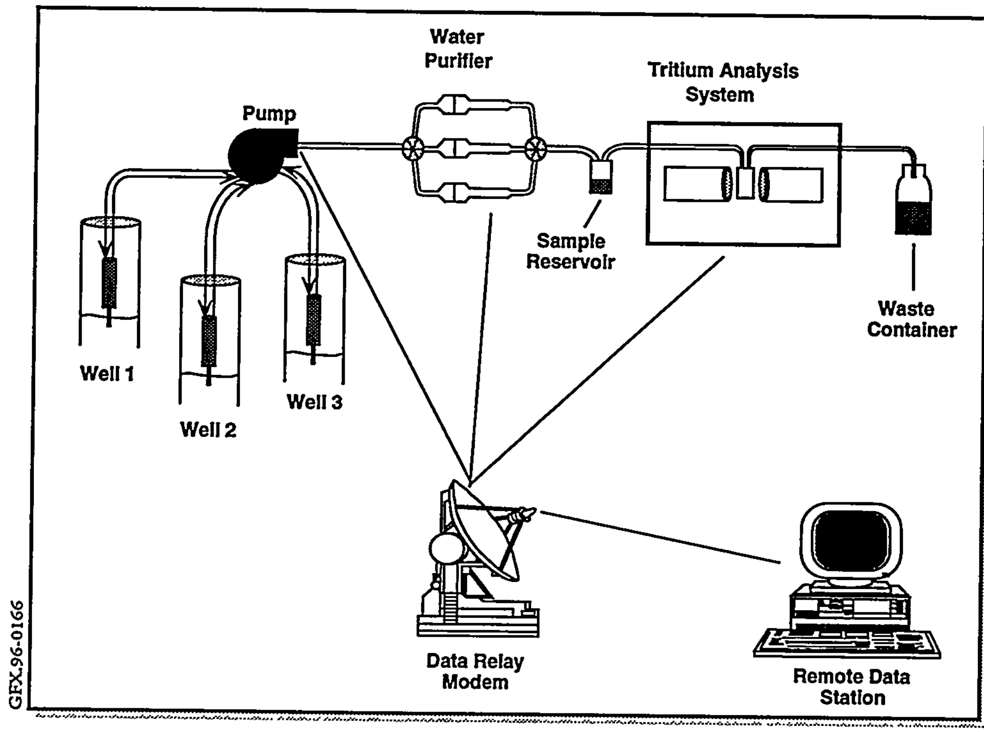

Figure 3.2-1. Remotely Operated Field Deployable Tritium Analysis System.

tritium contamination would optimize monitoring and remediation activities by eliminating potential down-time while samples are being analyzed. Improved monitoring would also help ensure that any uncontaminated water is not needlessly managed as a radioactive waste.

TECHNOLOGY DESCRIPTION

The objective addressed in the development of the TAS is to provide rapid field monitoring of existing plumes. The TAS being developed for the SRS will improve the monitoring of existing plumes and will allow the determination of hot spots in the ground and surface waters. The system is designed to be fully programmable for remote operation so that multi-site sampling, analysis, and data handling may be automated for unattended operations. The system incorporates a novel aqueous sampling device, a water purification system including commercially available ion exchange columns, and a modified Packard-based flow cell liquid scintillation counting (LSC) device. Communication between the field unit and the remotely-located control computer is achieved by modems.

BENEFITS

The advantages of the TAS include:

- Less costly sample gathering and analysis procedures
- Pseudo-real-time field screening of ground and surface waters on demand
- Reduction of investigation-derived waste

COLLABORATION/TECHNOLOGY TRANSFER

Researchers at the University of Georgia's Center for Applied Isotope Studies are developing the low-level tritium detection LSC capability and the interface software for the system. Savannah River Technology Center personnel are developing the sampler/purifier. Packard is exploring the possibility of commercializing the prototype detector. An undisclosed company specializing in sampling systems has shown interest in commercializing the sampling/purification device.

ACCOMPLISHMENTS

Recent accomplishments of this project include:

- A prototype TAS was developed with multi-site sampling capabilities, on-line sample and liquid scintillation cocktail mixing, and flow cell cleansing.

- Laboratory demonstrations using the TAS yielded backgrounds of 1.5 cpm, detection limits of 25 Bq/L (i.e., 675 pCi/L), and detector efficiency of 25 percent.
- TAS components were miniaturized and enclosed in a field-transportable housing.
- Development of an on-line water purification system was completed; the system effectively removes agents that can interfere with measurements.
- Remote-controlled operation of the TAS sampling, analysis, and cleanup cycles was demonstrated at the University of Georgia in February 1996.

TTP Information

Tritium Analysis System activities are funded under the following TTP:

TTP No. SR16PL41, Task 2, "SRS Tritium Analysis System"

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3.3 ENVIRONMENTAL MEASUREMENT-WHILE-DRILLING

TECHNOLOGY NEED

Sampling during environmental drilling is essential to fully characterize the spatial distribution of subsurface contaminants. However, the analysis of samples is expensive and time-consuming; off-site laboratory analysis can take weeks or months. Real-time information on environmental conditions, drill bit location, and temperature during drilling is valuable in many environmental restoration operations. This information can be used to provide field screening data and improve efficiency of site characterization activities.

TASK DESCRIPTION

The Environmental Measurement-While-Drilling (EMWD) System represents an innovative blending of new and existing technologies to obtain real-time data during drilling. The long-term objective of this project is to distinguish contaminated from non-contaminated areas in real time while drilling beneath a hazardous waste site.

In EMWD, down-hole sensors are located behind the drill bit and are linked by a rapid data transmission system to a computer at the surface (see Figures 3.3-1 and 3.3-2). Sandia-developed Windows™-based software is used for data display and storage. As drilling is conducted, real-time data are collected regarding the nature and extent of the subsurface contamination, enabling on-the-spot decisions about drilling and sampling strategies. Initially, the downhole sensor consisted of a simple gamma radiation detector, a Geiger-Mueller tube (GMT). The design includes data assurance techniques to improve safety by

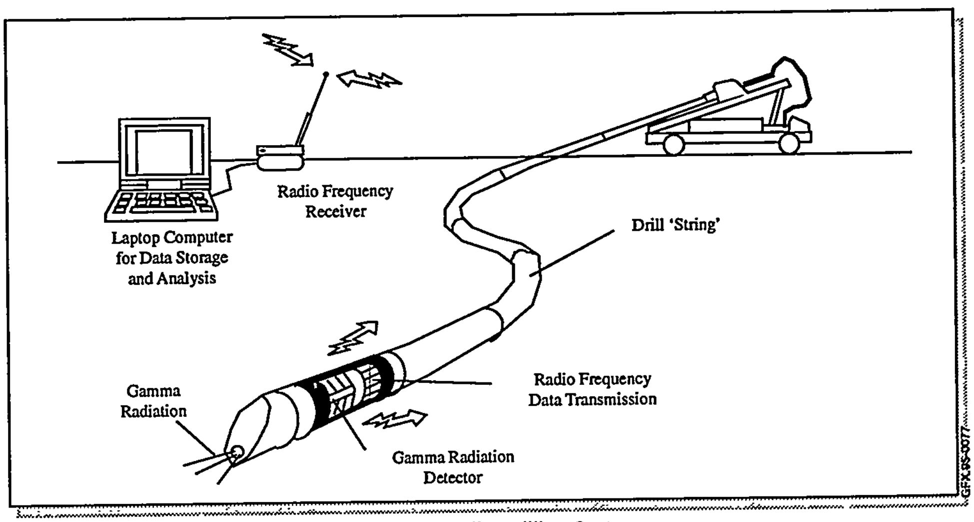

Figure 3.3-1. Environmental Measurement-While-Drilling System.

reducing the probability of giving a "false" safe indication where an unsafe condition actually exists.

The EMWD System has been improved by the integration of a gamma ray spectrometer (GRS) in place of the GMT. The GRS consists of a sodium iodide-thallium activated crystal coupled to a photomultiplier tube (PMT). The output of the PMT goes to a multichannel analyzer (MCA). The MCA data are transmitted to the surface via a signal conditioning and transmitter board similar to that used with the GMT.

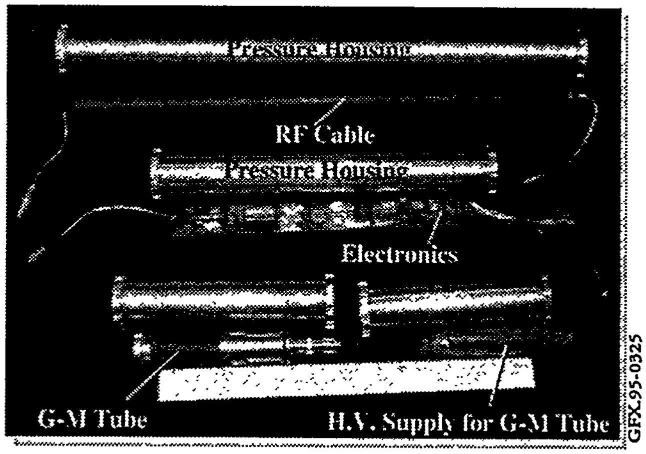

Figure 3.3-2. Gamma Radiation Detector and Supporting Equipment for Real-Time Measurements-While-Drilling.

The system is currently compatible with fluid miser drill pipe, a directional drilling technique that uses minimal drilling fluids and generates little or no secondary waste. Future work would adapt the radiological detection systems to other subsurface access equipment such as the cone penetrometer.

BENEFITS

There are time, cost, and safety advantages to using the field screening approach of the EMWD System:

- Data on the nature of contamination will be available in minutes, as opposed to weeks or months from an off-site laboratory.
- Substantial cost savings will result by minimizing the number of samples required for off-site confirmatory analyses.
- Worker safety will be enhanced as a result of minimizing waste generation and by quickly alerting field personnel to potentially hazardous conditions.
- A goal of this project is to produce a prototype system that costs less than $15,000. Operations and maintenance costs are likely to be low, while reoccurring costs will be limited to a spool of coaxial wire for each drilling operation.

Collaboration/Technology Transfer

The unique capability of real-time, high speed data transmission during drilling gives this EMWD System a high commercial potential. Its low cost and generic design, offering maximum flexibility to integrate additional sensors, make the EMWD System an attractive platform for a variety of downhole sensors.

A technical advance for patent filing has been processed for components of the EMWD System. A patent application is currently being filed for the coaxial cable coil component of the system.

To identify potential partners, the project placed an advertisement in the *Commerce Business Daily* to integrate the EMWD System with other sensors types and multiple sensor systems. A market analysis has been completed to determine the potential markets for the EMWD System. In addition to the environmental market sector, other potential users of EMWD include utility emplacement and petroleum industries. The system will be available for licensing in 1996 if the EMWD System is shown to be technically and economically feasible. Currently, this project involves collaboration with Charles Machine Works, Inc. (CMW, makers of Ditch Witch™), an international leader in the directional drilling industry. Testing of the EMWD System has been performed at the CMW directional boring test site in Perry, Oklahoma.

Accomplishments

Recent accomplishments of this project include:

- Data transmission techniques, data reduction software, and the coaxial cable coil winding method were transitioned from the Defense Programs and adapted to meet environmental needs.
- Preliminary field tests completed at the radioactive calibration facility at Grants, New Mexico, and at Sandia National Laboratories showed successful integration of the GMT- and GRS-EMWD Systems components.
- In 1994 and 1995, two directional borings at the CMW test site verified operation of the GMT-EMWD System.
- In February 1996, the GRS-EMWD System was successfully demonstrated at the CMW test site. Continuous spectral data were taken using the GRS-EMWD in a drill housing located behind the drill bit of a Ditch Witch™ JT2320 directional boring rig.
- In April 1996, the GRS-EMWD System was successfully demonstrated at the SRS F-Retention Basin. Cs-137 was tracked in several boreholes and compared with baseline data and sample collection methods.

TTP Information

Environmental Measurement-While-Drilling For Real-Time Screening of Contaminants activities are funded under the following TTP:

TTP No. AL26PL41, Task 4, "Environmental Measurements While Drilling"

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3.4 ELECTROKINETIC REMEDIATION OF UNSATURATED SOIL CONTAMINATED WITH HEAVY METALS

TECHNOLOGY NEED

A large portion of DOE's contaminated soil is unsaturated, containing small amounts of water, which is typical of the western states. In regions where contaminated saturated soils are more common, there also exists a zone of contaminated unsaturated soil (the vadose zone) lying above the saturated zone. There currently are no viable in situ methods for remediating heavy metal contamination from these unsaturated soils. Excavation and processing, or disposal at a licensed landfill, will not always be feasible and will always be expensive.

This research is investigating the use of electrokinetic remediation as an alternative. Specifically, the effort is directed at remediating chromate (CrO_4^{2}) contamination in unsaturated soil in Sandia's Chemical Waste Landfill (CWL), in Albuquerque, New Mexico, where chromium contamination has been detected. Other DOE sites contaminated with mobile negatively charged compounds (anions) [e.g., MoO_4^{2-}, SeO_4^{2-}, $HAsO_4^{2-}$, $UO_2(CO_3)_3^{4-}$, TcO^{4-}] should be treatable with this technology. These anions are highly mobile in soil because they typically do not adsorb strongly on the soil surface.

TECHNOLOGY DESCRIPTION

The passage of electrical current through soil pore water results in the movement of ions which is largely independent of the soil hydraulic properties. The placement of energized anodes and cathodes in soil allows the creation and manipulation of an electric potential gradient which results in the transport and accumulation of contaminant ions at the electrodes. Unsaturated soils present a more challenging situation for electrokinetic remediation. The patented Sandia method uses a vacuum to hold electrolyte solution under tension inside sealed porous ceramic electrode casings. The vacuum physically prevents the saturation of soil adjacent to the electrodes (which, if allowed to occur, would wash contamination to greater depths). The porous ceramic allows free movement of ions (and thus electrical current) and enough water to prevent drying near the anodes. Anionic contaminant ions accumulate inside the anode casings where they can be easily pumped to the surface for treatment.

This technology is currently being field demonstrated for chromate removal from unsaturated soils in an old chromic acid pit at CWL (see Figure 3.4-1).

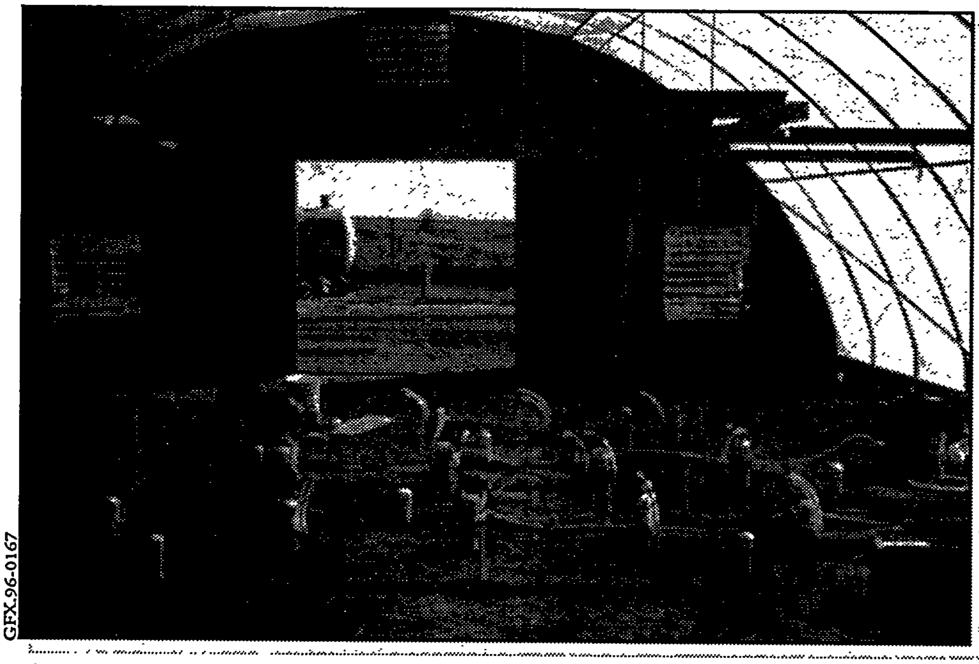

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Figure 3.4-1. Field Demonstration of Chromate Removal from Unsaturated Soils.

Benefits

There are no viable in situ methods for removing heavy metal contamination from unsaturated soils. Current baseline technology involves excavating the soil and subsequent processing by soil washing or disposal at a licensed landfill. Because excavation may not be technically, economically, or politically acceptable, development of a cost-effective in situ technology for removing contaminants is highly desirable. This is particularly true for the chromium contamination at the CWL, where contamination has been detected at depths as great as 75 feet. Excavation to such depths is not economically feasible. In situ technologies may also allow remediation underneath valuable existing structures. Processes involving excavation of soil cost $200 to $500 per ton. Electrokinetic remediation is expected to be much more economical. Estimates for electrokinetic remediation range from $50 to $150 per ton.

Collaboration/Technology Transfer

The main industrial collaborator is Sat-Unsat Inc., a small vadose hydrology consulting firm specializing in electrokinetic remediation. The principal hydrologist for Sat-Unsat Inc. is a co-inventor of the Sandia method.

Collaboration with New Mexico Technical University in Socorro, New Mexico, who has funding from the DOE Waste Management Education and Research Center to study and model electroosmosis in unsaturated soils, has also taken place.

Accomplishments

Recent accomplishments of this project include:

- The project obtained a Resource Conservation and Recovery Act (RCRA) Research Development and Demonstration (RD&D) permit for the proposed Sandia field demonstration.
- The inventors obtained a U.S. Patent.
- In May 1996, a field demonstration of the removal of chromate from unsaturated soils began at the Sandia Chemical Waste Landfill.

TTP Information

Electrokinetic Remediation of Heavy-Metal-Contaminated activities are funded under the following TTP:

TTP No. AL26PL41, Task 2, "Electrokinetics in Unsaturated Soil"

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3.5 IN SITU REMEDIATION BY ELECTROKINETICS

TECHNOLOGY NEED

Remediation of uranium-contaminated soil is one of the major cleanup tasks facing DOE. Radionuclide contamination in excess of established limits is known to be present at 59 waste sites at 14 DOE facilities. Potentially contaminated soils surrounding these sites extend for hundreds of square miles, making dig-and-treat technologies impractical and exceedingly costly. In situ treatment that is cost-effective and removes the contaminants without adversely affecting the physical, chemical, or agronomic characteristics of the soil is a high priority technology need for DOE. Electrokinetic remediation is a strong candidate technology meeting that need. In situ methods are needed that can remove enough uranium to reduce contaminant concentrations to acceptable levels and allow the soil to return to productive use. Electrokinetic methods are being evaluated for this purpose, and their applicability to uranium removal from saturated and partially saturated soils needs to be documented.

TECHNOLOGY DESCRIPTION

This project combines selective extractants to remove the uranium with the use of electrokinetics to transport the contaminants to ion exchange media. The media surrounding the electrodes capture and concentrate the uranium for later recovery or disposal.

Field-scale electrokinetic removal of uranium from contaminated soil will be demonstrated in this project based on bench-scale tests (see Figure 3.5-1). Site selection, treatability studies, and pilot-scale tests have been performed. A full-

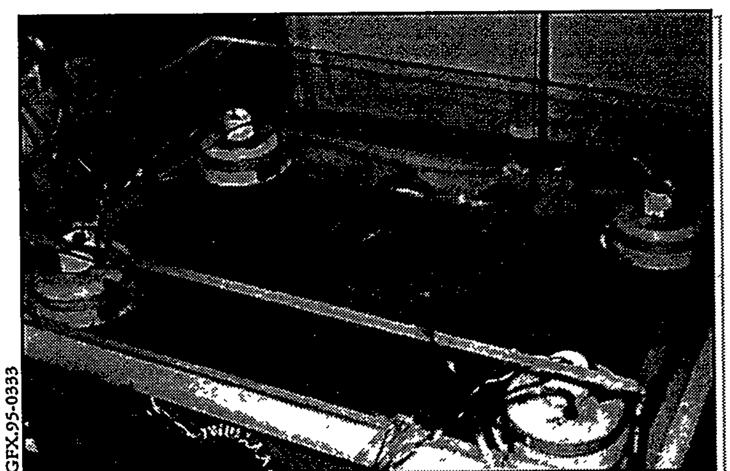

Figure 3.5-1. Bench-Scale Test of Electrokinetic Remediation.

scale field test is envisioned based on the positive results obtained from the pilot-scale tests. Removal efficiency, costs, control of added fluids, contaminant recovery and disposal, power consumption, mass balance, and control of soil pH must be evaluated to ensure that this process is viable. Technology advances made by Russian scientists in this area of environmental remediation will be used as much as possible. In order to make this technology more viable, late FY96 efforts will evaluate how solubilizer additions can best be applied to low permeability soil with minimal impacts to native vegetation. Additional work may be performed in future years to address electrokinetic remediation of co-contaminants (e.g., fission products and chlorinated solvents) which are found at most DOE waste sites.

Benefits

The benefits of electrokinetic remediation compared to baseline excavation and disposal methods include:

- Anticipated cost savings
- Reduced health risk
- Greatly reduced waste disposal volumes

Collaboration/Technology Transfer

DOE's Hazardous Waste Remedial Action Program (HAZWRAP) personnel have visited sites in Russia where electrokinetics have been used to remediate uranium contamination from soil. This information will be helpful in developing the technical specifications for a demonstration at a DOE site. Russian scientists provide technical expertise for the test designs and choice of leaching agents. ISOTRON Corporation is under contract to perform treatability studies and the pilot-scale demonstration of electrokinetic remediation.

Accomplishments

Recent project accomplishments include:

- ISOTRON completed treatability and pilot-scale studies on soils from a potential demonstration site (K-311-1 Diffusion Cascade Purge Vent).
- The pilot-scale results showed efficient removal of uranium from K-25 soils (residual concentration of <50 ppm) using electrokinetics and citrate solubilizer solutions.

- In FY96, a peer review of the pilot-scale results was conducted and additional work to optimize the applications of electrokinetic remediation was recommended.
- Russian scientists contributed to the studies by evaluating and recommending candidate leachants for uranium and by performing modeling studies for determining the characteristics of solubilizer diffusion into the soils.

TTP Information

In Situ Remediation by Electrokinetics activities are funded under the following TTP:

TTP No. OR16PL41, Task 1, "In Situ Remediation by Electrokinetics"

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ISOTRON Corp., HAZWRAP, and LMES. "Pilot Scale Tests for Electrokinetic Removal of Uranium from K-25 Soils" (November 1995).

3.6 ELECTROKINETIC REMOVAL OF HEAVY METALS AND MIXED WASTES FROM PARTIALLY AND FULLY SATURATED SOILS

TECHNOLOGY NEED

Because of the high costs of excavation and disposal, alternative approaches such as in situ soil remediation methods have been gaining interest. However, most in situ methods are not appropriate for low hydraulic permeability soils because of the difficulty of moving fluids in such a medium. Even in soils of moderate or high permeability, natural heterogeneity of the medium can lead to nonuniform contaminant movement and incomplete removal. There is a need for an in situ soil remediation method that will perform well in heterogeneous and/or low permeability soils.

TECHNOLOGY DESCRIPTION

This innovative technology uses low power, in situ electric fields to remove heavy metals and organic compounds from soils via electromigration (movement of charged contaminants) and/or electro-osmosis (bulk flow). These mechanisms are controlled by the applied electric field and can be made to cause uniform and complete removal of contaminants, even in tight or heterogeneous soils (see Figure 3.6-1). There are complex chemical and physical changes that can occur during the process, however, and much laboratory and numerical work is being performed to understand and control these changes. The next generation of challenges being addressed is enhancing removal of otherwise immobile contaminants by introducing appropriate mobilizing agents.

BENEFITS

Electroremediation has the in situ benefits of avoiding the high costs and human health risks of excavation and disposal. This technology may be the only practical in situ method for removing contaminants from low permeability soils. When electromigration is the primary removal mechanism, the resulting waste volume can be less than one-tenth of the initial contaminated volume.

COLLABORATION/TECHNOLOGY TRANSFER

Close cooperation among technology researchers and others who are attempting practical application of electrokinetic remediation at DOE sites is

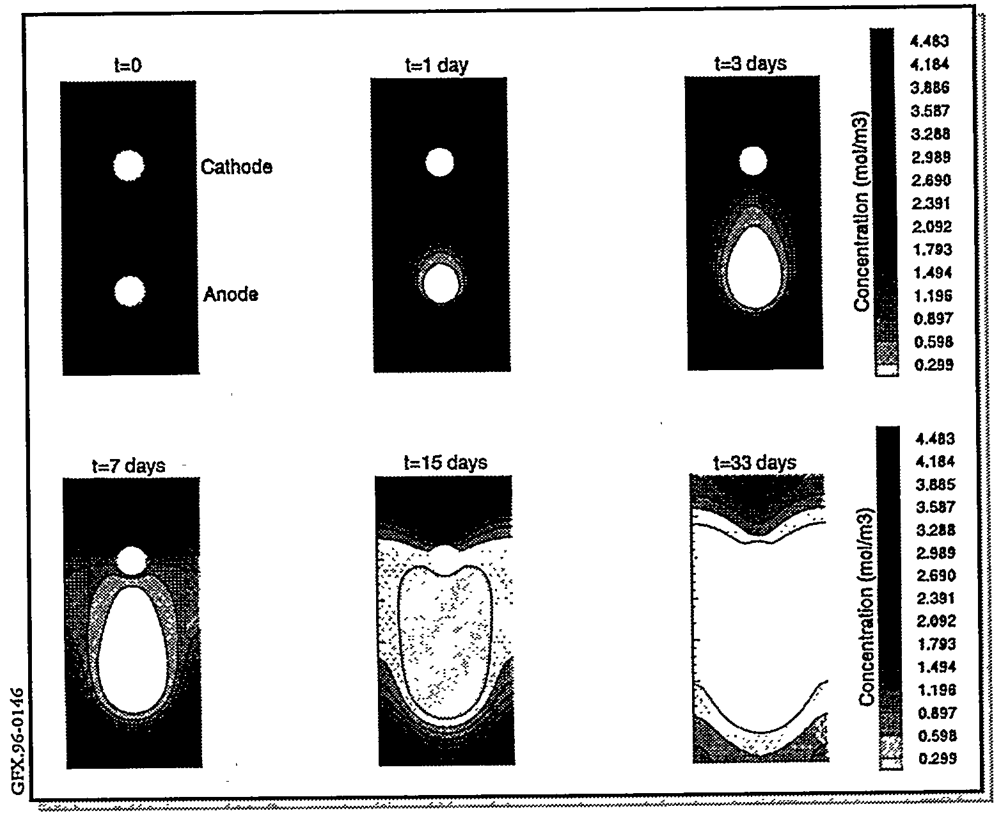

Figure 3.6-1. Calculated Phenol Removal from Clay Soil using Electroosmosis over a 33-Day Period.

being maintained. A general understanding of process fundamentals and methods of enhancing removal will be the key to applying the technology in an efficient and cost-effective manner.

ACCOMPLISHMENTS

The major accomplishments of this project include:

- A two-dimensional numerical model of the electrokinetic remediation process was completed and validated using laboratory experiments on the removal of phenol from a low permeability clay soil.
- Precipitated heavy metal contaminants were removed from a high permeability sandy soil in the laboratory by introducing a mobilizing agent.
- A surfactant that will be used for mobilizing non-aqueous phase liquids was successfully introduced into soil using electromigration.
- A framework for characterizing the effects of soil chemistry on electroremediation was developed and then implemented through numerical simulations to explain the experimental results.

TTP Information

Electrokinetic Removal of Heavy Metals and Mixed Wastes from Partially and Fully Saturated Soils activities are funded under the following TTP:

TTP No. SR06PL41, Task 1, "IAG-EPA Electrokinetic Removal of Heavy Metals and Mixed Waste"

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3.7 ENHANCED URANIUM RECOVERY

TECHNOLOGY NEED

A need exists for alternatives to conventional pump and treat remediation systems. Groundwater treatment through conventional means typically requires a lengthy amount of time, particularly when contamination is present near the water table and low extraction rates are required in order to flush contaminants from this zone. Technologies demonstrated by this project are expected to substantially shorten treatment times and to provide significant cost savings.

This project will focus on accelerating the cleanup of uranium-contaminated groundwater at the Fernald Environmental Management Project (FEMP). This technology could have application at many other sites, including DOE's 26 Uranium Mine Tailings Remedial Action sites and others with metal contamination. At the FEMP, over 135 acres of the Great Miami Aquifer (GMA) are contaminated with uranium above the applicable regulatory limit of 20 ppb. Significant portions of the contaminant plume have migrated off the site and are contaminating the residential and industrial users' water supply. The current FEMP baseline for treatment at this site is a pump and treat remediation with an estimated duration of 27 years. The current cleanup mission for the site has been accelerated, with the exception of aquifer remediation. Technology to expedite the aquifer remediation is thus needed to assure the complete closure of all operations at the site.

TECHNOLOGY DESCRIPTION

The goal of this project is to investigate the application of commercial in situ leaching technologies for the remediation and containment of uranium groundwater contamination. Groundwater reinjection is an integral part of the in situ mining process (see Figure 3.7-1). Enhanced uranium recovery will be accomplished by increasing the contaminant flushing process and limiting the groundwater drawdown where most of the uranium is located. In situ mining technologies may also be used for recovering or containing a large range of other contaminants, and the techniques can be modified to fit a variety of geologic and chemical conditions.

A large-scale demonstration of water injection is proposed to evaluate the improvement in performance over the baseline groundwater remediation strategy (i.e., pump and treat). This project will address technical uncertainties related to the application of injection technology. Modeling simulations of the

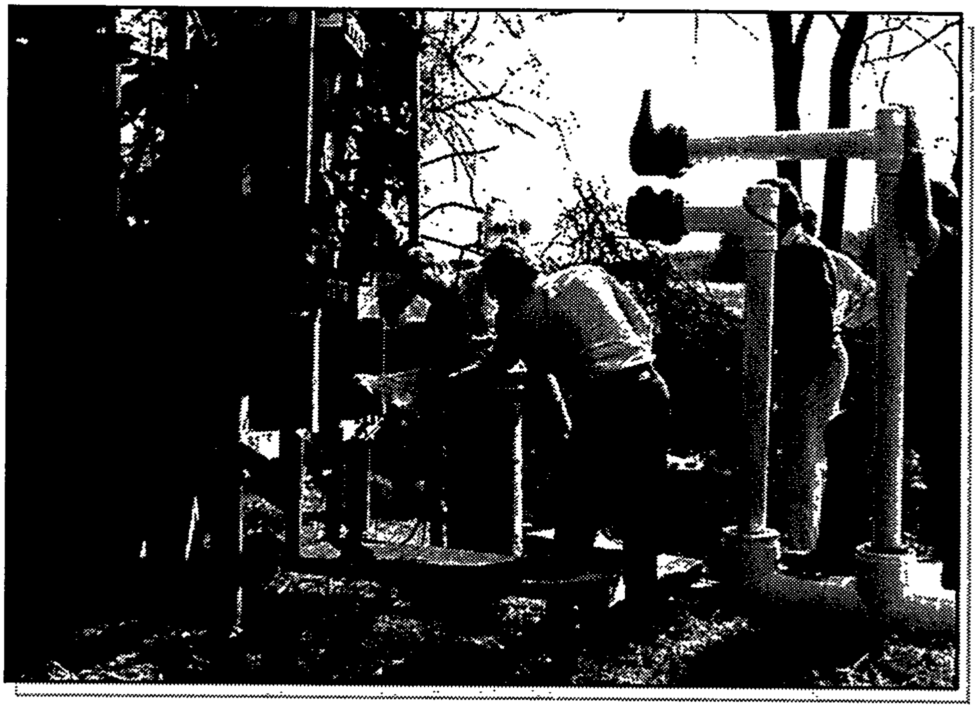

Figure 3.7-1. Injection Well for In Situ Mining at Fernald.

aquifer have shown that significant benefits are possible, but actual field data are needed in several areas. These areas include:

- Can injection be managed such that it does not expand the plume either horizontally or vertically?
- Can injection rates be delivered and maintained over a long period of time at reasonable costs?
- What specific conditions in the aquifer geochemistry cause problems with injection and how can these be minimized?
- Do modeled results showing increases in groundwater elevations for the large-scale demonstration agree with those actually observed during injection?

BENEFITS

The major benefit of this technology is that it has the potential to significantly reduce the duration of aquifer remediation projects. Other government agencies and a wide range of industries could gain cost savings by applying the technology. For instance, at the FEMP the potential reduction in time to remediate the GMA is 15 years, or even more. This translates into a potential savings of $60 million.

Collaboration/Technology Transfer

This technology investigation and application is being conducted as a joint effort between the FEMP and DOE's Western Environmental Technology Office (WETO), which is supported by MSE Technology Applications, Inc. In addition to the EM-40 and EM-50 collaboration with MSE Technology Applications, Inc. and FERMCO, the project has partnered with the commercial in situ uranium mining business. Industry partners include Rio Algom Mining Corporation and In-situ Incorporated; these businesses have formed a joint venture called Rio Algom Environmental Services.

Technology transfer is expected to take place from the industry partners to the DOE. However, the reverse is also true since the industry techniques will be applied in an area not yet developed by industry. In other words, industry partners will be gaining valuable experience in groundwater remediation and will have the opportunity to develop new lines of business. The demonstration of injection technology is being supported by over $12 million from the FEMP EM-40 site environmental restoration program.

Accomplishments

Recent accomplishments of this project include:

- Modeling of injection scenarios has determined a preferred strategy. This effort included investigations of more than 20 scenarios. Significant constraints that factored into the selection of a preferred strategy included: site soil remediation schedule, allowable discharges of treated water, and available treatment capacity.
- Modeling of the geochemistry was performed and key geochemical parameters of the aquifer were identified in preparation for an investigation of the aquifer geochemistry. This investigation will result in mapping the aquifer's geochemical properties.
- A short-term test of aquifer injectivity was performed. Modeled assumptions of aquifer response were verified relating to elevation increases near the well. Modeled injection rates were found to be sustainable and mechanical concerns with injecting water were not found to be a significant problem.
- System design activities for the conceptual design of a large-scale demonstration of injection have been initiated.
- In FY95 and FY96, nine "early start" extraction wells were installed using EM-40 funds. These extraction wells will be used during pilot-scale injectivity tests and during the full-scale demonstration.

- Project personnel have routinely held technology transfer meetings with industry partners since May 1995.

TTP Information

Enhanced Remediation activities are funded under the following TTPs:

TTP No. OH16PL41, Task 1, "Enhanced Uranium Recovery from Groundwater Plumes"

TTP No. PE16PL41, Task 2, "Investigation of In Situ Mining Techniques"

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3.8 BIOMASS REMEDIATION SYSTEM

TECHNOLOGY NEED

Widespread heavy metal and radionuclide contamination exists in soils and groundwater across the DOE complex. Much of this contamination is at low but environmentally significant concentrations. For contaminants in soils that are spread over wide areas or in relatively large volumes of water, removal and storage or remote treatment is very expensive. Phytoremediation technology could be less expensive than removal and treatment cleanup options depending on the size of the area, the topography of site under consideration, and the life-cycle economics of soil processing or pump and treat systems. Moreover, in situ treatment technologies such as phytoremediation may receive regulatory acceptance more easily than ex situ treatments.

TECHNOLOGY DESCRIPTION

Laboratory studies and field testing have confirmed that certain plants will accumulate, and in some instances concentrate, heavy metals and radionuclides from soil and water. Contaminant removal via phytoremediation is being developed in two primary ways. For cleanup of soils, contaminant transfer to aboveground plant (leaf and stalk) biomass is the mechanism for removal. Likewise, concentrating contaminants in roots biomass is the principal mechanism involved in removing contaminants from water in a process called rhizofiltration (see Figure 3.8-1) Contaminant mass transfer is the product of the concentration in plant tissues and overall biomass production. Improvement in contaminant mass transfer is a primary goal of the Biomass


GFX-96-0172

Figure 3.8-1. Rhizofiltration of Uranium Waste Water at RMI/Ashtabula, Ohio (courtesy of Phytotech, Inc.).

Remediation System (BRS) task. Overall process economics involve life-cycle costs for biomass production, contaminant uptake, and biomass processing and disposal. BRS task work is currently directed toward removing uranium, strontium, cesium, and heavy metals from soils and groundwater at specific DOE sites.

Benefits

The ability of certain plants to remove contaminants from soil and water is a relatively inexpensive and publicly appealing method to remediate widespread, low-level contamination by heavy metals and radionuclides. Environmental, safety, and health risks associated with implementing phytoremediation should be lower than those associated with baseline technologies. The vast extent of land and water contaminated with these constituents warrant use of such an economically and environmentally acceptable technology.

Collaboration/Technology Transfer

The USDA/Agricultural Research Service (ARS) Plant Soils and Nutrition Laboratory in Ithaca, New York, is a collaborator on this project through an interagency agreement between USDA and DOE. Research and development tasks conducted by USDA scientists augment and support phytoremediation field trials and demonstration activities.

In FY95, MSE Technology Applications, Inc., established a subcontract with Phytotech, Inc., of Monmouth Junction, New Jersey, to conduct pilot-scale testing and demonstration of phytoremediation at DOE sites for removing metals and radionuclide contaminants. Initial testing was conducted for removing uranium from wastewater at a DOE facility in Ashtabula, Ohio. The principal product of these activities will be technical performance and economic data suitable for the engineering design of full-scale commercial systems.

Papers summarizing work accomplished in FY94 were presented at technical conferences in Tucson, Arizona (March 1995) and in San Diego, California (April 1995). Presentations regarding FY95 BRS task work were given at technical conferences in Atlanta, Georgia (September 1995) and New Orleans, Louisiana (February 1996). Additional manuscripts documenting work performed by the USDA/ARS have been submitted for publication in April 1996.

ACCOMPLISHMENTS

Recent project accomplishments include:

- In 1995, a project for screening hundreds of plant species to identify those with promising characteristics for accumulating contaminants of concern was conducted with the USDA/ARS Plant, Soils, and Nutrition Laboratory in Ithaca, New York.
- Field tests were conducted in 1995 to evaluate metals and radionuclide uptake at two DOE sites (INEL-Test Area North and RMI Ashtabula, Ohio) and at a heavy metals Comprehensive Environmental Response, Compensation, and Liability Act site (Silver Bow Creek, Montana).
- Over 90 percent of uranium was removed from wastewater, which was achieved during initial testing of rhizofiltration by Phytotech Inc., at the Ashtabula, Ohio DOE facility.
- At the Silver Bow Creek site, metals removal was equivalent to 1 percent and 0.5 percent per growing season for zinc and cadmium, respectively.
- During an 8-week field trial at INEL, approximately 2 percent removal of strontium-90 from soils was achieved.
- Follow-up work is ongoing to improve uptake rates, develop sound economic data, and perform field demonstration tests at DOE sites.

TTP INFORMATION

Biomass Remediation System activities are funded under the following TTP:

TTP No. PE16PL41, Task 1, "Biomass Remediation System"

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3.9 IN SITU GASEOUS REDUCTION SYSTEM

TECHNOLOGY NEED

To avoid the excessive costs and risks to public health and worker safety associated with excavation, treatment, transportation, and disposal, The In Situ Gaseous Reduction System (IGRS) is being tested to immobilize metallic contaminants in the ground. The configuration currently under development uses a gaseous reagent in unsaturated soils to reduce the toxicity and mobility of hexavalent chromium. By reducing the mobility of this toxic metal in soil, the contaminant is prevented from migrating to underlying groundwater systems. Several sites in the DOE complex have chromium contaminated soil, including plumes at Sandia National Laboratories (SNL), Pantex, and Hanford. Chromium contamination is also quite common in the private sector.

Although current work is focused on chromium immobilization, this research can be used to provide solutions to a variety of other remediation problems. Further research could lead to technologies to immobilize other redox sensitive metals (e.g., uranium and lead) above and below the water table.

TECHNOLOGY DESCRIPTION

The major effort of this project is currently directed toward testing the feasibility of treating unsaturated soils by injection of reactive gases (see Figure 3.9-1). Diluted mixtures of hydrogen sulfide or nitrogen in air can potentially treat soils contaminated with heavy metals and radionuclides. Clean soils from several DOE sites have been used in treatability tests to verify that the approach is applicable to a variety of soil types, and to evaluate the impact of gas concentrations and residence time on treatment performance.

Testing of chromate-contaminated soil samples collected at the SNL Chemical Waste Landfill (CWL) has been performed. The resulting data will be used to optimize treatment procedures and to obtain an estimate of unit treatment costs. Engineering design and gas flow modeling activities have been conducted to develop approaches for ensuring the control of reactive gases and for obtaining effective treatment of large masses of contaminated soil. A field demonstration of the application of in situ gas treatment to remediate chromate-contaminated soil has recently been proposed for a waste site at the DOD White Sands Missile Range in central New Mexico.

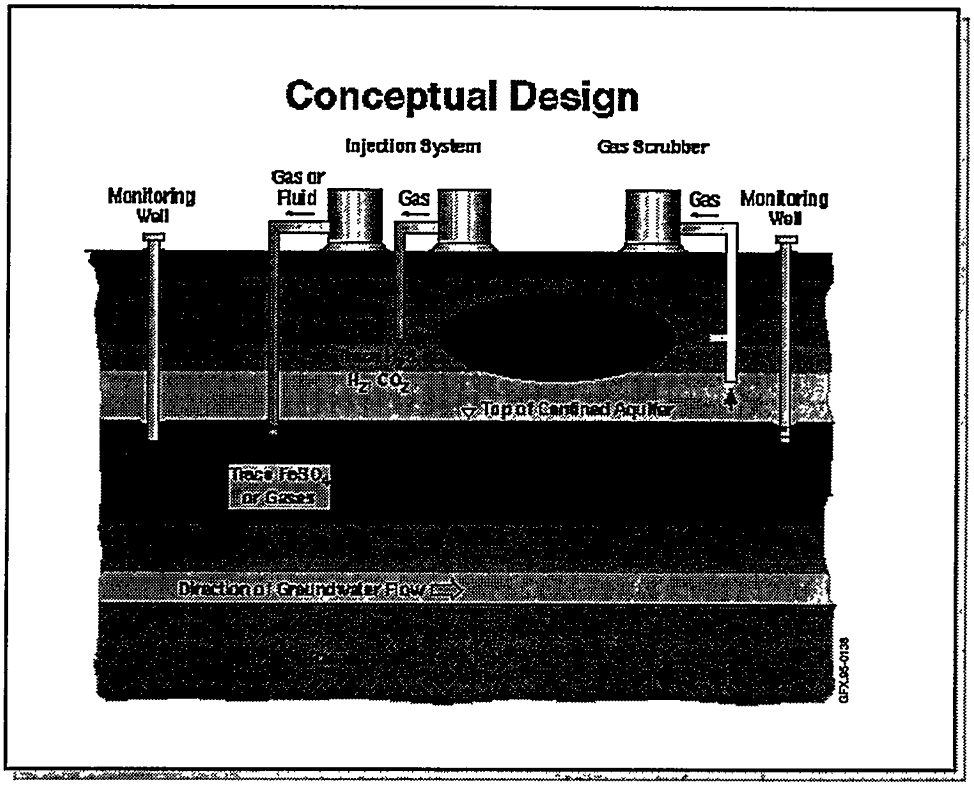

Figure 3.9-1. In Situ Chemical Treatment Conceptual Design.

BENEFITS

The benefits of this approach are:

- Using in situ immobilization of contaminants avoids the costs and risks to public health and worker safety associated with excavation, surface treatment, transportation, and disposal.
- Gaseous reactants, such as diluted H_2S, increase permeability of soils to gases. Gaseous mixtures will invade smaller soil pores to react with soil contaminants, thereby improving treatment effectiveness.

COLLABORATION/TECHNOLOGY TRANSFER

The first application of the use of gas treatment for remediation of chromate-contaminated soil has been proposed for a waste site located at the White Sands Missile Range. Several DOE sites anticipate utilizing this approach upon successful completion of this first demonstration. Inquiries have also been received from potential users in the private sector.

Accomplishments

Major project accomplishments include:

- The treatability testing project used soils from the 100-D Area of the Hanford Site, a metal-plating waste site at the CWL, and the Fernald Site.
- The project completed a treatability study involving chromate-contaminated soil from the CWL.
- The project designed and fabricated a prototype gas treatment system.

TTP Information

In Situ Gaseous Reduction System (IGRS) activities are funded under the TTPs:

TTP No. RL46PL41, Task 1, "In Situ Chemical Treatment"

TTP No. AL26PL41, Task 1, "Gaseous Reduction of Chromium"

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3.10 IN SITU REDOX MANIPULATION

TECHNOLOGY NEED

Subsurface contaminants at DOE sites occur in both the vadose and the saturated zones. Many of the groundwater plumes are already dispersed over large areas (square miles) and are located up to hundreds of feet below the ground. This type of dispersed contamination is difficult to treat using baseline excavation or pump and treat methods. One alternative is the in situ manipulation of natural processes to change the mobility or the form of the contaminants.

TECHNOLOGY DESCRIPTION

Controlling the oxidation-reduction (redox) potential of the unconfined aquifer may be a reasonable in situ method for immobilizing inorganic contaminants (metals, inorganic ions, and radionuclides) and destroying organic contaminants (primarily chlorinated hydrocarbons). The concept is to create a permeable treatment barrier by injecting reagents and/or microbial nutrients into the subsurface. The types of reagents and nutrients injected will be selected based on their ability to make the aquifer reduce, thereby destroying or immobilizing specific contaminants. This process is referred to as in situ redox manipulation (ISRM). Although the proposed target of this technology is chromate contamination in the Hanford 100 Areas, the concept should be applicable to a range of other contaminants, including uranium, technetium, chlorinated solvents, and energetic compounds.

A photograph of the ISRM field site at the Hanford 100-H Area is shown in Figure 3.10-1. As part of the pre-experiment site characterization, analyses of physical, geochemical, and microbiological data were collected on sediment samples from new wells installed by sonic drilling. Aquifer tests (i.e., slug and pump tests) were performed during and after drilling. Mathematical models were used in conjunction with reagent and site characterization information to define nominal specifications for the field experiments. The design models accounted for advection, dispersion, degradation, and transformation processes. The model examined and evaluated the proposed field operations that will deliver an effective concentration range of sodium dithionite in the desired aquifer volume for a period of time that allows the targeted ferric iron to be reduced.

An additional pilot-scale demonstration is proposed to occur in late FY96 or FY97 at the Hanford 100-D Area. The dimensions in the nominal design of the pilot-scale ISRM treatment zone are 200 feet long by 50 feet wide. The treatment zone would be emplaced within the chromium plume at the

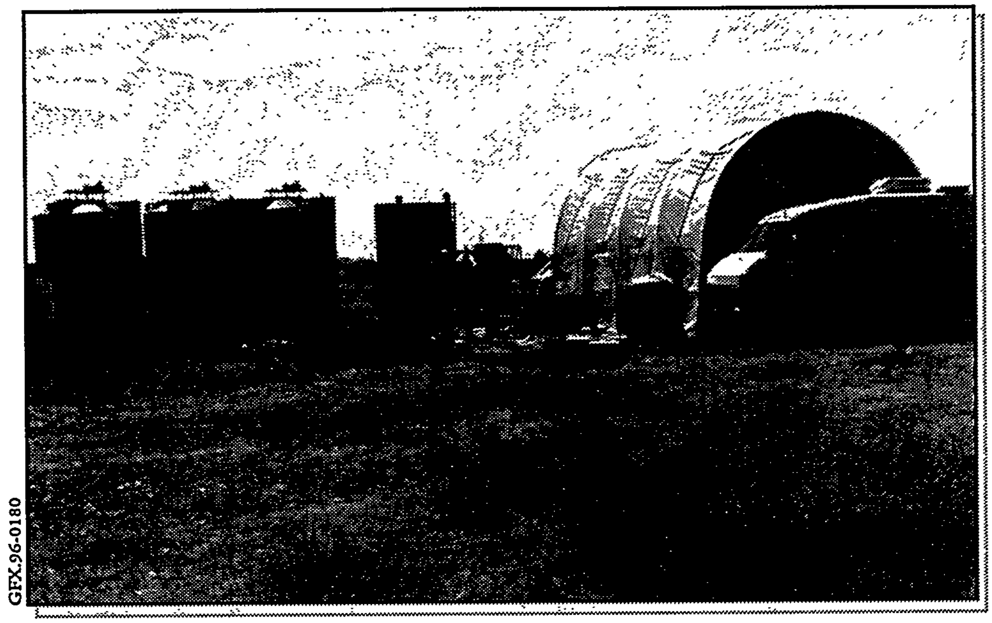

Figure 3.10-1. In Situ Redox Manipulation Field Site at Hanford.

100-D Area, downgradient from the 500 ppb isopleth. The maximum concentration of chromium in the 100-D Area groundwater in May 1992 was 2,020 ppb. The approach taken for the barrier emplacement is similar to that used for the FY95 ISRM field experiments in the 100-H Area. A long linear barrier will be created by coalescing a number of smaller reduced zones.

BENEFITS

Advantages of a redox manipulation permeable-barrier for remediation of contaminants in groundwater are:

- **Relatively inexpensive installation.** The installation cost for a permeable barrier will be comparable to that of the impermeable barrier.
- **Inexpensive operation.** During operation of this barrier, there is no need for an external energy source, management of large volumes of water containing low concentrations of contaminants, management of secondary waste, discharge permits, or purchases of rights.
- **Permanent solution.** The permeable barrier at Hanford, for example, would be a permanent solution for preventing contaminants from entering the Columbia River.
- **Safe.** Human exposure to potentially hazardous materials is greatly diminished because neither contaminated groundwater nor matrix material are brought above ground.

- **Unobtrusive.** No permanent external treatment or pumping systems are required.

- **Renewable barrier.** If groundwater monitoring demonstrates the necessity, the redox barrier can be replenished.

COLLABORATION/TECHNOLOGY TRANSFER

In response to a request from Bechtel Hanford, Inc. (BHI), a proposal was developed for the emplacement of a pilot-scale permeable treatment zone using ISRM for the treatment of chromium contaminated groundwater in the 100-D Area (part of the 100-HR-3 Operable Unit). The ISRM process has been incorporated into the Five Year Plan as a treatability study for the Hanford 100-HR-3 Operable Unit. Discussions are underway with environmental remediation firms interested in deploying this technology.

ACCOMPLISHMENTS

Recent accomplishments for this project include:

BENCH-SCALE EXPERIMENTS

- **Abiotic Reduction.** Batch laboratory experiments found that sodium dithionite reduces the structural ferric iron found in the clays of the Hanford soils. A half-life of about three days was identified for sodium dithionite in the Hanford soil, which should allow enough time for the reduction of solids and ensure that dithionite does not remain as a contaminant in the groundwater for extended periods of time.

- **Biotic Reduction.** In FY95, the project demonstrated that biogenic Fe(II), when sorbed to the surface of poorly crystalline or highly crystalline Fe(III) oxide minerals, reductively dechlorinated carbon tetrachloride.

- **Intermediate-Scale (Wedge) Experiments.** In May 1995, three types of experiments were conducted in a 7-meter-long, wedge-shaped flow cell: a bromide tracer test, a mini-injection experiment with sodium dithionite, and a full injection experiment with sodium dithionite. The full dithionite injection experiment in the wedge flow cell consisted of a 24-hour injection of sodium dithionite with a potassium carbonate buffer and a potassium bromide tracer.

HANFORD 100-H AREA FIELD-SCALE EXPERIMENTS

- **Tracer Test.** A conservative tracer (i.e., bromide) test was performed prior to reagent injection to provide baseline information for modeling transport processes and updates to the site characterization database.

- **"Mini" Dithionite Injection**. A "push-pull" test was completed in August 1995 and involved the injection of 1,000 gallons of 0.1 molar sodium dithionite solution (pH buffered) at the Redox Field Test Site at the Hanford 100-H Area, followed by the withdrawal of 5,000 gallons after a one day drift period. Analysis of the withdrawn water indicated that all trace metals, including arsenic, lead and chromium, were below the 0.1 ppm detection limit of the Inductively-Coupled Argon Plasma/Mass Spectrometry (ICAP/MS) method used.
- **Full-Scale Dithionite Injection**. The full-scale dithionite injection was initiated on September 7, 1995, at the Hanford 100-H Area. Data are still being interpreted, but initial results appear promising.

TTP INFORMATION

In Situ Redox Manipulation (ISRM) activities are funded under the following TTP:

TTP No. RL36PL41, Task 2, "In Situ Redox Manipulation"

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3.11 APPLICATIONS OF SELECTIVE POLYMER SEPARATIONS

TECHNOLOGY NEED

The pump and treat approach to groundwater plume remediation using conventional ion exchange technology is being implemented at various locations in the DOE complex, generally driven by regulators. These plumes typically have dilute concentrations of heavy metals and radionuclides, along with normal or elevated levels of common nontoxic or low-toxicity cations (such as calcium, magnesium, aluminum, iron, zinc, etc.) and anions (such as sulfate and chloride). Conventional ion exchange resins tend to be nonselective, so that while the contaminants of concern are removed, a large portion of the available resin capacity is taken up by the nontargeted ions present. This serves to increase costs, since either more resin must be supplied to provide this additional capacity, or a smaller amount of resin must be stripped and regenerated more frequently, using up the resin's life more rapidly. In addition, the resulting concentrated wastestream is larger, hence more costly and difficult to dispose due to the presence of the nontargeted ions (see Figure 3.11-1).

TECHNOLOGY DESCRIPTION

Recent research efforts have developed new materials that can selectively adsorb specific metal and radionuclide contaminants at dilute concentrations in the presence of competing cations or anions. The use of these materials in place of conventional ion exchange resins would result in much more efficient remediation, since a smaller quantity of material would be required and the

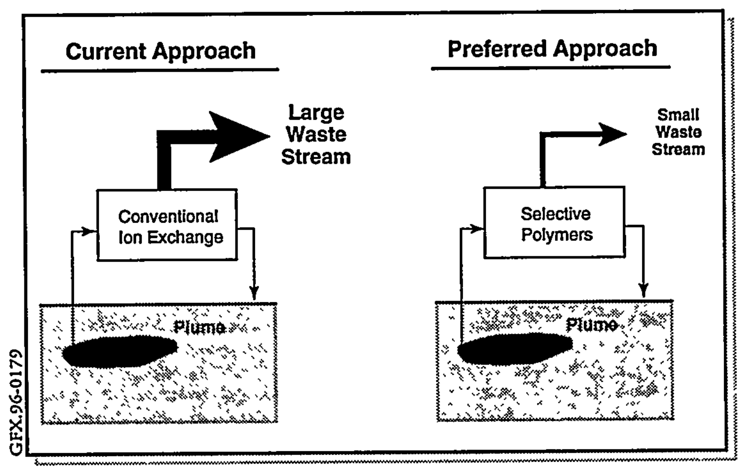

Figure 3.11-1. Effect of Using Selective Polymers Versus Conventional Ion Exchange in Pump and Treat Groundwater Remediation.

contaminants would be concentrated in a much smaller volume for disposal. However, these materials are still relatively undeveloped. Their specific capabilities and shortcomings related to dilute, complex solutions are not well understood. The objective of this project is to prepare a comparative evaluation of these technologies to better understand cost and performance parameters and their applicability to remediating priority groundwater plumes. Specifically, available data on capacity, selectivity, regenerability, kinetics, compatibility, product development lead time, and capital and operating costs will be compiled and compared. Laboratory or field testing may be required to fill gaps in existing knowledge for promising technologies.

Benefits

Obstacles to the implementation of new, innovative technologies often include a lack of stakeholder awareness of the technologies' existence and insufficient documentation regarding their capabilities and shortcomings. The primary benefit of this task will be the compilation of cost and performance data in to a single document, supported by test data on emerging technologies with the potential for significant cost savings when compared to conventional technologies.

Collaboration/Technology Transfer

Collaborators will include researchers and manufacturers of these innovative materials. Specific collaborators will be identified as the task proceeds. The comparative evaluation report will be updated as informational gaps are filled and will be made available to EM-40 as a tool to help select technologies for specific cleanup problems. The report is likely to have value to entities in the private sector as well as government agencies facing similar cleanup requirements.

Accomplishments

The task was initiated in February 1996. Preparation of the comparative evaluation report has been initiated.

TTP Information

Applications of Selective Polymer Separations activities are funded under the following TTP:

TTP No. PE16PL41, Task 5, "Applications of Selective Polymer Separations"

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None at this time.

3.12 Chemically Enhanced Barriers

Technology Need

Sr^{90} is the third most frequently occurring radionuclide in groundwater at DOE facilities. For example, at the DOE's Hanford Site (100-N Area), Sr^{90} is entering the Columbia River at concentrations that exceed the drinking water standard. Low cost remediation technologies are urgently needed to clean up Sr^{90} contaminated groundwater or to contain the contamination against further migration. The most frequently used approach to remediate Sr^{90} contaminated groundwater is pump and treat, which can be an effective containment approach. However, it is very costly and requires continuous maintenance for the life of the project. In addition, pump and treat requires continuous treatment of the contaminated water brought to the surface and disposal of the waste products generated.

Technology Description

Permeable chemically reactive barriers, which act as selective filters to contaminants, are being developed in response to the need for effective, low-cost technologies that can remediate contaminated subsurface environments (see Figure 3.12-1). These chemically reactive barriers are permeable to water and nontargeted-groundwater constituents, and impermeable to the targeted contaminants. One such barrier is composed of the zeolite clinoptilolite and is being applied to mitigate Sr^{90} migration. Bench-scale development of this technology has been completed and design of a field-scale demonstration is expected to begin construction in the summer of 1996. The purpose of the field

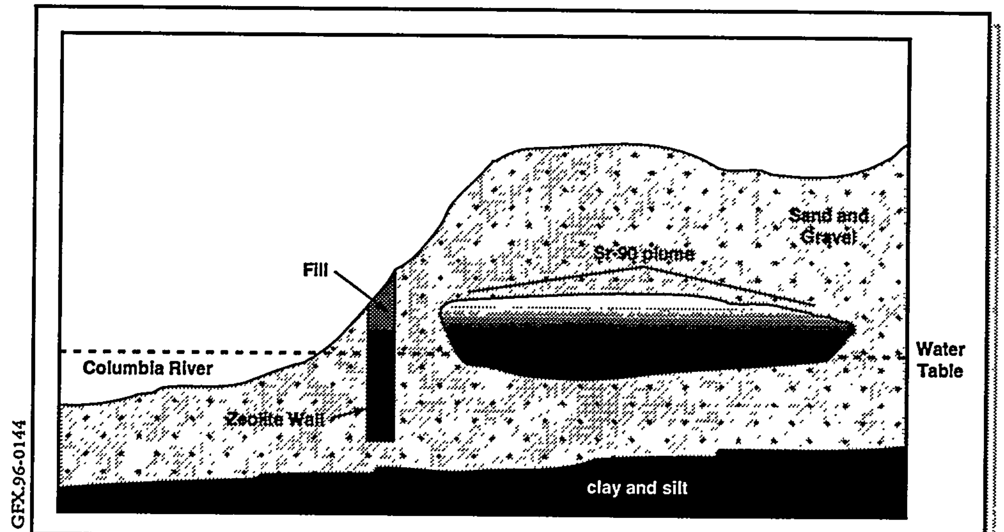

Figure 3.12-1. Proposed Chemically Enhanced Barrier to Adsorb Sr^{90} in Groundwater at Hanford.

demonstration is to determine if a reactive barrier composed of clinoptilolite can be successfully emplaced using available technology, and to determine the effectiveness of this technology in an actual field setting. Current barrier emplacement techniques include conventional backhoe trenching or drilling with 4-foot diameter augers. If the field demonstration is successful, this technology can be considered as a final remediation alternative at Hanford Site's 100-N Area or other sites with Sr^{90} contamination. Other barrier materials have been previously evaluated for a range of contaminants, but the Sr^{90} barrier was selected for the field demonstration because of the high priority need at Hanford.

BENEFITS

Because these systems are passive, operational costs are minimal and external energy is not required to operate the systems once they are installed. In addition, no secondary wastes are produced and discharge permits are not required. This will minimize worker exposure and waste disposal costs. Because the clinoptilolite is a natural alumino-silicate compound (a mineral), no adverse environmental impacts are expected. Clinoptilolite is a natural zeolite and is available at a relatively low cost (approximately $200 per ton). In addition, the reactive barrier is permeable to groundwater and as a result does not alter its natural flow. At the 100-N Area, the clinoptilolite is expected to reduce Sr^{90} migration by more than 99.7 percent using a one-meter thick barrier.

COLLABORATION/TECHNOLOGY TRANSFER

A field demonstration will be constructed during the summer of 1996 at DOE's Hanford Site (100-N Area). This demonstration is being conducted in collaboration with BHI. Pacific Northwest National Laboratory (PNNL) has been responsible for the bench-scale development of this technology and is currently providing the lead for the design of the field demonstration experiment. PNNL is also assisting in the design and selection of the emplacement methodology. BHI is responsible for the design, selection, and construction oversite of the emplacement methodology. Oregon State University has provided technical assistance with the bench-scale hydrologic and geotechnical measurements required for the design of the reactive barrier.

ACCOMPLISHMENTS

This project has completed:

- Bench-scale adsorption isotherms
- Bench-scale adsorption kinetics experiments

- Hydraulic conductivity and geotechnical characterization of clinoptilolite
- Development of a kinetic model for barrier design
- Field demonstration site selection at Hanford's 100-N Area based upon the need to treat seepage to the Columbia River

TTP Information

Chemically Enhanced Barriers activities are funded under the following TTP:

TTP No. RL36PL41, Task 1, "Chemically Enhanced Barriers to Minimize Contaminant Migration"

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3.13 PASSIVE TREATMENT BARRIERS

TECHNOLOGY NEED

The production of uranium fuels and weapons materials has resulted in the release of organic compounds, uranium, and other heavy metals into groundwater at DOE and other federal facilities. This groundwater contamination is often mobile and spreads over large areas and distances, posing a great risk to human health and the environment. Potential technology application sites include the Bear Creek Burial Grounds at Oak Ridge National Laboratory and the Mound Area (Operable Unit 2) at Rocky Flats.

TECHNOLOGY DESCRIPTION

In situ reactive barriers are water permeable barriers that possess properties that either alter or destroy contaminants of concern (COC) in place (e.g., certain VOCs), or bind the COC (e.g., uranium) to the barrier material (see Figure 3.13-1). The prime purpose of reactive barriers is to change the remediation strategy from advective pumping to passive capture under natural gradients, bypassing the diffusion limitation inherent in advective pumping. The barrier media must be placed in a manner that permits retrieval for extraction of bound contaminants and regeneration or replacement of the media. Zero valent iron and zeolites are two of the potential barrier materials being considered. Containment and retrieval of the reactive barrier media may be achieved by

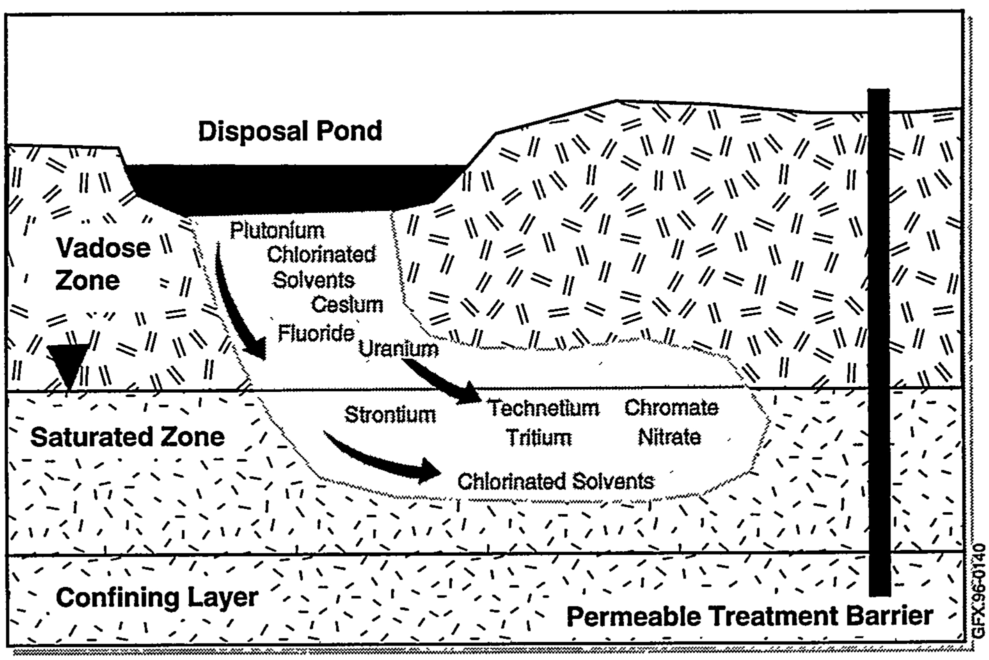

Figure 3.13-1. Permeable Treatment Barrier Concept for Treatment of Metals and Radionuclides.

producing bricks composed of the reactive material(s) or by producing foam bricks that have the reactive material dispersed in the foam matrix. These bricks would then be placed into a cassette that could be lowered into a cutoff trench designed to intercept contaminated groundwater flow. When the effectiveness of the reactive barrier diminishes, the cassette would be removed and either a freshly charged cassette would be installed or new foam blocks would replace the spent blocks. Appropriate down-gradient monitoring will alert operators when barrier replacement is required.

BENEFITS

Currently, contaminated groundwater plumes are remediated through conventional pump and treat processes and/or contained with a variety of impermeable barriers. Developing permeable barriers that selectively remove, and/or chemically alter, the COC will result in lower groundwater remediation costs. Furthermore, the technologies will generate smaller quantities of waste materials requiring disposal. Lower costs and less waste are expected because:

- Operational costs decrease significantly after the barrier and remote monitoring system are installed; the technology becomes passive at this point and requires only periodic maintenance.
- In situ destruction of VOC reduces potential for human exposure.
- The combined expertise of several national laboratories will be coordinated and focused on a common problem: in situ treatment of contaminant plumes.
- Other federal agencies, particularly the DOD, will derive similar benefits from the technologies developed and demonstrated by this project.

COLLABORATION/TECHNOLOGY TRANSFER

The Passive Treatment Barrier Technology Program, through its relationship with the Subsurface Contaminants Focus Area, will facilitate the transfer of in situ reactive barrier treatment technologies to DOE, DOD, other government agencies, and the private sector. An integrated and comprehensive remediation system will be developed. This remediation system will consist of specialized reactive barrier materials and matrices, techniques and equipment for containing and retrieving the barrier materials, and systems to remotely monitor groundwater conditions.

ACCOMPLISHMENTS

This new project, initiated in 1996, has established a project team to explore the technical, operational, and economic issues of passive treatment barrier technology. The team has begun working with the Reactive Barriers Subgroup of the Remediation Technology Development Forum (RTDF).

TTP INFORMATION

Passive Treatment Barriers activities are funded under the following TTPs:

TTP No. PE16PL41, Task 4, "Passive Treatment Barrier Technology"

TTP No. AL26PL41, Task 5, "Support to RTDF Permeable Barrier Working Group"

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None at this time.

3.14 MAG*SEP[SM] GROUNDWATER REMEDIATION

TECHNOLOGY NEED

Groundwater contaminated with heavy metals is a widespread problem at numerous DOE and private industry sites. Heavy metal contaminants include, but are not limited to, lead, chromium, nickel, and cadmium, as well as radionuclides. The contaminants have often leached from the soil into the groundwater, thus increasing their mobility and complicating remediation efforts. Contaminant concentrations can range from low levels, in the parts per billion range, to very high levels, in the hundreds of parts per million. Frequently, groundwater contamination is a result of such industrial operations as weapons production, metals finishing, printed circuit board and semiconductor manufacturing, and photographic processing. Heavy metal and radionuclide contamination has also been found in baby food, milk, and food products in the region surrounding the Chernobyl reactor accident site in the Ukraine.

A preliminary investigation of DOE sources indicates that hundreds of DOE sites are characterized by groundwater containing heavy metals or radionuclides. Examples of such DOE sites are Pantex, SWMU #133; Pinellas shallow water aquifer; INEL TRA 05 injection well; and Richland 1100 Area isolated Unit #1. These sites, along with acid mine drainage sites and industrial effluent treatment, represent some of the most important application areas for the MAG*SEP[SM] technology.

TECHNOLOGY DESCRIPTION

The MAG*SEP[SM] process is designed to remove target contaminants from groundwater or process streams by applying ion exchange principles (see Figure 3.14-1). The target contaminants are adsorbed onto the resin-coated

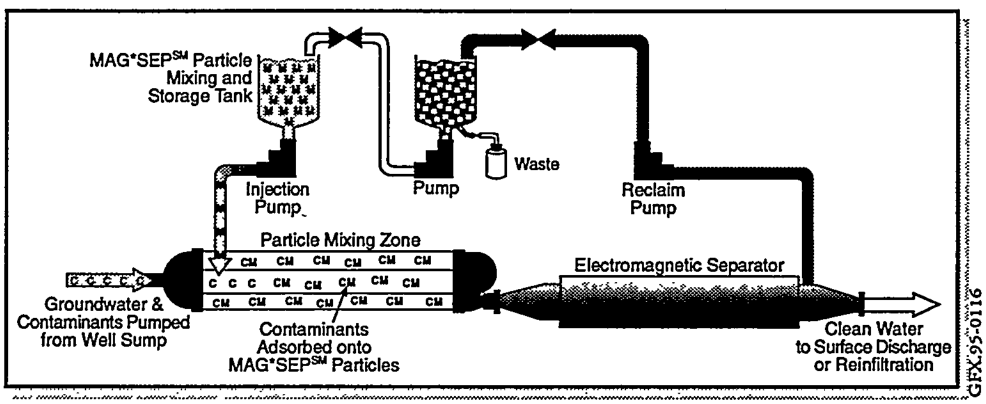

Figure 3.14-1. Above-Ground Demonstration of In Situ MAG*SEP[SM].

magnetic particles. Then, the particles are captured magnetically, and the contaminants are removed. Lastly, the particles are recycled for reuse. This process is conducted by pumping the groundwater into the particle injection/ mixing zone, where MAG*SEP^{SM} particles are injected and mixed with the groundwater. The MAG*SEP^{SM} particles are a composite resin material manufactured in an acrylic form, which should give them high durability. MAG*SEP^{SM} particles range in size from 25 to 300 microns and have a magnetic core with an acrylic coating. The functionalized resin, IDA, is attached to the acrylic coating for selective contaminant adsorption.

After a predetermined contact time has elapsed (approximately 2 minutes), the particle-groundwater slurry passes into a magnetic separator that removes the magnetically susceptible particles and allows the treated effluent to pass through. The particles are transferred into a regeneration system, where the metals are removed by using an acid wash (much in the same manner as ion exchange resin is regenerated). The waste acid is transferred into a waste container, where it is held until disposal. The particles are then reconditioned with a caustic solution for later reuse. This cycle is repeated until the waste stream has been fully treated.

This process is showing great promise in eliminating problems currently encountered with the ion exchange, which is the baseline technology for removing metallic contaminants from aqueous waste streams. Common ion exchange methods provide marginal selectivity for the compounds they accumulate. By collecting non-contaminant anions and cations commonly found in groundwater, these systems generate a large volume of waste, which must be transported and disposed. There are few licensed treatment, storage, and disposal facilities that can accept radioactive waste. The costs associated with this shortcoming are a major concern for DOE, which has many large radioactive groundwater plumes for which contaminant disposal would be extremely expensive.

An additional benefit this technology is the in situ nature of its deployment.

To demonstrate the capabilities of the MAG*SEP^{SM} process, DOE requested that Argonne National Laboratory (ANL) work with Selective Environmental Technologies, Inc. (Selentec) of Atlanta, Georgia to conduct a field demonstration of the MAG*SEP^{SM} process at the Savannah River Site D-Area Coal Pile Runoff Basin.

BENEFITS

The potential benefits of the MAG*SEP^{SM} technology include:

- Applications for the removal of heavy metals in process or effluent streams
- Minimal generation of waste

- Selective removal by selection of unique functionalized resin materials
- Use in slurries (high particulates) where conventional ion exchange would require filtration

Collaboration/Technology Transfer

The project team for this effort includes ANL; Selentec, Inc.; Westinghouse Savannah River Co.; and Framatome Technologies. Several technology transfer efforts are under way. Most notably, the MAG*SEP℠ technology is being considered for the cleanup of milk from the Ukraine in a project sponsored by the U.S. State Department.

Accomplishments

Since October 1995, the project team has been actively engaged in field testing. As of March 1996, the following accomplishments have been achieved:

- Completed fabrication, mobilization, and installation of the MAG*SEP℠ Treatment Trailer
- Completed planning documents, including the Sampling and Analysis Plan and Test Plan
- Received Wastewater Treatment Permit from the State of South Carolina
- Manufactured 20 kg of phenolic particles for testing
- Completed one steady-state test
- Completed eight system optimization tests
- Completed three magnet tests
- Developed acrylic-based particles

Preliminary results of the field testing have demonstrated that the MAG*SEP℠ process is capable of removing up to 90 percent of the nickel from the contaminated groundwater stream. In addition, preliminary testing of a two-stage magnetic separator system indicates that particle removal efficiencies of greater than 99 percent are achievable.

TTP Information

MAG*SEP℠ activities are funded under the following TTPs:

TTP No. CH26PL41, Task 1, "MAG*SEP℠"

TTP No. SR16PL41, Task 1, "MAG*SEP℠ Demonstration"

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3.15 ACT*DE*CON℠ TREATABILITY STUDY

TECHNOLOGY NEED

This technology deals specifically with the selective dissolution and recovery of plutonium from soil. Because of the large volume of contaminated soil within the DOE complex, efforts to improve the cost-effectiveness of soil treatment can provide a large payback over the life of the DOE complex cleanup. Much of the soil has a high silt and clay content; most of the contaminants are associated with the smaller soil particles. Conventional soil-washing techniques that use particle separation would generate a volume of waste too large to be economically feasible. This application deals with the demonstration of a technology for the treatment of soils in the Miami Erie Canal, near DOE's Mound Laboratory, Ohio, which has an estimated 1.5 million cubic feet of contaminated soils from past operation and disposal practices.

TECHNOLOGY DESCRIPTION

The ACT*DE*CON℠ process uses a chelant, carbonate, and an oxidant (typically hydrogen peroxide) to dissolve radionuclides (primarily actinides) from soil or other contaminated solid media. The oxidant is required to raise the oxidation state of the contaminant to the level at which it is soluble (e.g., uranium 4+, plutonium 6+). Following oxidation state adjustment, the chelant assists in the formation of the carbonate complex. These carbonate complexes are then selectively removed from the liquid phase after the liquid and solid components of the soil slurry are separated. This process is typically accomplished by the MAG*SEP℠ technology, which uses selective adsorbers on the surface of magnetically susceptible particles (the MAG*SEP℠ particles. See Figure 3.15-1.). These particles are finally removed from the spent ACT*DE*CON℠ by electromagnetic separation and are either regenerated or stabilized as final waste, allowing recycling of the spent ACT*DE*CON℠ solution.

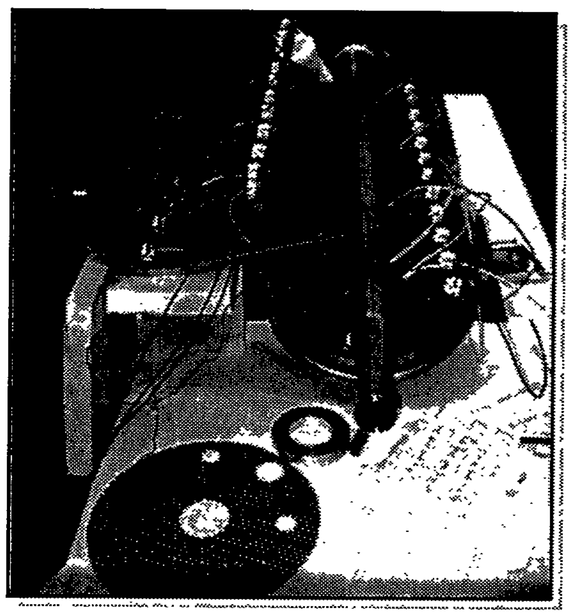

Figure 3.15-1. MAG*SEP℠ Process Equipment.

The application of the ACT*DE*CON℠ process has been demonstrated in a test cell with real, contaminated soil from the Mound Site, under idealized process conditions. To more accurately simulate field conditions, a larger pilot-scale testing system is proposed to occur in late FY96, pending successful project review. The objective of the next phase is to finalize the secondary waste (spent ACT*DE*CON℠) treatment and to design and construct a functional pilot-scale testing system that provides a reasonably accurate simulation of the processing conditions in the field. The pilot-scale unit will include all phases of the soil cleanup: 1) handling the excavated material, 2) slurrying the soil, 3) using counter-current extraction, 4) applying solid/liquid separation, and 5) waste handling/solution recycle. Upon successful operation of the pilot-scale system, a full-scale treatment system will be designed and fabricated by incorporating the lessons learned from the pilot-system operation.

BENEFITS

The major benefit of this technology is the reduction of radioactive/transuranic waste in the cleanup of contaminated soil and sediment.

COLLABORATION/TECHNOLOGY TRANSFER

The ACT*DE*CON℠ and MAG*SEP℠ technologies are proprietary to Selective Environmental Technologies, Inc. (Selentec). Their application to the Mound site is being developed under a joint project between Selentec and ANL.

ACCOMPLISHMENTS

Recent accomplishments include:

- Recent work has documented the process conditions (extraction sequence and kinetics) necessary to achieve the regulatory soil cleanup goal for the Mound Site. The test program was designed to optimize the application conditions to achieve Pu^{238} activities less than 75 pCi/g-natural moisture basis (nmb), with the ultimate objective of achieving less than 25 pCi/g-nmb, given starting activity in a contaminated soil sample of 300 to 600 pCi/g-nmb. Various application conditions were investigated under proven scale-up conditions to develop the parameters for pilot-scale application. Removal of plutonium has exceeded 97 percent under sequential extraction conditions. The treated soils were consistently treated to less than 63 pCi/g-nmb of the residual Pu^{238} activity, and 36 pCi/g-nmb was achieved in one case. These results indicate that the ACT*DE*CON℠ process is ready for demonstration at the pilot scale.

- Studies have been conducted to quantify the dissolution of such nonhazardous minerals as calcium, potassium, and iron from the soil during the treatment. The results indicate that such dissolution was contained at acceptable levels and would not impede remediation goals.
- Distribution coefficient (K_d) studies were also conducted on the ACT*DE*CON℠-treated soil/sediment to evaluate the effect of the treatment on the potential release of the residual plutonium in mobile forms to the environment (i.e., groundwater, plants). The results indicated that no increase in total relative mobility of the soil plutonium could be attributed to the treatment with ACT*DE*CON℠. In fact, this treatment appears to leave only the most insoluble forms of plutonium in the soil.
- The use of various filter aids and filtering equipment was investigated, along with the possible interactions between filter aids and plutonium dissolution chemistry. Results show that certain additives (both physical additives and chemical flocculating/coagulating agents) could decrease the time required to dewater the soil/sediment slurry by more than one order of magnitude.
- The MAG*SEP℠ filter was able to remove the magnetic particles from spent ACT*DE*CON℠ solution containing up to 5 percent solids.

TTP Information

Mound-Selentec Treatability Study activities are funded under the following TTP:

TTP No. CH26PL41, Task 2, "Mound-ACT*DE*CON℠ Treatability Study"

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3.16 RESOURCE RECOVERY PROJECT

TECHNOLOGY NEED

Heavy metal contaminated water is a nationwide and global problem. Heavy metals can pose a significant threat to human health and safety as well as to aquatic environments. DOE has identified heavy metals contamination at numerous facilities, and DOD has identified heavy metals contamination at over 900 installations. Thousands of abandoned mines contribute to ground and surface water contamination through release of acidic, metal-rich solutions. It is necessary to develop technologies to mitigate the environmental threat from these and other industrial sources. At the same time, it may be possible to recover heavy metals as useable products. Marketing these metals will improve the overall economics of environmental cleanup.

TECHNOLOGY DESCRIPTION

The Resource Recovery Project (RRP) demonstrates and evaluates pilot-scale technologies for the recovery of marketable metal products and clean water from heavy metals contaminated water. Economic analyses of each technology and the resources recovered are performed to provide estimates of resource recovery and/or remediation costs to be evaluated by DOE and industrial end users with similar remediation needs. Resource utilization addresses industrial, commercial, municipal/governmental, agricultural, and recreational uses of water, metals, and other resources.

Cost/benefit analyses are an integral part of the project and include potential revenues from sales of water and mineral resources. The cost and market data obtained can be employed by a variety of end users to evaluate which technologies are most effective at both recovering commercially marketable products and water.

Technologies demonstrated or currently planned for demonstration include:

TETRA Technologies Inc., High Density Solids. The TETRA technology uses a proprietary chemical precipitation approach with a recycling scheme in which the precipitated solids are recoated with fresh reagent to form new precipitation sites. The result is a much larger, denser particle resulting in slurries of 30 percent solids by weight. Typical slurries from a one-pass precipitation process contain 2 to 3 percent solids. Markets were identified for three of the four product streams with copper sulfate and zinc hydroxide being acceptable as feeds to metal smelters and iron-hydroxide-gypsum being acceptable as a micronutrient additive. Capital cost for the plant was estimated at $16.2 million, with an annual operating cost of $10.4 million. This compares favorably with the estimated costs for conventional treatment given in the Remedial Investigation/Feasibility Study for the Berkeley Pit (see Figure 3.16-1). That study estimates capital costs of $19.5 million and an annual operating cost of $12.1 million. The effluent water from the process met EPA's discharge standards. This demonstration is complete.

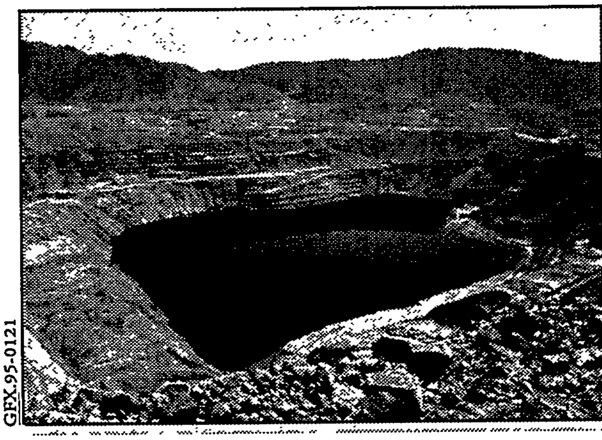

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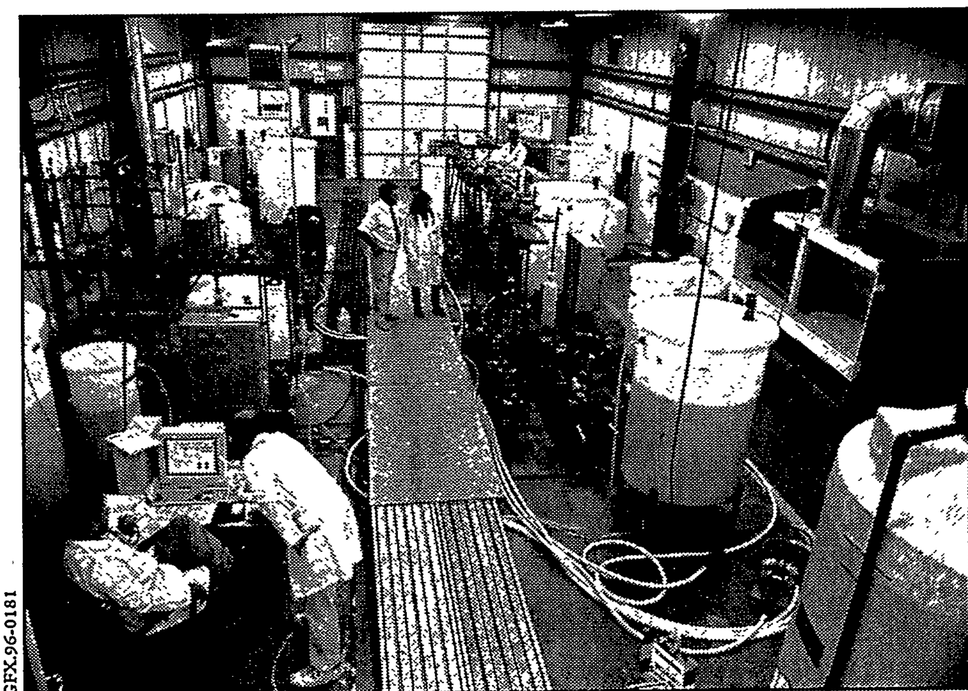
Figure 3.16-1. The Berkeley Pit Test Bed for the Resource Recovery Project.

<u>IBC Advanced Technologies Inc., Molecular Recognition Technology.</u> The Molecular Recognition Technology uses SuperLig® materials, which are synthesized organic macrocylic molecules bonded to solid substrates (see Figure 3.16-2). These materials, which have been developed for many metals and radionuclides, are capable of removing specific ions in complex solutions.

Previous to this demonstration, the SuperLig® materials had been used primarily in precious metal recovery and trace contaminant removal or recovery. In the demonstration, five separate units were used to sequentially



GFX.96-0181

Figure 3.16-2. Demonstration of Molecular Recognition Technology System (Courtesy of IBC Advanced Technologies, Inc.).

remove copper, iron, aluminum, zinc, and manganese as metal sulfates. A sixth unit was used to polish the water to meet regulatory standards. The materials showed good selectivity for the chosen metals. The metal sulfates produced will require additional processing to improve their marketability. The field portion of this demonstration is complete.

E-Rem, Inc., Clathrate Concentration. This technology preconcentrates the metals in water using clathrate concentration. Clathrate concentration is a chemical desalination process in which the water is mixed with small polyatomic gas molecules under strictly controlled temperature and pressure conditions to form clathrates. Clathrates are pseudo-solids consisting of the gas held prisoner in a cage-like structure of water molecules, with any solids dissolved in the water concentrated in a brine. The initial demonstration will determine the capability of the enclathration process to concentrate the metals, thereby producing clean water. If successful, the second phase will determine the scale and extent of a pilot demonstration. This demonstration is still in progress.

Chomatochem, Inc., Solid Phase Extraction. This technology uses conventional chelators bound to a solid substrate using long "linker" molecules. This binding method provides for enhanced kinetics, resulting in higher throughput and reduced equipment costs. Metal separations are achieved by a chromatographic effect in which the more weakly bound ions are displaced by more strongly bound ions, resulting in the selective and sequential removal of aluminum, copper, zinc and manganese. The demonstration is still in progress.

Selective Environmental Technologies Inc., MAG*SEP^{SM} Process and Donnan Dialysis. Selective Environmental Technologies, Inc., is performing bench studies of the applicability of the MAG*SEP^{SM} and Donnan dialysis technologies as pretreatment and primary technologies for removing iron and other metals from water. MAG*SEP^{SM} utilizes ion exchange resin attached to magnetic particles to capture specific ions. The magnetic qualities of the particle allow them to be removed from a flowing stream by conventional magnetic separation at low pressure. The Donnan permeable membranes can selectively separate ions based on valence. In this case, it is the ability to separate ferric iron from other metals that is being evaluated.

Global Technologies Inc., GASER Filter. Global Technologies is demonstrating the GASER filter, a technology licensed to them from the Moscow Engineering Physics Institute. The filter is a globular structure resin material, which acts like an ion exchange medium. The filter is being tested as a polishing process for Berkeley Pit water.

Albany Research Center, Liquid Emulsion Membranes. Albany Research Center has developed a technique that uses Liquid Emulsion Membranes to selectively extract and recover metals from waste waters and various difficult-to-process industrial solutions. Albany Research Center has previously conducted successful demonstrations at several mine sites where copper, zinc, and uranium have been recovered. The planned demonstration will determine the technology's effectiveness in recovering copper, zinc, and manganese from Berkeley Pit water. A preliminary cost evaluation based on the proposed flow sheet indicates a cost-effective approach for the treatment of Berkeley Pit water. This demonstration will be completed in FY96.

BENEFITS

The data gathered during the demonstration and evaluation of technologies will allow for timely and cost-effective selection of appropriate reclamation technologies. In addition, those technologies demonstrated through the RRP can be transferred to the mining industry, where acid mine drainage is a multibillion dollar problem as well as an environmental menace.

COLLABORATION/TECHNOLOGY TRANSFER

The RRP is an active national partner with many public and private sector interests. These include DOE, the State of Montana, Region 8 of the EPA, Western Governors Association, the Department of the Interior, and various universities. Private sector participants include mining and processing companies, Superfund potentially responsible parties, environmental public interest groups, and other technology stakeholders.

The first *Resources Through Technology* conference was attended by over one hundred firms representing government, universities, and private industry.

ACCOMPLISHMENTS

This project's major accomplishments include:

- Demonstration, evaluation, and report of the TETRA Technology, Inc.'s chemical precipitation process
- Demonstration of IBC Advanced Technology's molecular recognition technology
- Initiated the CCI, E-Rem, Global, Selentec and Albany Research Center demonstrations

TTP INFORMATION

Resource Recovery Project activities are funded under the following TTP:

TTP No. PE16PL41, Task 3, "Resource Recovery Project"

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4.0 SUBSURFACE ACCESS PRODUCT LINE

The Subsurface Contaminants Focus Area is developing drilling and access technologies to reduce the cost of characterization and to facilitate the installation of remediation systems. Many contaminated sites in the U.S. Department of Energy (DOE) complex are located in geologic environments where collecting subsurface samples and/or drilling boreholes are problematic. For example, drilling and sampling through boulders in glacial deposits at Hanford, or volcanic rocks interlayered with sediments at Idaho National Engineering Laboratory (INEL) and Lawrence Berkeley National Laboratory (LBNL), are costly and often yield poor sample recovery. The two drilling technologies in the Subsurface Access Product Line show much promise for improved subsurface access capabilities at a lower cost.

Better subsurface access methods are needed to install, monitor, and evaluate the performance of subsurface barriers. In future years, however, these activities will be managed under the dense non-aqueous phase liquids (DNAPLs) and Metals and Radionuclides Product Lines or other deployment sectors.

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4.1 ResonantSonic℠ Drilling

Technology Need

Reliable, cost-effective means for accessing underground regions within and adjacent to contaminated sites are required for most environmental characterization, monitoring, and remediation efforts. Such access is crucial for characterization technologies, for installation of vapor and groundwater extraction wells, and for barrier installation. Improved drilling technologies are needed to reduce cost, to minimize waste from drilling, and to maintain containment of drill cuttings and effluents.

ResonantSonic℠ drilling has proven to be a cost-effective and minimal waste-generating drilling technology. However, improvements are needed to minimize drill pipe failures caused by the intense mechanical loads associated with this drilling method. Improvements in instrumentation and operational feedback are expected to reduce drill pipe failures while improving maintenance and operational efficiencies.

Technology Description

The ResonantSonic℠ drilling system uses a combination of mechanically generated vibrations and rotary power to efficiently penetrate the soil. The oscillator or drill head operates at frequencies close to the natural frequency of the steel drill column (up to 150 cycles per second) and consists of two counter-rotating rollers that generate sinusoidal wave forces. (See Figures 4.1-1 and 4.1-2.) The vibration of the drill pipe, coupled with the weight of the drill pipe, and the downward thrust of the drill head, commonly result in rapid penetration. The ResonantSonic℠ method uses no circulation media, and thus produces very little secondary waste.

Dynamic simulation of the sonic drill system and its interaction with the formation is being conducted to predict the dynamic loads along the drill string and the fatigue life of various threaded drill pipe joint designs. In addition, discrete measurements of sonic drilling parameters are being collected to provide insight into the performance of sonic drilling under various conditions (e.g., formation type, depth, etc.). Operational and early warning instrumentation concepts are being evaluated under actual field conditions to provide real time feedback to the rig operators. The ability to predict failures in the sonic system or drill string promises to reduce downtime and provide additional savings for environmental drilling throughout the DOE complex.

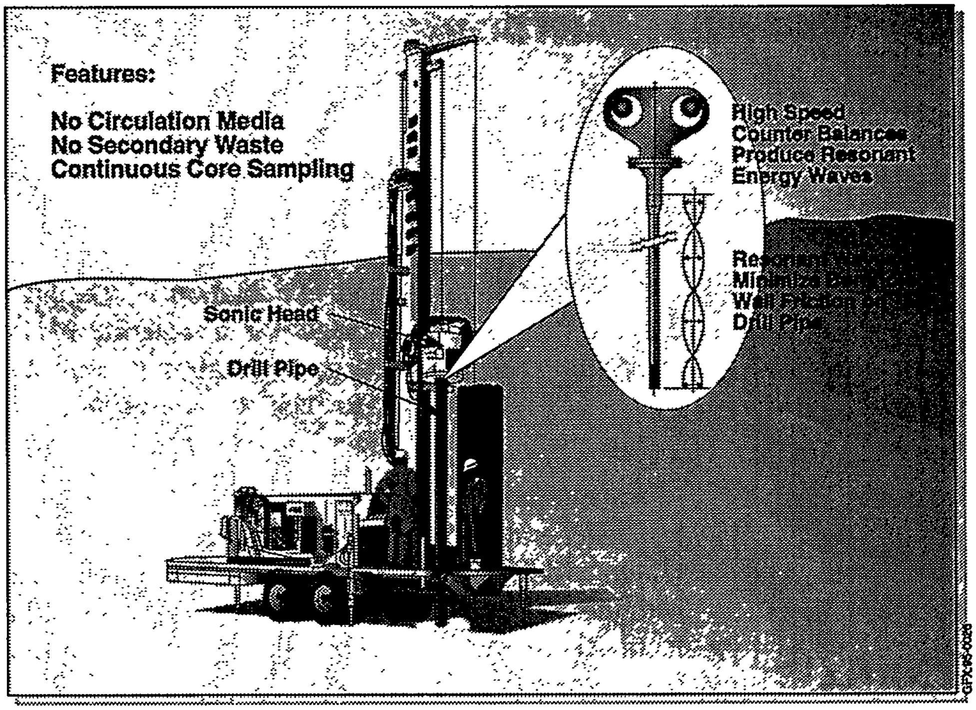

Figure 4.1-1. ResonantSonic℠ Operational Concept.

BENEFITS

The key advantages of the ResonantSonic℠ drilling method over the baseline drilling technology (e.g., cable-tool drilling), include:

- Increased drilling rate
- Containment of drill cuttings
- Minimization of secondary drilling waste
- High sample quality in formations where the baseline method cannot retrieve high quality samples (e.g., caliche, boulders, and cobbles)
- Increased safety due to less exposure to investigation-derived waste contaminants
- The ability of ResonantSonic℠ drill rigs to drill at any angle from 15 degrees off horizontal to vertical

COLLABORATION/TECHNOLOGY TRANSFER

The current research program is focused on enhancing the reliability and performance of the ResonantSonic℠ drilling method. The effort is being performed under a Cooperative Research and Development Agreement

(CRADA) involving Pacific Northwest National Laboratory (PNNL), Westinghouse Hanford Company (WHC), and industry partner Water Development Hanford (WDH). The ResonantSonic℠ enhanced drilling technology is being commercialized by Wstinghouse. WDH recently won a multi-year contract with BHI for installing vadose zone and ground-water monitoring wells in support of the Hanford Environmental Restoration (ER) program. The ResonantSonic℠ drilling technology is also being applied at Sandia National Laboratories-Albuquerque, Rocky Flats, and Savannah River Site (SRS).

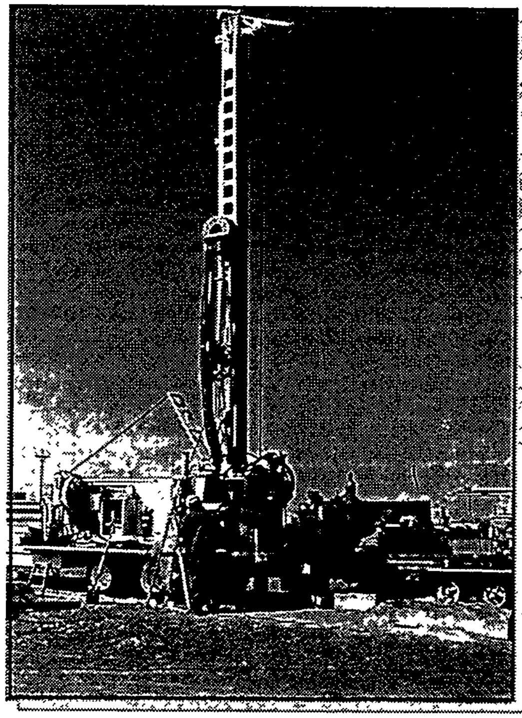

Figure 4.1-2. ResonantSonic℠ Drilling.

ACCOMPLISHMENTS

The project's recent accomplishments include:

- Installed 14 characterization/test boreholes and four groundwater wells as part of the Fiscal Year 1995 (FY95) CRADA activities
- Installed 11 groundwater wells in FY95 in support of the Hanford ER program, resulting in a documented cost savings of 25 percent and a reduction in well installation time of 50 percent
- Developed and demonstrated equipment and techniques to maintain acceptable core sample temperatures during volatile organic carbon sampling
- Demonstrated angle drilling capability and efficiency at a mixed waste site
- Tested a redesigned sonic drill head which reduced downtime to less than 10 percent
- Conducted instrument testing of a sonic drill rig to provide feedback to operators and to provide parametric data for dynamic simulations
- Developed and demonstrated a dynamic simulation model (finite element) of the sonic drilling system to predict drill string loads
- Modeled and predicted the failure loads for several threaded drill pipe joint designs

TTP Information

ResonantSonic[SM] Drilling activities are funded under the following TTP:

TTP No. RL36PL51, "ResonantSonic[SM] Drilling CRADA"

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4.2 STABILIZATION OF BOREHOLES BY FREEZING

TECHNOLOGY NEED

For sampling and remediation activity in loose or unconsolidated soils, there is a need for a method of drilling boreholes that does not allow pollutants to migrate along the borehole, that does not introduce new pollutants, and that does not alter the properties of the surrounding formations.

TECHNOLOGY DESCRIPTION

This project is developing an innovative method of borehole drilling which employs conventional air drilling equipment that has been modified so that the flushing fluid is super-cold nitrogen (see Figure 4.2-1). The cold gas flow freezes the moisture in the soil surrounding the hole and prevents collapse. Freezing has the advantage of preventing water or contaminants from entering the borehole and reaching the surface or other non-contaminated strata. The method may also allow a more accurate means of sampling subsurface solids and fluids.

Application of the cryo-drilling method requires a special drill string and swivel. These components must be made from stainless steel or other alloy(s) that do not become brittle at low temperatures and must be fitted to the rig. The current experience is that these operations are neither expensive nor technically difficult. This method also requires that liquid nitrogen be provided during the drilling operations, together with the necessary transport and handling equipment. Contrary to popular belief, liquid nitrogen is no longer an "exotic" material; it is commercially available in tonnage quantities, and can be delivered to most sites by road tanker. The liquid costs between 5 and 10 cents per liter, and the project estimates that the nitrogen costs for drilling typical

Figure 4.2-1. Cryo-Drilling with Super-Cold Nitrogen at Lawrence Berkeley National Laboratory.

wells will be a few hundred dollars at most. The additional costs of these two special items are offset by the reduced time that is required to drill the well, principally because of the reduction in "trouble time" associated with borehole collapse. Moreover, in the case of the wells that were cryo-drilled at LBNL, it was impossible to drill one of the holes by conventional means. In addition, there are time savings resulting from not having to install or remove a casing to stabilize the borehole and from being able to drill a smaller diameter borehole due to the lack of a casing. In the long run, this technology will reduce the total effective project cost.

BENEFITS

The benefits of this approach are:

- Development of the cryogenic method will enable the drilling of boreholes in areas and in ground that have not previously been accessible, or for which the difficulties in accessing the subsurface have made operations extremely expensive.
- There are numerous examples of drilling operations at LBNL, Hanford, SRS and INEL where drilling has been either very difficult or impossible. The cryo-drilling process offers the possibility of extending the range of ground and soil types that may be drilled, investigated, and treated.
- For boreholes requiring a casing, cryo-drilling offers a cost savings from not having to case the borehole while drilling and from reduced investigation-derived waste.

COLLABORATION/TECHNOLOGY TRANSFER

Wells drilled so far have been in conjunction with Westex, a drilling contractor local to LBNL, and UCISCO (Union Carbide). Various other companies have expressed interest in trying the cryo-drilling technology. Accomplishing technology transfer will not be difficult because the method is compatible with current drilling equipment and practices.

ACCOMPLISHMENTS

The major progress made during the past year was the successful drilling of two boreholes at LBNL:

- One hole was a 7-7/8-inch monitoring well, drilled in a formation that consisted of heavily fractured, water flooded, hard volcanic material underlain by sands and clays. This well was successfully drilled to the target depth of 25 feet, although some difficulties were experienced in dealing with the influx of water from the fractured volcanics.

- Another hole was a soil sampling hole measuing 52 feet deep by 4 inches in diameter, drilled in an area of mixed geology. The upper section consisted of approximately 12 feet of clay with boulders, underlain by a series of sands and sandy clays. The water table was at approximately 10 feet. Conventional auger equipment had failed in three previous attempts at 6, 8, and 9 feet, because the auger was unable to penetrate the boulders. The hole was drilled successfully to 52 feet (the limit of the drill pipe), and good quality samples were recovered every five feet from the dry, frozen hole. After drilling, the hole was allowed to warm up over a weekend. On subsequent examination, the hole was found to have flooded to 10 feet from the surface, and to have collapsed below 20 feet. These observations illustrate the advantages of cryo-drilling over conventional methods, particularly in terms of maintaining hole stability and preventing flooding of the hole during drilling.

TTP Information

Stabilization of Boreholes by Freezing activities are funded under the following TTP:

TTP No. SF16PL51, "Stabilization of Boreholes by Freezing"

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5.0 TRANSURANIC/MIXED WASTE IN ARID ENVIRONMENTS PRODUCT LINE

The Transuranic (TRU)/Mixed Waste in Arid Environments is one of the Product Lines within the U.S. Department of Energy (DOE) Subsurface Contaminants Focus Area. The mission of this Product Line is to demonstrate and facilitate deployment of emerging technology systems that offer solutions to problems associated with remediation and characterization of TRU-contaminated landfills in arid environments. The scope of the projects within these programs include engineering development, demonstration, and implementation support of technology systems that will enhance the capabilities of site characterization, removal, and in situ stabilization remedial alternatives.

These waste disposal sites must be remediated, or cleaned up, within the existing and evolving statutory and regulatory requirements. These requirements include the federal Facility Agreement and Consent Order, as well as other interagency agreements with legally binding milestones. Technology systems selected for development and demonstration are based on their potential contribution to enhance existing remediation systems, including site characterization, retrieval, and in situ stabilization.

Site Characterization

Site characterization technologies provide physical, chemical, and radiological information; interpretation of near-surface waste and other objects; and associated containment features. The buried waste remediation community needs nonintrusive technology to characterize the size, shape, depth, physical orientation, and constituent makeup of subsurface waste objects. This information will support the planning and execution of future remedial actions.

Retrieval

Retrieval technologies provide methods of retrieving buried TRU waste, for both hot spot applications and full-pit trench removal. The risk of human health and environment from the radioactive and other hazardous constituents of the buried waste must be mitigated by these technologies. Using remote operation, operators need to efficiently excavate and retrieve overburdened and buried waste matrix with little or no human exposure. Similarly, they must be able to maintain and service the equipment so that it does not become part of the problem. During retrieval, equipment may encounter corrosive, explosive, and radioactive materials, and must avoid spread of contamination within the working enclosure. New retrieval technologies are needed to accomplish this activity.

In Situ Stabilization

In situ stabilization technologies provide in situ disposal techniques to prevent migration of contaminants from buried waste and prevent subsidence of the waste. Application of these technologies involves creating multiple barriers and applying physical stabilization. Solutions for both of these functions must be stable over geological time periods.

The waste management community needs practical commercial technologies to mitigate contaminant migration and provide physical stabilization of buried waste. Assessing performance in the near term, by verifying integrity directly, and in the long term, through monitoring of the surrounding environment, must be part of these technologies.

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5.1 VERY EARLY-TIME ELECTROMAGNETIC SYSTEM

TECHNOLOGY NEED

This technology can characterize buried waste at the Idaho National Engineering Laboratory (INEL) Radioactive Waste Management Complex and other DOE sites. In addition, it can contribute to identifying plumes and buried objects by shape, orientation, and location, and can be used for long-term monitoring and verification of stabilization/remediation processes.

TECHNOLOGY DESCRIPTION

The goal of the Very Early-Time Electromagnetic (VETEM) project is to develop a versatile system, both of hardware and of modeling and interpretational software, to obtain high-resolution images of the shallow subsurface. The VETEM system, as shown in Figure 5.1-1, is designed to utilize a frequency band spanning classic inductive electromagnetic and ground-penetrating radar frequencies. The advantages of operating in this range are twofold. First, it provides higher resolution of the shallow subsurface than traditional inductive electromagnetic techniques, without the severe depth of exploration limitations often encountered with ground-penetrating radar systems. Second, systems operating in this frequency range are sensitive to both electrical conductivity and dielectric permittivity. The full waveform software is designed to be used with both the VETEM hardware and commercial systems to provide DOE with a practical and versatile electromagnetic system for shallow subsurface imaging. To accomplish this goal, the VETEM team includes expertise from the national laboratories, the U.S. Geological Survey, universities, and industry.

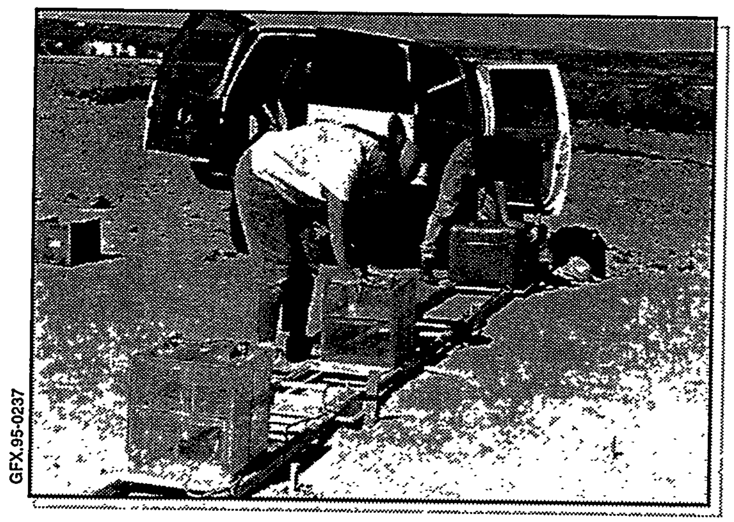

Figure 5.1-1. Very Early-Time Electromagnetic System Prototype.

Numerical models are used to determine instrument-design criteria, test processing, and interpretation algorithms. The full waveform modeling, interpretation, and imaging algorithms account for both diffusion and transmission effects. To integrate the VETEM instrument and interpretational software with commercial systems and encourage industrial participation, we sponsored the Electromagnetic Integrated Demonstration. Instruments recently developed in the commercial sector, and at other research institutions, are acquiring data at the INEL Cold Test Pit in Fiscal Year 1996 (FY96).

The data acquired in the Electromagnetic Integrated Demonstration will be integrated and interpreted with the algorithms developed as a part of the VETEM project. FY95 research focused on completing the three-dimensional modeling code and field testing of the instrumentation. The demonstration of commercially available systems will be complete in FY96.

BENEFITS

The VETEM system is designed for high resolution electromagnetic imaging of shallow environmental problems (less than 10 meters), such as buried waste, where traditional electromagnetic equipment and interpretation techniques do not produce satisfactory results. The system can operate effectively at sites where the physical properties of the soils make high-resolution ground-penetrating radar imaging problematic.

The Electromagnetic Integrated Demonstration displayed the rapid collection rate of the VETEM system and the utility of the VETEM software with other data collection systems. Accurate geophysical surveys can significantly reduce the cost of intrusive characterization methods. Cost savings can be estimated based on sampling and analysis costs of $300 per sample. If the use of nonintrusive characterization systems can reduce the intrusive sampling and analysis load by 75 percent of the samples, a typical sampling plan requiring 1,000 samples can be limited to 250, at a cost savings of $225 thousand per site, and result in reduced exposure risks to workers.

COLLABORATION/TECHNOLOGY TRANSFER

Many outside universities, companies, and national laboratories are collaborating in developing the VETEM technology. The participants include researchers at the University of California-Berkeley, the University of Arizona, the University of Utah, RUST Geotech, Inc., and Sandia National Laboratories (SNL). To include industry in all phases of the project and encourage commercialization, the project has an external review committee composed of presidents of leading geophysical companies and outstanding academics.

Annual workshops are also held to encourage transfer of the extensive modeling and interpretational software. Currently, the VETEM participants are in communication with several companies about commercialization.

ACCOMPLISHMENTS

- Developed and tested one-dimensional and three-dimensional numerical-modeling algorithms
- Conducted numerical experiments to increase understanding of the physics underlying the buried waste characterization problem, to optimize instrument design, improve survey design of the Electromagnetic Integrated Demonstration, and develop interpretational algorithms
- Created a graphical-user interface for the modeling algorithms
- Fabricated and field tested a prototype, time-domain, electromagnetic instrument during the Electromagnetic Integrated Demonstration at the Cold Test Pit

TTP INFORMATION

Very Early-Time Electromagnetic System technology development activities are funded under the following technical task plan (TTP):

TTP No. ID76LF21, "Site Characterization, Demonstration, and Evaluation"

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5.2 BURIED-WASTE DIGFACE CHARACTERIZATION

TECHNOLOGY NEED

There is an urgent need to develop technology that can characterize contaminated sites without excavation or sampling. The technology must be cost effective and result in the elimination, or minimization, of worker exposure and costly soil sampling. Excavation, sampling, and analysis of buried waste and contaminated soil are generally used for the purpose of characterizing hazardous waste sites. These methods are expensive, result in large amounts of excavated soils that are unnecessarily assumed to be contaminated, and pose safety hazards to remediation workers. The digface-characterization technology uses geophysical, chemical, and radiological sensors, is expected to meet the above needs.

TECHNOLOGY DESCRIPTION

The digface-characterization project demonstrates multiple sensors that can be used as part of a retrieval effort. The digface-characterization technology will allow continuous and continually improving monitoring and characterization of the site being remediated. The digface-characterization technique is integrated into the remediation process itself. As retrieval progresses, the capability to interpret sensor data improves through comparisons of interpreted data images with the retrieved targets.

Geophysical, chemical, and radiological sensors are deployed on a remotely controlled and monitored platform system. The sensors scan over the surface being remediated. As waste retrieval proceeds, the sensors are continuously deployed to characterize the remaining waste. Remediation proceeds in a methodical manner in which the characterization data are interpreted in real-time to support the retrieval process.

The primary objective is to develop and demonstrate a field-ready mobile platform that contains geophysical, chemical, and radiological sensors to provide constant surveillance and screening for all categories of hazards at the digface during excavation.

The digface system will be used later in 1996 to assist in the excavation of contaminated soils at the SNL Tech Area II Radioactive and Classified landfills. This demonstration of the digface technology will show its adaptability to various excavation strategies and its flexibility during a complicated, multi-phased remediation, such as the one planned at SNL.

Benefits

The digface system reduces environmental, health, and safety risks during cleanup of buried waste sites. Real-time data interpretation during the retrieval process allows for the incorporation of appropriate remediation equipment to maintain safety and environmental standards.

The digface system employs automatic and remote-deployment capability, with refined data interpretation techniques to support rapid, on-site target identifications for near real-time field decisions regarding excavation progress.

The digface system will allow cost savings by eliminating the need for unnecessary sampling and analysis of soils, and avoiding the generation of large amounts of clean, excavated soil that, under current procedures, must be assumed to be contaminated based on existing sampling protocol.

The digface technology, as developed under this project, will support the Western Governors' Association efforts to utilize DOE waste cleanup technologies in actual waste remediation.

Collaboration/Technology Transfer

The successful completion of demonstrations of the digface-characterization system at Mound Laboratory and SNL will result in a proven concept that is ready for technology transfer.

A successful deployment of this system at the SNL Tech Area II would show wide applicability, and that cleanup work can proceed in the presence of uncertain conditions, as well as a variety of waste sites containing various sets of conditions. Aguirre Engineering, Inc., the commercial remediation contractor for the SNL landfill work, will be using the digface system as part of their "tool kit" during the excavation and will be in a position to commercialize the technology, should it be successful at SNL.

The SNL Tech Area II remediation effort will have the attention of regulators, as was the case at Mound Laboratory, and will assist in the difficult process of regulatory acceptance of the technology for use in decision making during a remediation.

Disclosure of this research through professional journals and presentations at technical conferences will ensure transfer of this technology to a wider network of private-sector contractors that may be able to provide portions of the system, are performing waste-site remediation, or have other remote-retrieval characterization needs.

Accomplishments

- Demonstrated a track-mounted, trolley-platform, digface system at the EG&G Mound Laboratory in Ohio, in August 1995. The digface-characterization system was used to monitor a 20-feet-by-20-feet-by-5-feet excavation of a radiologically contaminated site at Mound, as shown in Figure 5.2-1. The spatial information produced by the digface system was used to direct the excavation activities into the area containing the contaminates, thereby saving the time and cost of excavating unnecessary soil. It was also used to develop options for handling the remaining excavation after the digface system was removed.

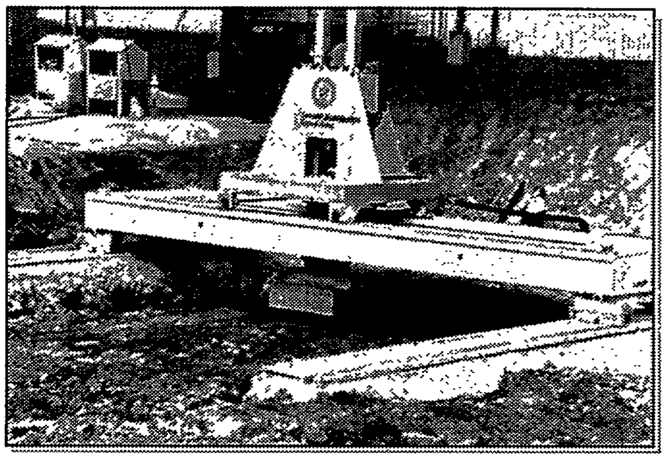

Figure 5.2-1. Digface Characterization System.

TTP Information

Buried-Waste Digface Characterization technology development activities are funded under the following TTP:

TTP No. ID76LF21, "Site Characterization, Demonstration, and Evaluation"

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5.3 IN SITU ENCAPSULATION OF BURIED WASTE

TECHNOLOGY NEED

Stabilization of 2 million cubic feet of buried TRU waste mixed with up to 8 million cubic feet of soil at INEL, and similar or greater quantities of low-level, TRU, and mixed waste buried at other DOE sites, might be necessary to prevent potential health and environmental hazards.

TECHNOLOGY DESCRIPTION

In situ encapsulation involves the injection of various grouting agents into soil/waste matrices that result in a soil/waste/grout monolith that has a natural analog of a long-lived material. Current grouting materials under evaluation include phosphoric solutions, iron-oxide solutions, long and short-chain organic polymers, and inorganic grouting materials. The grouting material cements the waste in place, thus encapsulating the waste in a cemented block that is impervious to water migration. The technique can also be used as an intermediate stage to solidify waste to prevent future aerosolization of contaminants, should retrieval be necessary.

Part of the concept is an analog of the natural processes that produce classic sedimentary rocks. The other part is to use organic polymers that also have natural analogs of long-lived materials such as the La Brea Tar Pits and natural amber. Loose, unconsolidated soil or sediment is converted into a hard, durable, impermeable rock by precipitation of minerals (cement) from groundwater between the particles of unconsolidated materials. The most common natural cements are calcite, hematite, opal, and apatite. The existence of such rocks in the natural environment for long periods of time requires that they be in chemical equilibrium with their surroundings. The success of using artificial analogs of natural cementing processes to encapsulate and isolate waste materials hinges on the ability of the aqueous cementing solutions to penetrate and permeate INEL soils.

The primary objective is to demonstrate encapsulation techniques using precipitating solutions and polymers injected into buried waste, resulting in a cemented block that is impervious to water migration. During FY96 a series of grouting experiments in implementation pits and positive mass balance culverts are planned to obtain field hydraulic conductivity data. The grouting agents include phosphoric and iron-oxide solutions, and inorganic and organic grouting materials.

BENEFITS

In situ remediation or stabilization technologies have the potential to significantly reduce worker exposure. In situ grout technology that is capable of isolating waste material from the natural environment has several unique features. The technology can stabilize a variety of DOE and Superfund sites; is compatible with complex mixtures of various contaminants; isolates and encapsulates buried materials containing radioactive and other hazardous waste, and TRU-element waste; is applicable to various waste forms and surrounding materials, and isolation of buried structures such as waste storage tanks; and has a natural analog, both in formation and longevity, in limestone, phosphoric ores, iron-oxide beds, and the La Brea Tar Pits.

The cost of retrieval, treatment, and disposal for the INEL Subsurface Disposal Area has been estimated between $2 and $10 billion. The cost of applying in situ encapsulation at the subsurface disposal area is in the $0.5 billion range.

COLLABORATION/TECHNOLOGY TRANSFER

The technology participants from INEL, Argonne National Laboratory (ANL), Brookhaven National Laboratory, and a private vendor (Applied Geotechnical Engineering and Construction) will aid in technology transfer. Additional industrial and university participants will be involved in the program as requirements and needs become better defined. The data obtained from each of the activities will allow technical evaluation for remediation by private, DOE, Environmental Restoration, and Waste Management concerns.

ACCOMPLISHMENTS

- Conducted demonstration involving jet-grouting portland cement mixed 1:1 with water, into a buried-waste site (during FY94). This demonstration showed a positive proof of concept that grouting materials can be emplaced into buried waste sites.
- Completed demonstration injecting a two-component organic polymer, called 3M-5750 and 5751, into a simulated buried-waste pit (during FY95). The injection system used a Casa Grande drilling and jet-grouting apparatus and a dual concentric-annulus drill stem. During that demonstration a positive proof of concept was shown in that the grout was injected, and a monolith was formed. A 90 percent reduction in dust spread was also achieved.

TTP INFORMATION

In Situ Encapsulation of Buried Waste technology development activities are funded under the following TTP:

TTP No. ID76LF23, "In Situ Stabilization of TRU/Mixed Waste"

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5.4 INNOVATIVE SUBSURFACE STABILIZATION

TECHNOLOGY NEED

Environmental Restoration and Waste Management have expressed interest in examining technologies required for the safe removal of contamination point sources (or hot spots) from within a waste-storage site. There are 2 million cubic feet of TRU waste commingled with up to 8 million cubic feet of soil in shallow land burial at INEL. Other sites, such as Hanford, also have this type of buried waste.

Using the grouting technique (see Section 5.3) to create a monolith, and then retrieving the waste, provides an inherent contamination control advantage because the contaminants are locked up in the solidified blocks.

Prior to conventional hot spot excavation, grout walls can be created around the perimeter of the hot spot. The walls will serve as shoring to protect against cave-ins during removal which would result in cross contamination of potentially clean-surface soils; less contaminated, subsurface waste materials; and associated soils. The shoring will also provide stability at the surface to aid support of the required excavation equipment.

TECHNOLOGY DESCRIPTION

The primary objective is to demonstrate an innovative grouting concept for buried waste retrieval involving a three-step process in a field environment. This process is illustrated in Figure 5.4-1. The first step is to grout the waste, causing an agglomeration of fine soil particles that may have become contaminated. Next, the monolithic-grouted block is fractured using a demolition grout. Finally, the debris is excavated in a relatively dust-free environment with remotely controlled equipment.

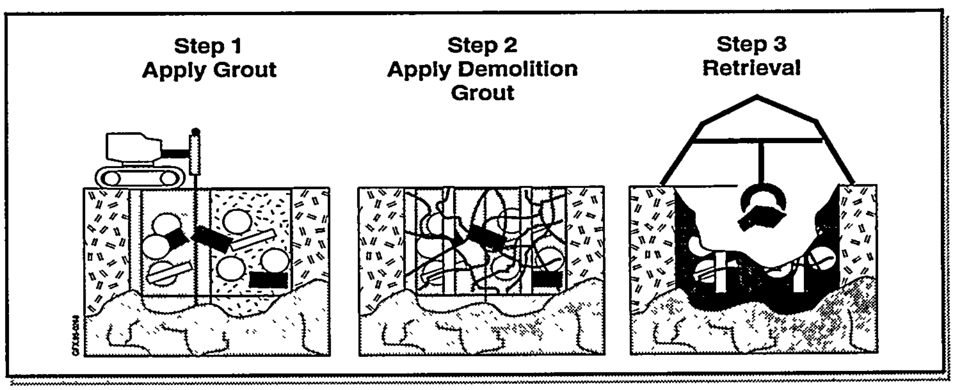

Figure 5.4-1. Grout Retrieval Process.

A secondary objective is to use the jet-grouting procedure to create a grout wall around a hot spot in the waste. The material within the wall can then be excavated without the surrounding waste sloughing into the pit, and thus, increasing excavated waste. The soil/waste matrix is grouted with a Casa Grande drill apparatus with special fittings at the surface for contamination control. The grout material is jet-grouted with up to 6,000-psi pressure into the soil/waste matrix. The fine, silty clay interstitial soils will be intimately mixed with the grout. The grout will readily fill voids in the waste matrix. The exact grout formulation and compatibility with INEL soils was determined through FY94 and FY95 field experiments.

During FY96, a 20-feet-by-20-feet-by-8-feet Cold Test Pit will be constructed at the INEL Cold Test Pit area for a FY97 full-scale cold demonstration, leading to a hot demonstration in FY98.

Benefits

This innovative technology accomplishes buried TRU-waste retrieval with less contamination spread. This grouting technique allows the waste to be confined prior to retrieval and treatment, contains the spread of contaminated soils by agglomeration of fine soil particles in the grout, and eliminates the need for elaborate contamination control strategies during retrieval and handling.

The innovative technology supports hot spot retrieval by providing support to the digface, providing an effective and inexpensive means of placing shoring material, and enabling walls to be left in place to hinder migration of certain waste products back into the vicinity of the dig.

Successful development of this system would enable remediation site contractors to reduce contamination control costs without jeopardizing worker safety during retrieval activities. The cost estimate of applying this technology for the retrieval of a one-acre pit is $15 million for retrieval and another $15 million for repackaging and assay. This compares to the estimated cost of $200 million for conventional retrieval (INEL Pit 9 estimate).

Collaboration/Technology Transfer

The concept can be transferred to the INEL Environmental Restoration Program for use by the private sector for remediation of TRU pits and trenches. The private sector could also use this technique on buried-waste sites where contaminant spread is a problem.

Accomplishments

- Conducted proof-of-concept demonstrations and evaluations of jet-grouting as a form of contamination control through agglomeration and encapsulation of waste (during FY94).
- Conducted demonstrations using an acrylic polymer from 3M, called 5751 (in FY95). During this demonstration, the 3M polymer was jet-grouted into a simulated waste pit, and the pit was then retrieved while taking air-monitoring data. A 90 percent reduction in dust spread was achieved using the acrylic polymer to cement the waste in place.

TTP Information

Innovative Subsurface Stabilization technology development activities are funded under the following TTP:

TTP No. ID76LF23, "In Situ Stabilization of TRU/Mixed Waste"

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5.5 Buried Transuranic-Tank-Waste Remediation and Removal System

Technology Need

The contents of many buried mixed-waste tanks are sufficiently radioactive to require remote handling and processing. The range of physical states of these tanks includes liquid, thick sludge, solid particulates, and combinations of these. The issues associated with handling these materials are greatly complicated by the requirement for remote handling and the lack of approved facilities to receive these wastes if they are removed. Doing nothing is not acceptable since the tanks in their current configuration pose a risk of being a source of contamination. Many of these tanks are placed quite deep (greater than 10 feet), which minimizes the risk they pose for an intrusion scenario, but does not minimize their potential for subsurface contamination in their present form. Altering the physical and/or chemical properties of the contents of the tanks is a viable approach to reducing the potential risk posed by the contents, with significantly lower cost and risk to workers than ex situ processing, and subsequent waste storage or disposal.

The stabilization of buried mixed-waste tanks presents several challenges:

- Adaptation of stabilization materials and placement techniques to tank geometry and contents
- Mixtures of organics, inorganics, and radionuclides
- Multiple phases and physical properties of tank contents
- Efficient and effective handling of partially full and damaged tanks

The stabilization system is expected to be most useful for areas that are difficult to reach because of surrounding facilities, tanks that contain wastes that are physically difficult to remove, and tanks that contain wastes which pose a significant health threat during removal. The objective is to reduce the risk posed by the contents of a tank so that it can either remain in its current location or be safely removed.

Technology Description

Development of integrated stabilization systems for tanks requires improvement and integration of several technical areas:

- Characterization
- Pretreatment

- Stabilization
- Decontamination
- Verification and monitoring technologies

The general approach for developing this system is to adapt existing commercial technologies, when possible, and develop innovative techniques when no commercial technique is available.

Characterization of the tank and tank contents is the first step in stabilizing a tank. The characterization of the tank includes evaluation of the structural integrity and internal structures of the tank, identification of the nature and status of tank connections, and verification of the volume of tank contents. Most of the basic technology required is available commercially and can be adapted for use in tanks and contaminated areas. The characterization of the tank contents includes quantification of the physical, chemical, and radiological properties of the tank contents. Improvements in the ability to analyze waste in situ are needed since many tanks are difficult to access, contain relatively higher radionuclide concentrations, and have more than one phase requiring sampling. In situ sampling will also minimize the cost and potential for personnel exposure.

In situ pretreatment of tank wastes can improve the ability of stabilization materials to reduce the mobility of contaminants in the waste. Many stabilization materials that are effective at immobilizing many metals and radionuclides sometimes have difficulties with organics, especially if the organics are present in high concentrations. One way to manage the organic contaminants is to adsorb them onto carrier materials, such as zeolites; the carrier materials can then be immobilized in a stabilization material. This approach can also be effective for metal and radionuclide contaminants. Another way to manage the organic contaminants is to convert them into compounds that are more compatible with stabilization materials, or that are less toxic to the environment.

The wide range of physical properties (viscosity, density, percent solids) of the contents and the limited accessibility of most tanks make it important to match stabilization materials and techniques to the conditions of the tank. Also, the potential for heat generation and chemical reaction must be addressed in selecting the materials and techniques for stabilization. The contents of the tank may require premixing and pressure grouting in layers, or simple permeation, but the type of stabilization material selected will depend on both the method of placement and the chemical and physical composition of the tank contents. There may be several options that meet the requirements; selection of the preferred approach is based on cost, implementation, and reliability. These factors must be carefully considered in selecting the preferred approach.

Decontamination of the interior of a tank can minimize the amount of stabilization material required and simplify closure of the tank. The cost of tank stabilization is strongly dependent on the amount of stabilization materials required, especially if the stabilization material required is of a specialized nature. The amount of contaminated material in many tanks is only a fraction of the total volume of the tank, although the walls of the tank are generally contaminated from the large volumes contained by the tanks in the past. Also, some tanks that are candidates for stabilization may have weak or damaged areas above the current content levels that may preclude filling the tank. Decontamination of the nonsubmerged areas of the tank can significantly reduce the amount of stabilization material required.

Commercial surface decontamination techniques (many of which do not produce a large amount of secondary waste) can be adapted for use in tanks and enable the decontamination of the nonsubmerged regions of a tank. In this approach, the bulk of the tank contents can be stabilized, the exposed interior of the tank decontaminated, and then any debris from the decontamination can be stabilized in the tank. The result is a tank where all exposed interior surfaces are free of contamination. The remaining volume of the tank can be filled with an inexpensive fill material if the tank is to remain in place. Alternately, if the tank is to be removed, the contamination can be contained, and the size of the monolith can be minimized.

Verification and long-term monitoring of the stabilized tank are important for demonstrating the long-term durability and effectiveness of the stabilization process. Various types of proven and innovative sensor technologies, such as acoustic, thermal, and time-domain reflectronmetry, are being demonstrated and adapted to monitoring tanks. During the stabilization process, sensors are used to monitor the setting of the stabilization material and monitor physical parameters, such as temperature. Once the stabilization is complete, sensors are used to detect parameters, such as cracking, moisture content, permeability, and contaminant migration. This work focuses on the application of proven and innovative sensing systems to the needs of tank stabilization.

This work was initiated in FY96 with a focus on stabilizing tank V-9 at the Test Area North facility at INEL, and a goal of moving to progressively more difficult tanks in subsequent years. Tank V-9 was chosen as a relatively simple buried mixed-waste tank since it was small in volume, expected to contain moderate levels of radionuclides, and had an access point symmetrical to the geometry of the tank.

Two additional hot demonstrations on more challenging tanks, as well as the removal and destructive analysis of tank V-9, are planned for FY97. Candidate tanks have been identified at the Savannah River Site (SRS) and INEL, and the potential for joint projects with the Waste Management and Environmental Restoration programs at those sites are being explored.

The goal of these demonstrations is to show the effectiveness and flexibility of the tank stabilization system approach. A cold demonstration, or mockup, will be completed prior to the hot demonstration to identify potential problems and improve coordination of the activities. The hot demonstration will be performed in phases, starting with pretreatment, and followed by initial stabilization, decontamination, final stabilization, and ending with closure and monitoring of the tank.

BENEFITS

DOE sites have a number of buried tanks containing radioactive and mixed wastes. Some of these tanks can be pumped and remediated with existing technology. However, some of the tanks are difficult to pump. The tank stabilization technology being demonstrated by this project is focused on handling tanks that are difficult to reach because of surrounding facilities, tanks that contain wastes that are physically difficult to remove, and tanks that contain wastes that pose a significant health threat during removal. Stabilizing the material within the tanks has several advantages: (1) it can save money by allowing appropriate risk reduction of the contents, without the expense of removing the waste; (2) for tanks that must be removed, it contains the waste so that contamination is minimized when the tank is removed, even if it is removed in sections; and (3) it can provide an interim solution for tanks posing an immediate threat while an appropriate storage or disposal facility is found for the material.

COLLABORATION/TECHNOLOGY TRANSFER

The technology will be demonstrated on an EM-40 Superfund site, and provide an alternative for remediating waste tanks at other EM-40 and 30 sites. It has potential for application to EM-60 tank-removal activities and commercial-sector tank problems. Transfer of this technology will be accomplished through several avenues: the results of the tank demonstration will be presented at a national waste management meeting, and/or in technical journals; Cooperative Research and Development Agreements (CRADAs) will be sought with monitoring, materials, and placement technology vendors, as appropriate; additional, jointly funded, hot demonstrations will be sought, focusing on larger or more difficult tanks.

Accomplishments

- Received initial approval for demonstration from state and federal regulators
- Completed tank stabilization requirements report
- Performed initial visual inspection of tank
- Initiated development of test plan for demonstration

TTP Information

Buried TRU-Tank-Waste Remediation and Removal System technology development activities are funded under the following TTP:

TTP No. ID76LF24, "Buried TRU-Tank-Waste Remediation System"

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5.6 COOPERATIVE TELEROBOTIC RETRIEVAL

TECHNOLOGY NEED

Current retrieval scenarios for buried waste indicate a need to selectively retrieve "risk-driven" hazard items from a buried-waste site. This technology will remove those items while maintaining the integrity of the containers in which the hazards were stored.

TECHNOLOGY DESCRIPTION

A value engineering study has determined the type of delivery system required to transport dual manipulation capability to a waste-retrieval digface. The delivery system, a gantry crane, can transport the manipulators and other retrieval equipment, as required, to support the waste-retrieval operation. Other equipment that could be deployed includes a sundering/vacuum system, digface-characterization equipment, and miscellaneous waste-handling tools.

The remotely operated, sundering/vacuum system, as displayed in Figure 5.6-1, will be used to remove soil and debris from around the waste objects. End-effectors for the sundering/vacuum system are designed to break up hard soil, carefully clean around buried objects, and ensure that large sheets of plastic and other objects do not plug the system. The vacuumed debris will be placed in a transport container for subsequent removal and treatment. The system has been developed for total remote control of the functions, including control of the delivery system, manipulator freedom, and sundering/vacuum system.

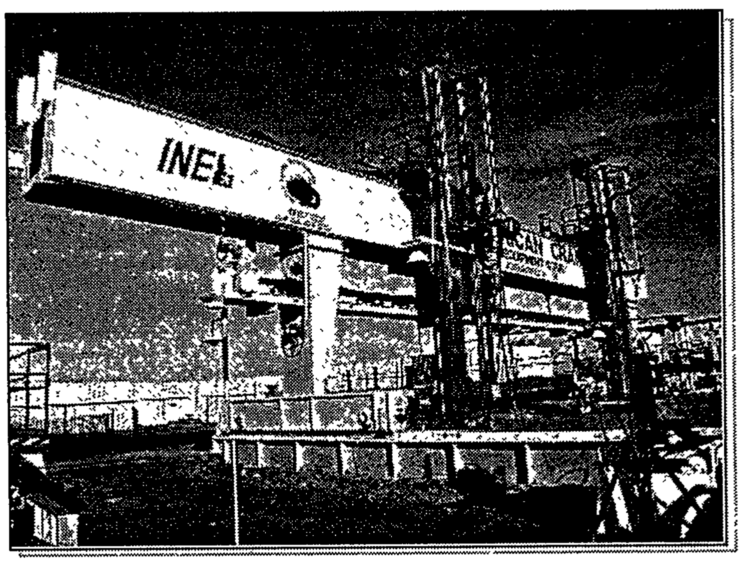

Figure 5.6-1. Remotely Operated Retrieval System.

As a common platform for support to a waste-retrieval operation, the gantry crane is equipped with two cooperative, telerobotic manipulators (multi-manipulator capability), each attached to a telescoping mast. A 5-ton hoist, also mounted on the gantry crane, supports the manipulators in deploying ancillary tools. The crane system will support:

- Archeological excavations (soil sundering/vacuum equipment)
- Digface characterization [INEL radiation, magnetics, volatile organic compound sensors, Pacific Northwest National Laboratory (PNNL) holographic impulse radar]
- Waste retrieval from the excavation
- Delivery of waste to the proposed transport system

The primary objective is to deploy a system with the capability to perform selective retrieval at a buried-waste site. Two robotic manipulators are installed on the delivery system. In tandem, these manipulators, along with the sundering/vacuum system, can selectively remove soils and debris from around an article, and retrieve that article.

BENEFITS

The system has been developed to demonstrate that available technology can be integrated and deployed in a realistic waste-remediation scenario. Since cost savings associated with this technology depend on the application and operation scenario, quantitative cost analyses have not been performed. The primary driver for the technology is improved worker safety. Cost savings are expected from removing workers from hazardous environments. Additional cost savings will be realized by reducing the need for personal protective equipment in hazardous environments.

COLLABORATION/TECHNOLOGY TRANSFER

Industry participation has been key to the present success of this project. American Crane and Equipment supported development of the delivery system (gantry crane) for this project. Advances made in the expansion of the control system were supported by Cinetrix Inc., and Schilling Development. Concepts Engineering Group supported and supplied the sundering/vacuum system. Dimension Technologies supplied and supported the stereovision system.

ACCOMPLISHMENTS

- Purchased the gantry crane, associated deployment mechanisms, telerobotic manipulators, hydraulic drive unit, and components of the system's control unit
- Integrated technologies developed under separate tasks or research efforts (i.e., digface characterization and soil vacuum/sundering tool), into the system
- Commenced individual component testing of the system in FY95, with integrated field testing to be conducted in FY96

TTP INFORMATION

Cooperative Telerobotic Retrieval technology development activities are funded under the following TTP:

TTP No. ID76LF25, "Landfill Retrieval Implementation"

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None at this time.

5.7 CRYOGENIC CUTTING

TECHNOLOGY NEED

Large objects unearthed during buried-waste retrieval operations may need to be made smaller prior to treatment. Current methods for size reduction include shearing, plasma-arc cutting, waterjet cutting, and other similar techniques. Shearing can be used for materials that are not too large or too strong for the shears. Plasma-arc cutting adds risk to operations because of the flame inherent in the operations, and the high temperature. Waterjet cutting adds an undesirable secondary waste stream to the process. Cryogenic cutting is a widely applicable technique and produces no secondary waste stream.

During decontamination and decommissioning of facilities, the need to remove surface contamination may be required. Once decontaminated, the facility may be reclaimed for future use or salvaged for usable components. If the facility is to be demolished and the rubble disposed of in a landfill, the facility again may need to be decontaminated in order to meet disposal requirements. The cryogenic cutting system can be used to perform the decontamination, without adding secondary waste that must also be disposed.

TECHNOLOGY DESCRIPTION

The primary objective of this project is to perform sizing of large objects during retrieval operations, and perform abrading operations during decontamination and decommissioning, using cryogenic cutting technology.

The cryogenic cutting system, as illustrated in Figure 5.7-1, uses high-pressure cryogenic nitrogen to perform cutting and abrading without introducing a secondary waste stream from the cutting medium. When necessary, carbon-dioxide pellets can be injected into the jetstream, thereby improving the cutting properties. Cryogenic cutting is an adaptation of the highly effective waterjet technique used in cutting a surface with high-pressure water and an abrading substance. Unlike the waterjet technique, the cryogenic cutting system does not introduce a secondary waste stream (water) as a cutting medium. Zero added

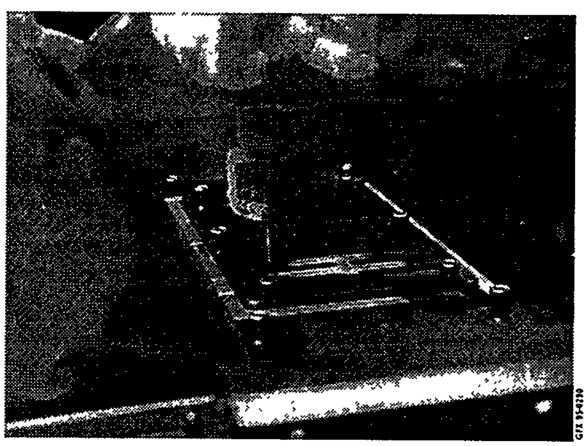

Figure 5.7-1. Cryogenic Cutting System.

waste is a highly desirable option for most waste management and environmental restoration activities. The cryogenic cutting technology has enhanced existing fluid systems to deliver high-pressure cryogenic nitrogen and solid carbon dioxide through a sophisticated nozzle to perform the abrading or cutting operation. The system will be evaluated by cutting select materials.

Benefits

This technology will be used to:

- Reduce the size of multiple types of material
- Eliminate the secondary waste stream inherent in waterjet cutting
- Clean, abrade, and scabble materials ranging from wood to stainless steel

This project is in the final evaluation phase, and the cost benefits have not been quantified. Cost savings will depend on the specific application; however, savings will be driven primarily by reduction of the handling and disposal costs for secondary waste streams.

Collaboration/Technology Transfer

Several companies have expressed interest in collaborating in the development of this technology. Interested parties include cutting-service companies, high-pressure pump companies, control-system companies, and cryogenic companies. The technology is presently licensed to Crycle Cryogenics (non-U.S. license). Cryogenic cutting may have wide applicability to site decommissioning where secondary waste streams are of concern.

Accomplishments

- Completed extensive upgrades of the existing cryogenic cutting system (during FY95) to improve cutting effectiveness. Upgrades included enhancements to existing fluid systems for the delivery of liquid nitrogen to the nozzle, development of robust control of the nozzle actuation, and evaluation of cutting on select materials. The nozzle was attached to a gantry crane to allow it to be operated in a volume of 18 by 18 by 18 cubic inches, providing sufficient movement to establish cutting rates with various materials. Using this technique, a plywood box can be opened in 15 minutes at a scan rate of 0.5 inch per second. A steel drum can be opened by directing the jet around the periphery of the drum. For one revolution, the travel speed was 0.012 inch per second, giving a depth of cut of 0.014 inch. At this rate, eight passes would be required to perforate the drum wall and would take approximately seven hours.

TTP Information

Cryogenic Cutting technology development activities are funded under the following TTP:

TTP No. ID76LF25, "Landfill Retrieval Implementation"

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Bibliography of Key Publications

None at this time.

5.8 MINIMUM-ADDITIVE WASTE-STABILIZATION PROGRAM

TECHNOLOGY NEED

Minimum-Additive Waste-Stabilization (MAWS) is aimed specifically at treating low-level and mixed wastes with vitrification. In order to achieve workable formulations for acceptable waste forms requiring minimum additives, innovative ways of combining wastes need to be investigated, along with appropriate integrating technologies. The strategy is to use, where possible, actual waste streams during evaluations and commercially mature technologies to be able to quickly tailor systems of interest to the DOE Offices of Waste Management and Environmental Restoration in meeting their compliance agreements.

Glass compositional effects must be understood to screen waste streams for necessary components and to combine them in optimal proportions to achieve a processable and durable waste form for disposal. Contaminated soils may provide one of the building blocks for making a vitrified waste form. Finding a composition that is both processable and durable, and combining wastes in an integrated system, can be quite challenging. A systems approach is needed to minimize additives and secondary waste generation. Individual supporting technologies are optimized to provide a better feed to the vitrifier. The ultimate goal is to produce a glass or vitreous ceramic that can be released to the environment. Flexibility is needed in the systems chosen, so as not to limit applicability, and to deal with the largely heterogeneous nature of many mixed wastes.

Of particular concern in many vitrification systems is the offgas system and potential release of contaminants to the air. Although vitrification is different from incineration, some organics may be part of the waste streams to be treated. The high temperatures can cause some problem contaminants to volatilize. Real-time monitoring equipment is needed to ensure that no releases occur. Also, consideration will be given to closed-loop-type systems and strategies to minimize volatilization or entrainment of contaminants in the offgas. Effective ways to deal with mercury are needed.

Emphasis will be given to technologies and integrated systems directed toward specific DOE waste problems, with abilities to test actual waste streams, and for which no other baseline treatment has been defined.

TECHNOLOGY DESCRIPTION

MAWS provides an environmentally sound cleanup alternative for large amounts of hazardous, low-level radioactive, and mixed wastes that exist across the DOE complex. A wide variety of waste streams often contain the basic chemical components from which a glass waste form can be made. The MAWS approach combines these resources to minimize the use of nonwaste additives, and produces an environmentally safe and acceptable final waste form. The final waste volume is minimized because little or no additives are used. Vitrification results in volume reduction through: (1) evaporation of water, (2) destruction of organics, and (3) consolidation of Resource Conservation and Recovery Act (RCRA) metals and radioactive material into a nonporous amorphous glass. Disposal costs are reduced, and future environmental risks/costs are minimized because the glass is both durable and leach resistant.

Integrated systems are used to apply the MAWS concept and to maximize benefits. Vitrification incorporates both primary and secondary waste streams into glassy waste forms. Supporting technologies may include thermal treatment, soil washing, biodegradation, gas scrubbing/filtration, and ion-exchange waste water treatment. Efforts are made to recycle any secondary waste streams from these supporting technologies back into the vitrification system. The particular suite of technologies chosen will depend on the waste streams available for treatment.

The MAWS Program is proceeding in five major areas: (1) materials science, (2) waste form durability/characterization, (3) technology process development and systems integration, (4) system demonstration at DOE sites, and (5) life-cycle cost savings/benefits. Compositional envelope development is the main focus for the materials science efforts. This involves investigating a variety of glass and vitreous ceramic compositions to determine processing properties and phase separation tendencies. Initial studies have focused on surrogates. Present efforts are directed towards studies with actual waste streams from the various sites so that interesting combinations of wastes can be screened as potential candidates for MAWS implementation. Through development of the compositional envelope, future candidate waste streams can be more quickly screened based on the known limits.

Closely tied to compositional envelope development is characterization of waste form durability. Glass compositions may vary widely and result in a broad range of durability defined by the tendency to dissolve or leach under various conditions. This effort is providing a database of durability information as measured by Toxicity Characteristic Leach Procedure and Product Consistency Test results, which can be used to optimize the waste forms. An effort is also planned to investigate appropriate tests and models to calculate long-term performance, given a set of assumptions. This effort will develop new or verify existing test methods and models that prove to be the best approach for making such projections.

Since vitrification is at the heart of the MAWS approach to treatment of wastes, a major effort is to develop higher-temperature melting systems. Such systems will provide the flexibility to address a broader range of waste streams, and generally produce more stable and durable waste forms. Systems under study include unique variations of joule-heated melters that can potentially minimize offgas generation so as to better trap the contaminants in the vitrified waste form. These technologies are being developed at the bench scale and will progress through various stages of scaleup and cold to hot testing as warranted.

An initial demonstration of joule-heated vitrification, in combination with soil washing and ion-exchange water treatment, was concluded at Fernald, Ohio. That demonstration successfully washed 57 cubic yards of contaminated soils to less than 35 pCi/g and produced several thousand kilograms of glass from high fluoride sludges and soils contaminated with uranium, thorium, and technetium.

Life-cycle cost analyses provide the required information to determine the best use of limited funds. For the MAWS program, these models are being developed to estimate full implementation costs in comparison to cementation or other appropriate baseline technologies. An initial model has been developed based on the information available from the Fernald demonstration. This model will be modified, as appropriate, to project cost savings for waste streams from other sites. Uncertainties are being quantified, and the sensitivities of the various parameters determined, through mathematical Monte Carlo analysis.

BENEFITS

The MAWS technology approach provides a lower-cost, vitrification alternative for the vast quantities of low-level and mixed wastes that exist across the DOE complex. This is possible because of the minimum use of additives and the high-waste loadings achieved (often greater than 90 percent). Cost savings result from reduced processing and disposal costs since, with vitrification, the waste tends to be concentrated rather than diluted. Volume reductions of 25 to 75 percent are common, whereas generally volume increases during other treatment options, such as grout or encapsulation. Therefore, in treating a combination of waste streams, a larger fraction of the time is spent actually processing waste and disposing of only waste rather than a lot of additives. The additives required for ease of vitrification are provided through optimum combination of the available wastes on site. Therefore, additive purchase costs are minimized.

In most cases, this allows vitrification to be cost competitive with other waste-treatment technologies, such as cementation, while providing a nonporous superior waste form in terms of durability and leach resistance (lowest leach index of all waste forms). This is the reason that glass has been chosen as the waste form of choice for disposal of high-level wastes.

Vitrification is a preferred treatment approach for many inorganic waste streams such as soils, sludges, asbestos, ashes, ion-exchange resins, D&D debris, etc. The wastes actually become a part of the glass matrix rather than merely encapsulating the waste in cement/grout, polymer, or asphalt. Through use of a systems approach, MAWS is able to recycle most secondary waste streams back into the melter to ultimately become glass. Implementation of a MAWS approach on a site-wide basis to treat multiple waste streams may avoid the need to build multiple smaller treatment facilities based on other technologies, thereby providing economies of scale.

Collaboration/Technology Transfer

There are a number of industry/university partners that have been instrumental in developing technologies for use in the MAWS treatment approach. The initial demonstration of the MAWS concepts at Fernald was made possible through a collaborative effort between GTS Duratek Corporation and Catholic University of America (CUA) to develop the vitrification and waste water treatment technologies, and Lockheed Environmental Services Corporation to develop the soil-washing technology. ANL provided project management and long-term glass performance testing.

GTS Duratek teamed with the Vitreous state Laboratory at CUA to develop a compositional envelope of glasses from Fernald wastes that are both durable and processable in the joule-heated melter developed by GTS Duratek. Together, they proceeded to develop and scale up a process from the bench (10- and 100-kilograms-per-day units) to pilot-scale units (300 kilograms per day) demonstrated at Fernald. GTS Duratek and CUA hold several patents on this unique melter design.

The experience gained by GTS Duratek in designing, installing, and operating the joule-heated melter during the Fernald demonstration has helped the company in bidding for other contracts to treat DOE wastes, such as 700,000 gallons of M-area sludges at SRS, and to demonstrate applicability for Hanford low-level wastes. In addition, GTS Duratek and Chem-Nuclear have formed a joint venture and signed an agreement to build a commercial low-level waste vitrification plant at Barnwell, South Carolina, leveraging off their experience gained from the Fernald demonstration melter.

For further development of suitable compositional envelopes for glass and vitreous ceramic waste forms, there is a three-pronged effort underway. CUA is continuing to develop the glass-waste forms area utilizing a variety of actual waste streams from several DOE sites including Hanford, Oak Ridge National Laboratory (ORNL), and INEL. Both ANL and PNNL are conducting similar studies on wastes and surrogates more appropriate to a vitreous ceramic (natural basalt-like) waste form. These studies are providing phase compositional processing and long-term performance data that will ultimately be part of an overall database and modeling effort initiated by CUA. This model and database should facilitate the initial screening of wastes appropriate for treatment into a vitrified waste form, and suggest likely formulations to be bench tested utilizing a MAWS approach. This should allow more rapid transfer of this technology approach to the other sites across the DOE complex, and ultimately to private industry.

Several efforts were conducted to enhance the capability to vitrify a greater variety of wastes requiring higher melting temperatures, and thereby minimize the use of additives. The first was a three-way effort where a series of tests on high metal-content feeds utilized a high-temperature centrifugal plasma melter to produce glassy-slag waste forms. This work initially involved a collaborative effort between Retech, Inc., and MSE, Inc., to test this concept in both a bench-scale and pilot-sized unit at each facility. In addition, ANL was involved in the design of the feed formulation matrix and evaluation of the glassy slags produced.

The most recent scaleup and duration tests on these high metal feeds in the pilot-scale unit at MSE, Inc., were funded by the Army Corps of Engineers through the U.S. Department of Defense (DOD) Construction Engineering Research Laboratory. Mississippi state University's Diagnostic Instrumentation and Analysis Laboratory provided capabilities to monitor enhanced real-time offgas. There is great interest in this plasma technology because it potentially minimizes the pretreatment and separation needs for many wastes, thereby resulting in a much simplified process flow scheme. In addition, the slag-like waste form has been shown to be comparable, and often better than, the glasses developed to contain high-level wastes.

Additional efforts are funded through CUA's Vitreous State Laboratory to develop other high-temperature technologies. Both the Vitreous State Laboratory and PNNL are working on improved electrodes for high-temperature joule-heated melting. The Vitreous State Laboratory is working on testing of new materials, while PNNL is investigating unique coatings and electrode biasing techniques to increase the electrode life.

Another collaborative effort has just concluded between the Air Force Institute of Technology and the Fernald Environmental Restoration Management Company to provide a life-cycle cost model for MAWS vitrification processes. Funding involves an Interagency Agreement. This provides a very general model and allows waste data from other sites to be easily input for rapid assessment of MAWS vitrification potential compared to other treatment technologies.

ACCOMPLISHMENTS

- Developed acceptable glass and vitreous ceramic waste forms, spanning a spectrum of compositions for candidate wastes. Developed good glass formulations from several Hanford, ORNL, and INEL waste streams.
- Achieved volume reductions of 25 percent and more with many DOE wastes, such as soils, sludges, and sediments, during the vitrification step.
- Oxidized metal loadings of up to 70 percent with soils into a stable, basalt-like ceramic using plasma-melting technology. The process and waste form quality has scaled well from bench through pilot tests.
- Developed stable, vitrified glass and vitreous ceramic waste forms that are able to meet U.S. Environmental Protection Agency (EPA) toxic-characteristics leaching-procedure criteria, and surpass product consistency testing standards developed for high-level waste glasses.
- Achieved waste loadings up to 94 percent with actual Fernald sludges and soils. Demonstrated, in other laboratory tests, waste loadings of 100 percent.
- Demonstrated, at Fernald, an integrated treatment system which contains a 300-kilograms-per-day melter, 0.25-cubic yard-per-hour soil washing unit, and a 100-GPM ion-exchange unit.
- Completed laboratory-scale soil-washing tests that reduced uranium concentrations to less than 35 pCi/g and achieved a volume reduction of greater than 80 percent with Fernald clay-type soils. The pilot-scale unit has successfully processed 57 cubic yards of contaminated site soils with a volume reduction of 70 percent for use in the pilot-scale vitrifier.
- Completed, successfully, tests with actual Fernald site radioactive sludges and soils in both the 10 kg/day and 100 kg/day melters at CUA, providing high-quality waste forms and necessary operational data for the 300 kg/day melter at Fernald. To date, the Fernald melter has produced several thousand kilograms of glass with actual radioactive sludges and soil concentrates.
- Captured the high levels of hydrogen fluoride volatilized from the melt via the Fernald offgas system on the 300 kg/day melter, and recycled it as sodium fluoride sludge back into the melter. Emissions were within prescribed limits.
- Completed a preliminary life-cycle cost analysis for vitrification of the OU-1 sludges and soils using the MAWS system concept, and indicated a minimum savings of $100 million, as compared to cementation.

TTP Information

Minimum-Additive Waste-Stabilization Program technology development activities are funded under the following TTP:

TTP No. ID76LF21, "Site Characterization, Demonstration, and Evaluation"

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5.9 STABILIZATION OF TRANSURANIC/MIXED WASTE

TECHNOLOGY NEED

The DOE is committed to meeting the challenge of remediating/containing contamination throughout the DOE complex. DOD, EPA, and private-sector commercial and industrial facilities are also dealing with the challenge of contaminated sites. New technologies are needed to provide more economical solutions to address these types of sites; many of the technologies are amenable to landfill disposal. Stabilization of contaminants is the focus of the work within this project. The tested and developed technologies will be demonstrated in conjunction with technology development related to landfill wastes contained at INEL and applicable to other DOE sites.

TECHNOLOGY DESCRIPTION

The purpose of the work described in this project is to provide government and private-sector industry with innovative and practical methods for stabilizing waste. Efforts under investigation support testing and development for material selection to stabilize wastes and for monitoring and verifying stabilized waste (monoliths). Specifically, the efforts and technologies under investigation are advanced methods for proving and ensuring the integrity of the stabilized waste, through measurement of monolith physical properties. Development of a number of technologies to evaluate subsurface grout emplacements continues to be desirable, with the increased demand for containing and/or stabilizing the waste existing in the subsurface. These technologies rely on variations of physical characteristics between the soils, grouts, and wastes, which define the interfaces between the materials. The ability to detect these interfaces and subsurface details is desirable to ensure containment/stabilization integrity.

Also included in this project, which is supportive of in situ waste stabilization and encapsulation experiments being performed by INEL at the Cold Test Pit near the Radioactive Waste Management Complex, is the performance of hydraulic conductivity tests on a combination of specially prepared test monoliths. Hydraulic conductivity measurements have been planned based on a grouted culvert system. The grouted culvert systems will support two types of hydraulic conductivity testing: positive mass balance and packer testing. Three material types and test sites are planned.

Benefits

DOE will benefit from development of new technologies through implementation of more cost-effective tools and methods to clean up contaminated sites. Development of verifiable stabilization and barrier technologies will eliminate the spread of contaminants.

Collaboration/Technology Transfer

Several aspects of stabilization of TRU/mixed waste are already being addressed by INEL. The enhanced measurement testing through additives and the conductivity testing of the culvert monoliths require collaboration between INEL and MSE-TA, Inc. Potential users of these technologies are widespread in the DOE complex, and in the country as a whole. Because the need is so widespread, stabilization technologies are readily transferrable for landfill applications outside DOE.

Accomplishments

- Completed initial selection of material for the monolith stabilization
- Initiated ordering process to obtain materials for the culvert demonstration systems

TTP Information

Stabilization of TRU/Mixed Waste technology development activities are funded under the following TTP:

TTP No. PE16LF23, "In Situ Stabilization of TRU/Mixed Waste"

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None at this time.

5.10 IN SITU VITRIFICATION AND STABILIZATION OF TRANSURANIC/MIXED WASTE

TECHNOLOGY NEED

In situ vitrification (ISV) technologies started in 1980, when the top-to-bottom approach was developed by Battelle, and patented in 1983. It was commercialized in 1989, with the formation of Geosafe Corporation. ISV technology is commercially available; therefore, issues associated with treatment of unconfined contaminated soils, at depths of less than 5 meters, are closed. No further development work is necessary.

While the contamination zones of many sites are in the upper 5 meters of the site, an even greater number have contaminated regions that extend below this depth. Preliminary surveys indicate that, at DOE sites alone, doubling the treatment depth capability would more than double the number of applicable sites for remediation. Therefore, enhancements to the ISV technology, which allow its extension to greater depths, will greatly expand its realm of applicability.

Similarly, many of the soils along the Eastern seaboard of the United States have low alkali concentrations, with consequent low conductivity. A technology enhancement that permits the extension of ISV to this type of soil will also greatly expand its applicability.

Safety is always a concern in applying any new technology; ISV is no exception. Since an offgas hood is required over the treatment area, one of the operating concerns is buildup of a combustible gas mixture. If this mixture is ignited, it could over-pressurize the hood and cause a release of hazardous/radioactive contaminants to the environment. One excellent way to mitigate this possibility is to control the gas composition before it enters the hood. Adding this feature will serve to allay this concern.

TECHNOLOGY DESCRIPTION

ISV is a thermal treatment technology being developed for permanent stabilization of radioactively contaminated soils. The technology is especially applicable to sites with a variety of contaminants (e.g., radionuclides, heavy metals, and organics). Most of the attention to date has focused on joule-heating technologies that heat the waste area from top to bottom. The ISV process produces a very durable waste form at a much lower cost relative to other existing technologies. Current methods show promise as a means of immobilizing contaminants to a depth of 6 to 7 meters from the surface. This project addresses the following limitations of top-to-bottom technologies:

- Increases ISV treatment depth
- Treats soils with low or high conductivity
- Presents offgas system safety concerns

Top-to-bottom technologies have not been economically feasible for immobilizing contaminated soils to depths greater than 5 meters; vitrification action ceases completely at depths approaching 7 meters. Accordingly, this project is structured to address treatment of contaminated areas deeper than 5 meters. The bottom-to-top approach has been demonstrated on a bench scale at shallow depths, but not under field conditions, and not at depths greater than 5 meters. In theory, it should be economically feasible to treat soils to depths much greater than 5 meters with this method.

Another difficulty frequently experienced with the top-to-bottom approach is soil conductivity. Since the current path in the vitrification process includes the soil being treated, conductivity is very important; it must fall within a relatively narrow range for the process to work properly. Bottom-to-top technology does not depend on soil conductivity, as it creates its own current path for the arc it generates.

This task will demonstrate the bottom-to-top technology at ORNL under field conditions. The proposed site for this demonstration is shown in Figure 5.10-1, in the clean area to the right of the pick-up truck. This site is located in Waste

Figure 5.10-1. Proposed Site for Bottom-to-Top and Top-to-Bottom Demonstrations.

Area Grouping 7 at ORNL. The Figure also shows current project activities using the top-down melting technology. A top-to-bottom demonstration will be conducted in FY96 in the same Waste Area Grouping proposed for the bottom-to-top demonstration. The results of both demonstrations will be analyzed and compared for glass quality, ease of melting, and homogeneity.

Top-to-bottom vitrification processes are typically conducted under reducing conditions. Adjustments to these conditions are difficult because considerable amounts of additives must somehow be introduced to the melt. With bottom-to-top technologies, these adjustments are simply made by changing the composition of the feed gases to the torch.

BENEFITS

Current top-to-bottom ISV technology has depth and soil-type limitations. There are also some safety concerns about the offgas systems associated with ISV treatment. Development of bottom-to-top ISV technology will greatly expand the applicability of ISV technology and potentially mitigate safety concerns associated with its offgas collection systems.

COLLABORATION/TECHNOLOGY TRANSFER

This project is a joint effort between DOE EM-40, EM-50, the Morgantown Energy Technology Center (METC), SRS, INEL, Western Environmental Technology Office, ORNL, and a successful contract bidder.

ACCOMPLISHMENTS

- Completed numerous demonstrations and commercial applications of top-to-bottom ISV technology at Hanford, SRS, and other sites. Completed demonstrations of bottom-to-top technology (bench scale) at Georgia Tech and Montech.
- Resolved, satisfactorily, controversies over patent rights. Development is proceeding. The scope of work and other documentation have been forwarded to METC procurement organization to issue as a Request for Proposal. After the Request is issued and proposals are received, proposal evaluation and contract award can proceed.

TTP Information

In Situ Vitrification and Stabilization of TRU/Mixed Waste technology development activities are funded under the following TTP:

TTP No. PE16LF23, "In Situ Stabilization of TRU/Mixed Waste"

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6.0 TRANSURANIC/MIXED WASTE IN HUMID ENVIRONMENTS PRODUCT LINE

This Product Line addresses technology needs associated with the stabilization, containment, and remediation of the U.S. Department of Energy (DOE) disposal sites in humid environments that contain transuranic (TRU) or other long-lived radionuclides. Of particular concern is the plutonium-238 contaminated waste currently at the Savannah River Site (SRS) that constitutes approximately 65 percent of the TRU waste radionuclide inventory in DOE.

This problem set poses unique technical problems during remedial actions due to the high toxicity and long life of these contaminants. In many cases, retrieval of the contaminated wastes or soils is required to ensure long-term protection of human health and the environment. Inherent to this action is the increased potential for worker exposure. The retrieved wastes or soils may require significant further processing to meet transportation and disposal requirements. The processing of these heterogeneous materials requires characterization to ensure safe operation and an acceptable waste product.

The Product Line places emphasis on robust, ex situ treatment systems for excavated wastes contaminated with TRU and other long-lived radionuclides. High-temperature technologies using graphite dc-arc furnaces, or hybrid induction/plasma furnaces, are the primary candidates. Engineering-scale systems have been built and are being demonstrated in both radioactive and nonradioactive service. As part of the systems, appropriate characterization, diagnostic, and offgas treatment technologies are also being developed. The waste forms resulting from treatment are being optimized to ensure disposal product acceptability. The Product Line leverages the retrieval technologies developed under the TRU/Mixed Waste in Humid Environments Product Line in addressing system needs for the problem set.

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6.1 GRAPHITE DC-ARC FURNACE

TECHNOLOGY NEED

There is a need to treat all types of buried waste (hazardous, low-level, and TRU), contaminated soils and containers, as well as ash, secondary waste, and soil. Organics must be destroyed, and radioactive and other hazardous metals need to be stabilized in a suitable, final waste form. Metals in the waste must be segregated into a separate waste stream. TRU species should preferentially segregate into the glasseous/slag phase.

TECHNOLOGY DESCRIPTION

The plasma-arc technology can treat buried waste, such as hazardous, low-level, and TRU, along with contaminated soils and containers. Organics are destroyed, and radioactive and other hazardous metals are stabilized in a suitable, final waste form. Ash, secondary waste, and soil can be treated. Metals in the waste are segregated into a separate low-level or hazardous waste stream. Transuranic species preferentially segregate into the glasseous/slag phase.

Two demonstration systems are being used to evaluate and provide waste-processing data from the graphite-electrode dc-arc furnace: a radioactive engineering-scale system (100 pounds per hour) and a nonradioactive pilot-scale system (1,000 pounds per hour). Descriptions of these systems follow.

Engineering-Scale Radioactive and Hazardous Waste Furnace

The radioactive furnace is a 3-feet-by-4-feet vessel in which a 12-inch inside-diameter hearth is situated. The system is scaleable to the Mark II and has all the Mark II features, plus improvements. The radioactive furnace, as shown in Figure 6.1-1, will operate at 250 kW and be capable of more than 100 pounds throughput per hour. Treatment of actual mixed waste will be demonstrated in this furnace during Fiscal Year 1996 (FY96). Special features include a bottom drain for both metals and glass, an overflow section proven in many Pacific Northwest National Laboratory (PNNL) melters, and a lined hearth that can operate in completely oxidizing environments.

Technology Attributes

Competing technologies include other arc-melter designs and joule-heated melters. Other arc-melters, or plasma furnaces, include designs using single metal electrodes and the arc-melter at the U.S. Bureau of Mines that uses three graphite electrodes. The single graphite-electrode design has the advantage

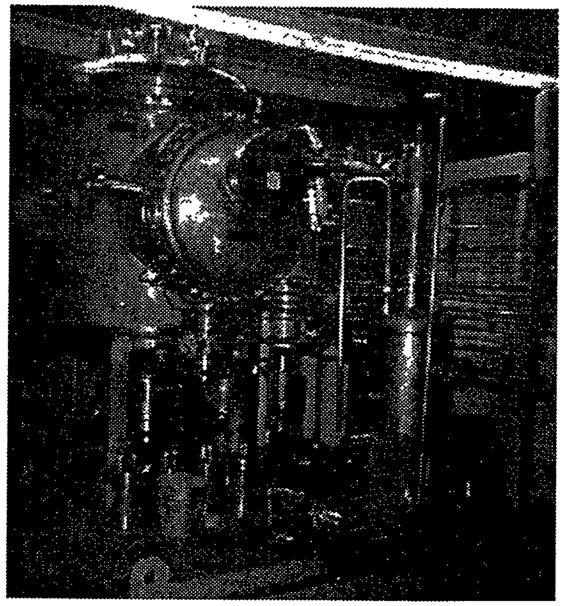

Figure 6.1-1. Radioactive Engineering-Scale DC-Arc Melter.

of potentially requiring less maintenance than do multiple electrode designs, while the use of graphite increases electrode lifetime with respect to metal electrodes.

In general, arc-melters have higher throughput capabilities than joule-heated melters. Arc-melters are well suited for contaminated soils and containers because of the high melting points required. Although data are available indicating a cost savings, it is not sufficient to quantitatively state the difference at this point.

Pilot-Scale Furnace

The pilot-scale Mark II furnace is a refractory-lined, carbon steel vessel measuring 23 feet high and 7 feet in diameter, with four soft-patch panels around the circumference to provide access for waste feed, glass discharge, and diagnostic equipment. The furnace is designed to provide power of up to 1 MW, thus allowing a processing rate of more than 1,000 pounds per hour.

The electrode assembly has a unique coaxial arrangement. The outer graphite electrode has an outside diameter of 14 inches and an inside diameter of 10 inches. The inner electrode is a solid 6-inch piece of graphite. The electrode assembly can be operated in the transferred-arc mode or the nontransferred-arc mode (arc between parts of the electrode).

Benefits

The graphite-electrode dc-arc furnace has several advantages:

- Handles large objects, such as 55-gallon drums.
- Destroys limited quantities of hazardous materials in tests with existing systems.
- Features ability to treat any type of buried waste (hazardous, low-level, and TRU), along with any contaminated soils and containers.
- Produces final waste form (i.e., slag or solidified residue) that is extremely durable and shows similarity to long-life natural analogs.
- Reduces secondary waste by using incoming waste to decrease offgasing.
- Processes material at a much faster rate as a result of the high-temperature-arc zone. This value is better than any reported value for the plasma-torch system, and is equal to that for joule-heated melters, and the in situ vitrification process.

Collaboration/Technology Transfer

Other commercial entities have expressed interest in the melter technology. Technology transfer is occurring with university (Massachusetts Institute of Technology) and industry (T&R Associates) partners on the project. Technical progress reports and design data will be transferred to other projects, especially similar vitrification efforts.

Accomplishments

- Built and demonstrated, with surrogate wastes, a nonradioactive engineering-scale furnace, the Mark I. Incorporated design improvements identified during the operation of the Mark I, into the larger, pilot-scale Mark II furnace system.
- Tested the Mark II furnace at a higher throughput than the Mark I, using a continuous-processing mode. Established a material balance, and compared submerged and unsubmerged-arc operations. Offgas emissions were dramatically reduced when the furnace was operated in the submerged-arc mode. Submerged-arc operation is also more energy efficient than unsubmerged operation.

- Completed, in late FY95/early FY96, a series of radioactive bench-scale tests. These tests provided data to evaluate the effects of composition and operating conditions on the fate of plutonium in a thermal treatment system. Selected tests (i.e., parameters with the greatest impact on plutonium fate) will be repeated in the larger radioactive engineering-scale system during FY96.

TTP Information

Graphite DC-Arc Furnace technology development activities are funded under the following Technical Task Plan (TTP):

TTP No. RL36LF32, "Removal/Treatment of TRU (PU-238) and Long-Lived Waste"

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6.2 SECONDARY TREATMENT OF OFFGAS USING NONTHERMAL PLASMA

TECHNOLOGY NEED

The nonthermal-plasma technology is an alternative, nonincineration treatment for destruction of volatile organic compounds (VOCs) and metal oxidation that can be used for remediation of contaminated soil and direct treatment of mixed waste. It also treats secondary waste gases from commonly used treatment processes for mixed waste (vitrification, incineration, and thermal stripping).

TECHNOLOGY DESCRIPTION

Nonthermal, electrical-discharge plasma can promote favorable chemistry to destroy hazardous chemicals. Figure 6.2-1 illustrates the details of the cylindrical, pulsed-corona, nonthermal-plasma reactor used to treat offgas from the arc-melter. The filter bank used to collect particulates is shown at the bottom of the Figure. Electrical energy directed into the process chemistry creates highly reactive free radicals that directly oxidize/reduce pollutants or fragment pollutants, or promote excited-state chemistry.

Silent-discharge plasmas consist of two parallel metal electrodes with a dielectric barrier between them and adjacent to one electrode. High voltage is applied between the electrodes, creating a microdischarge on gases flowing between them. The electrical energy is channeled into production of free radicals. This creates an active environment for destruction or neutralization of gaseous, hazardous organics.

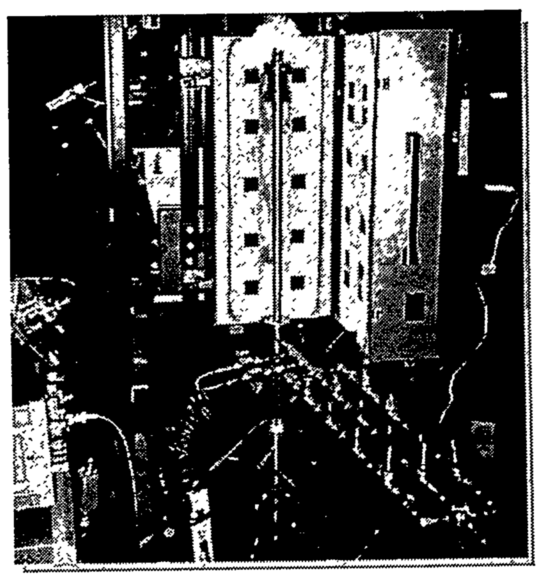

Figure 6.2-1. Nonthermal-Plasma Reactor.

The primary objective is to evaluate the nonthermal-plasma process for removal of VOCs, SO_x/NO_x, hazardous compounds, and high-vapor-pressure metals in melter offgases.

Benefits

Nonthermal-plasma technology has two major applications for treatment of hazardous waste:

- Primary Stage: treating gaseous-based wastes, such as VOCs in stack gas, as stand alone plasma devices
- Secondary Stage: treating the offgas stream of incompletely destroyed waste from primary-stage units and incinerators or furnaces

Competing technologies for VOC treatment include thermal-catalytic incineration and activated-carbon treatments. Selective catalytic-reduction techniques compete in the treatment of sulfur and nitrogen oxides. Nonthermal-plasma technology has the advantage of potentially being able to treat each of these waste gases, as well as high-vapor-pressure metals, simultaneously. This technology does not compete well on cost at first, because electrical processes are generally more expensive than thermal processes. Nonetheless, it may compete well on a more global scale, because of its ability to treat several waste gases simultaneously, and because the process produces less greenhouse gases than do thermal treatments.

This is an emerging technology, so cost and performance data are being acquired. One baseline comparison is for VOC abatement, for which it is projected that nonthermal-plasma technology is two to four times cheaper per kilogram than activated carbon.

Collaboration/Technology Transfer

DOE sites (such as SRS, Hanford, and Mound) and participants in the industrial sector (such as the chemical, electrical production, and paper and wood products industry) support technology transfer. The Electric Power Research Institute has cooperated with DOE on an air-toxics effort through a Cooperative Research and Development Agreement (CRADA) and technology commercialization with the private sector.

Under CRADAs with the Electric Power Research Institute and High Mesa Technologies, DOE has collaborated on the commercialization of nonthermal-plasma technology for hazardous air pollutants. As part of the CRADAs, two field trials with mobile units have recently been carried out on the removal of vacuum-extracted VOCs from soil and groundwater: a two-month field test at McClellan Air Force Base (November 1995 to January 1996), and a one-week test at Tinker Air Force Base (April 1996).

Based on the success of these tests, efforts to scale up the units for commercial service are being made.

ACCOMPLISHMENTS

- Completed construction and testing of nonthermal-plasma apparatus for high-temperature offgas operation
- Conducted a series of offgas tests using a small-scale arc-melter and a pulsed-corona, nonthermal-plasma reactor
- Designed a silent-discharge, nonthermal-plasma reactor prototype for high-temperature offgas treatment; procurement is underway

TTP INFORMATION

Secondary Treatment of Offgas Using Nonthermal Plasma technology development activities are funded under the following TTP:

TTP No. AL16LF32, "Removal/Treatment of TRU (PU-238) and Long-Lived Waste"

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7.0 Low-Level Waste/Other Contaminants in Arid Environments Product Line

The primary objective of this Product Line is to develop needs-driven technologies for the U.S. Department of Energy (DOE) complex. Current emphasis is on source-term containment by developing technologies and strategies for containment and monitoring systems. Containment of source-term contaminants results from restricting or confining the migration/leaching of contaminants beyond their confined domain. This can be accomplished by installing surface caps or covers and by emplacing engineered vertical or horizontal barriers. Barrier materials are chosen based on long-term durability, resistance to chemicals and corrosion, and impermeability to water. Site needs and characterization data will determine emplacement methods and locations around waste landfills.

Containment may be used in two ways: (1) as a long-term measure for final remedial action (site closure), or (2) as an interim action to prevent contaminant migration pending further remedial decisions, or during an in situ remediation process. Monitoring of containment systems is required to verify emplacement integrity and obtain performance data. This activity will be very important in achieving maximum deployment potential for containment systems.

Surface caps constructed of synthetic or natural geologic materials, such as clay, control the following: erosion, deep percolation, and biological intrusion. The spectrum of designs vary from simple soil barriers that have optimum configurations, plant cover, and surface slope, to more complex, multi-layered cover profiles incorporating engineered barriers that inhibit downward movement of soil moisture. Few have been constructed in the field and monitored in a way that would allow a complete evaluation of performance characteristics. Even these have been evaluated under very specific climate and environmental conditions. The Subsurface Contaminants Focus Area has taken the initiative and is leading in the efforts to develop field-tested, climate-specific, migration-barrier cover designs that can serve as a sole containment technology, or as part of an integrated barrier system that incorporates other barrier concepts to contain wastes.

Emplacement of subsurface barriers (vertical and horizontal) controls water infiltration and reduces contaminant release to the environment. These barriers are usually grout material, such as concrete, soil-bentonite, or cement-bentonite slurry materials. Typically, this emplacement is near surface and vertical. Subsurface horizontal to subhorizontal barriers that retard mass movement are not currently employed in civil engineering applications. New technology initiatives are geared toward the development of superplastic grouts and soil cement of significantly superior mechanical, electrical, and durability properties.

Monitoring systems and characterization technologies have been developed to assess contaminant species, location, concentrations, and track movement. These systems and technologies will be evaluated and incorporated into containment verification and monitoring systems. Further development will be conducted to increase the efficiency and accuracy of these systems. The future of containment technology deployment lies in the ability to verify emplacement continuity and provide reliable performance data that will facilitate regulatory acceptance.

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7.1 ALTERNATIVE LANDFILL COVER DEMONSTRATION

TECHNOLOGY NEED

A U.S. Environmental Protection Agency (EPA) study of 163 randomly selected landfills revealed that there is room for improvement in currently accepted landfill technologies. Minor to major problems were discovered at 146 of these sites. Problems included elevated chemical concentrations in on-site groundwater; contamination of groundwater at water supply well fields; surface water contamination; ecological impacts to local flora and fauna; and forced changes in the water supply for impacted communities where federal/state drinking-water-contamination standards were exceeded. Virtually all areas of the country have experienced some form of water contamination due to leaking leachate from landfills.

Current cover-design criteria emphasizes barrier layers that block infiltration of water through the cover into the waste. Saturated hydraulic conductivity is the measurement parameter chosen by the EPA to define the effectiveness of the barrier layer (i.e., the lower the hydraulic conductivity, the better the layer). This is not a practical solution in arid and semi-arid regions since saturation of soil layers is rarely, if ever, achieved.

The saturated-hydraulic-conductivity method can actually be detrimental to covers in arid and semi-arid regions. In order to achieve the low saturated-hydraulic conductivity required by the EPA, the barrier soil must be remolded by compacting it "wet of optimum," which eventually leads to the later drying, shrinking, and cracking of the barrier layer. These cracks provide pathways for the infiltration of water. This defeats the original purpose of creating a barrier layer to block the infiltration of water into the underlying waste. EPA admits, "In arid regions, a barrier layer composed of clay (natural soil) and a geomembrane is not very effective. Since the soil is compacted 'wet of optimum,' the layer will dry and crack."

TECHNOLOGY DESCRIPTION

The Alternative Landfill Cover Demonstration (ALCD) is a large-scale field demonstration comparing innovative landfill covers specifically designed for dry environments with currently accepted EPA cover designs as baselines. Elements of the ALCD are outlined in Figure 7.1-1. These covers are installed and instrumented in a side-by-side arrangement. Each test plot is 300 feet long and peaked in the middle, with 150 feet sloping at 5 percent toward the west, and the other 150 feet half sloping at 5 percent toward the east. The eastern half of each test plot will be evaluated under ambient conditions, with the western side evaluated under "stressed" conditions, controlled by a rain simulation system. The covers will be evaluated and compared based on construction, cost, and performance criteria.

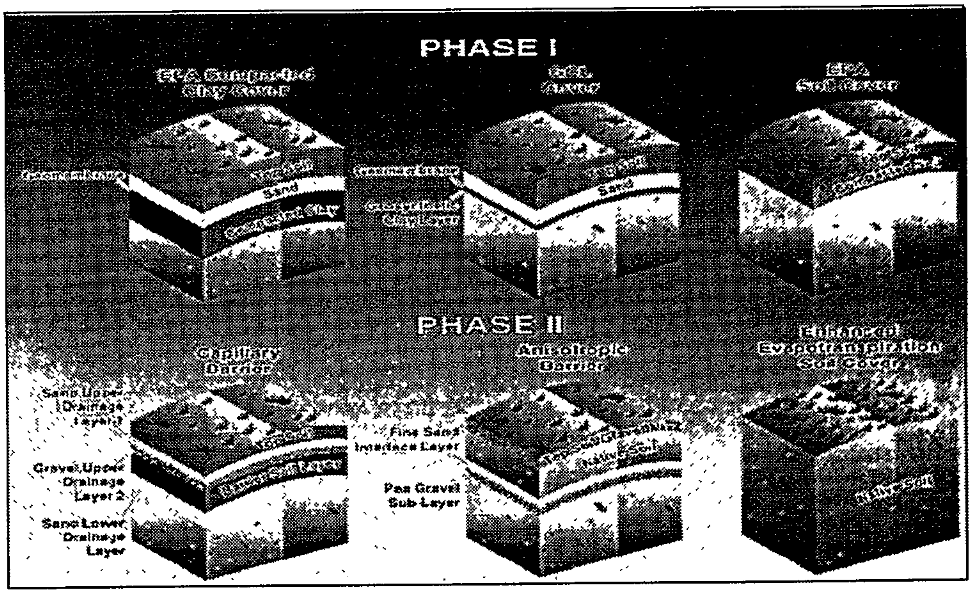

Figure 7.1-1. Alternative Landfill Cover Demonstration.

Some of the alternative designs will emphasize such things as unsaturated hydraulic conductivity, increased water storage potential to allow for eventual evaporation, and increased transpiration through engineered vegetative covers. The alternative covers were designed to take advantage of local materials to allow for easier construction of the covers at substantial cost savings.

The key to gaining general acceptance of any new environmental technology is obtaining regulatory approval. The ALCD is addressing this issue by involving the EPA and environmental divisions from the western states in the project. This is aiding in gaining acceptance of the new technologies and is encouraging interstate cooperation. The Western Governors Association and Committee to Develop On-Site Innovative Technologies are working with Sandia National Laboratories (SNL) to promote interstate cooperation.

BENEFITS

The ALCD is developing technology to improve upon current landfill cover systems. The project will provide alternatives to the EPA landfill cover designs that will work more effectively, be longer lasting, and be easier and less expensive to install in arid and semi-arid climates. It is also working to improve regulatory acceptance of alternative landfill cover designs.

COLLABORATION/TECHNOLOGY TRANSFER

The ALCD is a collaborative effort between SNL, Colorado State University, University of New Mexico, EPA, the Western Governors Association, and the New Mexico State Environment Department, as well as regulatory representatives from other western states.

ACCOMPLISHMENTS

- Received project endorsement by the Western Governors Association and the Committee to Develop On-Site Innovative Technologies. Past studies have shown that the likelihood of regulatory acceptance is the key determining factor in choosing environmental remediation technology. Recognizing this, regulators from most of the western states, as well as EPA, have been included from the beginning in working with the ALCD, increasing the possibility of this technology's acceptance.

TTP INFORMATION

Alternative Landfill Cover Demonstration technology development activities are funded under the following Technical Task Plan (TTP):

TTP No. AL26LF41, "Landfill Containment Systems for Arid Sites"

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Dwyer, S.F. "Alternative Landfill Cover Demonstration," *Landfill Closures: Environmental Protection and Land Recovery*, Geotechnical Special Publication No. 53. Presented at Annual ASCE Convention, San Diego, California (1995).

7.2 SUBSURFACE BARRIER-EMPLACEMENT DEVELOPMENT

TECHNOLOGY NEED

The state of the art for emplacement of subsurface barriers in near-surface soils lies primarily with vertically-emplaced barriers. Subsurface horizontal to subhorizontal barriers that retard vertical, mass movement are not currently employed in civil engineering applications.

TECHNOLOGY DESCRIPTION

The Subsurface Barrier-Emplacement Program, as shown in Figure 7.2-1, consists of placing a relatively impermeable barrier beneath an existing waste site. The barrier, which is composed of a grouting material, has to be emplaced without disturbing the waste form. Two emplacement technologies have been tested: permeation and jet grouting. Permeation grouting injects a low-viscosity grout into the soil at low pressure, filling the voids without significantly changing the soil structure or volume. In contrast, jet grouting injects grout at high pressure and velocity. This action completely destroys the soil structure. The grout and the soil are intimately mixed, forming a homogeneous mass. Initially, feasibility of each technique was evaluated, followed by evaluation of design parameters, such as borehole separation, depth, limitations, etc.

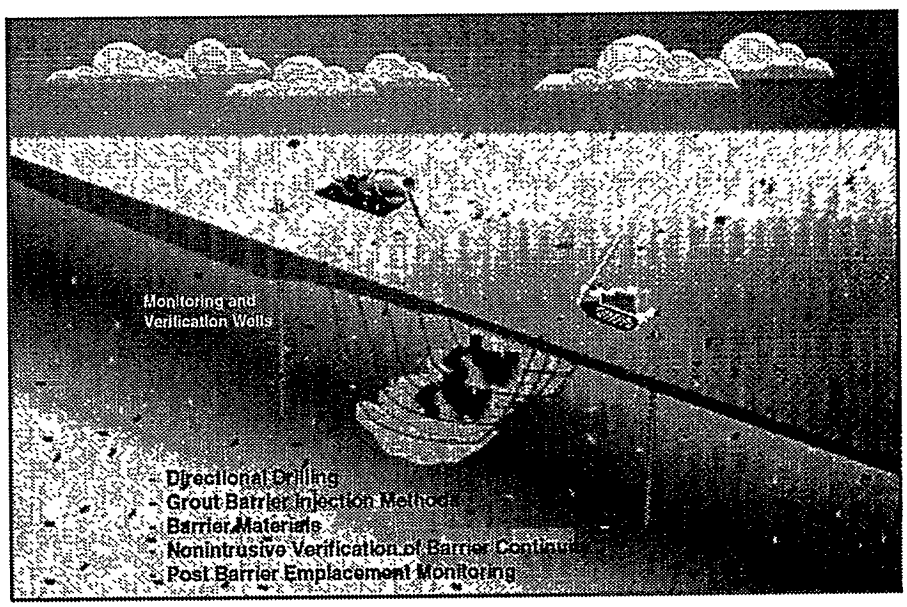

Figure 7.2-1. Subsurface Barrier Emplacement.

Benefits

The anticipated benefits of installed barriers are that the waste volume will remain fixed, allowing additional time to develop remedial treatments. In some instances, the remediation alternative may be enhanced by the installed barrier. In addition, the timing of cleanup becomes less critical.

Collaboration/Technology Transfer

The industrial partner is Applied Geotechnical Engineering and Construction, Inc., a small spin-off company from Westinghouse Hanford Company. They have a very strong interest in the success of subsurface barriers since they are based in Richland, Washington, and have many contacts and tremendous knowledge regarding the needs of Hanford and EG&G Idaho.

Accomplishments

- Completed report/literature review summarizing the technological aspects of all system components required for demonstrating a subsurface barrier emplacement.
- Completed field-scale permeation grouting experiment. Field-testing consisted of grouting in vertical and horizontal boreholes using four different barrier materials. The barrier materials used were two ultra-fine cements, a mineral wax/bentonite mixture, and a sodium-silicate grout. Numerous nonintrusive geophysical techniques were used to identify where the grout flowed. Geophysical techniques included: cross-hole seismic tomography, ground-penetrating radar, electromagnetic induction, neutron probe, and downhole-temperature logs. Finally, the cementitious-grout site was excavated, exposing the grout. Observations were compared with the crosshole-tomography results. Comparisons were quite favorable, but the geophysical techniques are still limited in that they can only identify grout masses, but not flaws in the continuity of the grouted soil.
- Completed field-scale jet-grout demonstration employing a variety of shapes, multiple materials. Installed configurations include v-trough, cone, and rectangular monolith. Again, geophysical techniques were employed to image subsurface grout bodies. The preliminary results again indicate that current geophysical techniques are inadequate to verify the continuity of a grout barrier.

- Completed field-scale jet-grout demonstration at Hanford, Washington, 400 Area. Emplaced a cone-shaped, close-coupled barrier beneath a simulated waste form. Barrier materials include cement and a high-molecular polymer. The barrier integrity was verified using nonintrusive, geophysical techniques; gas tracers; and a liquid-flood test. Intrusive excavation will be done for comparison to nonintrusive verification techniques.

TTP Information

Subsurface Barrier-Emplacement Development technology development activities are funded under the following TTP:

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7.3 DEVELOPMENT OF CAPILLARY-BARRIER DESIGN TOOLS

TECHNOLOGY NEED

Surface covers are an important component in the isolation strategy of waste management methods. Landfills, surface impoundments, waste piles, and some mine tailings are required to be covered with an engineered cover, or cap, upon closure. Conventional covers can be expensive, difficult to construct, and of questionable long-term performance. Capillary barriers, consisting of fine-over-coarse soil layers, have been suggested as an alternative component for surface covers. However, they have not been widely applied, and their performance has not been fully demonstrated. Although a relatively simple configuration, a capillary barrier should result in a long-lived, easily constructed, and low-cost barrier, compared to many conventional cover systems. Technical guidance documents and design tools exist for conventional covers, but no comparable guidance tools exist for capillary barriers. Capillary barriers are not included in the EPA Hydraulic Evaluation for Landfill Performance computer program that allows designers, regulators, and permitters to evaluate and compare covers easily.

TECHNOLOGY DESCRIPTION

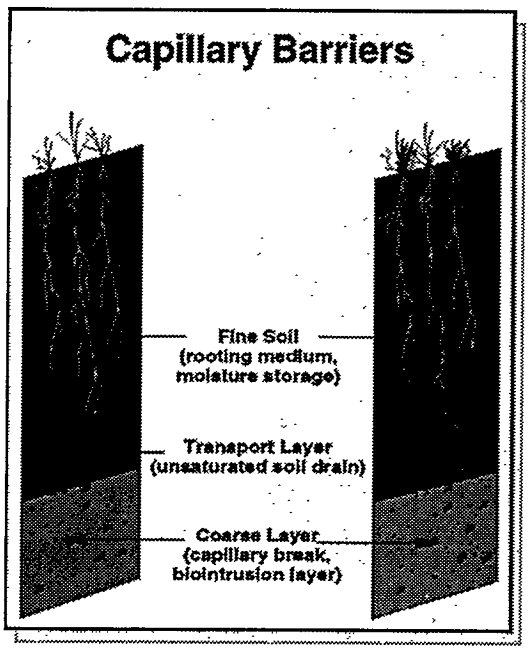

Figure 7.3-1. Capillary Barriers.

The overall objective of this project is to increase consideration of capillary barriers, displayed in Figure 7.3-1, as components of surface cover designs in many landfill closures, by comparing the performance of capillary barriers to conventional designs. Project goals include developing a numerical-analysis tool for capillary barriers based on the existing model for conventional barriers and preparing a technical guidance document comparable to those available for conventional covers. This project involves the following three subtasks.

Evaluate Capillary-Barrier Performance Data

Field experiments have particular relevance because of the scale and climatic variations that allow performance inferences to eventual full-size applications. A number of western states have had capillary barriers constructed on experimental sites. The results from these experiments will be compiled and evaluated to draw general and specific conclusions regarding capillary-barrier performance. The compiled data will be used to evaluate various predictive methods.

Assess Methods to Predict Capillary-Barrier Performance

Important questions remain about the ability of numerical models to accurately predict the behavior of capillary-barrier systems. The output of these simulations is dependent on the structure of the codes, material models used, parameters assumed for the material models, and details of discretization. A number of codes are theoretically capable of simulating capillary-barrier performance. Each will be evaluated for its ability to model capillary barriers. Ease of use, computational time and efficiency, documentation, and other factors will also be considered. A preferred code will be selected.

The approach to determining capillary-barrier equivalency would be improved if capillary-barrier performance could be simulated within the Hydraulic Evaluation for Landfill Performance computer program. In this way, only a single numerical model would be used, and the approach could be more readily applied.

Develop General Design Guidance

Capillary-barrier performance and design for many climates and conditions will be investigated using the equivalency approach. Laboratory testing will be conducted to develop ranges of material properties appropriate for storage, transport, and coarse layers. Design parameters, such as the number of layers, properties, thicknesses, and other quantities, will be specified. A technical design guide, usable by engineers and permit writers, will be published.

BENEFITS

A capillary barrier costs less than a conventional barrier because it emphasizes use of natural processes such as vegetative evapotranspiration (removing water from soil by means of evaporation from plants). It is also more stable because it emphasizes use of natural materials and configurations, which implies longevity. A capillary barrier retains more water than undisturbed topsoil. This condition encourages plant growth, which in turn limits erosion and removes water from soil.

The simple configuration of a capillary barrier also should result in a lower cost than most other cover systems. These costs are currently determined on a case-by-case basis because of construction material availability and design requirements at various site locations.

Collaboration/Technology Transfer

This is a new project; therefore, collaboration/technology transfer information is not available at this time.

Accomplishments

As this is a new initiative, accomplishments will be discussed in future issues of this publication.

TTP Information

Development of Capillary Barrier-Design Tools technology development activities are funded under the following TTP:

TTP No. AL26LF41, "Landfill Containment Systems for Arid Sites"

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Bibliography of Key Publications

None at this time.

7.4 GEOSYNTHETIC MEMBRANE MONITORING SYSTEM

TECHNOLOGY NEED

Geosynthetics are used extensively in landfill liners and covers. This use leads to questions regarding the stability of the geosynthetics in response to stresses and strains induced by subsidence, slumping, and water accumulation. A significant need arises to monitor the response of a geosynthetic liner. This proposal describes the development of a prototype monitoring system to address these needs. Since the use of geosynthetics is widespread, and monitoring systems are lacking, the commercial potential for this technology is tremendous.

TASK DESCRIPTION

This project, which started in the autumn of 1995, covers the development of a prototype monitoring system, as shown in Figure 7.4-1, to address the need to monitor barriers used for landfill sta bilization. This project is divided into two subtasks (D1 and D2).

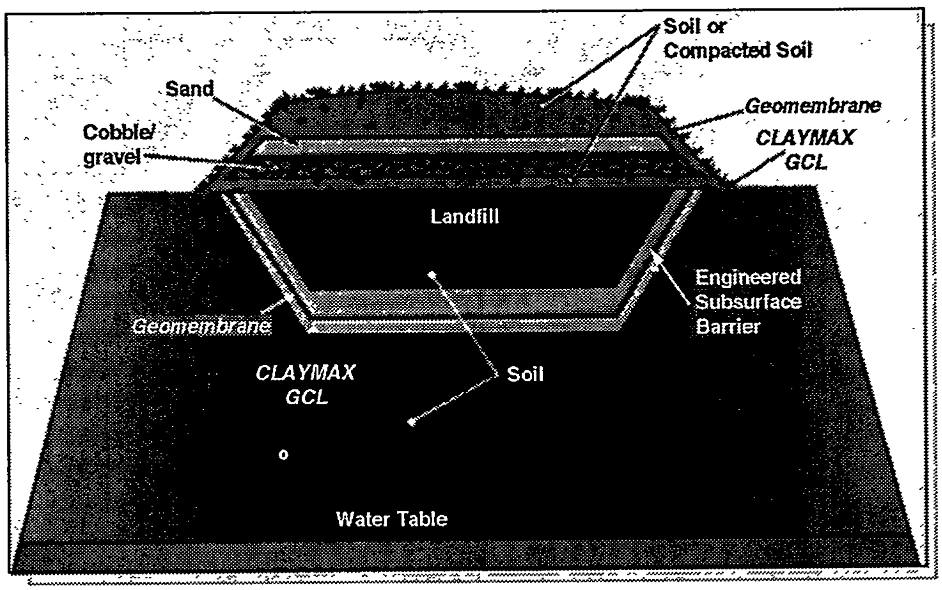

Figure 7.4-1. Geosynthetic Membrane Monitoring System.

Subtask D1: This task includes development of a sensor system, primarily based on optical fibers, and development of the technology used to incorporate the sensors into a geosynthetic membrane. Primarily, these sensors will be designed to measure strains experienced by the geosynthetic membrane.

This task consists of: (1) collaboration with the commercial partner to fabricate membranes with imbedded sensors; (2) selection, development, and laboratory-scale testing of fiber optic sensors for the geomembrane monitoring system; (3) development of constitutive and numerical models to predict geosynthetic membrane behavior; and (4) development of a field-scale testing program to demonstrate and validate the monitoring system.

Subtask D2: This task represents the parallel development of sensors that measure moisture content and chemical properties. These sensors will be monitored by a grid of fiber optics or electrically conductive fibers that are incorporated into the geosynthetic membrane system. This task consists of: (1) selection, development, and lab-scale testing of alternative sensors; and (2) development of an implementation plan to scale up these sensors to the field scale, and incorporate the sensors in a field-scale geomembrane.

BENEFITS

Cost-Benefit Analysis

This system is based on simple, physical principles, and is expected to add less than 20 percent to the cost of the geomembrane system.

Risk Evaluation

A significant need exists in environmental restoration to monitor the response of a geosynthetic liner, since there are significant questions regarding the stability of the geosynthetics in response to stresses and strains induced by subsidence, slumping, and water accumulation.

COLLABORATION/TECHNOLOGY TRANSFER

The Geosynthetic Monitoring System is a collaborative effort between SNL, the University of Missouri-Columbia, the University of New Mexico, and a large manufacturer of geosynthetics who asked to remain unnamed until completion of the Fiscal Year 1996 (FY96) testing.

ACCOMPLISHMENTS

- Measured temperature distribution within membranes that are extruded and laminated. Utilized the technique to measure the temperature distribution at the production scale, using the manufacturing line at the industrial partner's site.
- Completed preliminary analyses of the mechanical behavior of geomembranes. These analyses, which guide the selection and development of sensors, suggest that the membranes begin to fail at 5 percent strain.

- Incorporated fibers with sensors with the manufacturing of a geomembrane at near full-scale at the industrial partners test facility. The usability of the sensors after the manufacturing process is currently being analyzed in the laboratory.
  - Performed initial bench-scale test with fiber-optic sensors imbedded in laminate polyethylene at SNL. Placed laminate and sensors in a load-from-type device, and successfully monitored the deformation of the laminate by the fiber-optic-strain sensor.
  - Submitted patent application for SMART geomembrane monitoring systems.
  - Completed bench-scale test of laminated polyethylene with optic fiber sensor.
  - Initiated large-scale, proof-of-principle tests of the manufacture of an extruded membrane with an imbedded-fiber sensor.

TTP INFORMATION

Geosynthetic Membrane Monitoring System technology development activities are funded under the following TTP:

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7.5 LANDFILL ASSESSMENT AND MONITORING SYSTEM

TECHNOLOGY NEED

The system being developed includes all of the technologies for characterizing, monitoring, and remediating hazardous and mixed-waste contamination beneath landfill sites. More than one technology is usually required for adequate assessment and monitoring of hazardous and mixed-waste sites. Often, these technologies are used in sequential fashion, with little thought given to the synergy and savings in cost and time that can be gained by using an integrated system with compatible and complementary technologies.

Several components are necessary to implement a systems approach to site assessment and monitoring. These include technologies that are: (1) appropriate and suited for the site-specific conditions and needs of the project, (2) able to ensure that the technologies are compatible and complementary so that they support each other, and (3) selected and integrated into an optimum suite of technologies to adequately perform a job. The objective of the Landfill Assessment and Monitoring System (LAMS) is to ensure that the technologies developed are adequate and appropriate for their intended use, and that a systems approach is used, whenever possible, to maximize data gathered and minimize costs, worker exposure, and time expended for assessment and monitoring.

TECHNOLOGY DESCRIPTION

The LAMS is a method to assess hazardous and mixed-waste contaminants, sources, and their migration beneath landfills. The steps involved in this method are illustrated in Figure 7.5-1. The emphasis of the system is on minimally intrusive technologies and downhole sensors, when possible. The system focuses on using the best of available and emerging technologies, with minimal development work.

The LAMS is envisioned to be a start-to-finish system for landfill assessment, using compatible, complementary, and integrated technologies. The result is a savings in cost and time. The LAMS consists of five separate subsystems: (1) screening and sampling-optimization techniques, (2) innovative drilling technologies, (3) on-site analysis and in situ sensors, (4) subsurface monitoring technologies, and (5) data evaluation and risk-analysis techniques. In some instances, technologies may be combined to produce hybrid systems, such as directional boring and downhole sensing. The LAMS approach employs minimal or nonintrusive assessment, safer directionally drilled access, measurement while drilling, sample optimization strategy, membrane liners, in situ sensors, and on-site analyses.

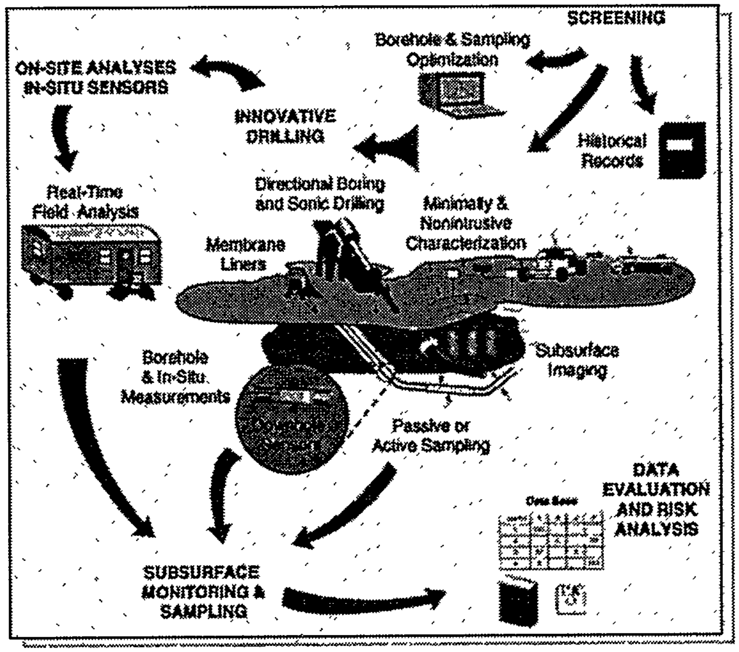

Figure 7.5-1. Landfill Assessment and Monitoring System.

An additional emphasis of the LAMS is on long-term monitoring, as this aspect of remediation and containment has become more important. Monitoring of active, in situ remedial actions, as well as post-closure and containment effectiveness, is being pursued. These activities include a Verification and Monitoring Options Study to evaluate research options needed in this area. In addition, field studies to monitor in situ chromium reduction, electrokinetic removal of chromium in unsaturated soils, subsurface barrier performance, and integrity of landfill caps and covers are also being conducted.

When individual technologies are used in conjunction with each other as a system, several advantages result. These include savings in time and cost. Also, a focus on minimally intrusive and in situ techniques reduces the risk of worker exposure to wastes or contaminated media. The LAMS provides better resolution of site characteristics, contamination sources, vertical and aerial extent of contaminant plumes, and monitoring of remedial and post-closure actions. Primary goals of the LAMS are rapid transfer and commercialization of these technologies throughout the DOE complex and the private sector.

COLLABORATION/TECHNOLOGY TRANSFER

Principle Investigator oversight and direction are important elements of the LAMS. The project involves assessment and monitoring Principle Investigators and their partners. These include SNL; Argonne National Laboratory; Pacific Northwest National Laboratory; Idaho National Engineering Laboratory; GeoCenters, Inc.; Charles Machine Works, Inc.; ConSolve, Inc.; Scitek

Corporation; Radiometer America Corporation; Science & Engineering Associates, Inc.; Hydrogeochem, Inc.; Allied Signal; and New Mexico State University.

The LAMS has produced numerous successful technology transfers through partnerships, commercialization, demonstrations, implementation at environmental restoration sites, and reports and presentations. Technology transfer plans include participation in a market analysis, continued interactions with environmental restoration personnel and regulators, presentations, participation in workshops or short courses, and site tours.

ACCOMPLISHMENTS

- Performed the Target Verification and Calibration task at SNL Technical Area II. This serves as an example of LAMS cost-savings potential. Eliminated numerous targets and areas of potential concern. It is estimated that this task, using the LAMS approach, saved over $500 thousand.
- Modified the Multi-Sensor Analysis Program for Environmental Restoration software for use on a field-portable personal computer. This system was demonstrated to and used by SNL Environmental Restoration site managers in FY95.
- Completed the Verification and Monitoring Options Study in FY95. This study reported on the current research needs for in situ monitoring and verification of containment actions and performance, contaminant remediation processes, and post-closure within the vadose zone.

TTP INFORMATION

Landfill Assessment and Monitoring System technology development activities are funded under the following TTP:

TTP No. AL26LF42, "Verification/Monitoring of Containment and Other Remedial Actions"

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7.6 Verification/Monitoring of Containment Systems Using Tracer Technology

Technology Need

In situ barrier materials and designs are being developed for possible containment options for leaking landfills, underground storage tanks, and other types of hazardous waste that must be contained. The intent of these designs is to prevent the movement of contaminants in either the liquid or vapor phase, essentially buying time until a decision is made on the appropriate remedial option. One possible option would be long-term containment. Quantifying the integrity of in situ barriers is necessary, but difficult. The need exists for a minimally intrusive, yet quantifiable, method for assessment of a barrier's integrity after emplacement, and monitoring of the barrier's performance over its lifetime. Existing surface-based and borehole geophysical techniques do not provide the degree of resolution required to assure the formation of an integral in situ barrier.

Technology Description

SNL and Science and Engineering Associates, Inc., are developing a quantitative, subsurface barrier-assessment system, SEAtrace™, using gaseous tracers. As depicted in Figure 7.6-1, the system integrates an autonomous, multipoint soil vapor sampling and analysis system with a global optimization modeling methodology to pinpoint leak sources and sizes in real time. SEAtrace™ is applicable to impermeable barrier emplacements in the vadose zone, providing a conservative assessment of barrier integrity after emplacement, as well as a long-term integrity monitoring function.

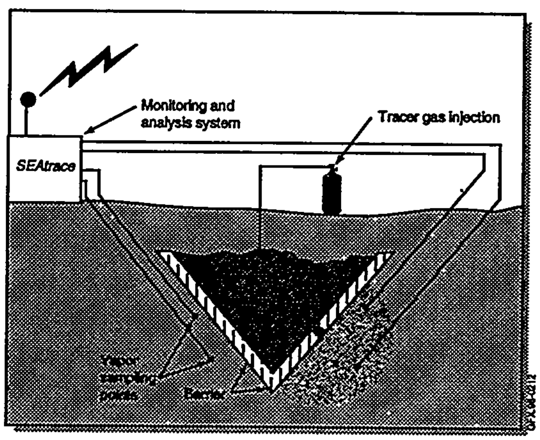

Figure 7.6-1. Barrier Test Configuration.

The system uses inexpensive and nonhazardous gaseous tracers injected inside the contained volume of a barrier to quantify the location and size of any leaks in the barrier. The vapor-sampling-point installation, which allows the collection of soil-gas samples from multiple points around the barrier installation, can be accomplished with conventional drilling or direct-push techniques. The system uses a field-proven, soil-gas analyzer in a sampling system that can monitor many sample points with relatively high time resolution. A rigorous global optimization code analyzes the measured tracer concentration histories and searches multidimensional "space" to simultaneously find the best fit for all input parameters. It determines the location and size of the breach(es), the time the leak(s) began, and the uncertainties in these determinations.

BENEFITS

The SEAtrace™ system uses gaseous tracer injection; in-field, real-time monitoring; and real-time data analysis to evaluate barrier integrity in the unsaturated zone. The design has the following features:

- The approach is conservative in that it measures vapor leaks in a containment system whose greatest risk is posed by liquid leaks.
- It is applicable to any impermeable barrier emplacement technology in the unsaturated zone.
- The methodology will quantify both the leak location and size.
- It uses readily available, nontoxic, inexpensive, nonhazardous gaseous tracers.
- The vapor injection and sampling points can be emplaced by direct-push techniques (such as Geoprobes) or the rapid ResonantSonic™ technique, avoiding excessive drilling costs and secondary waste generation.
- The methodology for unfolding the soil gas analysis data in real time uses a rigorous global optimization technique which accommodates uncertainties in field data.
- In addition to assessing initial barrier integrity, the system can also provide long-term monitoring of contaminant soil gases for surveillance of the containment system's performance over time.

COLLABORATION/TECHNOLOGY TRANSFER

This project is a collaborative effort with Science and Engineering Associates, Inc. The system has evolved from collaborative research conducted by Science and Engineering Associates, Inc., and SNL on the tracer gas and barrier testing research-development program. Science and Engineering Associates, Inc., will be commercializing the tracer monitoring and verification technology.

ACCOMPLISHMENTS

- Determined applicability of tracers as a verification method for field-scale, monolithic barriers. The bench-scale tests demonstrate that the SF^6 tracer diffuses through the Portland cement/soil samples on a time scale that makes it a possible candidate for verification of the integrity of this type of barrier. Additionally, the studies have shown that differences in the diffusion rate of the SF^6 through perfect and cracked Portland cement/soil samples, as well as air, can be quantified. This makes the SF^6 tracer technology a viable validation tool for the barrier verification.
- Completed testing on the Computer Methodology to locate and size leaks in subsurface barriers. The methodology locates and sizes leaks using measured concentration histories of soil gases (tracers) and spherical diffusion. It employs initial tracer-gas concentration, monitoring location, and tracer-gas concentration histories at monitoring locations to conduct the reverse calculation to determine the leak location, size, and time the leak started. The estimation of the size and location of a leak from measured concentration histories is an inverse problem of multiphase flow in porous media. The details of the functional design have been based on an idealized leak geometry of spherical diffusion in a homogeneous medium. This geometry was chosen as it was considered to be the most applicable to subsurface barriers. If a breach is small relative to the surface area of the barrier, the tracer gas will tend to diffuse away from the source in a spherical fashion. Global Optimization is used to reverse calculate flow and transport processes to understand unknown properties and transport conditions. This is accomplished with numerical analysis, depending upon which would allow near real-time assessment of recorded gas data. It determines the location and size of the breach(es), the time the leak(s) began, and the uncertainties in these determinations. Investigators conducted a series of tests on the computer code using simulated data to assess the accuracy of the methodology. Tests determined the leak location to within 0.1 meter (if there is no uncertainty in the location of the barrier wall or the monitoring point; if there is a 10 percent uncertainty, then one can determine leak location to within 1 meter), leak size to within approximately 10 percent, and time the leak started to within approximately 5 percent (one day in a 30-day monitoring period).

TTP INFORMATION

Verification/Monitoring of Containment Systems Using Tracer Technology technology development activities are funded under the following TTP:

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8.0 Low-Level Waste/Other Contaminants in Humid Environments Product Line

The primary objective of this Product Line is to develop needs-driven technologies for the U.S. Department of Energy (DOE) complex. Current emphasis is on the in situ containment and ex situ treatment systems for implementation in the humid environment. This is accomplished by developing new and innovative cover systems, original materials, and installation techniques for constructing in situ barrier systems, and ex situ reduction and treatment of organic wastes. Barrier construction materials and methodologies are being developed to provide long-term stability, easy repairs, and improved constructability.

Containment may be used in two ways: (1) as a long-term measure for final remedial action (waste-site closure), or (2) as an interim action to prevent contaminant migration, pending further remedial decisions, or during an in situ remediation process. To achieve maximum deployment potential for containment systems, monitoring systems will be very important.

Surface containment systems in humid environments are typically constructed of locally available, low-permeability clays. Clays are subject to expansion and contraction, which cause desiccation and have a negative impact on hydraulic performance characteristics. Improved materials and construction methodologies can increase performance and reduce closure-system failure. These innovative closure-system designs are being pursued and implemented under this Product Line. Additionally, repair technologies to mitigate closure-system failure are being developed for future implementation.

Emplacement of subsurface barriers (both horizontal and vertical) controls water infiltration and reduces contaminant release to the environment. These barriers are typically grout material, such as concrete and soil-bentonite, or cement-bentonite slurry materials. Additional innovative formulations, using both natural and synthetic materials, are used for permeation grouting. Typically, this emplacement is near the surface and vertical. Subsurface horizontal to subhorizontal barriers that retard mass movement are not currently employed in civil engineering applications. New technology initiatives are geared toward the development of superplastic grouts and soil-cement of significantly superior mechanical, electrical, and durability properties.

The ex situ treatment work involves the reduction and treatment of radiologically contaminated vegetation and the oxidation treatment of organic contaminants.

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8.1 SLURRY CARBONIZATION OF ORGANIC WASTES

TECHNOLOGY NEED

New solutions for recycling and converting the nation's waste into usable products are needed. This task will develop technical-basis information for commercialization of the "slurry carbonization" process. Slurry carbonization is a new "waste-to-energy" process which converts municipal solid waste (MSW) into a high-density slurried fuel. A key advantage is the removal of chlorine that could otherwise produce dioxin and furan emissions when combusted. In addition, the slurried fuel has a significantly higher energy density than the waste feed does.

TECHNOLOGY DESCRIPTION

Slurry carbonization offers the potential of diverting a significant portion of the MSW from landfills. The technology also presents to the MSW industry a cost-efficient method of converting waste to energy with greatly reduced emissions. With the slurry carbonization process, MSW would be beneficially used as a clean, renewable fuel resource. With MSW, slurry carbonization is used in conjunction with an established resource-recovery process that separates recyclable material (more specifically, the inorganic fraction) from the collected MSW through dry or wet-process technologies.

After being subject to resource recovery, the remaining MSW is often considered a refuse-derived fuel (RDF). RDF is a heterogeneous feedstock with a low heating value and a high chlorine content. Because of these characteristics, RDF producers often have a very difficult time finding an accepting market. EnerTech proposes to mix this RDF with water to form a pumpable slurry at 10 to 15 percent of weight solids with a heating value of 2,300 joules per gram. Processing as a fluid slurry, instead of a bulky solid, saves dramatically on operating and capital costs.

The feed slurry, now 10 to 15 percent solids, will be pumped and pressurized above the saturated steam pressure curve in order to prevent the slurry from boiling, and to minimize system thermal-energy inputs. Using heat exchangers, the temperature of the pumpable slurry will be raised to approximately 275 to 330 degrees Celsius. At this temperature and pressure, the slurry will molecularly rearrange, with the splitting off of carbon dioxide; reduction in particle size; and extraction of chlorine, sulfur, and slag-forming compounds. After partial cooling through the same set of heat exchangers, the slurry can be partially dewatered and concentrated to approximately 40 to 60 percent of weight solids, with a pumpable viscosity and an energy density of 13,000 to 18,000 joules per gram. By coal-water-fuel standards, this is considered to be an excellent slurry fuel. The resulting liquid fuel can be combusted directly in pulverized coal, oil, or grate boilers, and requires only 20 to 30 percent excess air for effective carbon burnout.

BENEFITS

In summary, slurry carbonization will produce a homogeneous liquid fuel (actually micron-size solid particle dispersed in water) from a bulky heterogeneous RDF. The homogeneous carbonized slurry fuel has improved combustion characteristics, including improved heating value (even when compared to the dry RDF), and can still be pumped as a liquid. It will also extract chlorine and ash concentrations, control moisture content of the product fuel, minimize excess air during combustion of the product fuel, and reduce air pollution control equipment requirements. Also, the liquid fuel produced from slurry carbonization will be readily marketable because it is in an excellent feed form for efficient combustion in industrial oil boilers; utility pc-boilers; state-of-the-art, pressurized, fluidized-bed combustion; or pressurized gasification.

COLLABORATION/TECHNOLOGY TRANSFER

This task is funded via a Cooperative Research and Development Agreement (CRADA) between Westinghouse Savannah River Company (WSRC) and EnerTech Environmental, Inc. EnerTech is commercializing their slurry carbonization process, and is seeking funding from investors and other government sources to support a pilot-scale demonstration. This demonstration may be conducted at the Savannah River Site (SRS), in conjunction with the Three Rivers Solid Waste Technology Center. This effort would culminate in the design of a commercial unit.

ACCOMPLISHMENTS

- Demonstrated the process, conceptually, with funding from DOE, the National Institute of Standards and Technology, the U.S. Environmental Protection Agency (EPA), the National Science Foundation, and commercial investors
- Demonstrated chlorine extraction rates up to 98 percent

TTP Information

Slurry Carbonization of Organic Wastes technology development activities are funded under the following technical task plan (TTP):

TTP No. SR16LF51, "Ex Situ Waste Treatment and Processing Systems"

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Bibliography of Key Publications

None at this time.

8.2 Emerging Continuous-Emissions Monitoring Technologies

Technology Need

The incineration and combustion industries need to identify and conduct long-term demonstration testing of emerging technologies for continuous monitoring of hazardous compounds in emissions from thermal treatment facilities. Continuous-emissions monitoring (CEM) of hazardous and mixed-waste thermal-treatment processes is desired for verification of emission compliance, process control, and public safety perception.

Technology Description

CEM of mixed-waste thermal processes is desired for both verification of emissions compliance and process control. Species of particular interest include heavy metals, particulates, radionuclides, and organics. Continued advancement and future implementation of these technologies require pilot-scale demonstrations in actual process environments.

The objectives of this test program include identifying two or three emerging CEM technologies ready for extended testing (30 to 60 days) in full-scale waste-treatment facilities. Several commercial full-scale hazardous-waste incinerators have been offered for these tests. The next step is selection from unit technologies ready for extended demonstration tests to determine reliability and durability of these monitors in a process environment. These tests will include long-term performance testing, along with limited EPA Reference Method verification and calibration, and zero-drift measurement.

Benefits

Results from this program will be used to assist CEM technology developers in bringing their technology to the marketplace, provide insight on current state of the art to potential CEM technology end users, and assist regulatory agencies in evaluating applicability of these technologies to future regulatory requirements.

Collaboration/Technology Transfer

Programs are currently being funded by DOE, EPA, and private industry to develop these technologies and systems. Each CEM developer will be responsible for, and actively engaged in, bringing its specific technology to the marketplace.

Accomplishments

- Developed a demonstration protocol to evaluate CEM technologies against defined criteria and EPA reference methods.
- Performed a series of short-term (five days) technology demonstration tests at the EPA Incineration Research Facility, a pilot-scale, rotary-kiln incinerator. This program revealed potential advantages and disadvantages with each technology and identified issues that could be encountered in a process environment. In addition to short-term performance information, these technologies require long-term performance testing to evaluate their suitability to real process environments.

TTP Information

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None at this time.

8.3 BIOMASS REMEDIATION

TECHNOLOGY NEED

There is a critical need at SRS (and other DOE sites) to develop a treatment technology that will stabilize and reduce the volume of contaminated vegetation that must be disposed. A treatment method is needed that will minimize the potential for personnel exposure during treatment and will result in a chemically and physically stable residue that can be buried in a landfill.

SRS contains approximately 40,000 cubic yards of radiologically contaminated vegetation growing on waste sites. Although this material must be disposed of as part of the regulatory-directed, waste-site-cleanup activities, at present there is no approved method for dealing with this material. Reduction of the material by physical or biological means would result in a greatly reduced amount of waste material that would have sufficient physical and chemical stability to be buried at the existing SRS waste site, or the material could be characterized for disposal at another approved waste site.

TECHNOLOGY DESCRIPTION

Both physical and biological methods could be developed for volume reduction and stabilization of contaminated vegetation. Physical methods include contained burning and collection of smoke and ash; grinding or chipping; followed by burial, or stabilization, of ash or chips in grout.

Biological reduction of volume would use microbial (primarily fungal) decay. Decay can be optimized by manipulating the environment in which the decay takes place, and adding microbes that are best suited for decaying vegetation. The environment can be optimized by: (1) control of moisture content by composting, irrigating, or enclosing in a suitable bioreactor; (2) fertilization or other addition of nutrients; (3) passive or active temperature control; and (4) manipulation of vegetation size (chipping or grinding).

Combinations of physical and biological treatments will be studied to determine the tradeoff between speed of treatment, potential for personnel exposure during treatment, and cost. With this information, it should be possible to choose the best treatment for individual cases.

The principal objective of this project is to evaluate and develop processes to treat radiologically contaminated vegetation at SRS in a manner that minimizes handling, processing, and treatment costs. Treatments will involve volume reduction of biomass, along with isolation and containment of radionuclides.

Benefits

Methods of vegetation treatment will be developed that can optimize the disposal of contaminated vegetation within the framework of regulatory requirements by minimizing personnel exposure, expensive handling of materials, and contamination of expensive equipment; and allowing burial of a stable residue on the waste site.

Collaboration/Technology Transfer

Collaborations have been initiated with the U.S. Forestry Service to further evaluate technologies and the technology need. The successful development of a superior process for remediating contaminated vegetation would be patentable and have numerous applications at other DOE sites and worldwide.

Accomplishments

As this is a new initiative, accomplishments will be discussed in future issues of this publication.

TTP Information

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None at this time.

8.4 WET CHEMICAL OXIDATION OF CONTAMINATED ORGANICS

TECHNOLOGY NEED

This technology has been developed specifically to address the needs at SRS, Rocky Flats, U.S. Department of Defense (DOD) facilities, commercial nuclear operations, hazardous waste generators in private industry, and small-volume generators such as university and medical laboratories. Of particular interest to the DOE complex is the destruction or decontamination of solid, transuranic (TRU)-contaminated, job-control waste (a heterogeneous mixture of plastics, cellulose, lead, rubber, resins, solvents, oils, steel, ceramics, HEPA filters, etc.). DOE has more than 1.2 million cubic meters of mixed low-level and mixed TRU waste. When this is added to the widespread needs of thousands of DOD installations (more than 200 million pounds of conventional munitions alone), the appropriateness of this process is clear. More specifically, Rocky Flats has 14,000 kilograms of TRU-contaminated solid waste, and the nuclear-power industry generates 180,000 cubic feet of contaminated ion-exchange resins each year.

TECHNOLOGY DESCRIPTION

The purpose of this program is to demonstrate a nitric-phosphoric acid destruction technology that can treat a heterogeneous waste by oxidizing the solid and liquid organic compounds while decontaminating noncombustible items. The process will operate at temperatures below 200 degrees Celsius, atmospheric pressure for most materials, and moderate pressures (less than 20 psig) for complex organics. It will convert hazardous organics, and organic substrates, to gases and inorganic salts, while simultaneously performing a surface decontamination of the noncombustibles. This development will produce a complete, closed-loop, engineering-scale process which generates little or no organic residue, and isolates radioactive and other hazardous metals from solutions as an iron-phosphate glass.

BENEFITS

The advantages of this process are that it is very simple (low-tech), uses common and relatively inexpensive reagents, performs at relatively low temperature and pressure, is general purpose (can destroy many types of "pure" organic materials and decontaminate nonorganic materials), and produces solutions that are compatible with normally used processing equipment. For organic wastes, the original waste volume can be reduced to near-zero percent. Radioactive-contaminated materials can be downgraded to low-activity waste. The process catalysts (nitric acid and palladium) are either not consumed, or can be regenerated, and should be resistant to a radioactive environment. If interfaced with an acid-recovery system that converts the produced NO^2 and NO gases back to nitric acid, the net oxidizer would be oxygen (from air), which is cheap and abundant. The acid-recovery system technology is well developed and can be purchased for any scale. Also, the final waste form is one that has been shown to be stable for long-term storage. Scale up should be quick and inexpensive because of the simplicity of the process.

The expected payoff for a successful program will be large for government agencies, particularly DOD and DOE. This technology will provide a simple treatment method for most types of hazardous organics, from lab-scale to production-scale quantities, and offer a relatively inexpensive alternative to incineration. Acid destruction would be a suitable technology for assisting in the cleanup of many DOE Defense Program sites. It will also aid DOD in remediating many of its hazardous and toxic materials. Government labs could install small units in laboratory facilities for the destruction of low volumes of hazardous research materials. The list of applications is seemingly endless because the process can destroy most liquid and solid organics, whether they are plastics, resins, solvents, oils, munitions, propellants, or toxic byproducts.

COLLABORATION/TECHNOLOGY TRANSFER

Because of the broad range of wastes that can be treated using this system, the technology transfer opportunities are many, including DOD and commercial nuclear installations. Discussions are ongoing with several companies who would like to see this technology mature to a successful engineering demonstration. The process is also amenable to treating hazardous organic wastes from low-volume generators, such as medical or university laboratories.

Products transferred to industry could range from data to system designs to development services. The process is robust and should require very few design changes between applications. A new user of the technology should not be faced with any significant issues, with the exception of normal regulatory permits. However, each application will have optimum operating conditions that could differ among waste types.

Accomplishments

- Oxidized many different organic components in nitric-phosphoric acid. Materials that have been quantitatively oxidized at atmospheric pressure and below approximately 80 degrees Celsius include neoprene, cellulose, ethylenediamine tetraacetate (EDTA), tributylphosphate, tartaric acid, and nitromethane.
- Decomposed, below 200 degrees Celsius and 20 psig, more stable compounds, such as polyethylene, benzoic acid, oils, and resins. Also, it is already known that phosphoric acid is better at dissolving plutonium oxide than nitric-HF, so decontamination capabilities are inherent to the system. At the same time, the process-chemicals and simplicity of the expected design allow the system to be robust, user friendly, cost effective, and quickly developed. It is also likely that a moderate throughput portable system can be built.
- Developed preliminary pilot-scale designs and initiated mini pilot studies.

TTP Information

Wet Chemical Oxidation of Contaminated Organics technology development activities are funded under the following TTP:

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Bibliography of Key Publications

None at this time.

8.5 MONITORING GEOSYNTHETIC TEST PADS

TECHNOLOGY NEED

Current containment and surface-barrier performance strategies use limited, indirect monitoring techniques, thus precluding early identification of problem areas, and negating early intervention. Development of a performance monitoring system for containment and surface barriers, using nonintrusive technologies to monitor subsurface contaminant and waste transport of remedial activities, is needed.

TECHNOLOGY DESCRIPTION

Closure-cover systems over hazardous waste layers typically require a Resource Conservation and Recovery Act (RCRA) type closure-cover system. This cover system is a multi-layered system with a low-permeability layer as the critical component to minimize infiltration, thus minimizing leachate production. The low-permeability layer component is constructed from a combination of a compacted clay layer and overlain by a geomembrane material. An unstable waste layer, such as a decomposing solid waste layer, poses a direct impact to the structural and hydraulic integrity of the low permeability layer component, namely the compacted clay layer. This lack of stability has led to the development of an alternative flexible and lightweight low-permeability layer, using composite geosynthetic materials. The field performance of this low-permeability layer, using composite geosynthetic materials, is lacking due to rather short development maturity. Long-term field performance of this cover system is needed to identify structural and hydraulic characteristics. SRS has received regulatory approval to install two closure-cover systems using composite geosynthetic materials. The documentation of long-term field performance characteristics is key to ensuring regulatory compliance and identifying solutions for typical potential failure mechanisms/scenarios.

The primary objective is to provide instrumented test platforms to monitor the long-term hydraulic and structural performance characteristics of a composite geosynthetic material closure-cover system, under operational field conditions.

Benefits

Verification of operational requirements and long-term performance characteristics establish the technical baseline for this alternative closure-cover system. This system identifies the parameters needed to develop life-cycle performance evaluations, and provide a low-cost alternative closure-cover system for radiological and other hazardous waste units.

Collaboration/Technology Transfer

The WSRC Environmental Restoration Department is the direct customer for this task and will incorporate results of this activity into current and future operational activities.

Secondary customers are industrial partners for the development/commercialization of monitoring techniques/methods of an alternative closure-cover system configuration, using composite geosynthetic materials.

Accomplishments

- Constructed three field test pads similar to solid waste trenches, using composite geosynthetic materials, and one test pad using natural soil to provide background data. Hydraulic and structural instrumentation in each of the test pads is a combination of embedded instruments and geophysical, nonintrusive monitoring techniques to provide realistic field data and establish the performance baseline of a closure-cover system, using composite geosynthetic materials and its structural and hydraulic performance characteristics.
- Evaluated the monitoring data collected based on operational performance requirements and regulatory guidelines to document an alternative cover-system equivalency to the regulatory configuration.

TTP Information

Monitoring Geosynthetic Test Pads technology development activities are funded under the following TTP:

TTP No. SR16LF52, "Stabilization/Containment Systems"

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BIBLIOGRAPHY OF KEY PUBLICATIONS

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8.6 SURFACE CONTAINMENT SYSTEMS REPAIR

TECHNOLOGY NEED

Compacted clay caps are often utilized for the closure of RCRA and Superfund waste sites. Upon closure, the caps must be periodically inspected for deterioration. Any deterioration detected must be repaired. Several clay-cap degradation mechanisms exist that can cause cracking of the barrier, including desiccation, subsidence, frost action, and biological intrusion. The baseline repair technology involves the excavation of vegetative and drainage layers, followed by the excavation and recompaction of the clay barrier. This baseline technology is an extremely intrusive and costly technology.

TECHNOLOGY DESCRIPTION

The following cost-effective and minimally intrusive cap-repair techniques are currently under evaluation and development:

- Injection grouting of low-viscosity colloidal silica (gel) or polysiloxane (polymer): the low viscosity material will be injected at the interface of the drainage and compacted clay layers (overlaying layers are left in place) so that cracks in the compacted clay layers are sealed. This technology may also have applicability to the repair of flexible membrane liners.
- Geosynthetic clay-liner placement: the vegetative and drainage layers are excavated while the clay barrier is left in place. Then the geosynthetic clay-liner is placed over the areas of cracked clay, and the vegetative and drainage layers replaced.

Laboratory pilot-scale testing of these technologies, as illustrated in Figure 8.6-1, is being conducted in Fiscal Year 1996 (FY96). Field-scale testing at SRS is scheduled for FY97.

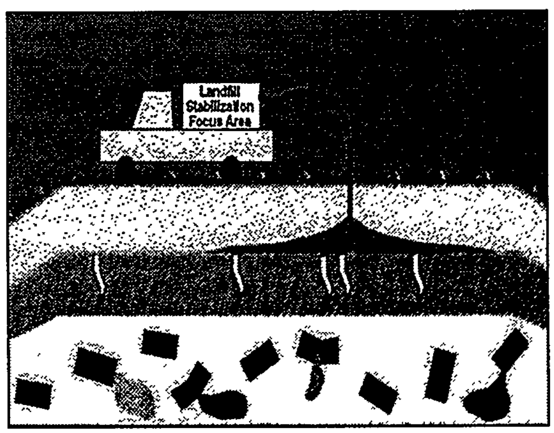

Figure 8.6-1. Surface Containment Systems Repair.

Benefits

Cost-effective and minimally intrusive (in situ) cap-repair techniques will become available for repairing compacted clay caps, and possibly flexible membrane liners.

Collaboration/Technology Transfer

Application of the technology is being developed in collaboration between the Savannah River Technology Center Environmental Sciences Section (as the lead organization), with support from Lawrence Berkeley National Laboratory. A field demonstration of the technology is planned for FY97. The field test will be implemented in conjunction with a grout injection contractor, possibly Bechtel, who will gain direct experience with the technology. Publication of the laboratory and field results in referenced journals and presentations at professional society meetings will transfer the technology to the private sector.

Accomplishments

- Completed selection and characterization of a test-kaolin cap at the SRS Bentonite Mat Demonstration Test Area for the FY97 field-scale demonstration
- Began FY96 laboratory pilot-scale testing, utilizing lysimeters with compacted kaolin layers

TTP Information

Surface Containment Systems Repair technology development activities are funded under the following TTP:

TTP No. SR16LF52, "Stabilization/Containment Systems"

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Moridis, G.J., P. Persoff, J. Apps, B. Freifeld, and K. Pruess. "Field Test of a Subsurface Barrier Technology Using a New Generation of Barrier Liquids: (1) Materials, Site Description, and Preparatory Work," *Eos*, 76(46): F247 (1995).

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Phifer, M.A., D. Boles, E.C. Drumm, and G.V. Wilson. "Comparative Response of Two Barrier Soils to Post Compaction Water Content Variations," *Proceedings of Geoenvironment 2000: Characterization Containment, Remediation, and Performance in Environmental Geotechnics, American Society of Civil Engineers*, New Orleans, Louisiana, p. 591-607 (February 22-24, 1995).

8.7 IN SITU INTRINSIC REMEDIATION OF LANDFILLS

TECHNOLOGY NEED

The purpose of this subtask is to provide biological data that supports intrinsic bioremediation as an acceptable remediation technology for regulators. In order to obtain regulatory acceptance, projections through the modeling of microbiological data of the contaminated areas must be made, and those areas must not extend to potential exposure points. Such a projection must be made based upon quantitative assessments of the rates of in situ bioremediation, hydraulic transport, and any other quantifiable loss or retardation. The accuracy of the projection can be evaluated by the presence, or absence, of the contaminant at the boundary of the projection.

The efficiency of intrinsic bioremediation to contain contaminant migration in groundwater systems can be quantitatively assessed by comparing rates of contaminant transport with rates of biodegradation. If transport rates are fast relative to rates of biodegradation, contaminants can migrate freely with groundwater flow and possibly reach a point of contact with human or wildlife populations. Conversely, if transport rates are slow relative to biodegradation rates, contaminant migration will be more confined, and less likely to reach a point of contact. In either case, the efficiency of intrinsic bioremediation can be assessed by evaluating the presence or absence of contaminant transport to predetermined points of contact. Thus, this assessment includes hydrologic rates of groundwater flow, microbiologic rates of biodegradation, and sociopolitical points of contact.

TECHNOLOGY DESCRIPTION

Intrinsic bioremediation is a risk management option that relies on natural biological processes to contain the spread of contamination from a source. The option is most appropriate when the concentration of contaminants is reduced to regulatory limits, before groundwater discharges to surface water or is collected by a pumped well. This requires that a projection of the potential extent and concentration of the contaminant plume in time and space be made based on historic variations in the contaminant plume, as well as the measured rates of contaminant attenuation. It is incumbent on the proponent of the technology to provide sufficient evidence to demonstrate that the mechanisms of intrinsic remediation will reduce contaminant concentrations to acceptable levels before potential receptors are reached.

In the past, remedial action plans have proposed the intrinsic remediation option based solely on the apparent attenuation of contamination in water from monitoring wells that are distant from the spill. These plans were often criticized because it was impossible to distinguish between the attenuation due to contaminant destruction and the attenuation due to simple dilution in the aquifer, or in the monitoring well. Convincing regulators that the wells with low concentrations of contaminants actually sample the plume of contaminated groundwater has been difficult. This lack of credibility has led to the "one-more-well" syndrome, with excessive investment in a monitoring approach that focuses on the compounds of regulatory concern, but fails to earn the confidence of the regulators.

BENEFITS

By combining ecofunctional enzyme and microbiology data, we will learn not only whether biological activity from different subsurface samples are dissimilar, but also the major groups responsible for the dissimilarity. These data, in combination with data on biodegradation rates, aquifer geochemistry, and soil properties, will provide a very detailed characterization of a contaminant plume. Based on these data, we will be able to recommend more accurate approaches for predicting plume behavior and managing subsurface contamination using intrinsic bioremediation.

COLLABORATION/TECHNOLOGY TRANSFER

University collaboration is ongoing with Clemson University and Oak Ridge Institute for Science and Education.

ACCOMPLISHMENTS

- Completed test plan for Subtask B
- Initiated field intrinsic bioremediation studies
- Selected initial model input parameters
- Submitted the following patent applications:
  - Fliermans, C.B. "Microbial Degradation of Tires for Recycling," SRS-96-0036 (1996)
  - Fliermans, C.B. "Solar Enhanced Intrinsic Bioremediation with Multi Horizontal Wells and Vapor Extraction," SRS-95-015 (1995)

TTP Information

In Situ Intrinsic Remediation of Landfills technology development activities are funded under the following TTP:

TTP No. SR16LF52, "Stabilization/Containment Systems"

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8.8 In Situ Plasma Vitrification

Technology Need

Across the DOE complex, there are a significant number of burial sites and basins containing hazardous chemicals in association with contamination from long-lived radioactive elements. These sites may be soil or sludge materials only, or they may contain buried heterogeneous wastes. Vitrification of these types of wastes generally produces superior waste forms that can contain a hazardous, including radioactive, element in the glass matrix for extended periods of time.

Technology Description

Plasma-arc in situ vitrification involves drilling or punching a shaft opening into contaminated soil to a required depth. This process is illustrated in Figure 8.8-1. A plasma torch or other plasma-generating device may be lowered to the bottom of the hole. The plasma torch is initiated and vitrification begins at the bottom and sides of the hole. After a pool of molten material has developed, the torch is slowly raised, and more material is melted into the bottom. This operation is continued until a column of vitreous material is formed and the contamination has been vitrified. Subsidence of the surface can be about 50 percent, if the complete column is vitrified. If an extended area requires vitrification, an array of shafts may be prepared so that the vitrified columns overlap each other. The offgas from the hole is contained and collected. At the present time, this concept has been tested in large tanks containing soil and simulated debris on a test-bed basis. No field trials have been completed.

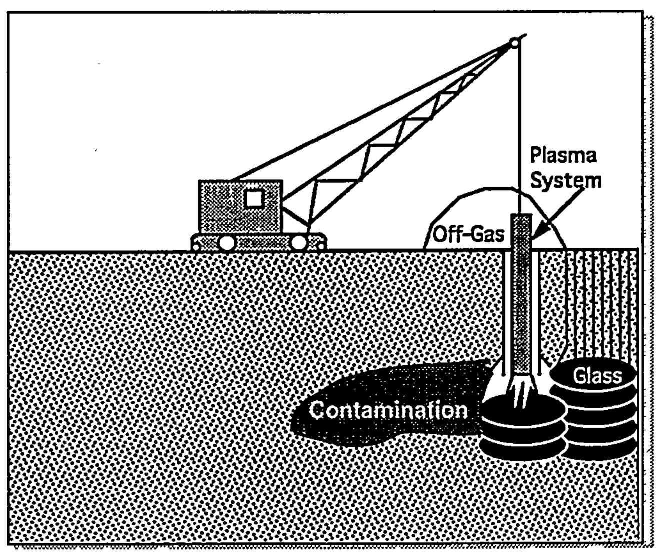

Figure 8.8-1. In Situ Plasma Vitrification.

Benefits

In situ vitrification avoids the excavation costs and material-handling safety concerns associated with ex situ stabilization techniques. Plasma-arc in situ vitrification offers potential cost and safety advantages for contaminated soil stabilization over the existing (joule-heated) in situ vitrification approach. The joule-heating approach generally requires heating at the surface and melting down to the contaminated level. Joule-heating with graphite electrodes was unable to vitrify the highly refractory Savannah River soil. Plasma vitrification from the bottom-up, with an open shaft, precludes almost any chance of developing pressure buildup under the melt. The vitrification procedure can be very specific to the layer or layers which are contaminated, and it is not necessary to melt the total volume of material in the specific area.

Collaboration/Technology Transfer

Laboratory trials have been conducted in large tanks filled with soil and debris at the Georgia Institute of Technology where this approach was initially conceived. A patent covering this process is held by Dr. Lou Circeo of Georgia Tech. The torch sizes employed to date have been limited to 100 and 200 KVA systems. Offgas analyses were conducted by Clark-Atlanta University. Additional crucible and graphite DC-melter trials are under way at the Clemson-DOE Industrial Center for Vitrification.

Accomplishments

- Demonstrated in situ vitrification without the addition of flux, via initial tank trials with highly refractory soil from SRS
- Provided scaling factors for future field experiments, via a side-by-side in situ vitrification (two columns)

TTP Information

In Situ Plasma Vitrification technology development activities are funded under the following TTP:

TTP No. SR16LF52, "Stabilization/Containment Systems"

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BIBLIOGRAPHY OF KEY PUBLICATIONS

Circeo, L.J., S.L. Camacho, G.K. Jacobs, and J.S. Tixier. "Plasma Remediation of In Situ Materials: The PRISM Concept," *In Situ Remediation: Scientific Basis for Current and Future Technologies* (1994).

Kielpinski, A.L., J.C. Marra, J. Ethridge, R. Kirkland, V. Rogers, and R.F. Schumacher. "Development of Plasma Vitrification Technology for Contaminated Soil at the Savannah River Site," *Proceedings of Waste Management '95* (1995).

8.9 VISCOUS BARRIERS

TECHNOLOGY NEED

Impermeable subsurface barriers may be used to prevent the further spread of subsurface contaminants. Some DOE facilities have experienced leaking underground tanks, uncontrolled dumps, and/or leaking controlled dumps. All of these situations can be prevented from causing further environmental harm by in situ emplacement of a containment barrier around the contaminated area.

TECHNOLOGY DESCRIPTION

This project is in support of a Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) action at SRS. The activities of this project are designated under a treatability study and are anticipated, if successful, to address an interim action for Retention Basin 281-3H.

Impermeable subsurface barriers can be used to prevent the spread of contaminants in the soil and groundwater. This project addresses the emplacement of a demonstration-level, viscous liquid barrier at SRS. Work is being accomplished by a project team having various capabilities to ensure the material selection, barrier design, barrier emplacement, and barrier verification and monitoring are adequately addressed.

The barrier to be emplaced will be constructed of colloidal silica and will contain Retention Basin 281-3H. A subsurface barrier will be placed around the waste basin.

The barrier material will be a viscous liquid, colloidal silica, which has been tested on a small scale for plume containment. The colloidal silica works by filling large and small pore spaces in the soil with a gel.

BENEFITS

DOE, along with other federal agencies and private industry, is faced with massive contaminated groundwater and soil-cleanup efforts to comply with current regulations. It is anticipated that billions of dollars will be required to return numerous federal and private facilities to acceptable conditions. DOE is attempting to meet the objective of cost-effective solutions at various contaminated sites. Development of suitable subsurface barrier technologies will greatly aid in this effort.

COLLABORATION/TECHNOLOGY TRANSFER

Collaboration by MSE-TA, Inc., with Lawrence Berkeley National Laboratory (material specification, barrier design, and barrier emplacement verification), Savannah River (SRS requirements and project coordination/management), a yet-to-be-determined material supplier(s) and emplacement subcontractor(s), and Sandia National Laboratories [SNL (follow-on monitoring)] is required.

ACCOMPLISHMENTS

- Assembled a project team and completed division of responsibilities
- Developed the colloidal silica material specification and initiated purchase of the material

TTP INFORMATION

Viscous Barriers technology development activities are funded under the following TTP:

TTP No. PE06LF52, "Viscous Barriers Materials Procurement"

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BIBLIOGRAPHY OF KEY PUBLICATIONS

None at this time.

8.10 CHEMICALLY REACTIVE BACKFILLS

TECHNOLOGY NEED

There is a need to identify and demonstrate emerging technologies (materials and emplacement techniques) for stabilization of contaminants in soils in humid environments. Potential applications include backfilling around excavated high-level waste (HLW) tanks to contain potential spills, barriers around Environmental Restoration remediation and low-level waste (LLW) sites, and barriers around future trench disposal of Consolidated Incineration Facility grouted ash waste.

TECHNOLOGY DESCRIPTION

This program consists of three parts. The first part of this program is a demonstration of the stabilization capacity of the chemically reactive materials that will constitute the barrier or backfill. Some of the materials that have been tested and may be specified for use in these backfills include clays, zeolites, phosphates, cements, and organic additives. Materials will be designed for stabilization of radionuclides and hazardous metals. In addition, efforts will be made to develop materials for stabilization of sodium salt species and for in situ destruction of organic compounds. Engineering properties of the backfill materials will be determined. Some materials have already been demonstrated in the laboratory and are suitable in a wide range of conventional construction applications. Additional materials will be developed and evaluated for the specific contaminants encountered in the demonstration sites.

The second part of this program involves demonstrating methods of emplacing these materials in contaminated environments. Emplacement methods that will be evaluated include slurry techniques used for Consolidated Low Strength Materials in the construction industry and an innovative soil hydrofracturing technique (horizontal subsurface barrier).

The third part involves performance modeling of the waste form. Verification of the modeled performance will utilize actual field data collected at the demonstration sites. Technology involved in the performance modeling includes innovative modifications to environmental transport codes currently in use at the Savannah River Technology Center.

Benefits

This effort will result in the demonstration of one or more chemically reactive backfills/barriers. These backfills and barriers have the potential to reduce the cost of future radioactive landfills and environmental remediation efforts, and improve containment of contaminants in existing and future sites. In addition, the environmental transport modeling and site characterization provide tools and metrics for documenting performance.

Collaboration/Technology Transfer

If the demonstration is successful, efforts will be made to establish a CRADA with one or more parties involved in the materials, landfill, construction, and environmental modeling businesses. Patent disclosures have been, or will be, prepared for the various materials and emplacement techniques developed. Patents and licensing agreements will be pursued by individual developers, as justified.

Accomplishments

- Completed first task milestone with issuance of report of prior year accomplishments.
- Identified HLW Tank Farm customer for demonstration.
- Continued with preparations for horizontal subsurface barrier field test in June.
- Continued testing reactive materials received from vendors.
- Issued task program plan (SRT-WED-96-0165) describing the work elements for: (1) reactive backfill demonstration, (2) laboratory survey of reactive backfill additives, and (3) the horizontal subsurface barrier field test.

TTP Information

Chemically Reactive Backfills technology development activities are funded under the following TTP:

TTP No. SR16LF53, "Solid Waste Disposal Systems"

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BIBLIOGRAPHY OF KEY PUBLICATIONS

Langton, C.A., and N. Rajendran. "Utilization of SRS Pond Ash in Controlled Low Strength Material (U)," WSRC-RP-95-1026, Westinghouse Savannah River Company (1995).

8.11 Closure of High-Level Waste Tanks Using Stabilized Contaminated Soils and Debris

Technology Need

There is a need to demonstrate technologies for closure of HLW tanks using stabilized soil and debris as a backfill to prevent subsidence and provide containment and stabilization of contaminants. Performance assessment modeling to determine the feasibility of using contaminated soil and debris as tank closure filler material is also needed.

Technology Description

This program consists of four parts. The first part involves development/ demonstration of the soil and debris stabilization material. Specification and evaluation of the engineering properties of the backfill material will also be conducted. Some of the materials which have already been tested for use in these backfills/barriers include zeolites, fly ash, and cements. Materials will be designed for stabilization of specific radionuclides and hazardous metals. In addition, efforts will be made to develop materials for stabilization of sodium salt that may be present as residues in the tanks.

The second part of this program involves demonstrating methods of emplacing these materials in HLW tanks. Emplacement methods that will be evaluated include slurry techniques, used for Consolidated Low Strength Materials in the construction industry, and jet grouting.

The third part involves developing the operating protocols for conducting a large-scale demonstration, and conducting the demonstration. The final part involves conducting performance modeling studies to determine tank "clean" limits, and to evaluate alternative materials and approaches for closing the HLW tanks. Technology involved in the performance modeling involves highly innovative modifications to environmental transport codes currently in use at the Savannah River Technology Center/SRS.

Benefits

This technology offers improved alternatives and options for disposal of soils from remediation sites, while at the same time, obtaining beneficial use of these soils and debris as empty tank-stabilization materials. This technology may provide a concept for lessening both the environmental consequences and the costs of contaminated soil disposal and tank stabilization against subsidence. If successful, consideration of using these tanks for emplacement of Saltstone and for grouted disposal of failed equipment and mixed wastes may be given. The potential savings in avoided Saltstone vault costs are estimated to be in the millions of dollars.

COLLABORATION/TECHNOLOGY TRANSFER

Discussions have taken place with Tanks Focus Area, Westinghouse Hanford, and SNL personnel concerning demonstration of this technology at SRS.

ACCOMPLISHMENTS

- Began work with SNL personnel to establish a regulatory logic flow chart for HLW Tank Closure
- Developed Performance Evaluation objectives
- Calculated preliminary Performance Evaluation limits for "no-action" Tank Closure Baseline Case and clean, grout-filled HLW tank
- Reviewed task for Environmental Advisory Committee to SRS and received support for study
- Developed and issued Scope of Work for South Carolina Universities Research and Education Foundation, Energy Research and Development Association contract solicitation

TTP INFORMATION

Closure of HLW Tanks Using Stabilized Contaminated Soils and Debris technology development activities are funded under the following TTP:

TTP No. SR16LF53, "Solid Waste Disposal Systems"

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Cook, J.R. "SEW Tank Closure Screening Analysis," SRT-WED-96-0177, Westinghouse Savannah River Company (1996).

8.12 CRYOCELL BARRIER

TECHNOLOGY NEED

The purpose of the Cryocell Barrier project is to provide DOE with an innovative technique for controlling waste migration in soils. This technique demonstrates the use of frozen soil barriers at an actual waste site for the containment of a contaminant plume. In conjunction with the barrier application, a systems approach is implemented to ensure that verifiable and transferable results are obtained. This consists of barrier formation, verification, and monitoring for the long-term use of the frozen soil barrier for plume containment. The verification and monitoring subtasks build on techniques that were determined to be effective in the Phase I demonstration. These may include electro-potential imaging and cross borehole ground penetrating radar (GPR). Data acquired during the demonstration will be used to evaluate the technology demonstration, determine its cost effectiveness, and provide final recommendations for application across the DOE complex.

The frozen barrier technology is best suited for plume containment in nonarid media. The technology significantly reduces the soil hydraulic conductivity by freezing the soil pore water, and therefore will work with most contaminants. The technology is applicable to sites that need a containment technique that will not generate a secondary waste. When containment is no longer needed, the system can be shut off. The soil will thaw. The soil characteristics will be the same as before freezing, other than a temporary increase in hydraulic conductivity caused by the expansion process of the freeze. The Cryocell Barrier is generally more useful for smaller waste sites.

TECHNOLOGY DESCRIPTION

This technology induces soil freezing artificially to freeze moisture, thereby reducing its hydraulic conductivity and holding the contaminant plume inside the boundaries of the freeze. The technology of using refrigerants to freeze soils has been employed in large-scale engineering projects for a number of years. This technology bonds soils to give load-bearing strength during construction; to seal tunnels, mine shafts, and other subsurface structures against flooding from groundwater; and to stabilize soils during excavation. Examples of modern applications include several large subway, highway, and water-supply tunnels.

The technology requires placing freeze pipes into the subsurface. Circulating refrigerant through dual tube boreholes spaced around the area to be contained forms a 4-to-6-feet-thick barrier around the waste, which can be maintained indefinitely. These pipes are used to transfer a brine solution which acts as the heat transfer media to the subsurface to remove heat from the soil. Above-ground refrigeration plants capable of handling the heat loads of the trench soil will cool the brine to the required temperatures to maintain the frozen soil barrier. Frozen soil barriers that provide complete containment (such as a "V" configuration) are formed by drilling and installing refrigerant piping (on 8-feet centers) horizontally at approximately 45 degree angles for sides, and vertically for ends, and then recirculating an environmentally-safe refrigerant solution through the piping to freeze the soil pore water. Freeze plants are used to keep the containment structure at subfreezing temperatures. Advantages of this technology include:

- It can provide complete containment.
- It uses benign materials (water/ice) as a containment medium.
- Frozen barriers can be readily removed (by thawing).
- Frozen barriers can be repaired in situ (by injecting water into the leakage area).

Benefits

This mature technology has an advantage over other barrier technologies in that it can be readily put in place and operated as needed. When the containment need is over, the system can be removed with the generation of wastes limited to only the freeze pipes that were placed into the ground. The baseline technology of grout encapsulation creates a monolith that must be excavated and removed for complete site remediation.

The technology is also very versatile in that soluble groundwater-transportable contaminants may be contained by this technique, since the hydraulic conductivity is significantly reduced to levels commensurate with granite, as suggested by laboratory studies conducted at the University of Washington. There is also evidence that soil freezing may induce contaminant concentration, and the groundwater could be cleaned of the contaminant. Other technology firms have proposed this as a method of soil remediation.

Cost of the Cryocell Barrier is competitive with slurry walls, but also provides lateral/vertical containment. The current technical focus is on controlled moisture addition at sites with insufficient soil moisture to form an impermeable barrier.

Collaboration/Technology Transfer

This project is a joint effort between EM-50; EM-40; the Hazardous Waste Remedial Action Program (HAZWRAP); EPA, and Cryocell, a commercial partner. The Cryocell Barrier technology will be demonstrated at an actual "hot" waste area to reduce risk and contain an environmental plume from reaching the White Oak Creek at the Oak Ridge site. The project will demonstrate containment of the release of radionuclides from the Oak Ridge National Laboratory (ORNL) Waste Area Grouping 9 Homogeneous Reactor Experiment impoundment pond. Figure 8.12-1 displays this demonstration site. HAZWRAP will coordinate and facilitate the barrier installation and system startup. ORNL Environmental Restoration (EM-40) will take the lead in obtaining any required permits and performing all management functions after initial installation and evaluation.

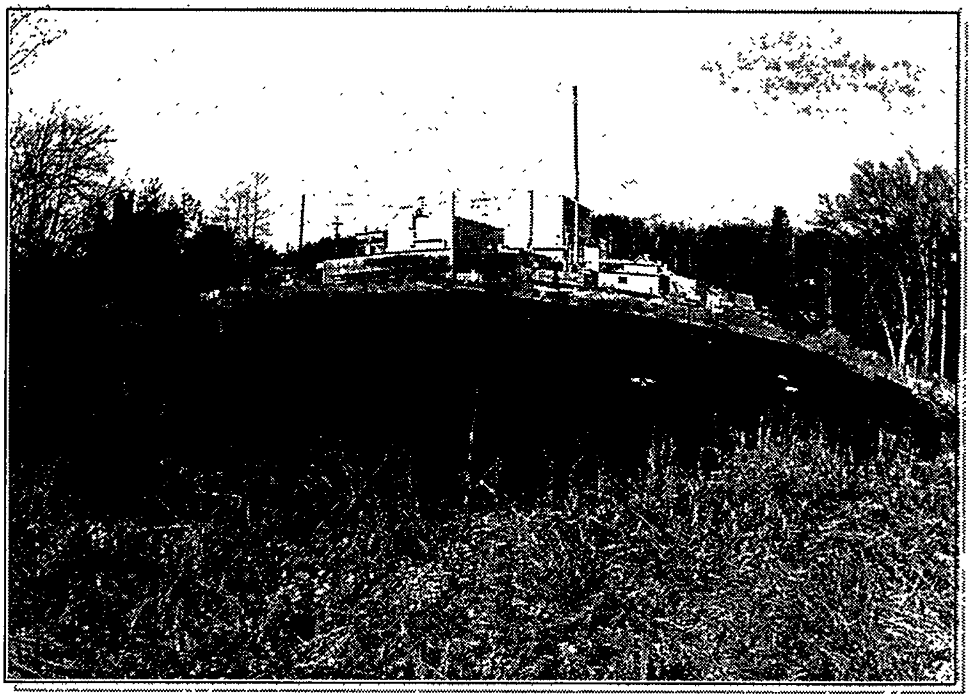

Figure 8.12-1. Homogeneous Reactor Experiment Impoundment Pond at the Oak Ridge National Laboratory.

ACCOMPLISHMENTS

Phase I of the project was completed in FY95. Phase I demonstrated and proved that the frozen soil barrier technology was applicable to a simulated contaminant plume from a leaking underground storage tank. In Phase I, the Cryocell Barrier was demonstrated at the Scientific Ecology Group (SEG) clean site on Gallaher Road in Oak Ridge, Tennessee. Figure 8.12-2 displays the setup of the Cryogenic Barrier demonstration equipment at this site.

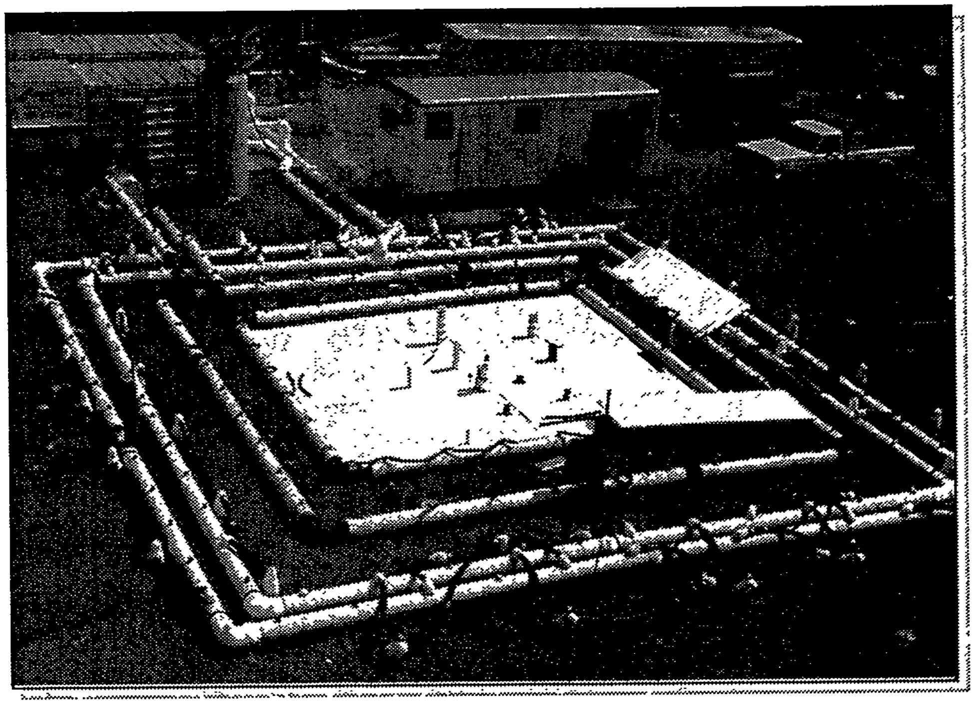

Figure 8.12-2. Cryogenic Barrier Demonstration Equipment at Scientific Ecology Group Clean Site in Oak Ridge, Tennessee.

Key results from Phase I of the project include:

- Time-constrained laboratory studies showed that effective frozen soil barriers (hydraulic permeabilities < 4X10E-10 cm/sec.) can be formed in saturated soils for chromate (4,000 mg/kg) and trichloroethylene (6,000 mg/kg). Tests with cesium-137 showed no detectable diffusion through the barrier, although sorption of the soil grains may have been responsible for the immobility.
- Soil movement can be predicted accurately for fine-grained soils based on past civil engineering practices.
- Computer modeling of heat transfer characteristics and soil temperature for fine-grained soils was validated.
- Costs associated with engineering, construction, operation, and maintenance of frozen soil barriers in fine-grained soils using full-scale equipment were established for a nonhazardous site.
- Electropotential studies utilizing frozen soil's low electrical conductivity properties showed low ionic transport across the frozen soil barrier, indicating that the barrier is an effective deterrent to ionic transport.

- Excavation of the nonfrozen soil within the contained area and GPR studies showed (1) the inner area to be in the predicted formation ("V" shape), and (2) the frozen wall thicknesses to be approximately 15 feet in the sand-trench area and 5 to 9 inches in the clay-dominated areas.
- Diffusion studies (with Rhodamine-WT as the tracer) conducted by the Los Alamos National Laboratory confirmed barrier integrity.
- An in-place temperature monitoring system provided soil temperature information confirming barrier formation.

TTP Information

Cryocell Barrier technology development activities are funded under the following TTP:

TTP No. OR16LF52, "Stabilization/Containment Systems"

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Bibliography of Key Publications

U.S. Department of Energy, Office of Environmental Management, Office of Technology Development. "Frozen Soil Barrier Technology," *The Innovative Technology Summary Report* (1995).

Scientific Ecology Group. "Final Report: Demonstration of Ground Freezing Technology at SEG Facilities in Oak Ridge, Tennessee," Prepared for Martin Marietta Energy Systems, Hazardous Waste Remedial Action Program (1995).

Morgan, D., and D. Lesmuth. "Ground Penetrating Radar Investigation of a Frozen Earth Barrier," Earth Resources Laboratory, Massachusetts Institute of Technology (1994).

9.0 CROSSCUTTING PROGRAMS

The Office of Environmental Management (EM) Office of Science and Technology (EM-50) has three Crosscutting Programs: Efficient Separations and Processing; Characterization, Monitoring, and Sensor Technology; and Robotics Technology Development. Two of these programs are developing technologies for the Subsurface Contaminants Focus Area. Examples of these include:

Efficient Separations and Processing

- Separation of tritiated water from water using composite membranes and reaction processes using hydrogen sulfide
- Evaluation of improved techniques for removing strontium and cesium from process wastewater and groundwater
- Selective in situ sorption of technetium from groundwater
- Removal and recovery of toxic metal ions from aqueous waste sites using polymer pendant ligands
- Extension of studies with commercial technologies for technetium and cesium removal from environmental systems field tests
- Inorganic sorbents made by the internal gelation process for radionuclide and heavy metal separations and removal of actinides and fission products from waste sludge leachate
- Derivatives of natural sequestering agents for the removal of actinides from waste streams based on molecular modeling and designs

Characterization, Monitoring, and Sensor Technology

- Portable acoustic wave sensor (PAWS) downhole monitoring
- Miniaturized chemical flow probe
- Ames integration of innovative, expedited site characterization techniques
- Cone penetrometer operations
- Screening and quantitative methods
- International environmental assessment
- Surface acoustic wave array detectors
- Contaminant transport studies at Pacific Northwest National Laboratory
- Analog site characterization of fractured rock

- Techniques to verify proper emplacement of barriers and their subsequent integrity over time
- Validation methods that ensure that measurements taken on soil, soil gas, and groundwater samples represent actual conditions in the subsurface
- Miniaturized electromagnetic sensor integrated into a 4-feet remotely piloted airplane to determine the location of buried waste, objects, and structures

For more information on the Crosscutting Programs, please see the 1996 Technology Summary Books for the Efficient Separations and Processing Crosscutting Program; the Characterization, Monitoring, and Sensor Technology Crosscutting Program; and the Robotics Technology Development Crosscutting Program.

DOE Business Opportunities for Technology Development

Working with the DOE Office of Environmental Management

The Office of Environmental Management (EM) provides a range of programs and services to assist private sector organizations and individuals interested in working with DOE in developing and applying environmental technologies. Vehicles such as research and development contracts, subcontracts, grants, and cooperative agreements enable EM and the private sector to work collaboratively. In FY95, 39 percent of Office of Science and Technology (OST) funding went to the private sector, universities and other federal agencies. EM's partnership with the private sector is working to expedite transfer of newly developed technology to EM restoration and waste management organizations, industry, and other federal agencies.

Several specific vehicles address institutional barriers to effective cooperation and collaboration between the private sector and DOE. These mechanisms include contracting and collaborative agreements, procurement provisions, licensing of technologies, consulting arrangements, reimbursable work for industry, and special consideration for small businesses.

Information on EM

The EM Center for Environmental Management Information provides the most current facts and documents related to the EM program. Through extensive referrals, the Center connects stakeholders to a complex-wide network of DOE Headquarters and Operations Office contacts.

To obtain information from the EM Center for Environmental Management Information, write or phone:

EM Center for Environmental Management Information
U.S. Department of Energy
P.O. Box 23769
Washington, DC 20026-3769
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The Cooperative Research and Development Agreement

The Cooperative Research and Development Agreement (CRADA) is a written agreement between one or more federal laboratories and one or more nonfederal parties through which the government provides personnel, facilities, equipment, and other resources, with or without reimbursement, to support a shared research agenda. The nonfederal parties may also provide funds, personnel, services, facilities, equipment, intellectual property, or other resources to support the research. DOE developed a modular CRADA to be responsive to the needs of participants while protecting the interests of the government and its taxpayers. DOE also has issued the small business CRADA to expedite agreements with small businesses and other partners that meet DOE's requirements. During FY95, EM entered into more than 60 CRADAs.

The Research Opportunity Announcement

The Research Opportunity Announcement (ROA) is a solicitation for industry and academia to submit proposals for potential contracts in basic and applied research, ranging from concept feasibility through proof-of-concept testing in the field. This mechanism is used when EM is looking for multiple solutions for a given problem. ROAs are issued annually by EM. The EM ROA provides multiple awards and is open all year. ROAs are announced in the *Commerce Business Daily*, and typically published in the *Federal Register.*

For questions on ROAs, contact:

Robert Bedick
U.S. Department of Energy
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To learn about EM Technology business opportunities, connect to the METC Homepage:

http://www.metc.doe.gov/business/solicita.html

The Program Research and Development Announcement

EM uses the Program Research and Development Announcement (PRDA) to solicit proposals from nonfederal parties for research and development in areas of interest to EM. The PRDA is used for projects that are in broadly defined areas of interest where a detailed work description might be premature. It is a tool to solicit a broad mix of applied research, development, demonstration, testing, and evaluation proposals.

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THE SMALL BUSINESS INNOVATION RESEARCH PROGRAM

Thé Small Business Innovation Research (SBIR) Program promotes small business participation in government research and development programs. This legislatively mandated program is designed for implementation in three phases from feasibility studies through support for commercial application. DOE publishes solicitation announcements through the Small Business Innovation Research Office each year to define research and development areas of interest.

For further information about SBIR programs, contact:

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BUSINESS AGREEMENTS

Cost-Shared Contracts
Nonfederal parties working under DOE contract can agree to share some of the cost of developing a technology for a nonfederal market. This arrangement may involve cash, in-kind contributions, or both.

Grants and Cooperative Agreements
These contractual arrangements provide the recipient with money and/or property to support or stimulate research in areas of interest to DOE. DOE regularly publishes notices concerning grant opportunities in the *Commerce Business Daily*.

Research and Development Contracts

This acquisition instrument between the government and a contractor provides supplies and services to the government. DOE may enter directly into research and development contracts, and DOE laboratories and facilities can subcontract research and development work to the private sector. Announcements on requests for proposals are published in the *Commerce Business Daily* and are available through the EM Homepage on the Internet: *www.em.doe.gov*

Licensing Technologies

DOE contractor-operated laboratories can license DOE/EM-developed technology and software. In situations where DOE retains ownership of a new technology, the Office of General Counsel serves as licensing agent. Licensing activities are conducted according to existing DOE intellectual property provisions and can be exclusive or nonexclusive, for a specific field of use, geographic area, for a United States or foreign usage. Information on licensing technologies may be obtained by contacting the Office of Research and Technology Applications (ORTA) representatives listed later in this section.

Technical Personnel Exchange Arrangements

Personnel exchanges provide opportunities for federal or DOE laboratory scientists to work together with scientists from private industry on a mutual technical issue. Usually lasting one year or less, these arrangements foster the transfer of technical skills and knowledge. These arrangements require substantial cost-sharing by industry, but DOE has an advanced class patent agreement in place for this provision and the rights of any resulting patents become the property of the private industry participant. Contact an ORTA representative for more information.

Consulting Arrangements

Consulting arrangements are formal, written agreements in which a DOE laboratory or facility employee may provide advice or information to a nonfederal party for the purpose of technology transfer, or a nonfederal party may consult with the laboratory or facility. Laboratory/facility employees participating in this exchange of technical expertise must sign a nondisclosure agreement. Contact an ORTA representative for more information.

Reimbursable Work for Industry

This concept enables DOE personnel and laboratories to perform work for nonfederal partners when laboratories or facilities have expertise or equipment not available in the private sector. Reimbursable Work for Industry is usually termed "work for others." An advanced class patent waiver gives ownership of any inventions resulting from the research to the participating private sector company. Contact an ORTA representative for more information.

Office of Research and Technology Applications

Each federal laboratory has an Office of Research and Technology Application. These offices serve as technology transfer agents for the federal laboratories. They coordinate technology transfer activities among laboratories, industry, and universities. ORTA offices license patents and foster communication between researchers and technology customers.

ORTA Representative:

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Brookhaven National Laboratory
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Idaho National Engineering Laboratory
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Lawrence Livermore National Laboratory
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PERIODIC TABLE
Of the Elements

	IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIII			IB	IB	IIIA	IVA	VA	VIA	VIIA	0
1	1 H Hydrogen																	2 He Helium
2	3 Li Lithium	4 Be Beryllium											5 B Boron	6 C Carbon	7 N Nitrogen	8 O Oxygen	9 F Fluorine	10 Ne Neon
3	11 Na Sodium	12 Mg Magnesium											13 Al Aluminum	14 Si Silicon	15 P Phosphorous	16 S Sulfer	17 Cl Chlorine	18 Ar Argon
4	19 K Potassium	20 Ca Calcium	21 Sc Scandium	22 Ti Titanium	23 V Vanadium	24 Cr Chromium	25 Mn Manganese	26 Fe Iron	27 Co Cobalt	28 Ni Nickel	29 Cu Copper	30 Zn Zinc	31 Ga Gallium	32 Ge Germanium	33 As Arsenic	34 Se Selenium	35 Br Bromine	36 Kr Krypton
5	37 Rb Rubidium	38 Sr Strontium	39 Y Yttrium	40 Zr Zirconium	41 Nb Niobium	42 Mo Molybdenum	43 Tc Technetium	44 Ru Ruthenium	45 Rh Rhodium	46 Pd Palladium	47 Ag Silver	48 Cd Cadmium	49 In Indium	50 Sn Tin	51 Sb Antimony	52 Te Tellurium	53 I Iodine	54 Xe Xenon
6	55 Cs Cesium	56 Ba Barium	57 *La Lanthanum	72 Hf Hafnium	73 Ta Tantalum	74 W Wolfram	75 Re Rhenium	76 Os Osmium	77 Ir Iridium	78 Pt Platinum	79 Au Gold	80 Hg Mercury	81 Tl Thallium	82 Pb Lead	83 Bi Bismuth	84 Po Polonium	85 At Astatine	86 Rn Radon
7	87 Fr Francium	88 Ra Radium	89 +Ac Actinium	104 Rf Rutherfordium	105 Ha Hahnium	106 Sg Seaborgium	107 Ns Nielsbohrium	108 Hs Hassium	109 Mt Meitnerium	110 110								

*Lanthanide Series	58 Ce Cerium	59 Pr Praseodymium	60 Nd Neodymium	61 Pm Promethium	62 Sm Samarium	63 Eu Europium	64 Gd Gadolinium	65 Tb Terbium	66 Dy Dysprosium	67 Ho Holmium	68 Er Erbium	69 Tm Thulium	70 Yb Ytterbium	71 Lu Lutetium
+Actinide Series	90 Th Thorium	91 Pa Protactinium	92 U Uranium	93 Np Neptunium	94 Pu Plutonium	95 Am Americium	96 Cm Curium	97 Bk Berkelium	98 Cf Californium	99 Es Einsteinium	100 Fm Fermium	101 Md Mendelevium	102 No Nobelium	103 Lr Lawrencium

GFX.96-0215

ACRONYMS

AC	Alternating Current
AFB	Air Force Base
ALCD	Alternative Landfill Cover Demonstration
ANL	Argonne National Laboratory
API	American Petroleum Institute
ARS	Agricultural Research Service
BHI	Bechtel Hanford, Inc.
BRS	Biomass Remediation System
CEM	Continuous-Emissions Monitoring
C	Centigrade
CHESS	Cornell High Energy Synchrotron Source
Cl-VOCs	Chlorinated Volatile Organic Compounds
CMST	Characterization, Monitoring, and Sensor Technology
CMW	Charles Machine Works, Inc.
COC	Contaminants of Concern
CRADA	Cooperative Research and Development Agreement
CUA	Catholic University of America
CWL	Chemical Waste Landfill
DCE	Dichloroethylene
DDB	Direct Dechlorinating Bacteria
DNAPL	Dense Non-Aqueous Phase Liquid
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
EDTA	Ethylenediamine Tetraacetate
EM	Office of Environmental Management
EMWD	Environmental Measurement-While-Drilling
EPA	U.S. Environmental Protection Agency
ER	Environmental Restoration

ES	Engineering Science
FEMP	Fernald Environmental Management Project
FY	Fiscal Year
GAC	Granulated Activated Carbon
GE	General Electric
GPR	Ground Penetrating Radar
GMA	Great Miami Aquifer
GMT	Geiger-Mueller Tube
GRS	Gamma Ray Spectrometer
HAZWRAP	Hazardous Waste Remedial Action Program
HLW	High-Level Waste
ICAP/MS	Inductively-Coupled Argon Plasma/Mass Spectrometry
IGRS	In Situ Gaseous Reduction System
INEL	Idaho National Engineering Laboratory
IRB	Iron Reducing Bacteria
ISRM	In Situ Redox Manipulation
ISV	In Situ Vitrification
LAMS	Landfill Assessment and Monitoring System
LANL	Los Alamos National Laboratory
LBNL	Lawrence Berkeley National Laboratory
LLNL	Lawrence Livermore National Laboratory
LLW	Low-Level Waste
LNAPLs	Light Non-Aqueous Phase Liquids
LPM	Low Permeability Soil and Geologic Media
LSC	Liquid Scintillation Counting
MAWS	Minimum-Additive Waste-Stabilization
MCA	Multichannel Analyzer
METC	Morgantown Energy Technology Center
MSW	Municipal Solid Waste

NAPL	Non-Aqueous Phase Liquid
OGI	Oregon Graduate Institute
ORNL	Oak Ridge National Laboratory
ORTA	Office of Research and Technology Application
OST	Office of Science and Technology
OTD	Office of Technology Development
PAWS	Portable Acoustic Wave Sensor
PCB	Polychlorinated Biphenyl
PCE	Perchloroethylene; Tetrachloroethylene
PGDP	Paducah Gaseous Diffusion Plant
PMT	Photomultiplier Tube
PNNL	Pacific Northwest National Laboratory
PRDA	Program Research and Development Announcement
PSVE	Passive Soil-Vapor Extraction
RCRA	Resource Conservation and Recovery Act
RCT	Research Corporation Technologies
RD&D	Research Development and Demonstration
RDF	Refuse-Derived Fuel
RF	Radio Frequency
ROA	Research Opportunity Announcement
RRP	Resource Recovery Project
RTDF	Remediation Technology Development Forum
SBIR	Small Business Innovation Research
SEG	Scientific Ecology Group
SELENTEC	Selective Environmental Technologies, Inc.
SITE	Superfund Innovative Technology Evaluation
SNL	Sandia National Laboratories
SPSH	Six-Phase Soil Heating
SR	Savannah River

SRO	Savannah River Operations
SRS	Savannah River Site
SSEB	Southern States Energy Board
STCG	Site Technology Coordination Group
SVE	Soil Vapor Extraction
TAS	Tritium Analysis System
TCA	Trichloroethane
TCE	Trichloroethylene
TEVES	Thermal Enhanced Vapor Extraction System
THP	Tunable Hybrid Plasma
TOC	Total Organic Carbon
TRU	Transuranic
TTP	Technical Task Plan
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
VETEM	Very Early-Time Electromagnetic
VOCs	Volatile Organic Compounds
WDH	Water Development Hanford
WETO	Western Environmental Technology Office
WHC	Westinghouse Hanford Company
WSRC	Westinghouse Savannah River Company