

GROUND-WATER TREATMENT TECHNOLOGY RESOURCE GUIDE

Office of Solid Waste and Emergency Response
Technology Innovation Office
Washington, DC 20460

EPA/542-B-94-009
September 1994

ABSTRACTS OF GROUND-WATER TREATMENT TECHNOLOGY RESOURCES

GUIDANCE/WORKSHOPS

Biotechnology Workgroup for Department of Defense Soil and Ground Water Decontamination Applications, Final Report for Period Ending March 1989.

Reuter, R. H., Life Systems, Inc., Cleveland, OH, Naval Civil Engineering Laboratory, Port Hueneme, CA, June 1991

NTIS Document Number: AD-A237 956/8/XAB

This report contains materials used in and generated by the Department of Defense Biotechnology Workshop on Soil and Ground-Water Decontamination Applications. Various bioremediation techniques for treating soil and water contaminated with sludges, solvents, toxins, acids, bases, and heavy metals were discussed as well as the overall place of biotechnology in Installation Restoration programs. Among the specific applications discussed were: biochemical sensors to determine environmental stress in organisms; in situ detoxification and biodecontamination of pollutants in soils and waste streams; sequestration, removal, and recovery of metals in waste streams with metal-binding proteins; and the use of vegetation to limit the transport to sequester and/or to remove contaminants from soil or water.

NPL Construction Completion Definition at Bioremediation and Soil Vapor Extraction Sites Directive.

U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Washington, DC,
June 1993

EPA Document Number: EPA/540/F-93/019

NTIS Document Number: PB93-963327/XAB

The report discusses EPA's policy for categorizing bioremediation and soil vapor extraction sites as Construction Completions. Technologies addressed are: in situ soil vapor extraction, in situ bioremediation, and ex situ bioremediation.

OVERVIEW DOCUMENTS

An Overview of Underground Storage Tank Remediation Options.

U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Washington, DC,
October 1993

EPA Document Number: EPA/510/F-93/029

This document contains a series of fact sheets to answer basic questions about selected alternative cleanup technologies and to provide an easy way to compare one another. The ground-water remediation technologies include: in situ air sparging with soil vapor extraction, in situ bioremediation, in situ bioventing combined with low flow air sparging (biosparging), and vacuum enhanced pump and treat.

Bioremediation.

Thomas, J. M.; Ward, C. H.; Raymond, R. L.; Wilson, J. T.; and Loehr, R. C., U.S. Environmental Protection Agency, Robert S. Kerr Environmental Research Laboratory, Ada, OK, National Center for Ground Water Research, Houston, TX, 1992

EPA Document Number: EPA/600/A-93/004

NTIS Document Number: PB93-149193/XAB

Bioremediation is defined in the article as the process by which microorganisms are stimulated to rapidly degrade hazardous organic contaminants to environmentally safe levels in soils, subsurface materials, water, sludges, and residues. Stimulation is achieved by the addition of nutrients and a terminal electron acceptor, usually oxygen, because most biological reactions occur faster under aerobic than anaerobic conditions. Under anaerobic conditions, nitrate has been used as the terminal electron acceptor. The microorganisms use the contaminants as a food source and convert the contaminants into biomass and harmless by-products of metabolism such as CO₂ and inorganic salts. Usually bioremediation is used to degrade contaminants that are sorbed to surfaces or dissolved in water rather than to degrade pure chemicals. As a result, the process is used in conjunction with other techniques in remediation of contaminated sites. The contaminants can be biodegraded in situ or removed and placed in a bioreactor, which can be placed off or at the site where the contamination occurred.

Critical Review of In Situ Bioremediation, Topical Report, January 1990-March 1992.

Rittmann, B. E.; Valocchi, A. J.; Seagren, E.; Ray, C.; and Wrenn, B., Illinois University at Urbana-Champaign, Newmark Civil Engineering Laboratory, North Dakota University, Grand Forks, ND; Energy and Environmental Research Center, Gas Research Institute, Chicago, IL; U.S. Department of Energy, Morgantown Energy Technology Center, Morgantown, WV, August 1992

NTIS Document Number: PB93-114247/XAB

In situ bioremediation, which is the managed, in-place cleanup of contaminated ground water aquifers and surface soils by microorganisms, is a promising technology because it is versatile and can have significant economic advantages. Many common contaminants are biodegradable, and new microbial capabilities for degradation are being discovered all the time. Success in the field and in laboratory studies point out the promise. On the other hand, the promises are not yet fulfilled, mainly because of the complexity of the subsurface situation. The report provides a comprehensive and in-depth critical review of in situ bioremediation. It is organized to evaluate the possibilities and restrictions inherent in all facets of in situ bioremediation, including microbiology, hydrodynamics, engineering, and legal and other nontechnical aspects. Several of the key conclusions are illustrated by case studies of successful field projects. Finally, the research needed to advance in situ bioremediation to become a reliable and acceptable tool is outlined.

Evaluation of Ground-Water Extraction Remedies: Phase 2, Volume 1, Summary

Report .

U.S. Environmental Protection Agency, Office of Emergency and Remedial Response, Washington, DC, February 1992

NTIS Document Number: PB92-963346/XAB

The report is the second phase of a study to evaluate the effectiveness of ground-water extraction systems being used to remediate ground-water contamination at hazardous waste sites. The report was prepared in two volumes. Volume 1 contains an executive summary and chapters which discuss the purpose, methodologies, and conclusions of the project.

Fifth Forum on Innovative Hazardous Waste Treatment Technologies: Domestic and International, Proceedings, Chicago, Illinois, May 3-5, 1994.

U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Technology Innovation Office, Office of Research and Development, Washington, DC, Risk Reduction Engineering Laboratory, Cincinnati, OH, May 1994

EPA Document Number: EPA/540/R-94/503

On May 3-5, 1994, the U.S. Environmental Protection Agency's Technology Innovation Office and Risk Reduction Engineering Laboratory hosted an international conference in Chicago, Illinois to exchange solutions to hazardous waste treatment problems. During the conference, scientists and engineers representing government agencies, industry, and academia attended over 40 technical presentations and case studies describing domestic and international technologies for the treatment of waste, sludges, and contaminated soils at uncontrolled hazardous waste disposal sites. A session was also held on opportunities in research and commercialization, which included presentations on export assistance programs and partnerships with EPA in developing innovative technologies. This compendium includes the abstracts of the presentations from the conference and many of the posters that were on display.

Fourth Forum on Innovative Hazardous Waste Treatment Technologies: Domestic and International, Technical Papers, San Francisco, California, November 17-19, 1992.

U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Technology Innovation Office, Office of Research and Development, Washington, DC, Risk Reduction Engineering Laboratory, Cincinnati, OH, February 1993

EPA Document Number: EPA/540/R-93/500

On November 17-19, 1992, the U.S. Environmental Protection Agency's Technology Innovation Office and Risk Reduction Engineering Laboratory, the Department of Energy, the Corps of Engineers, and the California Environmental Protection Agency, hosted an international conference in San Francisco, California, to exchange solutions to hazardous waste treatment problems. This conference was attended by approximately 1,000 representatives from the U.S. and 25 foreign countries. During the conference, scientists and engineers representing government agencies, industry, and academia attended 42 technical presentations and case studies describing domestic and international technologies for the treatment of waste, sludges, and contaminated soils at uncontrolled hazardous waste disposal sites. Technologies included physical/chemical, biological, thermal, and stabilization techniques. Presentations were made by EPA, their Superfund Innovative Technology Evaluation (SITE) program participants, other Federal and State agencies and their contractors, international scientists, and vendors. This document contains abstracts of the presentations from the conference and many of the posters that were on display.

Guidance for Evaluating the Technical Impracticability of Ground-Water Restoration.

U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Washington, DC, September 1993

EPA Document Number: EPA/540/R-93/080

NTIS Document Number: PB93-963507/XAB

This guidance clarifies how EPA will determine whether ground water restoration is technically impracticable and what alternative measures or action must be undertaken to ensure that the final remedy is protective of human health and the environment. Topics covered include the types of technical data and analyses needed to support EPA's evaluation of a particular site and the criteria used to make a determination. As technical impracticability (TI) decisions are part of the process of site investigation, remedy selection, remedial action, and evaluation of remedy performance, the guidance also briefly discusses the overall framework for decision making during these phases of site cleanup.

Innovative Treatment Technologies: Annual Status Report, Fifth Edition.

Fiedler, L., U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Technology Innovation Office, Washington, DC, September 1993

EPA Document Number: EPA/542/R-93/003

NTIS Document Number: PB93-133387/XAB

This annual report contains site-specific information on Superfund sites (both remedial and emergency response actions) and non-Superfund sites (within the Departments of Defense and Energy) where innovative treatment technologies have been or are being used. Innovative treatment technologies are treatment technologies for which a lack of data on cost and performance makes their selection and use at Superfund sites more difficult. The report documents the use of the following innovative treatment technologies to treat ground water in situ; soils, sediments, sludge, and solid-matrix wastes; bioremediation (ex situ); bioremediation (in situ); chemical treatment; dechlorination; in situ flushing; in situ vitrification; soil vapor extraction; soil washing; solvent extraction; thermal desorption; and other technologies.

Innovative Treatment Technologies: Overview and Guide to Information Sources.

Quander, J. and Kingscott, J., U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Technology Innovation Office, Washington, DC, October 1991

EPA Document Number: EPA/540/9-91/002

NTIS Document Number: PB92-179001/XAB

The document is a compilation of information on innovative treatment technologies being used in the Superfund program and is intended to assist site project managers, consultants, responsible parties, and owner/operators in their efforts to identify current literature on innovative treatment technologies for hazardous waste remediation on corrective action. The technologies addressed in the guide include the following: incineration, thermal desorption, soil washing, solvent extraction, dechlorination, bioremediation, vacuum extraction, vitrification, and ground-water treatment. Also included in the guide for the user's reference are summary statistics of EPA's selection and application of innovative treatment technologies between 1982 and 1990. In addition, for each technology the guide provides a detailed description, status of development and application, strengths, weaknesses, and materials handling considerations. A comprehensive bibliography for each

technology can be found within each chapter.

In Situ Bioremediation of Contaminated Ground Water.

Sims, J. L.; Suflita, J. M.; and Russell, H. H.; U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Washington, DC, February 1992

EPA Document Number: EPA/540/S-92/003

NTIS Document Number: PB92-224336/XAB

In-situ bioremediation, where applicable, appears to be a potential cost-effective and environmentally acceptable remediation technology. Suflita (1989) identified characteristics of the ideal candidate site for successful implementation of in-situ bioremediation. These characteristics included: (1) a homogeneous and permeable aquifer; (2) a contaminant originating from a single source; (3) a low ground-water gradient; (4) no free product; (5) no soil contamination; and (6) an easily degraded, extracted, or immobilized contaminant. Obviously, few sites meet these characteristics. However, development of information concerning site-specific geological and microbiological characteristics of the aquifer, combined with knowledge concerning potential chemical, physical, and biochemical fate of the wastes present, can be used to develop a bioremediation strategy for a less-than-ideal site.

In Situ Bioremediation of Ground Water and Geological Material: A Review of Technologies, Research Report.

Norris, R. D.; Hinchee, R. E.; Brown, R.; and McCarty, P. L.; Semprini, L.; Dynamac Corporation, Ada, OK, U.S. Environmental Protection Agency, Robert S. Kerr Environmental Research Laboratory, Ada, OK, July 1993

EPA Document Number: EPA/600/R-93/124

NTIS Document Number: PB93-215564/XAB

The report provides the reader with a detailed background of the technologies available for the bioremediation of contaminated soil and ground water. The document has been prepared for scientists, consultants, regulatory personnel, and others who are associated in some way with the restoration of soil and ground water at hazardous waste sites. It provides the most recent scientific understanding of the processes involved with soil and ground-water remediation, as well as a definition of the state-of-the-art technologies with respect to circumstances of their applicability and their limitations. In addition to discussions and examples of developed technologies, the report also provides insights to emerging technologies that are at the research level of formation, ranging from theoretical concepts, through bench-scale inquiries, to limited field-scale investigations. The report centers around a number of bioremediation technologies applicable to the various subsurface compartments into which contaminants are distributed. The processes that drive these remediation technologies are discussed in depth along with the attributes that direct their applicability and limitations according to the phases into which the contaminants have partitioned. These discussions include in situ remediation systems, air sparging and bioventing, use of electron acceptors alternate to oxygen, natural bioremediation, and introduction of organisms into the subsurface. The contaminants of major focus in the report are petroleum hydrocarbons and chlorinated solvents.

In Situ Bioremediation of Ground Water, Summary Paper.

U.S. Environmental Protection Agency, Robert S. Kerr Environmental Research Laboratory, Ada, OK, January 1993

EPA Document Number: EPA/540/S-92/017

NTIS Document Number: PB93-146850/XAB

The Robert S. Kerr Environmental Research Laboratory (RSKERL) has developed a number of issue papers and briefing documents that are designed to exchange up-to-date information related to the remediation of contaminated soil and ground water at hazardous waste sites. In an attempt to make the content of these documents available to a wider audience, RSKERL is developing a series of summary papers that are condensed versions of the original documents. There are a number of techniques that may potentially be used for dealing with problems resulting from the contamination of ground water with organic compounds. Ground water can sometimes be treated in place using chemical or biological processes. An emerging technology for the in situ remediation of ground water is the use of microorganisms to degrade contaminants that are present in aquifer materials. Although in situ bioremediation has been used for a number of years in the restoration of ground water contaminated with petroleum hydrocarbons, its application to other classes of contaminants is relatively recent. This is discussed in the summary paper.

In Situ Treatment of Contaminated Ground Water: An Inventory of Research and Field Demonstrations and Strategies for Improving Ground Water Remediation Technologies.

U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Technology Innovation Office, Washington, DC, January 1993

EPA Document Number: EPA/500/K-93/001

NTIS Document Number: PB93-193720/XAB

The predominance of ground-water contamination at hazardous waste sites and the dearth of methods to efficiently treat this contamination is a problem that the U.S. Environmental Protection Agency (EPA) is examining. The contaminated ground water found at most Superfund sites is often the limiting factor for complete site remediation. The purpose of the document is to describe recent research, development, and application of technologies that either treat ground-water contaminants in place or improve the solubility and mobility of contaminants to enhance pump-and-treat remediation effectiveness. The report discusses techniques that can be applied in situ and excludes pumping methodologies or surface treatment systems. In addition, the publication presents conclusions based on observations of the survey. Finally, strategies for action for stakeholders concerned with in situ ground-water technology development are presented. The study has not defined the extent or activities of research and development outside of EPA-supported groups.

Superfund Innovative Technology Evaluation (SITE) Program: Innovation Making a Difference.

U.S. Environmental Protection Agency, Office of Research and Development, Risk Reduction Engineering Laboratory, Cincinnati, OH, May 1994

EPA Document Number: EPA540/F-94/505

The SITE Program encourages commercialization of innovative technologies for characterizing and remediating hazardous waste site contamination through four components: demonstration; emerging technology; monitoring and measurement programs; and technology transfer activities. The information presented in this brochure addresses the demonstration segment of the program. The demonstration component evaluates promising innovative remedial technologies on site and provides reliable performance, cost, and applicability information for making cleanup decisions. This document lists the advantages of the SITE Program, as well as statistics such as the percentage of RODs using innovative technology, cost savings with innovative technologies for 17 sites, and market activities as reported by SITE vendors.

Superfund Innovative Technology Evaluation Program: Technology Profiles, Sixth Edition.

U.S. Environmental Protection Agency, Office of Research and Development, Risk Reduction Engineering Laboratory, Cincinnati, OH, November 1993

EPA Document Number: EPA/540/R-93/526

NTIS Document Number: PB93-163053/XAB

This document contains a collection of abstracts describing innovative technologies being implemented in the Superfund Innovative Technology Evaluation Program for treating contaminated ground water, soils, and sludges. Each technology profile contains a: 1) technology description, 2) discussion of waste applicability, 3) schematic diagram or photograph of the process, and 4) summary of demonstration results. The document contains over 30 abstracts concerning ground-water remediation.

Surfactants and Subsurface Remediation, Journal Article: Published in Environmental Science Technology, v26n12, pg. 2324-2330, 1992.

West, C. C. and Harwell, J. H., U.S. Environmental Protection Agency, Robert S. Kerr Environmental Research Laboratory, Ada, OK, Oklahoma University Research Institute, OK, 1992

EPA Document Number: EPA/600/J-93/005

NTIS Document Number: PB93-149854/XAB

Because of the limitations of pump-and-treat technology, attention is now focused on the feasibility of surfactant use to increase its efficiency. Surfactants have been studied for use in soil washing and enhanced oil recovery. Although similarities exist between the applications, there are significant differences in the objectives of the technologies and the limitations placed on surfactant use. This article reviews environmental studies concerned with the fate and transport of surface-active compounds in the subsurface environment and discuss key issues related to their successful use for in situ aquifer remediation, particularly with respect to nonaqueous-phase liquids.

Synopses of Federal Demonstrations of Innovative Site Remediation Technologies.

U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Technology Innovation Office, Washington, DC, Prepared by the Member Agencies of the Federal Remediation Technologies Roundtable, October 1993

EPA Document Number: EPA/542/B-93/009

NTIS Document Number: PB94-151065/XAB

This collection of abstracts describes demonstrations of innovative technologies to treat hazardous waste including remediation costs and contacts. The collection is intended to be an information resource for hazardous waste site project managers for assessing the availability and viability of innovative technologies for treating contaminated ground water, soils, and sludge. It is also intended to assist government agencies in coordinating ongoing hazardous waste remediation technology research initiatives, particularly those sponsored by the U.S. Environmental Protection Agency, U.S. Department of Energy, and U.S. Department of Defense. In total 75 demonstrations in seven different categories are described.

TCE Removal from Contaminated Soil and Ground Water.

Russell, H.H.; Matthews, J.E.; and Sewell, G.W. Robert S. Kerr Environmental Laboratory, Ada, OK, U.S. Environmental Protection Agency, Office of Research

and Development, Office of Solid Waste and Emergency Response, Technology Innovation Office, Washington, DC, January 1992

EPA Document Number: EPA/540/S-92/002

NTIS Document Number: PB92-224104/XAB

The purpose of this paper is to present a synopsis of physiochemical properties and reactive mechanisms of Trichloroethylene (TCE) and to delineate and discuss promising remediation technologies that have been proposed and/or demonstrated for restoring TCE-contaminated subsurface environmental media. The technologies discussed include air stripping, granular activated carbon adsorption, soil venting, in-well aeration, bioremediation of extracted ground waters/subsurface air streams, and in situ bioremediation.

Technologies to Remediate Hazardous Waste Sites.

Falco, J.W., Battelle Pacific Northwest Laboratories, Richland, WA, March 1990

NTIS Document Number: DE90-011946/XAB

Technologies to remediate hazardous wastes must be matched with the properties of the hazardous materials to be treated, the environment in which the wastes are imbedded, and the desired extent of remediation. Many promising technologies are being developed and applied to remediate sites including biological treatment, immobilization techniques, and in situ methods. The management and disposal of hazardous wastes is changing because of Federal and State legislation, as well as public concern. Future waste management systems will emphasize the substitution of alternatives for the use of hazardous materials and process waste recycling. On site treatment will also become more frequently adopted.

Technology Assessment of Soil Vapor Extraction and Air Sparging.

Loden, M. E.; Camp Dresser and McKee, Inc., Cambridge, MA, U.S. Environmental Protection Agency, Risk Reduction Engineering Laboratory, Cincinnati, OH, September 1992

EPA Document Number: EPA/600/R-92/173

NTIS Document Number: PB93-100154/XAB

Air sparging, also called "in situ air stripping" and "in situ volatilization," injects air into the saturated zone to strip away volatile organic compounds (VOCs) dissolved in ground water and adsorbed to soil. These volatile contaminants transfer in a vapor phase to the unsaturated zone where soil vapor extraction (SVE) can then capture and remove them. In addition to removing VOCs via mass transfer, the oxygen in the injected air enhances subsurface biodegradation of contaminants. Air sparging is a relatively new treatment technology. Research efforts have not yet fully elucidated the scientific basis (or limitations) of the system, nor completely defined the associated engineering aspects. However, a substantial body of available information describes the effectiveness and characteristics of air sparging systems. This document summarizes the available literature and addresses case studies of practical air sparging applications. It also identifies needs for further research.

Technology Catalogue, First Edition.

Department of Energy, Office of Environmental Management, Office of Technology Development, Washington, DC, February 1994

DOE Document Number: DOE/EM-0138P

NTIS Document Number: DE94-008866/XAB

The catalogue provides performance data on the technologies developed by the Office of Technology Development (OTD) to scientists and engineers assessing and recommending technical solutions within the Department's clean-up and waste management programs, as well as to industry, other Federal and State agencies, and academic community. The Technology Catalogue features technologies that have been successfully demonstrated in the field through Integrated Demonstrations (IDs) and are considered sufficiently mature to be used in the near term. The catalogue also discusses the status of the development of these innovative technologies. Forty-three technologies are featured: 22 characterization/monitoring technologies; and 21 remediation technologies.

VOCs in Arid Soils: Technology Summary.

U.S. Department of Energy, Office of Environmental Management, Office of Technology Development, Washington, DC, February 1994

DOE Document Number: DOE/EM-0136P

NTIS Document Number: DE94-008864/XAB

The Office of Technology Development at the U.S. Department of Energy developed cost effective mechanisms for assembling a group of related and synergistic technologies to evaluate their performance individually or as a complete system in correcting waste management and environmental problems from cradle to grave called Integrated Demonstrations. An Integrated Demonstration for Volatile Organic Compounds (VOCs) in Arid Soils is discussed in this document. The document discusses technologies to clean up VOCs and associated contaminants in soil and groundwater at arid sites and includes information on drilling, characterization and monitoring, retrieval of contaminants, above ground treatment of contaminants, and in-ground treatment of contaminants. Technologies discussed include, heavy-weight cone penetrometer drilling, directional drilling, ResonantSonicSM drilling, borehole samplers, halosnifs, portable acoustic wave sensors, unsaturated wave apparatus, and supercritical fluid extraction / field detection. Processes and technologies used to complete them which are discussed include in-well vapor stripping, off-gas membrane separation, supported liquid membranes, steam reforming, turnable hybrid plasma, and in situ bioremediation of groundwater.

STUDIES AND DEMONSTRATIONS

Documents Focusing on Test Design

Combining Treatability Studies and Site Characterization for Rational Design of In Situ Bioremediation Using Nitrate as an Electron Acceptor.

Hutchins, S. R.; Kampbell, D. H.; Cook, M. L.; Pfeffer, F. M.; and Cosby, R. L.; U.S. Environmental Protection Agency, Robert S. Kerr Environmental Research Laboratory, Ada, OK, ManTech Environmental Technology, Inc., Ada, OK, Dynamac Corporation, Ada, OK, 1993

EPA Document Number: EPA/600/A-93/172

NTIS Document Number: PB93-221901/XAB

Rational design relates laboratory treatability studies at field scale to the distribution of contaminants and to the residence time of remedial fluids. The electron acceptor is usually the limiting factor in bioremediation. Ideally, the electron acceptor should not be depleted as water or air moves across the region contaminated with oily phase material. When all of the contaminated mass receives adequate supplies of electron acceptor, the course of redemption

should parallel that established in the laboratory study. If regions of the contaminated mass are not adequately supplied, the course of remediation at field scale is not predicted in any straightforward way from the laboratory study. Rational design compares the residence time and concentration of electron acceptor at field scale to the demand demonstrated for the electron acceptor in the laboratory to ensure that the engineered implementation of in situ bioremediation is adequate.

Effects of Ground Water Chemistry on Co-Metabolism of Chlorinated Solvents by Methanotrophic Bacteria.

Palumbo, A. V. and Strandberg, G. W., U.S. Department of Energy, Oak Ridge National Laboratory, Oak Ridge, TN, 1990

NTIS Document Number: DE91-014223/XAB

Degradation of chlorinated alkenes such as trichloroethylene (TCE) by methanotrophic bacteria is a promising technology for the remediation of contaminated ground water. Ultimately, the success of this approach may be dependent on the influence of ground-water chemistry on degradation rates and extent. TCE can rapidly be reduced to low levels in laboratory cultures growing on defined media. However, if major changes in ground-water chemistry are necessary to achieve substantial TCE degradation, field application of processes (i.e., above-ground and in situ treatment) may be limited by cost or logistic problems. For example, the presence of competitive inhibitors may limit the extent of TCE degradation. The goal of the research is to quantify the potential effects of ground-water chemistry on the biodegradation of TCE by methanotrophs and to define concentrations of methane that need to be added to the system to produce maximum rates of TCE degradation. This includes evaluation of major nutritional requirements (e.g., PO₄) in addition to the focus on competitive inhibition.

Experimental Evaluation of the Mathematical Model for In Situ Aquifer Restoration Processes.

Short, T. E. and Yeh, G. T., U.S. Environmental Protection Agency, Robert S. Kerr Environmental Research Laboratory, Ada, OK, Pennsylvania State University, University Park, PA, U.S. Department of Civil Engineering, 1993

EPA Document Number: EPA/600/A-93/147

NTIS Document Number: PB93-212363/XAB

An experimental investigation using an artificial aquifer was conducted on in situ denitrification. Methanol substrate was injected into the aquifer to enable denitrifying bacteria to convert the nitrates into nitrogen. The experiment in the study provided a database that was used to evaluate mathematical simulations of the processes involved. Numerical dispersion was found to be a critical characteristic of the numerical solution technique. Density drive and plugging of the aquifer due to biological growths were found to be important processes that need to be considered in future simulations.

In Situ Bioremediation of Spills from Underground Storage Tanks: New Approaches for Site Characterization, Project Design, and Evaluation of Performance.

Wilkinson, J. T.; Lowell, E. L., Michalowski, J.; Vandergrift, S.; and Callaway, R., U.S. Environmental Protection Agency, Robert S. Kerr Environmental Research Laboratory, Ada, OK, July 1989

EPA Document Number: EPA/600/S2-89/042

NTIS Document Number: PB89-219976/XAB

This report presents a systematic approach for the design of in situ

bioremediation of hydrocarbon contamination in ground water from the determination of the total quantity of hydrocarbons in the aquifer to the utilization of that information in an actual field demonstration. This report explains why the total quantity of hydrocarbons in an aquifer can only be determined by collecting cores. A procedure to acquire cores from a contaminated aquifer is described. The procedures described in the report were field tested in designing a demonstration of the bioremediation of an aviation gasoline leak. The performance of the demonstration was consistent with the expected performance based on the preliminary site characterization using the described procedures.

In Situ Redox Manipulation: Enhancement of Contaminant Destruction and Immobilization.

Fruchter, J. S., Battelle Pacific Northwest Laboratories, Richland, WA, U.S. Department of Energy, Washington, DC, January 1993

NTIS Document Number: DE93-007877/XAB

This report discusses a project to develop, test, and evaluate in situ methods for immobilizing inorganic contaminants (metals, inorganic ions, and radionuclides) and destroying nitrates organic contaminants, (primarily chlorinated hydrocarbons). This research work is being performed for the U.S. Department of Energy through the In Situ Remediation Integrated Program.

Methodologies for Evaluating In Situ Bioremediation of Chlorinated Solvents, Research Report 21, August 19, 1989 - June 19, 1991.

Semprini, L.; Grbic-Galic, D.; McCarty, P. L.; and Roberts, P. V.; Stanford University, CA, U.S. Department of Civil Engineering, U.S. Environmental Protection Agency, Robert S. Kerr Environmental Research Laboratory, Ada, OK, March 1992

EPA Document Number: EPA/600/R-92/042

NTIS Document Number: PB92-146943/XAB

The report summarizes the behavior of and requisite conditions for a class of natural biological processes that can transform chlorinated aliphatic compounds. These compounds are among the most prevalent hazardous chemical contaminants found in municipal and industrial wastewaters, landfills and landfill leachates, industrial disposal sites, and ground water. Biological degradation is one approach that has the potential for destroying hazardous chemicals so that they can be rendered harmless for all time. Methodologies are presented that are useful for evaluating the potential for bioremediation of ground water contaminated with chlorinated aliphatic compounds. Section 1 provides an introduction and an overview of the problems with chlorinated aliphatic compounds in ground water. Section 2 presents a review of the processes affecting the movement and fate of chlorinated aliphatics in the subsurface, including advection, dispersion, sorption and relative mobility, diffusional transport, and immiscible transport. Methodologies and results are presented for evaluating the presence of a native methanotrophic community and its ability to degrade the contaminants of concern, determining the sorption of contaminants to the aquifer material, and preliminary designing of an in situ treatment approach using the model previously described.

Novel Closed Loop Air Stripping Process for VOC Removal from Contaminated Water, Final Report.

Bhowmick, M.; Sontag, T. K.; and Semmens, M. J.; Minnesota University, Minneapolis, MN, Department of Civil and Mineral Engineering, U.S. Geological Survey, Water Resources Division, Reston, VA, December 1990

NTIS Document Number: PB92-218247/XAB

The study presents an approach for the treatment of contaminated ground water, which includes Volatile Organic Compounds (VOCs) stripped from the water using hollow fiber membranes or using conventional air stripping technology and then the VOCs are oxidized in the gas phase using UV oxidation or a combination of photo oxidation and photo-catalysis with Titanium Dioxide (TiO₂). The work on the photooxidation of VOCs is applicable to both water and soil treatment techniques, such as air stripping and in situ vacuum extraction. The study is divided into five major segments. Each segment includes relevant sections on the experimental methods employed, the results from the tests conducted, the development of models, and the conclusions that were drawn from the work.

Office of Technology Development Integrated Program for Development of In Situ Remediation Technologies.

Peterson, M., Battelle Pacific Northwest Laboratories, Richland, WA, U.S.
Department of Energy, Washington, DC, August 1992

NTIS Document Number: DE93-001312/XAB

The Department of Energy's Office of Technology Development has instituted an integrated program focused on development of in situ remediation technologies. The development of in situ remediation technologies will focus on five problem groups: buried waste, contaminated soils, contaminated ground water, containerized wastes, and underground detonation sites. The contaminants that will be included in the development program are volatile and nonvolatile organics, radionuclides, inorganics, and highly explosive materials, as well as mixtures of these contaminants. The In Situ Remediation Integrated Program (ISRIP) has defined the fiscal year 1993 research and development technology areas for focusing activities, and they are described in this paper. These R&D topical areas include: nonbiological in situ treatment, in situ bioremediation, electrokinetics, and in situ containment.

Preliminary Evaluation of Selected In Situ Remediation Technologies for Volatile Organic Compounds Contamination at Arid Sites.

Lenhard, R. J.; Gerber, M. A.; and Amonette, J. E., Battelle Pacific Northwest Laboratories, Richland, WA, U.S. Department of Energy, Washington, DC, October 1992

NTIS Document Number: DE93-002182/XAB

To support the Volatile Organic Compounds-Arid Site (VOC-Arid) Integrated Demonstration (ID) in its technical, logistical, institutional, and economical testing of emerging environmental management and restoration technologies, Pacific Northwest Laboratory is evaluating several in situ remediation technologies for possible inclusion in the demonstration. The evaluations are made with respect to the initial focus of the VOC-Arid ID: the carbon tetrachloride contamination at the Hanford Site, where it was disposed to the vadose zone along with other volatile and nonvolatile organic wastes, heavy metals, acids, and radionuclides. The purposes of this report are (1) to identify candidate in situ technologies for inclusion in the program, (2) to evaluate the candidate technologies based on their potential applicability to VOC contamination at arid sites and geologic conditions representative of the ID host site (i.e., Hanford Site), and (3) to prioritize those technologies for future U.S. Department of Energy support.

Savannah River: Horizontal Wells for In Situ Remediation of Ground Water and Soils.

Kaback, D. S.; Looney, B. B.; Corey, J. C.; Wright, L. M.; and Steele, J. L., DuPont de Nemours (E.I.) and Company, Aiken, SC, Sirrine Environmental Consultants, Greenville, SC, U.S. Department of Energy, Savannah River Laboratory, Aiken, SC, 1989

NTIS Document Number: DE89-010456/XAB

Two horizontal wells were installed adjacent to an abandoned process sewer line at the Savannah River Plant. Documented leaks from the process sewer have contaminated the underlying vadose zone and ground water with volatile organic compounds. The wells were installed to test new methods of in situ remediation of soils and ground water. A deep horizontal well, installed below the water table, is to be used as an air-injection well to strip volatile organics from the contaminated ground water. The shallow horizontal well, installed in the vadose zone, is to be used to remove vapor-phase volatile organic compounds from the vadose zone and to recover the organics purged from the ground water. Horizontal wells were selected for injection and extraction because this geometry should maximize the surface area available for in situ remediation reactions to occur. Target zones for the lateral well screens were selected on the basis of (1) concentrations of volatile organic compounds in ground water from nearby monitoring wells, and (2) porosity and permeability of the sediments as determined by core analysis, geophysical logs, and sieve analyses.

Savannah River: In Situ Remediation System for Contaminated Ground Water, Patent Application.

Corey, J. C.; Looney, B. B.; and Kaback, D. S., U.S. Department of Energy, Savannah River Laboratory, Aiken, SC, August 1988

NTIS Document Number: DE91-017331/XAB

A system for removing volatile contaminants from a subsurface plume of contamination comprising two sets of wells, a well for injecting a fluid into a saturated zone on one side of the plume and an extracting well for collecting the fluid together with volatilized contaminants from the plume on the other side of the plume, is described. The fluid enables the volatile contaminants to be volatilized and carried through the ground to the extracting well. Injecting and extracting wells are preferably horizontal wells positioned below the plume in the saturated zone and above the plume in the vadose zone. The fluid may be air or other gas or a gas and liquid mixture depending on the type of contaminant to be removed and may be preheated to facilitate volatilization. Treatment of the volatilized contamination may be by filtration, incineration, atmospheric dispersion, or the like.

Savannah River: Test Plan for In Situ Bioremediation Demonstration of the Savannah River Integrated Demonstration Project, DOE/OTD TTP No. SR 0566-01. Revision 3.

Hazen, T. C.; Westinghouse Savannah River Company, Aiken, SC, U.S. Department of Energy, Washington, DC, September 1991

NTIS Document Number: DE92-013973/XAB

This project is designed to demonstrate in situ bioremediation of ground water and sediment contaminated with chlorinated solvents. Indigenous microorganisms will be simulated to degrade trichloroethylene (TCE), tetrachloroethylene (PCE) and their daughter products in situ by addition of nutrients to the contaminated zone. In situ biodegradation is a highly attractive technology for remediation because contaminants are destroyed, not simply moved to another location or immobilized, thus decreasing costs, risks, and time, while increasing efficiency and public and regulatory acceptability. Bioremediation has been found to be among the least costly technologies in applications where it will work.

Solvent Extraction for Remediation of Coal Tar Sites, Final Report.

Luthy, R. G.; Dzombak, D. A.; Peters, C.; Ali, M. A.; and Roy, S. B., Carnegie-Mellon University, Department of Civil Engineering, Pittsburgh, PA, U.S. Geological Survey, Water Resources Division, Reston, VA, September 1992

NTIS Document Number: PB93-118347/XAB

The report presents the results of an initial assessment of the feasibility of solvent extraction for removing coal tar from the subsurface or for treating contaminated soil excavated at manufactured gas plant (MGP) sites. In situ solvent extraction would involve injection, recovery, and reclamation for reinjection of an environmentally-benign, water-miscible solvent. Both laboratory experiments and engineering evaluations were performed to provide a basis for the initial feasibility assessment. Laboratory work included identification and evaluation of promising solvents, measurement of fundamental properties of coal tar-solvent-water systems, and measurement of rates of dissolution of coal tar in porous media into flowing solvent-water solutions. Engineering evaluations involved identification of common hydrogeologic features and contaminant distributions at MGP sites, and identification and evaluation of possible injection-recovery well deployment schemes.

STUDIES AND DEMONSTRATIONS (CONT'D)

Documents Focusing on Study Results

Applied Geologic, Microbiological, and Engineering Constraints of In Situ BTEX Bioremediation, Journal Article: Published in Remediation, v3n1, pg. 83-110, Winter 1992-1993.

Kennedy, L. G. and Hutchins, S. R., U.S. Environmental Protection Agency, Robert S. Kerr Environmental Research Laboratory, Ada, OK, American Environmental Consultants, Inc., Norman, OK, February 1993

EPA Document Number: EPA/600/J-92/450

NTIS Document Number: PB93-141513/XAB

An in situ bioremediation project has been designed and constructed for a site in south-central Kansas just north of Wichita. A pipeline leaked an unknown quantity of refined fuels in the 1970s. The spill was undetected until hydrocarbons were found in a nearby municipal water supply well. Of concern, from a regulatory perspective, are the alkylbenzene components found in the ground water, including benzene, toluene, ethylbenzene, and xylene (BTEX). Initial abatement procedures, including free product removal and pumping, had become ineffective. In situ bioremediation was selected to complete the restoration process. The project emphasizes the need for a strong understanding of the geologic and hydrogeologic conditions prevalent under the site. Site studies were conducted to determine the distribution and mass of the contaminant and the hydraulic regime. Laboratory microbial studies were used to determine the efficacy of nitrate as a primary electron acceptor. Information from site studies was used to design a treatment system tailored to the requirements of the site. The treatment system is designed to deliver the maximum amount of nutrient-enriched water to the contaminated zone while maintaining hydraulic control of the site.

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

Buckley, L. P.; Killey, D.; Vijayan, S.; and Wong, P., Argonne National Laboratory, Chemical Technology Division, August 1993

DOE Document Number: DOE/CH-9201

A project to remove groundwater contaminants by an improved treatment process was performed during October 1990 to March 1992 by Atomic Energy of Canada Limited for the United States Department of Energy, managed by Argonne

National Laboratory. The goal was to generate high-quality effluent while minimizing secondary waste volume. Two effluent target levels, within an order of magnitude or less of the U.S. Drinking Water Limit, were set to judge the process effectiveness. The program employed mixed waste feeds containing cadmium, uranium, lead, iron, calcium, strontium-85-90, cesium-137, benzene, and trichloroethylene in simulated and actual groundwater and soil leachate solutions. A combination of process steps that included sequential chemical conditioning, cross-flow microfiltration and dewatering by low temperature-evaporation, and filter pressing were effective for the treatment of mixed waste having diverse physicochemical properties. Overall test results revealed a three-step chemical treatment / microfiltration sequence combined with a final dewatering step is optimal.

Characteristics of the Volatile Organic Compounds – Arid Integrated Demonstration Site.

Last, G. V.; Lenhard, R. J.; Bjornstad, B. N.; Evans, J. C.; and Roberson, K. R., Battelle Pacific Northwest Laboratories, Richland, WA, U.S. Department of Energy, Washington, DC, October 1991

NTIS Document Number: DE92-003882/XAB

The Volatile Organic Compounds – Arid Integrated Demonstration Program (VOC-Arid ID) is targeted at demonstration and testing of technologies for the evaluation and cleanup of volatile organic compounds and associated contaminants at arid DOE sites. The initial demonstration site is an area of carbon tetrachloride (CCl₄) contamination located near the center of the Hanford Site. The movement of CCl₄ and other volatile organic contaminants in the subsurface is very complex. The problem at the Hanford Site is further complicated by the concurrent discharge of other waste constituents including acids, lard oil, organic phosphates, and transuranic radionuclides. In addition, the subsurface environment is very complex, with large spatial variabilities in hydraulic properties. A thorough understanding of the problem is essential to the selection of appropriate containment, retrieval, and/or in situ remedial technologies. The effectiveness of remedial technologies depends on knowing where the contaminants are; how they are held up in a given physical and chemical subsurface environment; and knowing the physical, chemical, and microbiological changes that are induced by the various remedial technologies.

Chemical Enhancements to Pump-and-Treat Remediation.

Palmer, C.D. and Fish, W., Robert S. Kerr Environmental Laboratory, Ada, OK, U.S. Environmental Protection Agency, Office of Research and Development, Office of Solid Waste and Emergency Response, Technology Innovation Office, Washington, DC, January 1992

EPA Document Number: EPA/540/S-92/001

NTIS Document Number: PB92-180074

The document looks into the use of chemical enhancement to improve groundwater remediation efficiencies using pump-and-treat technologies and points out arenas of contamination where such techniques are not practical. While various chemical enhancement methods must be evaluated with regard to specific site conditions, there are general concepts applicable to all chemical enhancement methods, and they are discussed in this document. In addition, this document poses key questions that should be answered before any chemical-enhancement scheme is initiated and stimulates discussion on the merits and limitations of chemical enhancement methods.

Comparison of Bioventing and Air Sparging for In Situ Bioremediation of Fuels.

Kampbell, D. H.; Griffin, C. J.; and Blaha, F. A., U.S. Environmental Protection Agency, Robert S. Kerr Environmental Research Laboratory, Ada, OK,

Solar Universal Technologies, Inc., Traverse City, MI, Coast Guard Civil Engineering Unit, Cleveland, OH, 1993

EPA Document Number: EPA/600/A-93/178

NTIS Document Number: PB93-221968/XAB

Bioremediation pilot-scale subsurface venting and sparging systems were operated at a low aeration rate at an aviation gasoline spill site. Bioventing removed 99 percent of vadose zone contamination in eight months with minimal surface emissions. The biosparging process is presently operating and has removed one-third of oily phase residue below the water table in one year. The ground-water plume has been cleansed of benzene, toluene, ethylbenzene, and xylene (BTEX) components by sparging.

E.I. DuPont De Nemours & Company/Oberlin Filter Company Microfiltration Technology: Applications Analysis Report.

U.S. Environmental Protection Agency, Office of Research and Development, Risk Reduction Engineering Laboratory, Cincinnati, OH, October 1991

EPA Document Number: EPA/540/A5-90/007

NTIS Document Number: PB92-119023/XAB

This document discusses the Superfund Innovative Technology Evaluation (SITE) Program Demonstration of the DuPont/Oberlin microfiltration technology. This document evaluates the microfiltration technology's ability to remove metals (present in soluble or insoluble form) and particulates from liquid wastes while producing a dry filter cake and a filtrate that meet applicable disposal requirements. In addition, it presents economic data from the SITE demonstration, and discusses the potential applicability of the technology. The DuPont/Oberlin microfiltration technology combines Oberlin's automatic pressure filter with DuPont's new microporous Tyvek filter media. It is designed to remove particles that are 0.1 micron in diameter, or larger, from liquid wastes, such as contaminated ground water. This report also summarizes the results from three case studies. All three facilities treated process waste waters containing metals and total suspended solids (TSS) ranging from several parts per million to several percent.

Enhanced Bioremediation Utilizing Hydrogen Peroxide as a Supplemental Source of Oxygen: A Laboratory and Field Study.

U.S. Environmental Protection Agency, Robert S. Kerr Environmental Research Laboratory, Ada, OK, February 1990

EPA Document Number: EPA/600/S-29/006

NTIS Document Number: PB90-183435/XAB

Laboratory and field-scale studies were conducted to investigate the feasibility of using hydrogen peroxide as a supplemental source of oxygen for bioremediation of an aviation gasoline fuel spill. Ground water data from the enhanced in situ bioremediation pilot field study indicates that hydrogen peroxide successfully increased the concentration of available oxygen downgradient. In this study, however, it was observed that there was a measurable increase of oxygen in the soil gas area where hydrogen peroxide was injected. This indicated that a significant fraction of hydrogen peroxide rapidly decomposed to oxygen gas and escaped into the unsaturated zone.

Experimental Examination of Integrated Soil Vapor Extraction Techniques, Journal Article: Published in Proceedings of the Petroleum Hydrocarbons and Organic Chemicals in Ground Water: Prevention, Detection, and Restoration, pg. 441-452, November 1992.

Johnson, R. L.; Bagby, W.; Perrott, M.; and Chen, C. T., Oregon Graduate Institute of Science and Technology, Department of Environmental Science and Engineering, Beaverton, OR, U.S. Environmental Protection Agency, Risk Reduction Engineering Laboratory, Cincinnati, OH, 1992

EPA Document Number: EPA/600/J-92/280

NTIS Document Number: PB93-131738/XAB

Soil vapor extraction (SVE) has been shown to be effective at removing hydrocarbons from the unsaturated zone. However, at many spill sites significant fractions of the mass are at or below the water table, in which case SVE is far less effective. To improve its efficiency in cases where gasoline is trapped below the water table, SVE can be used in conjunction with other techniques to get at that trapped mass. In the last few years the direct injection of air into the formation below the water table (i.e., in situ sparging) has become a popular technique. Another approach is to lower the water table to improve airflow in the vicinity of the trapped product. This can be accomplished either in the localized area of a ground water draw down cone or as the result of larger scale dewatering. In experiments conducted at the Oregon Graduate Institute (OGI), hydrocarbon spills into a large three-dimensional physical model filled with sand are being used to study the efficiencies of SVE combined with other techniques. Experiments to date have examined SVE operating as a stand-alone technique, as well as in conjunction with air sparging below the water table, dewatering of the "smear zone" (i.e., where product is trapped as residual below the water table), and air injection into the dewatered smear zone.

Feasibility of Biodegradation of Tetrachloroethylene in Contaminated Aquifers, Final Report.

Fogel, S., Cambridge Analytical Associates, Inc., Bioremediation Systems Division, Boston, MA, National Science Foundation, Division of Industrial Science and Technological Innovation, Washington, DC, September 16, 1988

NTIS Document Number: PB91-199778/XAB

Tetrachloroethylene (TCE), a solvent and de-greasing agent, is widely spilled and disposed of on soil. It is easily transported in ground water, causing wide-spread aquifer contamination. Conventional technology for the treatment of solvent-contaminated aquifers, which involves pumping out the water and above-ground treatment by physical/chemical techniques, is slow and expensive. Cambridge Analytical Associates Bioremediation Systems has carried out experiments to demonstrate the feasibility of in situ biodegradation of TCE. The process would involve controlled addition of nutrients to the ground water to stimulate the activity of naturally occurring bacteria. A 23 liter laboratory aquifer simulator was constructed and filled with soil, and amended ground water was recirculated throughout the soil. Methanogenic conditions were brought about in the reactor within 15 days and TCE was shown to degrade rapidly to dichloroethylene. Oxygen was then introduced and the oxidation of dichloroethylene by methanotrophic bacteria was initiated. The aquifer simulator experiment indicated that aquifer conditions can be manipulated in situ to bring about the complete degradation of TCE.

Influence of Microbial Transport Processes on "In Situ" Biodegradation of Ground Water Contaminants, Technical Progress Report, Final.

Cunningham, A. B. and Characklis, W. G.; Montana State University, Bozeman Institute for Biological and Chemical Process Analysis, MT, U.S. Geological Survey, Water Resources Division, Reston, VA, 1991

NTIS Document Number: PB91-234732/XAB

A fundamental understanding of both transport and transformation processes is essential to the development of technically sound remediation strategies for

ground water contamination. Accordingly, the goal of the project is to enhance the rate and efficiency of in situ microbial degradation of subsurface contaminants through an improved understanding of processes that govern transport, attachment, growth, and activity of microorganisms in porous media. The report is organized into the following sections: 1) Transport Processes: contains experimental methods and results that document the effect of biofilm accumulation on the transport of water, nutrients, and suspended cells in one-dimensional porous media flow reactions, 2) Effects of Cell Starvation and Motility: presents experimental procedures and results describing transport characteristics of starved vs. growing and motile vs. nonmotile cells in porous media, 3) Modeling Microbial Transport and Activity: describes development of a mathematical model that simulates contaminant biodegradation/biosorption, nutrient depletion and biomass accumulation in one-dimensional porous media flow, and 4) Bioremediation Guidelines: summarize relevant information in the form of guidelines useful to decision-makers concerned with bioremediation of contaminated water and soil.

In Situ Biodegradation Treatment.

U.S. Environmental Protection Agency, Office of Emergency and Remedial Response, Washington, DC, Office of Research and Development, Cincinnati, OH, April 1994

EPA Document Number: EPA/540/S-94/502

In situ biodegradation may be used to treat low-to-intermediate concentrations of organic contaminants in place without disturbing or displacing the contaminated media. Although this technology has been used to degrade a limited number of inorganics, specifically cyanide and nitrate, in situ biodegradation is not generally employed to degrade inorganics or to treat media contaminated with heavy metals. During in situ biodegradation, electron acceptors (e.g., oxygen and nitrate), nutrients, and other amendments may be introduced into the soil and groundwater to encourage the growth of an indigenous population capable of degrading the contaminants of concern. These supplements are used to control or modify site-specific conditions that impede microbial activity and, thus, the rate and extent of contaminant degradation. Depending on site-specific clean-up goals, in situ biodegradation can be used as the sole treatment technology or in conjunction with other biological, chemical, and physical technologies in a treatment train. In the past, in situ biodegradation has often been used to enhance traditional pump and treat technologies. As of Fall 1993, in situ biodegradation was being considered or implemented as a component of the remedy at 21 Superfund sites and 38 RCRA, Underground Storage Tank, Toxic Substances Control Act, and Federal sites with soil, sludge, sediment, or groundwater contamination. This bulletin provides information on the technology's applicability, the types of residuals produced, the latest performance data, the site requirements, the status of the technology, and sources for further information.

In Situ Bioremediation of Hanford Ground Water.

Skeen, R. S.; Roberson, K. R.; Workman, D. J.; Petersen, J. N.; and Shouche, M., Battelle Pacific Northwest Laboratories, Richland, WA, U.S. Department of Energy, Washington, DC, April 1992

NTIS Document Number: DE92-012350/XAB

Liquid wastes containing radioactive, hazardous, and regulated chemicals have been generated throughout the 40+ years of operations at the U.S. Department of Energy's (DOE) Hanford Site. Some of these wastes were discharged to the soil column and many of the waste components, including nitrate, carbon tetrachloride (CCl₄), and several radionuclides, have been detected in the Hanford ground water. Current DOE policy prohibits the disposal of contaminated liquids directly to the environment, and remediation of existing contaminated ground waters may be required. In situ bioremediation is one

technology currently being developed at Hanford to meet the need for cost effective technologies to clean ground water contaminated with CCl₄, nitrate, and other organic and inorganic contaminants. This paper focuses on the latest results of an ongoing effort to develop effective in situ remediation strategies through the use of predictive simulations.

In Situ Generation of Oxygen By Electrolysis and the Electrochemical Effects on Microorganisms' Population, Final Report, September 19, 1990 - November 19, 1991.

Han, M. K.; Wyza, R. E.; and Olfenbuttel, R. F., Battelle Columbus Laboratories, OH, Naval Civil Engineering Laboratory, Port Hueneme, CA, June 1992

NTIS Document Number: AD-A252 358/7/XAB

The objective of this program was to quantitatively assess the effectiveness of in situ electrolysis of ground water on the growth of soil microorganisms. The electrolysis method was used to supply oxygen to soil microorganisms to enhance bioremediation of sites that are contaminated with hydrocarbons. Electrochemical tests were performed with two different types of soils in a 10-gallon glass container. Experimental variables examined included driving voltage, current, and electrode spacing. Stainless steel mesh was used for both the anode and the cathode. Depending on the soil, a sustained supply of dissolved oxygen up to 16 ppm was achieved. The population of soil microorganisms increased with increasing the oxygen content in the ground water. A slight decrease in the population was seen at the cathode, which might have been due to an increase in the pH at the cathode.

In Situ Steam Extraction Treatment, Engineering Bulletin.

Science Applications International Corporation, Cincinnati, OH, U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Office of Emergency and Remedial Response, Washington, DC, May 1991

EPA Document Number: EPA/540/2-91/005

NTIS Document Number: PB91-228064/XAB

In situ steam extraction removes volatile and semivolatile hazardous contaminants from soil and ground water without excavation of the hazardous waste. Waste constituents are removed in situ by the technology and are not actually treated. The use of steam enhances the stripping of volatile contaminants from soil and can be used to displace contaminated ground water under some conditions. The resultant condensed liquid contaminants can be recycled or treated prior to disposal. The steam extraction process is applicable to organic wastes but has not been used for removing insoluble inorganics and metals. Steam is injected into the ground to raise the soil temperature and drive off volatile contaminants. Alternatively, steam can be injected to form a displacement front by steam condensation to displace ground water. The contaminated liquid and steam condensate are then collected for further treatment. Two types of systems are discussed in the document: 1) the mobile system and 2) the stationary system. The bulletin provides information on the technology applicability, limitations, a description of the technology, types of residuals produced, site requirements, the latest performance data, the status of the technology, and sources for further information.

Laboratory Evaluation of the In Situ Chemical Treatment Approach for Remediation of Contaminated Soils and Ground Water.

Thorton, E. C.; Jurgensmeier, C. A.; and Baechler, M. A., Westinghouse Hanford Company, Richland, WA, U.S. Department of Energy, Washington, DC, October 1991

NTIS Document Number: DE93-006901/XAB

Bench-scale solution and soil tests were conducted in a proof of principle demonstration of the in situ chemical treatment approach to the remediation of metal and radionuclide contaminated soil and ground water. These tests were directed specifically towards treatment of Cr6 contaminated solutions and unsaturated soil as an application of the approach. Testing was planned and conducted to provide general information relating treatment agent concentrations to effect. This approach served to define the amount of a specific agent required to achieve acceptable results and provided information regarding treatment rates and pH effects associated with the treatment reactions.

Performance Evaluation of a Ground Water and Soil Gas Remedial Action.

Hansen, M. C. and Hartnett, S. L., U.S. Department of Energy, Argonne National Laboratory, IL, July 1990

NTIS Document Number: DE90-017659/XAB

Volatile organic compounds (VOCs) continue to be remediated by a ground-water extraction system and an in situ vapor extraction system at a Midwest agricultural site. Carbon tetrachloride (CCl4) and chloroform (CHCl3) contamination levels were detected at maximum concentrations of 4000 parts per billion (ppb) and 360 ppb, respectively, for on-site ground-water samples and 6000 ppb and 1800 ppb, respectively, for on-site gas samples. Ground water from a domestic well and a monitoring well located at least 2300 ft. downgradient from the site also had CCl4 and CHCl3 contamination. Furthermore, a public water supply well, located downgradient of the site, was found to have ground water contaminated with CCl4. During two years of operation of the remedial action, ground-water and soil gas samples have been analyzed to monitor potential migration of contaminants from the site and to track the overall progress toward cleanup. Results demonstrate a decrease in ground-water contamination in both on- and off-site monitoring wells and a decrease in soil gas air emissions from the site. This paper presents the sampling results for the site over the last two years and discusses trends indicating the effectiveness of the remedial action system in controlling contaminant migration and overall progress toward reducing the source of contamination in the unsaturated subsoils.

perox-pure™ Chemical Oxidation Technology Peroxidation Systems, Inc.: Applications Analysis Report.

U.S. Environmental Protection Agency, Office of Research and Development, Risk Reduction Engineering Laboratory, Cincinnati, OH, July 1993

EPA Document Number: EPA/540/AR-93/501

NTIS Document Number: PB94-130325/XAB

This document discusses the Superfund Innovative Technology Evaluation (SITE) Program Demonstration of the perox-pure' chemical oxidation technology's ability to remove volatile organic compounds (VOC) and other organic contaminants present in liquid wastes. The perox-pure' chemical oxidation technology was developed to destroy dissolved organic contaminants in water. The technology uses ultraviolet (UV) radiation and hydrogen peroxide to oxidize organic compounds present in water at parts per million levels or less. This treatment technology produces no air emissions and generates no sludge or spent media that require further processing, handling, or disposal. Economic data and the results from three case studies are also summarized in this report. The contaminants of concern in these case studies include acetone, isopropyl alcohol (IPA), TCE, and pentachlorophenol (PCP).

Reductive Dehalogenation: A Subsurface Bioremediation Process, Journal Article: Published in Remediation, Winter 1990-1991.

Sims, J. L.; Suflita, J. M.; and Russell, H. H., U.S. Environmental Protection

Agency, Robert S. Kerr Environmental Research Laboratory, Ada, OK, Utah Water Research Laboratory, Logan, OK, Oklahoma University, Department of Botany and Microbiology, Norman, OK, 1990

EPA Document Number: EPA/600/J-90/259

NTIS Document Number: PB91-144873/XAB

Introduction and large-scale production of synthetic halogenated organic chemicals over the last 50 years has resulted in a group of contaminants that tend to persist in the environment and resist both biotic and abiotic degradation. The low solubility of these types of contaminants, along with their toxicity and tendency to accumulate in food chains, make them particularly relevant targets for remediation activities. Among the mechanisms that result in dehalogenation of some classes of organic contaminants are stimulation of metabolic sequences through introduction of electron donor and acceptor combinations, addition of nutrients to meet the needs of dehalogenating microorganisms, possible use of engineered microorganisms, and use of enzyme systems capable of catalyzing reductive dehalogenation. The current state of research and development in the area of reductive dehalogenation is discussed along with possible technological application of relevant processes and mechanisms to remediation of soil and ground water contaminated with chlorinated organics. In addition, an overview of research needs is suggested, which might be of interest for development of in situ systems to reduce the mass of halogenated organic contaminants in soil and ground water.

Removal of Radionuclides by Electrokinetic Soil Processing, Journal Article: Published in Journal of the National Technical Association, Spring 1993.

Parker, R. A., U.S. Environmental Protection Agency, Office of Research and Development, Risk Reduction Engineering Laboratory, Cincinnati, OH, 1993

EPA Document Number: EPA/600/J-93/296

NTIS Document Number: PB93-222875/XAB

Electrokinetics promises to be an innovative treatment process for in situ treatment of soils and ground water contaminated with heavy metals and radionuclides. Electrokinetics refers to the movement of ionic liquids and charged particles relative to one another under the action of an applied direct current electric field. The paper summarizes the results of laboratory tests for the removal of uranium, thorium, and radium, conducted from February 28, 1991, to March 30, 1991, and a review of progress to date.

Retrospective Performance Evaluation on In Situ Bioremediation: Site Characterization.

Wilson, J. T. and Kampbell, D. H., Robert S. Kerr Environmental Research Laboratory, Ada, OK, 1993

EPA Document Number: EPA/600/A-93/173

NTIS Document Number: PB93-221919/XAB

Performance of in situ bioremediation was demonstrated at a shallow water site with subsurface contamination of used crank case oil, diesel fuel, gasoline, and other oily phase products. Treatment involved ground-water amendment by hydrogen peroxide and nutrients by a recharge gallery. The system was operated for 2 1/2 years. During treatment benzene and total BTEX concentrations in ground water were reduced in magnitude exceeding ten and twenty times, respectively. Vertical profile core samples showed a two-foot thick interval near the water table containing significant amounts of hydrocarbons. The center of the interval had not been depleted of BTEX compounds, but the surrounding cortex had been physically and biologically

weathered. The interval material was fine textured which restricted flow of remedial fluids resulting in little opportunity for bioremediation.

Savannah River: Field Demonstration of In Situ Air Stripping Using Horizontal Wells.

Looney, B. B. and Kaback, D. S., Westinghouse Savannah River Company, Aiken, SC, U.S. Department of Energy, Washington, DC, 1991

NTIS Document Number: DE92-009963/XAB

Under sponsorship from the U.S. Department of Energy, technical personnel from the Savannah River Laboratory and other DOE laboratories, universities, and private industry have completed a full scale demonstration of environmental remediation using horizontal wells. The 139-day long test was designed to remove volatile chlorinated solvents from the subsurface using two horizontal wells. One well, approximately 90 m long and 45 m deep drilled below a contaminant plume in the ground water, was used to inject air and strip the contaminants from the ground water. A second horizontal well, approximately 50 m long and 20 m deep in the vadose zone, was used to extract residual contamination in the vadose zone along with the material purged from the ground water. The test successfully removed approximately 7250 kg of contaminants. A large amount of characterization and monitoring data was collected to aid in interpretation of the test and to provide the information needed for future environmental restorations that employ directionally drilled wells as extraction or delivery systems.

Savannah River: Full-scale Field Test of the In Situ Air Stripping Process at the Savannah River Integrated Demonstration Test Site.

Looney, B. B.; Hazen, T. C.; Kaback, D. S.; and Eddy, C. A., Westinghouse Savannah River Company, Aiken, SC, U.S. Department of Energy, Washington, DC, June 1991

NTIS Document Number: DE92-009749/XAB

Under sponsorship from the U.S. Department of Energy, technical personnel from the Savannah River Laboratory (SRL) and other DOE laboratories, universities, and private industry have completed a full-scale demonstration of environmental remediation using horizontal wells. This demonstration was performed as Phase I of an Integrated Demonstration Project designed to evaluate innovative remediation technologies for environmental restoration of sites contaminated with organic contaminants. The demonstration utilized two directionally drilled horizontal wells to deliver gases and extract contaminants from the subsurface. The resulting in situ air stripping process was designed to remediate soils and sediments above and below the water table as well as ground water contaminated with volatile organic contaminants. The 139-day long test successfully removed volatile chlorinated solvents from the subsurface using the two horizontal wells. One well, approximately 300 ft (90 m) long and 165 ft (50 m) deep drilled below a contaminant plume in the ground water, was used to inject air and strip the contaminants from the ground water. A second horizontal well, approximately 175 ft (53 m) long and 75 ft (23 m) deep in the vadose zone, was used to extract residual contamination in the vadose zone along with the material purged from the ground water. Pre-test and post-test characterization data and monitoring data during the demonstration were collected to aid in interpretation of the test and to provide the information needed for future environmental restoration that employs directionally drilled wells as extraction or delivery systems. Contaminant concentration data and microbiological monitoring data are summarized in this report; the characterization data and geophysical monitoring data are documented in a series of related project reports.

Savannah River: Ground Water and Soil Remediation: In Situ Air Stripping Using Horizontal Wells.

Kaback, D. S.; Looney, B. B.; Eddy, C. A.; and Hazen, T. C., Westinghouse Savannah River Company, Aiken, SC, U.S. Department of Energy, Washington, DC, 1990

NTIS Document Number: DE92-009906/XAB

An innovative environmental restoration technology, in situ air stripping, has been demonstrated at the U.S. Department of Energy (DOE) Savannah River Site (SRS) in South Carolina. This process, using horizontal wells, is designed to concurrently remediate unsaturated-zone soils and ground water containing volatile organic compounds (VOCs). In situ technologies have the potential to substantially reduce costs and time required for remediation, as well as improve effectiveness of remediation. Horizontal wells were selected to deliver and extract fluids from the subsurface because their geometry can maximize the efficiency of a remediation system and they have great potential for remediating contaminant sources under existing facilities. The first demonstration of this new technology was conducted for a period of twenty weeks. A vacuum was first drawn on the vadose zone well until a steady-state removal of VOCs was obtained. Air was then injected at three different rates and at two different temperatures. An extensive characterization program was conducted at the site and an extensive monitoring network was installed prior to initiation of the test. Significant quantities of VOCs have been removed from the subsurface (equivalent to an eleven-well, 500-gpm, pump-and-treat system at the same site). Concentrations of VOCs in the ground water have been significantly reduced in a number of the monitoring wells.

Savannah River: Immunological Techniques as Tools to Characterize the Subsurface Microbial Community at a Trichloroethylene Contaminated Site.

Fliermans, C. B.; Dougherty, J. M.; Franck, M. M.; McKinzey, P. C.; and Hazen, T. C., Westinghouse Savannah River Company, Aiken, SC, U.S. Department of Energy, Washington, DC, 1992

NTIS Document Number: DE93-007443/XAB

Effective in situ bioremediation strategies require an understanding of the effects pollutants and remediation techniques have on subsurface microbial communities. Therefore, detailed characterization of a site's microbial communities is important. Subsurface sediment borings and water samples were collected from a trichloroethylene (TCE)-contaminated site, before and after horizontal well in situ air stripping and bioventing, as well as during methane injection for stimulation of methane-utilizing microorganisms. Subsamples were processed for heterotrophic plate counts, acridine orange direct counts (AODC), community diversity, direct fluorescent antibodies (DFA) enumeration for several nitrogen-transforming bacteria, and Biolog (regsign) evaluation of enzyme activity in collected water samples. Plate counts were higher in near-surface depths than in the vadose zone sediment samples. During the in situ air stripping and bioventing, counts increased at or near the saturated zone and remained elevated throughout the aquifer, but did not change significantly after the air stripping. Sporadic increases in plate counts at different depths as well as increased diversity appeared to be linked to differing lithologies. AODCs were orders of magnitude higher than plate counts and remained relatively constant with depth except for slight increases near the surface depths and the capillary fringe. Nitrogen transforming bacteria, as measured by serospecific DFA, were greatly affected both by the in situ air stripping and the methane injection. Biolog (regsign) activity appeared to increase with subsurface stimulation both by air and methane. The complexity of subsurface systems makes the use of selective monitoring tools imperative.

Savannah River: Savannah River Integrated Demonstration Program.

Westinghouse Savannah River Company, Aiken, SC, U.S. Department of Energy, Washington, DC, 1991

NTIS Document Number: DE92-009587/XAB

Leakage of solvents (trichloroethylene and tetrachloroethylene) from an underground process sewer line has contaminated soils and underlying ground water at the Savannah River facility of the Department of Energy (DOE). This site was chosen for an experimental project, conducted as part of DOE's integrated demonstrated program for environmental remediation. The project demonstrated a new in situ remediation technology that has the potential to reduce clean-up costs and time. Known as in situ air stripping, the new technology involves injection of air through underground horizontal wells to strip ground water and soils of volatile organics; the resulting diffused air is collected, and the hazardous chemicals are removed to the surface for further processing. This brochure briefly describes the use of the integrated demonstration approach, and in situ air stripping with horizontal wells as a viable new remediation method.

Stabilization of Microorganisms for In Situ Degradation of Toxic Chemicals, Progress Report, Year Two.

Crawford, R. L. and Stormo, K., Idaho University, Moscow, ID, U.S. Department of Energy, Washington, DC, March 1991

NTIS Document Number: DE92-040792/XAB

Methods were developed to microencapsulate a petachloro-phenol (PCP)-degrading Flavobacterium and a p-cresol (PCR)-degrading Pseudomonas within beads of 5-100 am diameter, and these entrapped cells were examined for their ability to mineralize PCP and PCR in the presence of subsurface soils and waters obtained from the University of Idaho (UI) Ground-Water Research Site (GRS). Matrices employed to make beads included alginate, agarose, polyurethane, agarose coated by polyurethane, and novel polyurethanes containing cross-linked sources of supplemental carbon and/or nitrogen sources. A low-pressure-nozzle apparatus was developed for the production of microspheres. Results showed that microencapsulated cells survived better and were catabolically more active than free cells in the presence of aquifer materials. Microcosm studies reported here confirmed that microbeads containing long-lived pollutant-degrading bacterial cells can be readily prepared in sizes that will travel through subsurface sand/gravel aquifer matrixes. Microencapsulated bacteria at PCP concentrations up to 275 ppm and free cells at PCP concentrations <150 ppm can remain active for extended periods under simulated aquifer conditions. Periods of several months are certainly attainable. This should be sufficient time to effect significant environmental restoration through biodegradation of specific targeted pollutants.

Surfactant Flooding Technology for In Situ Cleanup of Contaminated Soils and Aquifers--A Feasibility Study.

Porzucek, C., U.S. Department of Energy, Los Alamos National Laboratory, NM, November 1989

NTIS Document Number: DE90-003989/XAB

The process of in situ, surfactant-enhanced soil washing has been investigated to determine its usefulness and limitations. Previous work on this subject has been reviewed critically. Entrapment/displacement mechanisms of nonaqueous phase liquids (NAPLs) in porous media have been identified and are discussed. The effect of surfactant on each of these mechanisms has been investigated. A joint research project has been initiated with Howard University personnel to determine the effect of surfactant on contaminants that have adsorbed onto soil surfaces. Results of this research are necessary to more fully determine the limitations of in situ, surfactant-enhanced soil washing. However, based on field observations of NAPLs and modification of an existing mass-transfer-based model, it is apparent that in situ, surfactant-enhanced soil washing alone will not be a sufficient remedial action plan because it cannot displace enough contaminant to clean the soil to within the

Environmental Protection Agency's guidelines of cleanliness. The process shows the most promise when it is used in conjunction with another remedial action plan such as bioremediation.

Terra Vac In Situ Vacuum Extraction System: Applications Analysis Report.
Stinson, M., Foster Wheeler Enviroresponse, Inc., Livingston, NJ, U.S.
Environmental Protection Agency, Office of Research and Development, Risk Reduction Engineering Laboratory, Cincinnati, OH, July 1989

EPA Document Number: EPA/540/A5-89/003

NTIS Document Number: PB90-119744/XAB

The report analyzes the results from the Superfund Innovative Technology Evaluation Program's 56-day demonstration at the Valley Manufactured Product Company's site in Groveland, Massachusetts. Conclusions were reached concerning the technology's suitability for use in remediations involving both similar and different materials at other sites. Operational data and sampling and analysis information were monitored carefully to establish a database against which vendor's claims for the technology could be evaluated. Additional data on the technology's performance at other sites is also discussed. The conclusions from the results of the Groveland demonstration test and from other available data are: 1) the process can be used to remediate a site contaminated with VOCs; 2) the process can remove VOCs from soils with permeabilities as low as 10⁻⁸ cm/s; 3) the process operates well in all weather conditions; and 4) the process implementation costs can be as low as \$20/ton, depending on various site-specific conditions.

Treatability of Contaminated Ground Water and Aquifer Solids at "Town Gas" Sites, Using Photolytic Ozonation and Chemical In Situ Reclamation, Final Report.

Peyton, G. R.; LeFaivre, M. H.; and Smith, M. A., Illinois State Water Survey Division, Champaign, Aquatic Chemistry Section, Illinois Department of Energy and Natural Resources, Champaign, Hazardous Waste Research and Information Center, August 1990

NTIS Document Number: PB90-267253/XAB

The feasibility of cleaning up contaminated ground water and aquifer solids from so-called "town gas" sites using photolytic ozonation and chemical in situ aquifer reclamation (CISR) techniques was investigated in the laboratory. At the actual site, coal was thermally oxidized to produce methane for municipal distribution. The degradation left a coal which, if released into the ground, could contaminate ground water and aquifer solids with a number of organic substances, including aromatic hydrocarbons such as benzene, toluene, xylene (BTX), and polynuclear aromatic hydrocarbons (PAHs) at environmentally significant concentrations. A chemical in situ treatment method using persulfate as a source of free radicals destroyed organic contaminants that were adsorbed to the aquifer solids. PAHs were reduced by 34 percent after 12 days of treatment and by 52 percent after 40 days.

OTHER RESOURCE GUIDES

Bioremediation Resource Guide.

U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Technology Innovation Office, Washington, DC, September 1993
(see abstract below)

EPA Document Number: EPA/542/B-93/004

Physical/Chemical Treatment Technology Resource Guide.

U.S. Environmental Protection Agency, Office of Solid Waste And Emergency Response, Technology Innovation Office, Washington, DC, September 1994
(see abstract below)

EPA Document Number: EPA/542-B-94/008

Soil Vapor Extraction (SVE) Treatment Technology Resource Guide.

U.S. Environmental Protection Agency, Office of Solid Waste And Emergency Response, Technology Innovation Office, Washington, DC, September 1994

EPA Document Number: EPA/542-B-94/007

These documents are intended to support decision-making by Regional and State Corrective Action permit writers, Remedial Project Managers (RPMs), On-Scene Coordinators, contractors, and others responsible for the evaluation of innovative treatment technologies. These guides direct managers of sites being remediated under RCRA, UST, and CERCLA to bioremediation, ground-water, physical/chemical, and soil vapor extraction treatment technology resource documents; databases; hotlines; and dockets, and identify regulatory mechanisms (e.g., Research Development and Demonstration Permits) that have the potential to ease the implementation of these technologies at hazardous waste sites. Collectively, the guides provide abstracts of over 300 guidance/workshop reports, overview/program documents, studies and demonstrations, and other resource guides, as well easy-to-use Resource Matrices that identify the technologies and contaminants discussed in each abstracted document.