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ITEP: A Survey of Innovative Environmental Restoration Technologies in the Netherlands and France

William J. Roberds, Charles F. Voss, Scott A. Hitchcock
Golder Associates, Inc.
Redmond, WA 98052

Prepared by
Sandia National Laboratories
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ITEP: A SURVEY OF INNOVATIVE ENVIRONMENTAL RESTORATION TECHNOLOGIES IN THE NETHERLANDS AND FRANCE

William J. Roberds, Charles F. Voss, and Scott A. Hitchcock
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Sandia Contract No. 87-3497

ABSTRACT

The International Technology Exchange Program (ITEP) of the Department of Energy's (DOE's) Office of Environmental Management (EM) is responsible for promoting the import of innovative technologies to better address EM's needs and the export of US services into foreign markets to enhance US competitiveness. Under this program, potentially innovative environmental restoration technologies, either commercially available or under development in the Netherlands and France, were identified, described, and evaluated. It was found that 12 innovative environmental restoration technologies, which are either commercially available or under development in the Netherlands and France, may have some benefit for the DOE EM program and should be considered for transfer to the United States.

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This report was prepared under the direction of Dr. Rudy V. Matalucci, Principal Investigator of the International Technology Exchange Program, Sandia National Laboratories, Albuquerque, New Mexico. This report was reviewed by James L. Rea and Darrell E. Munson.

The DOE Program Manager responsible for the preparation of this report is David W. Geiser, formerly of the International Technology Exchange Staff, EM-52.1, Washington, D.C.

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PREFACE

The information cited in the descriptions and profiles of the innovative foreign technologies in this report represents a summary of the information available at the time of printing. No independent tests or evaluations were performed on the technologies in this report.

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EXECUTIVE SUMMARY

Golder Associates Inc. (Golder), under contract to Sandia National Laboratories (SNL), has conducted an in-depth survey of The Netherlands and France, with the objective of identifying potentially innovative (i.e., better, cheaper, faster, safer, and/or more acceptable) technologies that could meet the environmental restoration (ER) needs of the Department of Energy (DOE). This study is in support of the Office of Technology Development (OTD) within the DOE's Office of Environmental Management (EM).

The initial objective of this survey was to identify Dutch and French ER technologies at all levels of development that:

- could potentially fulfill one or more of the DOE's ER needs,
- are innovative, and
- are not currently available in the United States.

Technologies in earlier stages of development were subsequently determined to be a lower priority, so that during the study the focus evolved towards mature technologies.

The survey consisted of two approaches: a Direct Approach, based on contacting technology developers, was used to quickly identify several candidate technologies; and a Systematic Phased Approach, based on an extensive literature search and attendance at conferences, was used to identify other candidate technologies in a more comprehensive manner.

In the Direct Approach, Golder arranged interviews with leading Dutch and French ER technology developers such as TAUW, TNO, SCG, and TU Delft in The Netherlands and BRGM and Soletanche in France. During each interview, the developer was asked to present information on ER technologies at all stages of development, with an emphasis on the technologies they considered particularly innovative.

Following this, Golder developed a Systematic Phased Approach, based on an extensive literature search and attendance at conferences, in an effort to identify ER technologies developed by less well-known sources and to select the ones best meeting the survey objective. In this approach, at each successive phase fewer (but more relevant) technologies were evaluated in greater detail. In the first phase, a comprehensive data base of Dutch and French ER technologies was developed through literature searches and conference attendance. The second phase involved classifying the technologies in the data base on their degree of innovation and level of maturity. In phase three, the most innovative and mature technologies were compared with technologies available through US vendors, and in the process those technologies that were not unique were eliminated. In the fourth and final phase, detailed evaluations of these technologies were conducted, including discussions with the developers. These were documented in a specific format, suitable for incorporation into the DOE's EnviroTRADE

Information Systems and later incorporated in the International Technology Catalogue developed by Sandia National Laboratories for the DOE.¹

As a result of this survey, 12 ER technologies were identified and evaluated as being sufficiently innovative to warrant consideration for application to the DOE's ER needs. They include (in no specific order):

- BIOPUR[®] - a commercially available, convenient, portable plant for on-site, ex situ treatment of both extracted groundwater and soil vapor contaminated with organic compounds, using a relatively efficient and stable aerobic, plug flow, fixed film trickling filter bioreactor.
- PAH-Field Analysis - a commercially available, quick and relatively inexpensive field method for analyzing polycyclic aromatic hydrocarbons in soil samples based on chemiluminescence.
- Electrochemical Dehalogenation of Toxic Organic Compounds - an immature (laboratory phase) process for ex situ treatment of extracted groundwater or waste water contaminated with chlorinated compounds (e.g., pentachlorophenyl, PCP) via electrolysis.
- Biochemical Treatment of Heavy Metals Contamination - an immature (laboratory phase) process for ex situ treatment of solids (e.g., excavated soils, sludges, ash, and mine tailings) contaminated with heavy metals (e.g., radionuclides). The metals are leached with sulfuric acid produced in a bioreactor and the effluent subsequently treated in a sulfate-reducing bioreactor.
- Biological Dehalogenation of Chlorinated Ethylenes - an immature (laboratory phase) process for ex situ treatment of excavated soil or extracted groundwater or air contaminated with chlorinated ethylenes using an anaerobic bioreactor to degrade pentachloroethylene (PCE) and trichloroethylene (TCE) to 1,2-cis-dichloroethylene (DCE) and an aerobic bioreactor to subsequently degrade DCE.
- HYDROFRAISE[®] - a commercially available system (including special equipment) for efficiently excavating and constructing vertical, low permeability containment barriers up to 125 m deep in a variety of subsurface conditions, including rock.
- Electro-Reclamation - a commercially available process for in situ or ex situ treatment of heavy metal contamination (e.g., radionuclides) of low permeability soils. The process

¹ EnviroTRADE is a database of environmental restoration and waste management technologies that have been matched to applicable waste sites. This database is sponsored by the US DOE and has been developed by Sandia National Laboratories.

uses charged electrode arrays to mobilize the contaminants and a continuous chemical circulation system to extract and treat the contaminants.

- Ex Situ Bioremediation of Heavy Metals Using Sulfate-Reducing Bacteria - a commercially available plant for ex situ treatment of extracted groundwater or waste water contaminated with heavy metals and sulfates, using an anaerobic bioreactor to reduce sulfates to sulfides and an aerobic bioreactor for sulfide oxidation.
- In Situ Removal of Decanoic Acid by Flushing with NaOH - a demonstrated process for enhancing the extraction of weak, highly viscous, low solubility acid from contaminated soil in situ by flushing with NaOH (to increase solubility) in conjunction with groundwater extraction.
- In Situ Removal of Cadmium and On-site Treatment by Ion Exchange - a demonstrated process for enhancing the extraction of cadmium from contaminated soil in the vadose zone in situ, by leaching with HCl (to desorb the cadmium) in conjunction with lateral drains (to recover the percolate) and ex situ resin ion exchangers (to remove and concentrate the cadmium from the percolate).
- Ex Situ Extraction of Organic Bromine Compounds From Soils Using NaOH - an efficient, commercially available plant for ex situ treatment of excavated soil contaminated with bromine compounds, using NaOH as an extracting agent during soil washing (two in-line modified screw classifiers) in conjunction with subsequent treatment.
- ECOSOL[®] Contaminant-Adsorbing Grout - a commercially available grout technology used in containment barriers. The grout can be designed to promote precipitation and adsorption of specific organic and heavy metal contaminants.

With the exception of one set of publications, the survey of the Netherlands and France was relatively comprehensive, so that most of the current innovative and mature ER technologies in those countries are represented in the above list.

It is thought that:

- The above candidate ER technologies have been adequately evaluated to determine their applicability to DOE needs.

It is recommended that:

- The applicability of each of the candidate ER technologies to the DOE's needs (either problem units or R&D projects) be evaluated and transfer actively pursued.
- Less mature technologies be evaluated in more detail and the German literature be evaluated.

1 INTRODUCTION

One of the primary goals of the Department of Energy's (DOE's) Office of Environmental Management (EM) is to remediate waste sites throughout its complex and bring the facilities into full compliance with US environmental regulations by the year 2019. Within EM, the Office of Technology Development (OTD) has the charter to develop environmental restoration (ER) technologies to support the cleanup goal. In addition to developing and demonstrating US ER technologies, OTD is looking for foreign ER technologies that may better address the DOE's needs. The International Programs Division (IPD) has the responsibility within OTD of cooperating with foreign governments, industries, and educational institutions to identify, evaluate, and, if appropriate, transfer promising ER technologies. Secondarily, the IPD is identifying foreign ER needs as possible market opportunities for US businesses.

As part of this effort, Golder Associates Inc., under contract to the IPD and Sandia National Laboratories (SNL), performed a regional survey to identify the countries with the greatest potential for exchange of ER technologies (Golder, 1993a). The evaluation was limited to Canada, Australia, Mexico, New Zealand and 13 western European countries, excluding Germany and Great Britain, which were surveyed in FY92 (Golder, 1992a). The objective of the survey was to provide ranking of the countries based on their potential for providing innovative (i.e., better, safer, cheaper, faster, and/or more acceptable) technologies to meet the ER needs of the DOE, and their market potential for environmental service companies in the US. As a result, The Netherlands and France were identified as having the greatest potential for meeting the DOE's goals among the countries evaluated. Similar surveys were conducted for other countries as described in the IPD Work Plan (Golder, 1993b).

Following completion of the regional survey, Golder was directed to perform an in-depth survey of The Netherlands and France, with the objective of identifying innovative foreign technologies that could meet the ER needs of the DOE. Information obtained from the regional survey (Golder, 1993a) was used to select leading technology developers that were subsequently interviewed. As a result of this Direct Approach, several innovative ER technologies at various stages of development were identified (Section 2-1). Following this, a Systematic Phased Approach was developed and applied to complete the survey focusing on mature technologies (Section 2-2). The Systematic Phased Approach resulted in the identification and screening of innovative ER technologies in several phases, with more detailed evaluations conducted on fewer technologies in each successive phase. Brief summaries of the technologies identified in this survey are presented in Section 3, followed by Golder's conclusions and recommendations in Section 4.

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2 APPROACH

The initial objective of this survey was to identify Dutch and French ER technologies at all levels of development that:

- could potentially fulfill one or more of the DOE's ER needs (ASL, 1993a),
- are innovative, and
- are not currently available in the US.

The survey consisted of two approaches: a Direct Approach, based on contacting technology developers, was used to quickly identify several candidate technologies; and a Systematic Phased Approach, based on an extensive literature search and attendance at conferences, was used to identify other candidate technologies in a more comprehensive manner.

2-1 Direct Approach

The first step in identifying ER technologies that met the survey objective was to build on information already gathered. Information on the location and current activities of leading ER technology developers had been acquired as background information for, but not presented in, the regional survey presented by Golder (1993a) to SNL in March of FY93. This information was used to direct the initial effort designed to quickly identify innovative ER technologies through the most obvious sources (i.e., the leading ER technology developers).

Golder arranged interviews with the Dutch and French companies and institutions listed below. Appendix A provides brief descriptions of these companies.

- The Netherlands
 1. TAUW, a consulting firm
 2. TNO, a research institute
 3. SCG, a government agency
 4. TU Delft, a university
- France
 1. BRGM, a government agency
 2. Soletanche, a contractor
 3. HydroExpert, a consulting firm

During each interview, the developer was asked to present information on ER technologies at all stages of development, with an emphasis on the technologies they considered particularly innovative. In addition, these interviews provided leads on identifying other, less well known, ER technology developers. The following technologies were identified through these interviews:

- BIOPUR®, a biological groundwater/soil vapor treatment system (TAUW, The Netherlands);
- PAH-field analysis (TAUW, The Netherlands);
- Electrochemical dehalogenation of toxic organic compounds (TNO, The Netherlands);
- Biochemical treatment of heavy metals contamination (TNO, The Netherlands);
- Biological dehalogenation of chlorinated ethylenes (TNO, The Netherlands); and
- Hydrofraise®, a drilling machine used for constructing subsurface containment barriers (Soletanche, France).

Subsequent interviews with the developers provided more detailed information for input in the EnviroTRADE database (Golder, 1993c). These six technologies are summarized in Section 3.

These technologies were subsequently evaluated by Applied Sciences Laboratory (ASL, 1993b) in terms of potentially applicable DOE problem units and related OTD R&D projects.

Subsequent to identifying technologies through interviews with developers, Golder was directed to focus on mature technologies (i.e., technologies for which development is largely complete and for which there has been a full-scale demonstration). Providing details on technologies at the bench or pilot scale was deemed a lower priority.

2-2 Systematic Phased Approach

In an effort to identify ER technologies developed by less well-known sources and to select the ones best meeting the survey objective, Golder developed a Systematic Phased Approach (Figure 1) based on an extensive literature search and attendance at conferences. In this approach, at each successive phase fewer (but more relevant) technologies are evaluated in greater detail.

2-2-1 Phase I

The objective of Phase 1 was to develop a comprehensive data base of Dutch and French technologies (regardless of their degree of innovation, maturity, or uniqueness) which are potentially applicable to the DOE's ER needs (ASL, 1993a). Literature searches conducted in Seattle, WA, USA and in Celle, Germany focused on material published within the last 5 years.

In Seattle, most of the articles and proceedings related to ER technologies were obtained through the University of Washington Library. Some of the most relevant are:

- Proceedings of the contaminated soil conferences held in 1985, 1988, and 1990;
- EPA assessment of international technologies for superfund applications, 1989; and
- Proceedings of the EPA forums on innovative hazardous waste treatment technologies: domestic and international held in 1989, 1991, and 1992.

On-line searches of domestic and international databases were carried out at Golder through services such as "Dialog" to broaden the survey and obtain access to international publications.

Golder Associates' office in Celle, Germany provided access to a network of international databases through libraries in Germany. Table 1 summarizes the primary databases searched.

Individuals from Golder's European offices also attended three conferences in Europe, including:

- Geotechnica '93, held in Germany;
- Contaminated Soil '93, held in Germany; and
- Geoconfine '93, held in France.

These conferences provided details on international ER technologies. Proceedings articles were reviewed and selectively incorporated into the database.

Approximately 400 articles on ER technologies developed in The Netherlands and France were obtained, about half of them through Golder's Seattle office (see Appendix B) and the rest from Golder's office in Celle, Germany. The articles obtained from Germany were not evaluated further at the time of this report.

Figure 1. Systematic phased approach used to screen ER technologies.

2-2-2 Phase 2

The objective of Phase 2 was to efficiently screen the database of technologies developed in Phase 1. To accomplish this, a classification system was devised to rank technologies on their degree of innovation and level of maturity, as well as to determine whether they were applicable to the DOE's ER needs.

In this classification scheme (Figure 2), technologies that are mature and judged to be innovative, relative to baseline (i.e., commonly applied) technologies, are classified as "alternative." Technologies are classified as "promising" if they are judged to be innovative or moderately innovative but have only been demonstrated at the pilot-plant scale. Also classified as "promising" are the technologies judged to be mature but only moderately innovative. Technologies judged to be innovative but demonstrated only at bench scale (i.e., laboratory demonstration) are classified as "emerging" technologies. Moderately innovative, bench-scale technologies and baseline technologies at all levels of development were classified as "not of interest."

The technologies were reviewed by several environmental scientists and classified based on their judgment. The evaluation of the degree of innovation was supported by NATO's study entitled

Table 1. Primary databases used to identify ER technologies.

Database	Description	Contact
Compendex Plus	Provides worldwide abstracted coverage of approximately 4,500 journals and selected government books and reports. Subjects include civil, energy, environmental, geological, and biological engineering; electrical, electronics, and control engineering; chemical, mining, metals, and fuel engineering; mechanical, automotive, nuclear, and aerospace engineering; and computers, robotics, and industrial robots.	Dialog Information Services, Inc. 3460 Hillview Ave. Palo Alto, CA 94304 (800) 334-2564
Enviroline	Provides indexing and abstracting coverage of more than 5,000 international publications reporting on all aspects of the environment. Included are such fields as management, technology, planning, law, political science, economics, geology, biology, and chemistry as they relate to environmental issues. Literature covered includes periodicals, government documents, industry reports, proceedings of meetings, newspaper articles, films, and monographs.	Dialog Information Services, Inc. 3460 Hillview Ave. Palo Alto, CA 94304 (800) 334-2564
Pascal	Provides indexing and abstracting from international sources, including journals, dissertations and masters theses, reports, conference proceedings, and books. Major subjects covered include life sciences, biology, and medicine; chemistry, applied chemistry, and pollution; energy metallurgy, mechanical and civil engineering; transportation; food and agriculture sciences; earth sciences; physics and space sciences; and computer sciences and engineering.	Dialog Information Services, Inc. 3460 Hillview Ave. Palo Alto, CA 94304 (800) 334-2564
NTIS	The National Technical Information Service supplies copies of government-sponsored research, development, and engineering, plus analyses prepared by federal agencies and their contractors. Includes reports from NASA, DDC, DOE, HUD, DOT, DOC, and 240 other agencies.	Dialog Information Services, Inc. 3460 Hillview Ave. Palo Alto, CA 94304 (800) 334-2564
CA	The <i>Chemical Abstracts</i> (CA) database covers all areas of chemistry and chemical engineering. CA contains records for documents reported in <i>Chemical Abstracts</i> from 1967 to the present. Sources include journals, patents, technical reports, books, conference proceedings, and dissertations from all areas of chemistry and chemical engineering worldwide.	STN International c/o Chemical Abstracts P.O. Box 3012 Columbus, OH 43210 USA
CORDIS	(European) Community Research and Development Information Service (CORDIS). The objective of CORDIS is "to disseminate public information on the Framework programme and all Community Research, Technology and Development (RTD) Activities and their results, for the purpose of enhancing awareness of the activities, assisting interactions and cooperation among individual programmes and their participants, and helping to promote cooperation with similar RTD activities in Member States." The CORDIS databases that were searched are RTD-Projects, RTD-Results, RTD-Publications.	ECHO Airport Center, 5 rue Hohenhof L-1736 Senningerberg Luxembourg 352/34981-200

Figure 2. Classification system used to rank technologies.

"Demonstration of Remedial Action Technologies for Contaminated Land and Groundwater" (NATO, 1993), which is an overview of baseline technologies and comments on their deficiencies. The evaluation of maturity was readily based on information presented in articles, whereas the evaluation of applicability to DOE needs was supported by ASL's (1993a) paper describing DOE technology needs. After eliminating overlaps, out of 200 technologies, 13 technologies were judged to be potential "alternatives" to baseline technologies.

This strategy allowed for rapid evaluation of all technologies in the database and quickly established their relative potential value. The "alternative" technology category was given the highest priority for subsequent evaluation, followed by "promising" technologies and, finally, "emerging" technologies.

2-2-3 Phase 3

The objective of Phase 3 was to better determine the degree of innovation of the technologies identified in Phase 2 as being "alternative." A detailed comparative evaluation against US technologies was performed using VISITT (EPA, 1993), an EPA database containing summaries on many of the most common US ER technologies. VISITT provides for key word searches on categories such as technology type and waste type. For each of the promising foreign ER technologies, a key word search was used to identify US vendors that provide the same or similar technologies.

Of the 13 potentially "alternative" technologies, 7 were found to be the same or similar to technologies already provided by US vendors (Table 2). Hence, the screening resulted in the selection of 6 technologies that:

- could potentially fulfill one or more of the DOE's ER needs (ASL, 1993a);
- are innovative;
- are mature; and
- are not currently available in the United States.

2-2-4 Phase 4

The objective of Phase 4 was to conduct a detailed evaluation of the candidate technologies including:

- Electro-reclamation (Geokinetics, The Netherlands);
- Ex situ bioremediation of heavy metals using sulfate-reducing bacteria (Paques BV, The Netherlands);
- In situ removal of decanoic acid by flushing with NaOH (Delft Geotechnics & BMS Environmental Soil Systems, The Netherlands);
- In situ removal of cadmium and on-site treatment by ion exchange (TAUW Infra Consult BV, The Netherlands);
- Extraction of organic bromine compounds from soils using NaOH (HWZ Bodemsamering & TNO, The Netherlands); and
- ECOSOL[®] Contaminant Adsorbing Grout (Soletanche, FRANCE).

These detailed evaluations included discussions with the developers. Summary descriptions of these technologies are given in Section 3. Descriptions of these technologies were also matched to DOE problem units and OTD R&D projects (ASL, 1993b). In addition, details were compiled in EnviroTRADE format for these technologies and are presented in the International Technology Catalogue (SNL, 1995).

Table 2. Potential "alternative" foreign technologies which match with US technologies in VISITT (EPA, 1993).

Foreign Technology	Developer	US Vendor (from VISITT)
Three-Phase Slurry Bioreactor (air injection)	G. Annokkee, TNO, The Netherlands*	IT Corporation
Air Injection and In Situ Soil Vapor Extraction	Pijls, TAUW Infra Consult B.V., The Netherlands*	Environmental Resource Services Battelle Pacific Northwest Laboratories Terra Vac, Inc. Engineering Science, Inc.
Soil Vapor Extraction of Hydrocarbons In Situ and On-Site Biological Treatment	S. Coffa, TAUW Infra Consult B.V., The Netherlands*	Groundwater Technology, Inc. IEG Technologies Corporation Terra Vac, Inc. ABB Environmental Services, Inc. Battelle Pacific Northwest Laboratories Engineering Science, Inc. Environmental Resource Services Groundwater Technology, Inc.
Extractive Methods for Soil Decontamination (i.e., soil washing)	J. W. Assink, TNO, The Netherlands*	ABB Environmental Service, Inc. Alternative Remedial Technologies, Inc. AWD Technologies, Inc.
Heijmans Soil Washing Operation	W.P.J. Kemmeren, Heijmans Mileutechniek B.V., The Netherlands	ABB Environmental Service, Inc. Alternative Remedial Technologies, Inc. AWD Technologies, Inc.
Cum Bac Enhanced Biotechnological Remediation System	E. Ten Brummeler, Heidemij Realisatie B.V., The Netherlands	ABB Environmental Services, Inc. Alternative Remedial Technologies, Inc. AWD Technologies, Inc.
Boundary Film Evaporators with Carbon	A.B. van Luin, Institute for Inland Water Management and Wastewater Treatment, The Netherlands	* This organization is no longer pursuing this technology.

* See Appendix A.

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3 RESULTS

Twelve innovative Dutch and French ER technologies were identified through the program described in Section 2. Subsections 3-1 through 3-6 summarize the 6 technologies selected through the Direct Approach (Section 2-1). Subsections 3-7 through 3-11 summarize the 6 technologies selected through the Systematic Phased Approach (Section 2-2).

3-1 BIOPUR®

Developer:

ir. E.H. Marsman and ir. H.B.R.J. van Vree
TAUW Infra Consult BV
Handelskade 11, Postbus 479
7400 AL Deventer
The Netherlands

Tel: 31-5700-99617
Fax: 31-5700-99666

Description:

BIOPUR® is an ex situ biological treatment technology for both extracted groundwater (or process water) and soil vapor contaminated with organic compounds. Under aerobic and methanotrophic conditions, TCE- and PCE- contaminated groundwater and soil vapor can also be treated. BIOPUR® is an aerobic, plug flow, fixed film bioreactor system in which contaminated groundwater and soil vapor are passed through a reticulated polyurethane growth medium with a high specific contact area. The high specific contact area results in high biomass concentrations and, thus, high reaction rates over short retention times. In contrast to most bioreactors, the soil vapor and groundwater are treated simultaneously, and BIOPUR® is less prone to iron clogging. The system is conveniently packaged and mobile, allowing for quick startup. Operation of the system is relatively stable and involves simply reading meters and refilling nutrient solutions. BIOPUR®, being an ex situ system, must be integrated into a groundwater/soil vapor extraction (including possibly reinjection) system.

Although the effectiveness of BIOPUR® varies with rate, retention time, and original concentration, the system is relatively effective in degrading a variety of organic compounds. The bioreactor's effectiveness in treating chlorinated hydrocarbons is under investigation. For example, the effectiveness in degrading BTEX (benzene, toluene, ethylbenzene, and xylene) is typically greater than 95%.

BIOPUR® is patented in the US and Europe but is currently available only in The Netherlands. Many case studies exist. The cost is about \$0.35/m³ at a circulation rate of 10 m³/hr, which is about 30% cheaper than stripper/activated carbon. As the circulation rate increases, the cost decreases. More important, the technology results in no secondary wastes. Performance will vary depending on the specific contaminants involved.

3-2 PAH-Field Analysis

Developer:

ir. H.B.R.J. van Vree
TAUW Infra Consult BV
Handelskade 11, Postbus 479
7400 AL Deventer
The Netherlands

Tel: 31-5700-99561
Fax: 31-5700-99666

Description:

Polycyclic aromatic hydrocarbons (PAH)-field analysis consists of a compact, portable instrument that provides a method for rapidly characterizing or monitoring soil samples for PAH contamination. PAH-field analysis can produce semiquantitative results within five minutes and, therefore, presents a useful aid to the supervision of soil remediation. In contrast, conventional high performance liquid chromatography (HPLC) and gas chromatography (GC) are more time-consuming and expensive.

The PAH-field analysis may be described as collective quantification; i.e., the individual PAHs are not separated. In operation, a chemical reagent is added to a soil sample causing chemiluminescence in the presence of PAH. The intensity of this light, measured by photoelectric cells, gives an indication of the total concentration of PAH in the sample (with the exception of naphthalene).

For each location under investigation, a calibration factor is determined by analyzing a few samples in parallel with both the HPLC analysis and the PAH-field analysis. Concentrations of PAH in other soil samples can then be determined by measuring the intensity of chemiluminescent light produced and comparing this to the established calibration factor. This method is mature (patent pending) and has been successfully applied in numerous occasions, both in The Netherlands and abroad.

3-3 Electrochemical Dehalogenation of Toxic Organic Compounds

Developer:

Dr. Ir. D. Schmal
TNO Institute of Environmental Sciences
Schoemakerstraat 97
P.O. Box 6011
2600 JA Delft
The Netherlands

Tel: 31-15-696022
Fax: 31-15-616812

Description:

Electrochemical dehalogenation of toxic organic compounds is a technology being developed for the ex situ treatment of chlorinated phenols in waste water or contaminated groundwater. The toxicity and biodegradability of chlorinated compounds is in part determined by their chlorine content. This technology removes chlorine atoms from organic molecules to facilitate subsequent biological treatment. Electrolytes such as NaOH and Na₂SO₄ are added to waste water containing chlorinated phenols, such as PCP. Small amounts of organic solvents are also added to increase the solubility of the phenol contaminants. Afterward, electrolysis is applied in a cell where the cathode and anode are separated by a cation-permeable membrane to remove the chlorine atoms from the phenol. Small-volume laboratory tests suggest 98% reduction in the PCP concentration. Field-scale performance has not been demonstrated, although a continuous flowthrough system has been given some design consideration.

This technology provides several advantages over other available methods: there are no additional chemicals required; treatment is performed at ambient temperature; the process provides selective removal of chlorine without destroying the organic skeleton of compounds that can be digested by biological means; and the process produces a less toxic compound than concentration methods such as carbon filtration, membranes, etc.

The cost of the process is estimated at \$/m³ waste water. Application of this technology requires groundwater extraction or a waste-water discharge source, an electrical power supply, and processing of residual phenols (e.g., microbial degradation).

3-4 Biochemical Treatment of Heavy Metals Contamination

Developer:

Dr. H.J. Doddema and J.J.D. van der Steen
TNO Institute of Environmental Sciences
Schoemakerstraat 97
P.O. Box 6011
2600 JA Delft
The Netherlands

Tel: 31-15-696022
Fax: 31-15-616812

Description:

This technology is a biochemical version of acid leaching and can be applied on-site as ex situ treatment in a batch plant of large volumes of soils, industrial sludges, fly ashes, and possibly mine tailings contaminated with heavy metals (including radionuclides). This process involves: (1) mixing contaminated soil, air, sulfur and specific microbial cultures (e.g., *Thiobacillus ferrooxidans*) in a bioreactor to produce sulfuric acid, which in turn dissolves the heavy metals; (2) washing and reconditioning (for reuse) the remaining solids, and reprocessing or disposing of the separated and possibly contaminated fines; (3) separating (and reprocessing or disposing of) any remaining solids in the acid effluent from the liquids in a solid/liquid separator; and (4) adding reduced carbon (to eliminate oxygen create suitable redox conditions) to precipitate the dissolved heavy metals out of the acid effluent in a sulfate reduction bioreactor, possibly producing H₂S (which must be treated). The heavy metals are recovered, and the remaining effluent is treated, recycled through the process or disposed of. This technology must be integrated with excavation and handling of contaminated soil (or other material), soil washing and reuse, and handling and processing of recovered heavy metals. The bioreactors for sulfate production and sulfate reduction have been successfully demonstrated only under laboratory conditions to date. Bench-scale tests have demonstrated this technology's relatively high effectiveness for removing most metals, especially Zn, Cd, As, and Ni. For optimum performance, this process must avoid high alkalinity, high ionic concentrations and other biota (weeds). It is expected that this technology would also be effective for radionuclides, although neither this nor the interaction of other contaminants is currently known. A pilot test with a planned capacity of 1 ton of contaminated soil per day is planned for 1994, and a field demonstration is expected in another 1-4 years.

This technology should be relatively inexpensive because it does not need expensive growth media and because sulfur is relatively inexpensive compared to sulfuric acid. Although the reaction rate may be relatively slow for a biological process, it should be marginally safer than conventional acid leaching.

3-5 Biological Dehalogenation of Chlorinated Ethylenes

Developer:

Dr. H.J. Doddema
TNO Institute of Environmental Sciences
Schoemakerstraat 97
P.O. Box 6011
2600 JA Delft
The Netherlands

Tel: 31-15-696022
Fax: 31-15-616812

Description:

This is a biological technology, for ex situ treatment of soil, groundwater, or air contaminated with chlorinated ethylenes. A secondary use of this technology could be in situ treatment of soil contaminated with chloroethylene.

For extracted groundwater or soil vapor, the process uses two consecutive biological processes in a treatment facility: anaerobic partial dehalogenation followed by aerobic complete dehalogenation and mineralization (through microbial co-oxidation). The remediated groundwater is returned with some biomass to the soil. Any air used or escaping during the process is treated in a biofilter to remove any remaining volatile chlorinated compounds. For contaminated soil, microorganisms from granulated anaerobic sludge are mixed with the soil.

In ex situ applications, the treatment facility must be integrated with the groundwater/soil vapor extraction (including possibly reinjection) system. The process has been demonstrated in the laboratory. In laboratory studies, PCE in water was quickly degraded into TCE and then much more slowly degraded into DCE. The further aerobic complete dehalogenation and mineralization of DCE (i.e., the second step of the process) and the interaction of other contaminants remains to be investigated. Compared to air stripping/carbon filtration, the candidate technology minimizes secondary wastes (and thus may be marginally cheaper, safer, and more acceptable), but is slower and may be less widely applicable to various contaminants.

3-6 HYDROFRAISE®

Developer:

Gérard Evers
Soletanche
6, Rue de Watford
92000 Nanterre
France

Tel: 33(1) 47 76 42 62
Fax: 33(1) 47 75 99 10

Description:

Hydrofraise® is a commercially available drilling machine for constructing subsurface containment walls in a variety of soil types. This device consists of two cutter drums mounted on a heavy metal guide frame that is typically suspended from a crawler (track mounted) crane. The cutter drums are fitted with tungsten carbide tipped teeth which rotate in opposite directions to break up the soil. A pump placed just above the drums evacuates the loosened soil which is carried to the surface by drilling mud. Following excavation of a "slot," the barrier material is pumped into the bottom of the excavation to displace the drilling fluid. Subsequent slots overlap existing barrier portions to provide a competent large-scale containment system. All required equipment and support are available from Soletanche, including barrier material, a mixing plant, and injection pumps. The barrier material is typically ECOSOL slurry (see Section 3.12) with a geomembrane insert. Cement and bentonite-based material have been applied in Europe and the United States.

The design of the system (patented) makes it possible to drill thin diaphragm wall elements in a wide range of soil conditions from cohesionless soils to hard rock. The equipment is capable of installing high quality containment walls up to 125 m deep and has been used successfully in Europe and Japan to construct low-permeability barriers around contaminated soils and landfill sites. Hydrofraise can operate only in a vertical mode. Applications require the existence of a horizontal barrier at depth and possibly a cover to prevent recharge and contaminant transport within the contained region.

3-7 Electro-Reclamation

Developer:

R. Lageman
Geokinetics
Steenoven 2-6, Postbus 151
4190 CD Tricht
The Netherlands

Tel: 313-455-79211
Fax: 313-455-79315

Description:

Electro-reclamation provides in situ or ex situ treatment of soil (especially for low permeability) and groundwater contaminated with heavy metals (including radionuclides) and can also act as a subsurface barrier.

The core of an electrokinetic installation consists of the electrode array(s) and their housing. Charging of the array produces electroosmosis, electrophoresis, and/or electrolysis, which transport the contaminants toward the anode cathode. For in situ applications, the electrode array(s) can be installed at any depth, either vertically or horizontally. The cathode and anode housings form two separate circulation systems filled with different chemical solutions. These housings are specially prepared, electrically inert, filter pipes that allow the contaminated groundwater to mix freely with the solutions, which in turn capture the pollutants (e.g., heavy metals) and concentrate them in situ. The solutions are in a continuous circulation system that is connected to the surface treatment facility, although loss of solution into the ground may be an issue. The groundwater (and anode/cathode solution) treatment system is installed in the surface treatment facility together with the solution tanks, measuring devices, and monitoring devices. After treatment to remove the contaminants and recharge the solutions, the solutions are recirculated through the anode/cathode housings. Electrical energy is supplied externally but does not need to be continuous (i.e., can be turned on at low-demand times to take advantage of cheaper rates).

Electro-reclamation is patented in the EC and has been demonstrated at field scale in The Netherlands, where relatively high (> 80%) efficiencies have been obtained for some heavy metals. However, the efficiencies are a function of: (1) soil resistivity, duration, array layout, and power input; and (2) pH, the presence of conductive or insulating objects, and the nature of the contamination, all of which can be mitigated by pretreatment (although that may require excavation and ex situ treatment).

Typically, the cost is on the order of tens to hundreds of dollars per ton of treated soil, and may be the only feasible alternative to excavation/disposal for low-permeability soils.

3-8 Ex Situ Bioremediation of Heavy Metals Using Sulfate-Reducing Bacteria

Developer:

C.J.N. Buisman
Paques B.V.
T. de Boerstraat 11
Postbus 52 - 8560 AB Balk
The Netherlands

Tel: 31 5140 3441
Fax: 31 5140 3342

Description:

This technology incorporates the use of sulfate-reducing bacteria in a process train to simultaneously remove sulfate and heavy metals from contaminated groundwater ex situ. In this

process, the sulfate is reduced to sulfide by anaerobic bacteria, resulting in the precipitation of metal sulfides.

In operation, water extracted from wells is pumped into the process train of a surface treatment plant at a rate of approximately 200 gallons per minute. The main units of the treatment plant are a tank to buffer variations of influent flow and concentration; a mixing tank for the addition of substrate and nutrients; an anaerobic upflow air-sludge blanket for sulfate reduction (patented); an aerobic fixed film reactor for sulfide oxidation; a tilted plate settler for the removal of solids; DynaSand sand filter as a final polishing step; and a gas-handling system for H₂S scrubbing and flaring methane. A central computer controls the process parameters and is supported by on-line analytical equipment. The treatment plant has been demonstrated and is commercially available. The technology tends to be more effective, although not necessarily cheaper, than normal precipitation or ion exchange methods.

3-9 In Situ Removal of Decanoic Acid by Flushing with NaOH

Developer:

W. Visser
Delft Geotechnics
P.O. Box 69
2600 AB Delft
The Netherlands

Tel: 31-15-69-3500
Fax: 31-15-61-0821

C.C.D.F. van Ree
BMS Environmental Soil Systems
P.O. Box 238
2650 AE Berkel En Rodenrijs
The Netherlands

Description:

This technology consists of in situ treatment of soils contaminated with a weak acid by flushing with alkaline solutions. The process is based on the principle that the dissociation of a weak acid is dependent on pH. For example, in the case of decanoic acid (which has a high viscosity and low solubility), reaction with an alkali solution reduces the acid to a more water-soluble compound. The new compound can then be extracted by conventional pumping methods. A subsurface barrier below the alkaline infiltration zone may be required to prevent groundwater contamination below.

The method was successfully used in situ to remediate a decanoic acid spill below a storage tank located at a petrochemical site in The Netherlands. This method appears to be much more effective than standard pump and treat methods for highly viscous, low-solubility weak acids and is less expensive to use than excavation and ex situ treatment.

3-10 In Situ Removal of Cadmium and On-site Treatment by Ion Exchange

Developer:

L.G.C.M. Urlings
TAUW Infra Consult BV
P.O. Box 479
7400 AL Deventer
The Netherlands

Tel: 31-5700-99617
Fax: 31-5700-99666

J.C. van Woudenberg
MOURIK BV
P.O. Box 2
2964 ZG Groot Ammers
The Netherlands

Description:

This is a several-step process that uses in situ leaching to desorb cadmium (Cd) from the contaminated soil in the vadose zone followed by surface treatment of the collected percolate by an ion exchange resin to concentrate the Cd. The process may be applicable to other heavy metals as well.

In the first step of this process, Cd is desorbed from the soil by in situ leaching with hydrochloric acid (HCl, 10^{-3} mol, pH = 3.5). A system of horizontal drains (e.g., 10 cm dia.) recovers the percolate, which is then pumped through vertical wells to a surface treatment system. A subsurface barrier below the drains may be required to prevent groundwater contamination below the treated area. The surface-water treatment system uses a Rohm and Haas IMAC GT-73 resin which, through sorption (ion exchange), removes the Cd from the groundwater and concentrates it in the resin. The ion exchange resin is subsequently regenerated, with the resulting CdCl solution requiring off-site treatment or disposal. The cleaned acidic water is then infiltrated again into the polluted soil. Once the cleanup goals have been achieved, acidification is stopped and the soil is neutralized with NaOH.

The method has been demonstrated at a site in The Netherlands at a site contaminated with 725 kg of Cd. Percolation rates through the site were about 250 m³/hr and resulted in Cd concentrations generally < 1 mg/kg. The method is less expensive than conventional methods of excavating and ex situ treatment.

3-11 Ex Situ Extraction of Organic Bromine Compounds from Soils Using NaOH

Developer:

Rulkens
HWZ Bodemsamering
Vanadiumweg 5
3812 PX Amersfoort
The Netherlands

Tel: 31-33-622-999
Fax: 31-33-083-80-34648

Assink and Van Gemert
TNO
P.O. Box 214
2600 AE Delft
The Netherlands

Description:

Organic bromine compounds can be extracted from excavated soils using a NaOH solution as follows:

1. Pretreating soil to separate large objects.
2. Mixing soil with 0.2 percent NaOH solution (extracting agent), with a soil/water ratio of about 3 to 1 by weight.
3. Extracting and washing the soil with clean extracting agent in counter-current flow using two modified screw classifiers (in line).
4. Dewatering the soil before redeposition where the remaining alkalinity of the soil will be largely neutralized by absorption of CO₂ from the ambient air.
5. Moving the overflow of the first modified screw classifier into a settling tank for fine mineral particles. Particles with diameters of between 35 µm and 60 µm that settle are collected from time to time and washed separately by mixing them with NaOH solution.
6. Adding lime as coagulant and polyelectrolyte as flocculent to form a sludge which is separated in a tiltable plate separator.
7. Dewatering the sludge in a bowl centrifuge with scroll discharge.
8. Effluent polishing by deep bed filtration, activated-carbon adsorption, and finally anion exchange to remove any bromides formed by hydrolysis. The cleaned extracting agent can be recycled to the extraction process in the screw classifiers.

Pilot-scale experiments have shown that it is possible to remove the bromine compounds from soil down to a level of 1 mg Br/kg or less. The cleaned extracting agent contains less than 0.6 mg Br/kg, the main part of which is bromine and the wastewater sludge.

This method is generally more effective than conventional soil washing but more expensive to perform. It is less expensive than thermal treatment but less effective because it only concentrates the waste.

3-12 ECOSOL® Contaminant-Adsorbing Grout

Developer:

D. Gouvenot
Soletanche
6 rue de Watford
92000 NANTERRE
France

Tel: 33-1-4776-4262
Fax: 33-1-4775-9910

Description:

ECOSOL® grout was designed specifically for use in subsurface barriers. This grout is not a single material, but rather a compound that is customized with various substances to promote precipitation and adsorption of specific organic and heavy metal contaminants. Retention mechanisms for this technology include precipitation, oxidation, complexation, and absorption among others.

Precipitation is mainly used for retaining acidic industrial wastes containing metallic ions in solution, such as iron, zinc, nickel, copper, lead, cadmium, and trivalent chrome. These cations

are precipitated as metallic hydroxides according to chemical reactions controlled by pH. The desirable pH is maintained by plugging the ECOSOL® mixture with calcium oxide. Other precipitating agents are used when the metallic species is insoluble, regardless of pH.

Adsorption is a physicochemical reaction depending on the specific surface area of porous material, typically clays and activated charcoal in this case. These materials adsorb pollutants by allowing them to pass through the material, but in close proximity to the surface for one of several binding mechanisms to take place. These binding mechanisms include physical, van der Waals attraction, ionic exchange, and surface tension. The greater the surface area, the more pollutant that can be held. In general, these adsorbing reactions are reversible and depend on the equilibrium thermodynamics and kinetics.

The design and performance assessment of barriers using this technology are carried out through numerical simulations, which consider:

- certain characteristics of the hydraulic regime, to calculate the fluid velocity;
- the initial concentration of the pollutant;
- the temperature of the system (constant);
- the barrier thickness, diffusive properties, porosity, permeability, coefficient of dispersion, and Freundlich coefficients.

In simulations, it has been shown that conventional barriers can begin to break down after 2-3 years, at which time solutions with effluent concentrations of nearly 57% emerge from the downstream side of the barrier. In contrast, ECOSOL® lasts nearly 120 years, and the maximum effluent concentration never exceeds 4%. ECOSOL® is patented and generally more expensive than traditional grouts.

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4 CONCLUSIONS AND RECOMMENDATIONS

Golder has conducted an in-depth survey of The Netherlands and France to identify potentially innovative ER technologies. Twelve ER technologies are sufficiently innovative to warrant consideration for application to the DOE's ER needs. They include (in no specific order):

- BIOPUR®, a biological groundwater/soil vapor treatment system,
- PAH-Field Analysis,
- Electrochemical Dehalogenation of Toxic Organic Compounds,
- Biochemical Treatment of Heavy Metals Contamination,
- Biological Dehalogenation of Chlorinated Ethylenes,
- HYDROFRAISE®, a drilling machine used for constructing subsurface containment barriers,
- Electro-Reclamation,
- Ex Situ Bioremediation of Heavy Metals Using Sulfate-Reducing Bacteria,
- In Situ Removal of Decanoic Acid by Flushing with NaOH,
- In Situ Removal of Cadmium and On-site Treatment by Ion Exchange,
- Ex Situ Extraction of Organic Bromine Compounds from Soils Using NaOH, and
- ECOSOL® Contaminant-Adsorbing Grout.

The various technical and business aspects of these technologies were adequately evaluated and documented to determine their applicability to DOE needs.

The survey of The Netherlands and France was relatively comprehensive, so most of the current innovative and mature ER technologies in those countries have been identified. However, the data base developed from the German literature search has not yet been screened and may contain additional innovative ER technologies.

As a result of this survey, Golder recommends the following:

- The applicability of the 12 high-priority technologies to DOE's ER needs and their relationship to ongoing OTD R & D projects should be determined (e.g., through CROSSWALK);
- Each of the DOE problem units and related OTD R & D projects identified should be contacted and provided background information on the appropriate technology;
- Issues brought up by DOE problem units and/or OTD R & D projects regarding the applicability, limitations, status, benefits, etc. of the technology should be resolved with the developer (e.g., DuCharme et al., 1992);

- If issues are satisfactorily resolved and if warranted, mechanisms should be evaluated and subsequently implemented for transferring the technology to US vendors for application to DOE problem units (if mature) or to US developers for further development and commercialization (if immature);
- The technologies should be presented at appropriate forums (e.g., Innovative Technology Forum) for wide distribution and to solicit additional interest;
- Technologies which have been evaluated as innovative but not yet mature, and thus of interest to US developers rather than US vendors, should also be evaluated in greater detail;
- Preliminary evaluation and screening of the publications obtained from the German literature review should be completed.

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APPENDIX A

Descriptions of Dutch and French ER Technology Developers Interviewed

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Descriptions of Dutch and French ER Technology Developers Interviewed

Institution	Contact(s)	Description
<p>TAUW Infra Consult BV Handelskade 11, Postbus 479 7400 Al Deventer The Netherlands tel: 31-5700-99911 fax: 31-5700-99666</p>	<p>ir. F. Spuij and ir. E.H. Marsman</p>	<p>TAUW originated as a consulting firm with a focus on civil engineering 70 years go. Projects at that time were mostly related to the design of water canals in Holland. Now, with more than 600 people employed, TAUW has a strong environmental engineering and research side. TAUW entered the environmental market about 15 years ago and is one of only two labs in Holland that perform dioxin analysis.</p>
<p>TNO Institute of Environmental Sciences Schoemakerstraat 97 P.O. Box 6011 2600 JA Delft The Netherlands tel: 31-15-696022 fax: 31-15-616812</p>	<p>Dr. J.W. Lyklema, Dr. H.J. Doddema and Dr. ir.D. Schmal</p>	<p>TNO is a research institute that is partially (30%) supported by the Dutch government and partially (70%) by private industry. Because of this mix of funding sources, TNO has a focus on practical implementations of innovative technology that will ultimately be transferred to industry. TNO is a good source of emerging technology, and there is apparently no reluctance to transfer technology outside of Holland. If a foreign company provides funding for research, that company can eventually acquire a patent for the technology.</p> <p>TNO's department of environmental biotechnology has focused its efforts on the abatement and prevention of pollution in air, water, and soil by application of biological systems alone or in combination with electrochemical techniques. Consequently, the research is focused on biofiltration of offgases and air, biological wastewater treatment, soil bioremediation, and detoxification, vaporization, or reduction of solid wastes.</p>

Institution	Contact(s)	Description
<p> VROM Ministry of Housing, Physical Planning and Environment Directorate-General for Environmental Protection Directorate for Policy Affairs/660 Department of Environmental Investments Rijnstraat 8 P.O. Box 30945, 2500 GX The Hague The Netherlands tel: 31-70-339-47-46 fax: 31-70-339-13-04 </p>	<p> Piet Kruithof and Heidi Scholte </p>	<p> VROM's environmental technology division was not able to provide information on specific technologies related to remediation. VROM administers a financial incentive program for technology developers. However, this program is focused on waste minimization and pollution minimization rather than remediation of existing sites. </p> <p> VROM has implemented an accelerated depreciation program to speed technological innovation and to facilitate the diffusion of new, environmentally sound technologies. Many OECD governments have become interested in the possibility of using economic instruments to attain certain environmental outcomes. It is extremely difficult to predict the results of the use of economic instruments in this context. There are countless factors in any given context that can obscure and distort the intended effect of the instrument. The Dutch depreciation allowance program is an important example of one country's actual experience with a specific economic instrument. </p> <p> The Dutch program is directed by the Directorate General for Environmental Protection. Specific technologies which qualify for the accelerated depreciation allowances are placed on a list; only the technologies listed are eligible for the program. Selection for the accelerated depreciation list is based on several criteria. First, the technology is evaluated by calculating increased earnings based on the energy saved by the new technology. The payback time on investment in the technology has to be between 3-7 years, but exceptions are made if the technology is especially environmentally beneficial. Every year the list is updated. These annual re-evaluations take into account changes in energy price levels, which can change the investment payback time, and other relevant economic factors. When the technologies have reached 30% market penetration, they are no longer eligible for accelerated depreciation and are removed from the list. </p>

Institution	Contact(s)	Description
<p>SCG Service Center Soil Cleaning Europalaan 250 3526 KS Utrecht The Netherlands tel: 31-30-899499 fax: 31-30-882664</p>	<p>ir. S.H. Brunekreef</p>	<p>Nearly 5 years ago, the Service Centre for Soil Cleaning (SCG) was founded by the Dutch government to take over part of the tasks of the provinces and cities in Holland.</p> <p>SCG is charged with the supervision of ex situ soil cleaning in Holland. This was done to introduce greater unity in the implementation of the projects, because what was considered to have been cleaned properly in one province was deemed to be not clean enough in another province. In some towns, the soil was even reused without having been cleaned.</p> <p>Since January 1, 1990, all cleaning projects being financed by the Dutch government are managed by SCG.</p> <p>SCG is sort of national broker for contaminated soil, which invites tenders for the cleaning of the projects and sells the cleaned soil as a regular building material afterwards. The main objectives of SCG are:</p> <ol style="list-style-type: none"> 1. The cleaning of polluted soil into a useful building material, 2. The registration of the soil "stream," 3. The judgment of the possibilities for soil cleaning, 4. The decision about cleaning or temporary storage on a TOP, 5. The judgment of the cleaning results, 6. The reuse of the cleaned soil, due to the replacement of rare materials. <p>The role of SCG is one of project management so there is no direct technology development. However, SCG supplied a list of ex situ soil cleaning operators. These operators were contacted to identify the specific technologies used and their applicability to US DOE needs.</p>

Institution	Contact(s)	Description
TU Delft Delft University of Technology Mijnbouwstraat 120 P.O. Box 5028, 2600 GA Delft The Netherlands tel: 31-15-78-51-92 fax: 31-15-78-48-91	P.M. Maurenbrecher	A technology based research university in The Netherlands. TU Delft has programs focusing on environmental reclamation as well as other technology based industries.
HydroExpert 15 Allee du Pre Lambese 91190 GIF Syr Yvette FRANCE tel: 33-1-64-46-37-48 fax: 33-1-69-07-73-46	Mark Bonnet	HydroExpert is a small geotechnical consulting firm in France that has no ER technologies at this time but has expressed an interest in importing U.S. technology.
Soletanche 6 Rue de Watford 92000 Nanterre FRANCE tel: 33-1-47-76-42-62 fax: 33-1-47-75-99-10	Gerard Evers	Soletanche is an independent group of companies specializing in subsurface barrier technologies. The technologies developed at Soletanche originally focused on civil engineering problems such as diaphragm walls used in the construction of dams and reservoirs. Soletanche has expanded the technology to include development of geomembranes that are permeable to groundwater and have an affinity for heavy metals and chlorinated solvents. Subsidiaries of Soletanche are involved in hazardous waste site remediation projects that involve ex situ processes such as soil washing and thermal treatment. However, these technologies have been developed by foreign partners.
BRGM Avenue de Coneyr BP6009 45060 Orleans Cedex 2 FRANCE tel: 33-38-64-39-12 fax: 33-38-64-30-13	Jacques Ricour	BRGM is the French version of the U.S. Geological Survey but with a commercial side added. In 1991, 57% of BRGM's funding was taken from private industry for service activities. BRGM provides an environmental consulting and research base for France. Unfortunately, BRGM believes that most of the environmental remediation technologies used in France are derived from the U.S. There were discussions of a biological remediation technology under development but BRGM would not release any information on the progress or application of this technology. This technology is being developed under contract and is considered proprietary.

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