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International Technology Catalogue: Foreign Technologies to Support the Environmental Restoration and Waste Management Needs of the DOE Complex

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Prepared by
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**INTERNATIONAL TECHNOLOGY CATALOGUE:
Foreign Technologies to Support the Environmental Restoration and Waste
Management Needs of the DOE Complex**

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ABSTRACT

This document represents a summary of 27 foreign-based environmental restoration and waste management technologies that have been screened and technically evaluated for application to the cleanup problems of the Department of Energy (DOE) nuclear weapons complex. The evaluation of these technologies was initiated in 1992 and completed in 1995 under the DOE's International Technology Coordination Program of the Office of Technology Development. A methodology was developed for conducting a country-by-country survey of several regions of the world where specific environmental technology capabilities and market potential were investigated. The countries that were selected from a rank-ordering process for the survey included: then West Germany, the Netherlands, France, Japan, Taiwan, the Czech and Slovak Republics, and the Former Soviet Union. The notably innovative foreign technologies included in this document were screened initially from a list of several hundred, and then evaluated based on criteria that examined for level of maturity, suitability to the DOE needs, and for potential cost effective application at a DOE site. Each of the selected foreign technologies that were evaluated in this effort for DOE application were subsequently matched with site-specific environmental problem units across the DOE complex using the Technology Needs Assessment CROSSWALK Report. For ease of tracking these technologies to site problem units, and to facilitate their input into the DOE EnviroTRADE Information System, they were categorized into the following three areas: (1) characterization, monitoring and sensors, (2) waste treatment and separations, and (3) waste containment. Technical data profiles regarding these technologies include title and description, performance information, development status, key regulatory considerations, intellectual property rights, institute and contact personnel, and references.

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The DOE Program Manager supporting this effort was David W. Geiser, of the International Technology Exchange Staff, EM-52.1, Washington, DC. Jeff Lenhart of the DOE Albuquerque Operations Office, Office of Science and Technology, provided program oversight. The contractor project manager responsible for the assembly of this document is Richard Jimenez of ASL. Key ASL contributors to this document include Charlene Esparza-Baca, John Reardon, and Patricia Trujillo.

TABLE OF CONTENTS

PREFACE	i
ACKNOWLEDGMENTS	ii
1.0 INTRODUCTION.....	1
1.1 Program Status	1
1.2 Scope of This Document	2
1.3 Methodology	2
1.4 Potential DOE Applications	5
1.5 Technology Profiles	5
1.6 Summary	9
2.0 CHARACTERIZATION, MONITORING AND SENSOR TECHNOLOGY PROFILES	
Glass Melter Sensor Technology	13
Laser Evaporation Techniques for Environmental Sample Preparation	15
PAH-Field Analysis Using Chemiluminescence	19
Remote Contaminant Sensor Technology	21
SENSOR® Leak Detection Technology	27
3.0 TREATMENT AND SEPARATION TECHNOLOGY PROFILES	
Adsorption Technology for Decontamination of Low and Medium Level Aqueous Solutions from Long-Lived Radionuclides	33
Biochemical Treatment of Heavy Metals	37
Biological Dehalogenation of Chlorinated Ethylenes	41
BIOPUR® Biological Soil and Groundwater Treatment System	45
Chrompik Vitrification Process for Dried Liquid, Spent Nuclear Fuel Waste	49

Cobalt Dicarbolide Separation Technology for Radioactive Waste	53
Composite Inorganic-Organic Ion-Exchange Materials	57
Electrochemical Dehalogenation of Toxic Organic Compounds	61
Electro-Reclamation	65
Ex Situ Bioremediation of Heavy Metals using Sulfate Reducing Bacteria	75
Ex Situ Extraction of Organic Bromine Compounds from Soils Using NaOH	81
In Situ Removal of Cadmium and On-Site Treatment by Ion-Exchange	85
In Situ Removal of Weak Acid by Flushing with NaOH.....	91
In Situ Treatment of VOCs by Recirculation Technologies	95
Plasma Furnace Technology for Vitrification of TRU Contaminated Wastes	99
Plastic Solidification Process for Radioactive Wastes.....	103
Polluted Water Cleaning with Two-Stage Heterogeneous Discharge.....	107
Vitrification of Liquid Radioactive Waste with Low and Medium Level Activity from Nuclear Power Stations.....	111

4.0 CONTAINMENT TECHNOLOGY PROFILES

ECOSOL® Contaminant Absorbing Grout	117
Hydrofraise® Subsurface Containment Wall Construction.....	121
In Situ Barrier Construction with Montan Wax Emulsion	125
Integrated Grouting Technology	129

5.0 CONCLUSIONS135

REFERENCES 137

Figure 1	Methodology Applied to Identify Foreign-Based Environmental Management Technologies for Potential Applications to U.S. DOE Sites.....	3
Table 1	Potential Applications of Foreign Technologies to Environmental Problem Units in DOE Operations.....	6

PREFACE

The information cited in the descriptions and profiles of the innovative foreign environmental technologies contained in this catalogue represents a summary of the data available at the time of printing. Therefore, this document represents current work-in-progress, and is intended to serve as a means of disseminating early data to the U.S. environmental industry and interested stakeholders. There were no independent tests or evaluations performed on the foreign technologies identified in this catalogue. This version of the International Technology Catalogue was prepared to facilitate early collaborations between U.S. businesses and foreign technology developers, and is not meant to represent a foreign technology performance or consumer report.

Introduction

Section 1.0

1.0

INTRODUCTION

The U.S. Department of Energy's (DOE's) Office of Environmental Management (EM) manages the remediation of all DOE sites, as well as wastes from current operations. The goal of EM programs is to minimize risks to human health, safety and the environment, and to bring all DOE sites into compliance with federal, state, and local regulations.

The Office of Technology Development (OTD) was established in November 1989 as an element of DOE's EM program. OTD is responsible for developing environmental restoration (ER) and waste management (WM) technologies that are safer, faster, more effective and less expensive than those currently available. OTD's International Technology Exchange Staff (ITES) is responsible for fostering EM cooperation with foreign governments, industries, and educational institutions.

Starting in fiscal year (FY) 1992, a portion of EM's international programs included the import of innovative and cost-effective foreign environmental technologies for applications at DOE sites. ITES facilitates interactions between U.S. businesses and foreign technology developers so that these technologies can be imported to the U.S. through business collaborations with U.S. commercial partners. Sandia National Laboratories (SNL), Albuquerque, New Mexico, supports ITES through the coordination and integration of various international activities conducted within DOE's Office of Environmental Management.

EM's international programs were broadened in FY 1994 to include demonstrations of OTD-sponsored technology development at foreign sites as a means of enhancing the knowledge and performance of OTD technologies. An important secondary motivation for these technology demonstrations is to increase opportunities for technology export to the world-wide marketplace through commercial partnerships, licensing agreements and other arrangements that serve to enhance the competitiveness of the U.S. environmental industry.

1.1 PROGRAM STATUS

In FY 1992, DOE tasked SNL to initiate a systematic program to identify and conduct preliminary evaluations of environmental restoration and waste management technologies from West Germany and the former Soviet Union. As a result, 10 technologies were recommended for detailed evaluation and were later evaluated under DOE funding with the technical support of the DOE laboratories ^[1]. A number of these technologies were accordingly transferred from ITES to other EM organizations for potential application to the DOE complex problems. The effort was conducted by the International Coordination task team assembled by SNL through support and funding by DOE/EM-52.1.

Efforts to identify and evaluate foreign technologies increased during FY 1993 based on the growing emphasis on work with the former Soviet Union. As a result, a program dedicated to the evaluation and

pilot-scale demonstration of innovative Russian waste separations technologies was initiated. During FY 1993 as well, efforts to identify innovative and cost-effective foreign technologies expanded to France, the Netherlands, Japan, Taiwan, and the Czech and Slovak Republics ^[2-8]. Several additional technologies were determined to be sufficiently innovative to warrant more detailed evaluations ^[8].

Successful elements of the FYs 1992-93 technology import efforts were expanded, integrated, and transferred into the DOE's site clean-up considerations through the FY 1994 program. Foreign technologies were linked to specific environmental problem units throughout the DOE complex. Results were coordinated with DOE and contractor personnel at sites which could most benefit through the import and application of these technologies ^[9].

Opportunities for acquisition and/or demonstration of innovative and cost-effective foreign technologies continue to be coordinated with EM's Office of Waste Management (EM-30), Office of Environmental Restoration (EM-40), and the Office of Technology Development (EM-50). Future activities will be established in accordance with DOE's "New Approach to Environmental Research and Technology Development" to support the five focus areas and three crosscutting programs ^[10]. In addition, efforts will continue to emphasize and promote the enhancement of U.S. competitiveness, world-wide ^[11].

1.2 SCOPE OF THIS DOCUMENT

This document features the results of the preliminary evaluations of 27 foreign environmental management technologies which were originally screened from a field of several hundred and that originated from several countries, including West Germany, France, the Netherlands, Japan, Taiwan, and the Czech and Slovak Republics. The information is presented in a format similar to OTD's Technology Catalogue ^[12,13] to help ensure uniform comparison of the attributes of U.S. OTD and foreign technologies.

To further improve the versatility and efficient utilization of this document, the 27 foreign technologies are divided into the following technology classifications: (a) characterization, monitoring and sensors; (b) waste treatment/separation; and (c) containment. In addition, the foreign technologies are linked to those DOE field offices which have environmental problem units that can be supported by the technologies.

1.3 METHODOLOGY

Highlighted below are the fundamental elements of the methodology developed and applied to identify and evaluate foreign-based environmental management technologies for potential applications by EM. The methodology also included a process for coordinating technology innovations with appropriate personnel of the DOE and operations contractors at sites across the complex. A simplified representation of this methodology is presented in Figure 1.

1.3.1 Review of DOE High-Priority Environmental Technology Needs

Efforts to identify foreign-based environmental management technologies were driven by the needs of the DOE complex. During FY 1992, a detailed review of available technology needs information was conducted. Information on DOE's high-priority needs which were used to focus the efforts of this

Figure 1. Methodology Applied to Identify Foreign-Based Environmental Management Technologies for Potential Application to U.S. DOE Sites.

program are provided in the FY 1992 Final Report of the System Analysis/Environmental Restoration in Western Europe task (AL-223305) ^[1]. The central source of needs information applied at that time was the DOE Technology Needs Assessment performed by the Grand Junction Projects Office and published in January 1993 ^[14].

1.3.2 Selection of Countries for Investigation

A country-by-country survey of several regions of the world was performed in order to better focus efforts for evaluating foreign environmental restoration (ER) and waste management (WM) technologies that can be applied to specific environmental problem units of the DOE complex. Key factors used in the country-selection process were the technology capabilities and market potentials of the countries investigated. Countries were rank-ordered under the FY 1993 efforts. The results of this selection process were applied in several subsequent-year programs.

The following countries were selected for identification of ER and WM technologies: the Netherlands, France, Japan, Taiwan, the Czech and Slovak Republics, and the former Soviet Union. Although a secondary objective, additional emphasis was placed on those countries that offered market opportunities for U.S. businesses engaged in providing ER and WM services and product lines on the international marketplace. The results of the selection process are summarized in the FY 1993 year-end report of the DOE International Coordination Task ^[8].

1.3.3 Identification and Screening of Promising Environmental Technologies

Efforts to identify foreign ER and WM technologies which are potentially applicable to the DOE complex required an initial screening of hundreds of technologies. Key factors in this screening process included the maturity of technologies and their applicability to DOE's high-priority needs. Sources of information used ranged from publications to the open literature and direct one-on-one discussions with representatives of the international scientific community. Technologies selected for evaluation are described in the FY 1993 year-end report of the International Coordination task ^[8]. As described below, these evaluations were performed by the SNL task team.

1.3.4 Evaluations of Foreign Technologies Based on Developed Criteria

Foreign technologies were selected for evaluation from a field of several hundred. Selected technologies were carefully reviewed and evaluated. The primary evaluation factors included the maturity, innovativeness and cost effectiveness of the foreign-based technologies. The results of this evaluation process were presented on a profile format consistent with that applied for the DOE OTD Technology Catalogue of emerging U.S. ER and WM technologies. This was done to optimize current and future efforts to compare the attributes of foreign and OTD technologies. In addition, the technology descriptions were subsequently formatted to permit convenient and efficient transfer of information to the DOE EnviroTRADE[®] Information System ^[15], an OTD-sponsored environmental information system.

1.3.5 Matching of Foreign Technologies with DOE Environmental Problem Units

Each of the foreign technologies evaluated were matched with environmental problem units across the DOE complex. The primary reference source to perform this matching process was the Technology Needs Assessment Crosswalk Report developed by Chem-Nuclear Geotech, Inc. for the DOE Grand Junction Projects Office under funding from EM-40 ^[14].

1.3.6 Identification of Related DOE/OTD Programs

Each of the evaluated foreign technologies were also matched with ongoing OTD-funded development efforts. This was done to broaden the potential applicability of foreign technologies as a means of enhancing OTD's development efforts. The primary reference for this effort was also the Technology Needs Assessment Crosswalk Report ^[14].

1.3.7 Preliminary Coordination of Results with DOE EM and Site Personnel

Efforts to coordinate the results of the FYs 1992-93 program with DOE site personnel were initiated in the FY 1994 program. During FY 1994, several site visits were held with DOE and contractor site

personnel to discuss the merits and limitations of those foreign technologies that appeared to be most promising for eventual import to the DOE complex. Site-coordination visits were held at the Nevada Test Site, Savannah River Site, Oak Ridge National Laboratory, and Hanford National Engineering Laboratory. The FY 1994 year-end report features the results from the individual site visits and correlates the potentially applicable foreign technologies with the problem units at the site ^[9].

1.4 POTENTIAL DOE APPLICATIONS

A top-level analysis was performed to match environmental problem units of the DOE complex with the 27 foreign technologies that were evaluated. Potential applications of these technologies were identified by correlating the cleanup requirements for specific problem units at DOE sites with the technology descriptions. This was done by selecting "keywords" from the Keyword Index of the Technology Needs Crosswalk Report ^[14] that represent the foreign technology. These keywords were then used to electronically search for and identify problem units.

The results of the foreign technology/problem unit matching process are presented in Table 1. Technologies are presented in the following categories: (a) characterization, monitoring and sensor technologies; (b) treatment and separation technologies; and (c) containment technologies. This matrix represents the correlation between the 27 foreign technologies and the potential applications at sites in 10 of DOE's field offices.

As shown, there are a total of 529 entries in the matrix, corresponding to between four and 72 "matches" at any one site within a field office for all 27 technologies within the DOE complex. The largest number of potential applications exist for the Chicago and Oak Ridge Operations Offices. Multiple entries in the matrix imply that a particular foreign technology may be applicable to more than one problem unit at a site and should be evaluated for possible application.

1.5 TECHNOLOGY PROFILES

The International Technology Catalogue (this report) features several technologies which were evaluated for their potential applications across the DOE complex. These foreign-based technologies were screened from a field of several hundred and determined to offer innovative, cost-effective and mature options to U.S. baseline technologies. By successfully importing and applying these technologies, the DOE could reduce the costs and the schedule for remediation of the complex.

Twenty-seven foreign technologies are featured in this document. These include five characterization, monitoring or sensor technologies, eighteen treatment and separation technologies, and four containment technologies. To varying degrees of success, each of these technologies has been coordinated with DOE and contractor site personnel across the complex. Some of these technologies are undergoing further evaluation, including demonstrations at DOE sites.

Each technology is summarized in a profile designed to provide the reader with a concise and comprehensive summary of technical performance and cost data. In addition, the profile format is consistent with that applied by the OTD Technology Catalogue ^[12,13] to help ensure uniformity in comparing the attributes of U.S. OTD and foreign technologies. The topical areas listed below are included for each technology profile. These topical areas were arrived at after a comparison of similar non-DOE

Table 1. Potential Applications of Foreign Technologies to Environmental Problem Units in DOE Operations

Foreign Technology	Albuquerque (AL)			Chicago (CH)			FN	ID	NV	Oak Ridge			RF	RL	SF		SR
	LANL	SNL	Other	ANL	BNL	BCL	FEMP	INEL	NTS	ORNL	K-25/ Y-12	Other	RFO	RLO	LLNL	ETEC	SRO
Characterization, Monitoring and Sensor Technologies																	
1. SENSOR® Leak Detection Technology							1	2	1		1	1					1
2. Polycyclic Aromatic Hydrocarbon (PAH)-Field Analysis									1		1	2					
3. Glass Melter Sensor Technology	1	2	4	3	2		4	1	1			3		2			
4. Laser Evaporation Techniques for Environmental Sample Preparation	2	1	1	1	7	1	7	9	8	1	3	7	7	5		1	2
5. Remote Contaminant Sensor Technology	1		7	2	6	1	1	4	3			8					1
Treatment/Separation Technologies																	
6. Adsorption Technology for Decontamination of Low and Medium Level Aqueous Solutions from Long-Lived Radionuclides			1		7	1	4	5	3	1		5	7	2		1	1
7. Biochemical Treatment of Heavy Metals			4					2	2			1	1	3			
8. Biological Dehalogenation of Chlorinated Ethylenes							1				1	4	1		1	1	2
9. BIOPUR® Biological Soil and Groundwater Treatment System			4		3									1			

Table 1. (continued) Potential Applications of Foreign Technologies to Environmental Problem Units in DOE Operations

Foreign Technology	Albuquerque (AL)			Chicago (CH)			FN	ID	NV	Oak Ridge			RF	RL	SF		SR
	LANL	SNL	Other	ANL	BNL	BCL	FEMP	INEL	NTS	ORNL	K-25/ Y-12	Other	RFO	RLO	LLNL	ETEC	SRO
10. Chrompik Vitrification Process for Dried Liquid Radioactive Waste					2	1	2		2	1				1			
11. Cobalt Dicarbolide Separation Technology for Radioactive Waste	2	2		4	4	2	1	6	6				1	4			1
12. Composite Inorganic-Organic Ion-Exchange Materials					1	1	3		2	1							
13. Electrochemical Dehalogenation of Toxic Organic Compounds			3		1		1				1	1					
14. Electro-Reclamation	2				2		2	5	3		2	4	2	3			3
15. Ex Situ Bioremediation of Heavy Metals Using Sulfate Reducing Bacteria			4		3		1	3	1			4	6	1	1		1
16. Ex Situ Extraction of Organic Bromine Compounds from Soils Using NaOH			2	1	1			1	4	1	1	5	1	1			2
17. In Situ Removal of Cadmium and On-Site Treatment with Ion-Exchange		1	1	1					3	1	1	4	1	1			2
18. In Situ Removal of Weak Acid by Flushing with NaOH		2	1	1				1	3	1	1	4	1	1			1
19. In Situ Treatment of VOCs by Recirculation Technologies			5		2							1	1		2		2
20. Plasma Furnace Technology for Vitrification or TRU Contaminated Wastes	2	1			5		4	7	6		2	5	5	4			2

Table 1. (continued) Potential Applications of Foreign Technologies to Environmental Problem Units in DOE Operations

Foreign Technology	Albuquerque (AL)			Chicago (CH)			FN	ID	NV	Oak Ridge			RF	RL	SF		SR
	LANL	SNL	Other	ANL	BNL	BCL	FEMP	INEL	NTS	ORNL	K-25/ Y-12	Other	RFO	RLO	LLNL	ETEC	SRO
21. Plastic Solidification Process for Radioactive Wastes					1	1	3	3	3					1			
22. Polluted Water Cleaning with Two-Stage Heterogeneous Discharge				2	2			5					1				
23. Vitrification of Liquid Wastes from Nuclear Power Stations					2		1	4				2	3				
Containment Technologies																	
24. ECOSOL® Contaminant Absorbing Grout		2		1	1				4	1	2	3					5
25. Hydrofracture	2	1			2		2	1			1			1			2
26. In Situ Barrier Construction with Montan Wax Emulsion		2		1	1				4	1	2	3					5
27. Integrated Grouting Technology	1		2	2	2		1	2	2		1	5		4	1		1
Subtotals	13	14	39	19	57	8	39	61	62	9	20	72	38	35	5	4	34
Total																	529

technology documentation efforts (e.g., the U.S. Environmental Protection Agency), coordination with the staff of the DOE and its contractors, and feedback on the versatility of the format from the OTD Technology Catalogue effort.

The International Technology Catalogue addresses the areas listed below for each evaluated technology.

- Technology title and description
- Technical performance and cost data
- Applicable waste types and forms
- Development status
- Key regulatory considerations regarding the application of the technology
- Potential commercial applications
- Baseline comparison technology
- Intellectual property rights
- Points-of-contact and references for more information

For some of the foreign technologies evaluated, there was only limited performance and cost data available from the developers. For other technologies, considerable information is available regarding comparisons with baseline technologies.

1.6 SUMMARY

The International Technology Catalogue summarizes the efforts to evaluate foreign-based environmental management technologies which are considered cost-effective and innovative options to U.S. baseline technologies. Further joint foreign and U.S. technical evaluations and assessments of the applications of the technologies to specific DOE site problem units is warranted before the suitability of site demonstrations can be verified. Additional technical and economic assessments through U.S. business partnerships are recommended to assure cost-effective applicability of these technologies to DOE site-specific problem units.

The International Technology Catalogue is structured to allow direct comparisons with technologies which are reported in the OTD Technology Catalogue of emerging U.S. environmental management technologies developed under funding by the DOE's Office of Environmental Management. The information presented in this document has also been transferred to the DOE EnviroTRADE® Information System.

Characterization and Monitoring Technology Profiles

Section 2.0

GLASS MELTER SENSOR TECHNOLOGY

HVG and Friedrich-Schiller Univ. Jena
Germany

DESCRIPTION

The combination (vitrification) of hazardous wastes and glass melt to produce various waste glasses is sometimes performed for waste stabilization. This sensor technology performs real time, in-stream characterization/monitoring of waste glass within a melter for quality and operational control. The sensor determines the melter oxidation/reduction state (redox) and the glass composition (by determining transition metals content and the total alkalinity of the melt).

TECHNICAL PERFORMANCE

The technology can sufficiently characterize waste glass for quality control. The technology may also be very effective in characterizing the secondary phases of the glass, which may be detrimental to melter operation (causes shorting). The sensor does not directly analyze the waste glass composition, but infers the composition based on simplifying assumptions. The sensor may require regular calibration (using some standard post-melt sampling and laboratory testing). This technology is seen as a way to reduce normal sample load by approximately 75% (by reducing analysis time), while increasing the assurance of the product.

Further development may lead to sensors that can be used within the melter during extreme operating conditions. Further development may also lead to techniques for obtaining better correlations of the measured parameters with actual glass composition (especially while using heterogeneous waste forms).

WASTE APPLICABILITY

Although applicable to all toxic materials, vitrification is anticipated only for HLW, TRU and possibly LLW. The general method is applicable to transition metals in solution.

STATUS

The technology is currently entering the U.S. field demonstration stage. Although existing German technology has been demonstrated overseas, the technology must be adapted and qualified for DOE needs. Development steps include: (1) obtaining the existing German technology; (2) performing a laboratory demonstration; (3) installing the technology in a melter to monitor simulated waste processing; and (4) installing the technology in a melter to monitor actual radioactive-waste processing. The estimated time needed to carry out the development steps is 3 years.

REGULATORY CONSIDERATIONS

Since the technology is a sensor technology, no additional regulatory considerations are required beyond those associated with glass-melt vitrification. Sensors may significantly protect melters as well as reduce glass rejection rates and reduce delays caused by laboratory analyses. Waste vitrification requires permits and NEPA documentation. The sensor technology may have to be supplemented with some standard elemental glass analysis to ensure calibration.

POTENTIAL COMMERCIAL APPLICATIONS

This technology is applicable to any process where waste glass characterization during waste treatment (vitrification) of HLW, TRU, and LLW or other toxic materials is needed. Site conditions are irrelevant. Glass-melt vitrification is being utilized at many sites throughout the DOE complex (e.g., Savannah River Site).

BASELINE TECHNOLOGY

The baseline technology consists of sampling the glass after melting and testing in the laboratory. No reasonable alternative exists for this technology's ability for real-time, in-line analysis.

INTELLECTUAL PROPERTY RIGHTS

HVG and Friedrich-Schiller Univ. Jena own the patent rights on one of the sensors.

DOE holds license of the SRTC Sensor; D. Bickford: "Sensors for Monitoring Waste Glass Quality and Method of Using the Sensor." US Patent No. 5,294,313 (March 15, 1994).

Collaborative U.S. development (including NSF funding) ensures access to the technology.

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1. DuCharme, Arthur R., William J. Robards, and Richard D. Jimenez, "Matching Leading DOE Waste Management and Environmental Restoration Needs with Foreign-Based Technologies: FY 92 Final Report", System Analysis/Environmental Restoration in Western Europe, TTP No. AL-2233-05, International Technology Exchange Program, October 1992.

LASER EVAPORATION TECHNIQUES FOR ENVIRONMENTAL SAMPLE PREPARATION

V.G. Khlopin Radium Institute
Russia

DESCRIPTION

In order to analyze radioactive hazardous waste, samples must first be prepared. This preparation costs time and resources in the environmental restoration process. This innovative technology utilizes a laser to evaporate waste, such as plutonium and uranium in soils, for high-resolution spectroscopic analysis utilizing a tunable-laser.

The technology involves the spectroscopic analysis of small samples of material to determine if specific elements/isotopes are present within the material. Due to the advantage of increased sensitivity, this technology utilizes laser spectroscopy

instead of nuclear decay detection. The biggest advantage of this method is in its ability to detect ultra-low concentrations of slow decaying isotopes. The technology uses one laser to evaporate atoms/ions from a sample and a second tunable laser to perform the laser spectroscopic analysis utilizing optical transitions in the atoms/ions.

Each element/isotope has its own spectroscopic characteristics. Within the spectrum of a particular element/isotope are certain spectroscopic lines (fluorescence at a certain wavelength) that are unique to that element/isotope. A tunable laser derives its name from the fact that the wavelength of the laser light can be varied over a wide range.

Since the intensity of a spectroscopic line is dependent on the wavelength of the incident laser light, a tunable laser is needed to determine if certain lines exist - which indicates that certain elements/isotopes exist.

All elements/isotopes can be detected in this fashion if the variation in wavelength of laser light is large enough. The tunable laser used was a rodamin dye laser with a wavelength range of 540-650 nm.

Experimental Set-up for Investigation of the Laser Evaporation Process and Isotope Composition Analysis of Samples

With this range in wavelength, 25 elements can be detected. The list of 25 includes technetium (Tc), thorium (Th), uranium (U), neptunium (Np), and plutonium (Pu). By changing the dye more elements/isotopes can be detected.

One important and unique aspect of this particular technology is in its ability to transform the material into a gaseous state so the atoms/ions can be effectively analyzed. This is accomplished by the use of a pulsed copper vapor or YAG:Nd⁺ laser to evaporate the sample material. Each pulse of the laser lasts about 10-20 ns and the wavelength used is either 511 or 1064 nm. The average power per area delivered to the sample in order to produce the pulsed beam of atoms/ions ranges from 10⁷-10⁹ W/cm². Under vacuum (in a vacuum chamber at about 10⁻⁶ torr) and with the use of an optical system, a computer, detectors (photomultiplier tubes, ion detectors, etc.), and other equipment, the samples are evaporated and analyzed.

TECHNICAL PERFORMANCE

From the results to date, the developers conclude that the sensitivity of the technology is about 10¹²-10¹³ atoms per sample (in comparison, Avogadro's number is 6.02 x 10²³ atoms). The selectivity of various isotopes for the transuranic elements is about 10⁻⁶ (which means that isotopes that differ in concentration by more than 10⁶ times can be individually identified).

The developers investigation into the affects of sample preparation on analysis lead to the conclusion that samples pressed into tablets produced the best signal to noise ratio. Thus, the density of the prepared samples is very important for this analysis technique. For soil samples, the developers utilized a density of more than 0.43g/cm³. In addition, the introduction of various admixtures into the sample material (to aid tablet forming) did not lead to significant changes in the signal to noise ratio.

With improvements in the experimental setup, the sensitivity could possibly be improved to about 10⁷-10⁸ atoms per sample.

WASTE APPLICABILITY

This measuring technology is applicable to soils contaminated with specific elements (depending on the lasers used). The tunable laser used was a rodamin dye laser with a wavelength range of 540-650 nm. With this range in wavelength, 25 elements can be detected. The list of 25 includes actinium (Ac), americium (Am), barium (Ba), dysprosium (Dy), erbium (Er), europium (Eu), gadolinium (Gd), hafnium (Hf), lanthanum (La), lutetium (Lu), manganese (Mn), sodium (Na), neodymium (Nd), neptunium (Np), plutonium (Pu), scandium (Sc), samarium (Sm), Tantalum (Ta), technetium (Tc), thorium (Th), thulium (Tm), uranium (U), yttrium (Y), ytterbium (Yb), and zirconium (Zr). By changing the dye more elements/isotopes can be detected.

STATUS

The technology consists of a combination of laboratory instrumentation and equipment. Refinements in technique are estimated to yield more accurate results.

REGULATORY CONSIDERATIONS

United States regulatory issues are not known.

POTENTIAL COMMERCIAL APPLICATIONS

Potential commercial applications are very wide ranging. Any industry that needs quick and accurate soil analysis for determining the presence/amount of specific elements could benefit from use of this technology. This technology could be applied to analyze soils at various remediation sites throughout the DOE complex.

BASELINE TECHNOLOGY

Nuclear decay detection and wet chemistry are the baseline technologies. In comparison to nuclear decay detection, this technology has the advantage of being able to detect ultra-low concentrations of slow decaying isotopes. In comparison to wet chemistry, this technology is 1-2 orders of magnitude higher in precision, takes minutes versus days to complete, and provides 2 orders-of-magnitude reduction in cost per sample.

INTELLECTUAL PROPERTY RIGHTS

None.

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PAH-FIELD ANALYSIS USING CHEMILUMINESCENCE

TAUW Milieu BV
The Netherlands

DESCRIPTION

PAH-Field Analysis is a field analytical method which can rapidly characterize or monitor soil samples for PAH contamination (polycyclic aromatic hydrocarbons). PAH-Field Analysis can produce unresolved quantitative results within 15 minutes and, therefore, presents a useful aid to the remediation of soils. In conventional High Performance Liquid Chromatography (HPLC) and Gas Chromatography (GC), the PAH derivatives are separated by means of chromatography, after which detection and further quantification take place. PAH-Field Analysis may be described as collective quantification, that is to say the individual PAH are not separated. Once a suitable reagent has been added a specific chemical reaction will (due to the presence of PAH) produce light (chemiluminescence). The intensity of this light, which is 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 number of samples in parallel with both the HPLC analysis and the PAH-Field Analysis. On the basis of measured intensity of the light and the established calibration factor, the concentrations in the soil can be determined. This method has been successfully applied on numerous occasions, both in the Netherlands and abroad.

TECHNICAL PERFORMANCE

When adequately calibrated with HPLC (high performance liquid chromatography) PAH-Field Analysis provides accurate measurement of total PAH concentrations. This technique is rapid, analysis in less than 15 minutes, and inexpensive.

No specific performance or cost data have been provided.

WASTE APPLICABILITY

This measuring/monitoring technology is applicable to soils contaminated with polycyclic aromatic hydrocarbons. Current equipment cannot be used on groundwater, but this application is being explored. The method uses chemiluminescence to determine total PAH concentration.

STATUS

The method has been successfully applied on numerous occasions, both in the Netherlands and abroad. Development is complete.

REGULATORY CONSIDERATIONS

There are no US regulatory issues known which would restrict the use of this technology. PAH-Field analysis would need to be calibrated on-site with HPLC or GC methods. This technique only determines total PAH concentration, whereas specific contaminant concentrations may be required.

POTENTIAL COMMERCIAL APPLICATIONS

This technology is potentially applicable to industries such as gasoline storage, transport and refueling stations which have soil contamination problems (naphthalene concentrations in the gasoline would not fluoresce). This field analytical technique is applicable for site characterization and monitoring during remediation especially where only monitoring of total PAH concentration is required.

Specific DOE needs include site monitoring and site characterization for soils contaminated with PAH.

BASELINE TECHNOLOGY

Some baseline technologies currently used in the United States for PAH analysis are liquid and gas chromatography and nuclear magnetic resonance (NMR). The PAH-Field Analysis technology is much cheaper and faster, although not as accurate or specific, compared to chromatography or NMR, but it needs HPLC for calibration.

INTELLECTUAL PROPERTY RIGHTS

The TAUW Infra Consult company has patents pending in the Netherlands and in Europe.

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REMOTE CONTAMINANT SENSOR TECHNOLOGY

Institute of Radiochemistry
Kernforschungszentrum Karlsruhe, Germany

DESCRIPTION

As part of a collaboration between the Nuclear Chemistry Division at Lawrence Livermore National Laboratory (LLNL) and the Institute of Radiochemistry (IRCh) in the Kernforschungszentrum Karlsruhe (KfK) in Germany, two types of sensors were transferred for demonstrations at LLNL and the Savannah River Site (SRS).

The first is a fiber-optic based sensor, the Evanescent Field Absorption Sensor (EFAS), for the

detection of organic molecules, particularly chlorinated hydrocarbons such as trichloroethylene (TCE), 1,1-dichloroethene (DCE), and chloroform. The second is an Opto-chemical Plastic Disc Sensor (OPDS) for the detection of heavy metals, such as cadmium (Cd), mercury (Hg), and lead (Pb).

Evanescent Field Absorption Sensor. The EFAS is based on internal reflection spectroscopy. Light entering a fiber-optic at an angle greater than the critical angle is totally reflected off the core/cladding interface as it propagates through the fiber. At each reflection point, a small portion of light penetrates into the cladding. This is known as the evanescent wave (see Figure 1). In this fiber-optic sensor, the absorption of the evanescent wave in the fiber cladding is what is actually being measured. When immersed in an analyte solution, non-polar organic solvents diffuse into the cladding of the fiber. Absorption spectra in the near-infrared wavelength range are used to characterize the analyte solution. Water, which has a strong absorption in the near-infrared, is repelled by the hydrophobic polysiloxane cladding. Thus, the evanescent wave only sees the organics; the large background due to water absorbance is eliminated.

This sensor has many advantages over other sensors for volatile organic compounds, in particular TCE. It is based on a completely reversible physical interaction and not a chemical reaction. Measurements are made directly in the water and not in the headspace above the water level, which also allows for monitoring of concentration gradients in groundwater. This is significant since many organics are more dense than water and will sink to the bottom. The time to reach equilibrium is 15 to 20 minutes. The linear dynamic

Figure 1. Evanescent Interaction with TCE in the Hydrophobic cladding.

Core diameter = 400 microns

Cladding diameter = 500 microns

range spans from trace levels to solubility limit, 1 to 1100 ppm.

Opto-chemical Plastic Disc Sensors. In this sensor, a porphyrin dye is immobilized in a cation exchange membrane. Metal ions that diffuse into this membrane form a complex with the dye and the characteristic spectra can be obtained. A clear plexiglass disk acts as a suitable substrate for the membrane allowing for absorbance spectra to be obtained perpendicular to the surface (see Figure 2).

Figure 2. Diagram of the Operation of the Opto-chemical sensor. M-TMPyP refers to the metal dye complex. Nafion Membrane thickness = 3-5 microns on a 1/16-inch thick plexiglass disc.

Porphyrin dyes are well known as highly sensitive indicators for the spectrophotometric determination of metal ions. The complexation rate is relatively fast (timescale of minutes) and the resulting absorbance spectra of the complexes can be well distinguished and correlated to different metals.

These sensors are inexpensive and simple to produce with materials that are commercially avail-

able. A solution of Nafion, a cation exchanger, is pipetted onto a small plexiglass disc. After briefly spinning off the excess, a thin film of Nafion is obtained. Immobilizing the dye in the membrane is achieved by simply immersing the coated disc in an aqueous solution of the porphyrin dye for several days. Prior to use, the sensors are rinsed with distilled water and stored in a buffered solution. The sensors show excellent chemical and mechanical stability and can be used several weeks without loss in sensitivity.

Due to its strong ion exchange properties, Nafion extracts cations from the solution. The kinetics of the complex formation and increase of the absorption band of the complex have been correlated with the metal ion concentrations.

TECHNICAL PERFORMANCE

Evanescent Field Absorption Sensor. Current limits of detection for the EFAS are shown in Table 1. Results of the field tests at LLNL are summarized in Table 2 and indicates which wells were monitored, the depth to water, the depth at which the measurements were made, the TCE con-

Table 1. Detection Limits for EFAS.

Contaminant	Detection Limit
Trichloroethylene	800 ppm
Chloroform	18 ppm
Dichloromethane	40 ppm

centration found, and the TCE concentration reported from laboratory analysis and the date the sample was chemically analyzed. No TCE was found in Well 116, where it was reported to be present in concentrations below the detection limit of the instrument. Laboratory results of samples from Well 351 were acquired four months prior

to the field test. The results from the EFAS correspond to the laboratory reported values.

Table 2. Results from LLNL Field Tests for TCE found with EFAS measured on July 21 and 24, 1992.

Well	Water Depth (ft)	Measure Depth (ft)	TCE This Work (ppm)	TCE Chemical Analysis (ppm)	Date of Chemical Analysis
116	90	95	0	20 ^a	6/4/92
351	75	80	2.85	3.3	3/3/92
351	75	110	2.88	3.3	3/3/92

^a Below detection limit for TCE with EFAS sensor.

Performance tests were also conducted at SRS. The detection of TCE in three wells are presented in Table 3. Samples were obtained on the same day as the tests (August 4) and were analyzed on August 20 by GC/MS. Concentrations found may have been higher than those reported by the laboratory due to losses of volatile organic compounds from outgassing in the processes of retrieving and transporting a sample to the laboratory. Table 3 also reports PCE concentrations; a contaminant of interest in the tests.

Table 3. TCE Results from SRS measured on August 4, 1992.

Well	Water Depth (ft)	Measure Depth (ft)	TCE This Work (ppm)	TCE Chemical Analysis ^b (ppm)	PCE Chemical Analysis ^b (ppm)
MHT-1D	135	140	1.41	2.0	1.1
MHV-7	107	110	5.96	2.55	0.996
MSB-3D	130	125 ^c	6.53	d	d
MSB-3D	130	147	37.6	d	d

^a EFAS sensor is not calibrated for PCE, see text.

^b Determined by GC/MS.

^c Detected in the air above water.

^d Not tested due to regulatory restrictions on removing samples at this concentration.

Opto-chemical Plastic Disc Sensors. Using the same spectrometer and computer as with the EFAS, the opto-chemical plastic disks were also tested in the field at SRS. Water from three wells (78, 90, 97) was retrieved for analysis. Due to the presence of pumps in the wells, in situ measurements were not possible with the system with its configuration. The sensor was modified to fit into a 1-in diameter well opening allowing for in situ measurement of Well 97 at a depth of 5 ft. Spectra obtained with the sensor in Well 97 showed no change from the uncomplexed dye reference spectrum in the acidic form. All three wells tested with the plastic disk sensor were found to be very acidic (pH range of 3-4). Table 4 summarizes the results of the instruments performance. Since the sensor operates in the neutral to basic range, the results were understood given the conditions.

Table 4. Summary of Opto-chemical Plastic Disk Performance.

Element	OPD Detection Limit (ppb)	ICP-AES Detection Limit ^a (ppb)	Drinking Water Regulatory Levels ^b (ppb)
Cd	6	2	10
Pb	not available	40	50
Hg	40	50	2

^a J. W. Robinson, "Atomic Spectroscopy," (Marcel Dekker Inc., NY) 1990.

^b Barclay's California Code of Regulations.

Samples drawn from the three wells were adjusted to pH 9 with a buffer solution. Sensors were then immersed in these samples and stirred overnight. The sample from Well 78 showed no change (i.e., no complexation) from the reference dye spectra. In Well 90, complexation of a metal with the dye could be detected; however, the component was not one of the reference metals (Cd, Hg, Pb, Zn). In Well 97, Zn was detected with the sensor although the concentration could not be determined.

Lab reported values from Cd and Pb were on the order of 4 to 40 ppb, respectively, both of which are below the current detection limit of this sensor and drinking water regulatory levels (see Table 4).

WASTE APPLICABILITY

The EFAS is applicable to the detection of chlorinated hydrocarbons such as TCE, DCE and chloroform in groundwater. The OPDS is applicable to the detection of heavy metals such as Cd, Hg, and Pb in groundwater.

STATUS

The EFAS and the OPDS were transferred from Karlsruhe to LLNL. Demonstrations of the sensors were performed at LLNL and SRS in 1992.

The only development issues remaining are how sensitive, inexpensive, and portable the instruments can be made. The development and transfer of the technology is expected to take about three years.

REGULATORY CONSIDERATIONS

Eye injury or burns can result from laser beam exposure. Exposure to laser dyes/solvents can produce toxic and/or mutagenic effects. Although absorption spectroscopy is a mature and well-accepted laboratory procedure, since this technology represents a different procedure for verifying performance (monitoring), it will probably have to be supplemented/calibrated by traditional sampling/laboratory testing methods.

POTENTIAL COMMERCIAL APPLICATIONS

This technology could be applied by any organization (public or private) that needs to real-time characterize water containing transuranics, organics, toxic metals, or colloids. Some potential customers are institutions within the chemical industry, power industry, and government. This tech-

nology could be applied to help remediate sites throughout the DOE complex.

BASELINE TECHNOLOGY

The baseline technology for waste-water analysis is sampling and testing in the laboratory.

INTELLECTUAL PROPERTY RIGHTS

Due to their collaborative development, both LLNL and Karlsruhe Nuclear Research Center own the intellectual property rights. Primary transfer would be accomplished by personnel exchanges between German groups and LLNL. The field equipment will be developed at LLNL.

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SENSOR® LEAK DETECTION TECHNOLOGY

Slovak Republic

DESCRIPTION

A technologically-advanced sensor system has been developed for early warning leak detection in lined waste-disposal ponds, industrial surface impoundments, basins, pipelines, tunnels, and other similar contained structures. Correlations between localized water flow and electrical current are often observed in soils since most electrical conduction is by means of migration of dissolved ions. This system exploits this phenomenon by detecting anomalies in measured components of current density as the basis for detecting breaches in liners, pipelines, and other containment systems holding liquid chemical wastes. Basic electrical parameters are measured which reflect the decomposition of current density, which is relatively easy to measure, as opposed to actual fluid flow which is often difficult to measure. The active and passive components of the SENSOR® system are such that migration of local groundwater can also be detected and defined. This is an added benefit to the leak detection technology and possibly a useful secondary application.

A "lined waste pond" is essentially a liquid volume enclosed in a plastic membrane. Typical contents may range from toxic chemicals to domestic refuse. The goal is to detect leakage or breaches in the lining membrane, both before and after filling of the impoundment. The detection system consists of five components: a passive sensing electrode array, active current electrodes, a monitoring center, cables, and a data acquisition station. Using specially developed data processing and graphics presentation software, the

location of a leak can be detected and graphically described with high sensitivity and precision.

Two versions of the system have been developed, a "permanent system" for installation into new lined landfills or containment structures, and a "portable system" for use with existing lined landfills and containment structures.

TECHNICAL PERFORMANCE

Full-Scale Applications:

1. Location: Budmerice (Western Slovakia), Istrochem Bratislava (one of the largest chemical companies in Slovakia). This was a permanent modification installed in a PVC and geotextile liner, in Sept. 1991; 8,000 m². There were 10 leaks detected which consisted of welding errors, tears, and punctures. The liner was used to contain chemical and municipal waste.
2. Location: Cleon (North West France), Sotrap, liner installing company. This was a portable installation in a HDPE double liner with a drainage layer. Installed Sept. 1992; 20,000 m². There were 36 leaks detected which consisted of punctures. The liner was used to contain industrial waste.
3. Location: Anger (Western France), France Dechets. This was a permanent modification in a HDPE liner. Installed Oct. 1992; 6,000 m². The liner was used to contain industrial waste.

4. Location: Budmerice II (Western Slovakia), Istrochem Bratislava. This was a permanent modification in a HDPE and geotextile liner. Installed in Oct. 1992. The liner was used to contain chemical and municipal waste.
5. Location: Sete (Southern France), Sud Fertisant. This was a portable modification in a HDPE liner. Installed in November 1992. Two leaks were detected which consisted of tears and welding errors. The liner was used to contain phosphoric acid.
6. Budmerice III (Western Slovakia), Istrochem Bratislava. This was a permanent modification in a HDPE and geotextile liner. Installed in February 1993; 4,000 m². The liner was used to contain liquid chemical waste.

Cost Data:

Description	\$U.S./m ²
Permanent (20 yrs. monitoring)	\$94.50 - 170.10
Permanent (1-3 yr. monitoring)	\$44.10 - 75.60
Portable System	\$75.60 - 94.50

Exchange Rate (08/93: 6.3 French Francs = \$1.00 US.

WASTE APPLICABILITY

This technology is applicable for the monitoring and detection of leaks that occur in lined waste-disposal excavations and other containment systems for chemical liquid wastes. It is principally applicable to leak and damage detection for lined waste storage ponds and landfills. The method is equally applicable to pipeline and sewer system

leak detection. This technology is also applicable for site monitoring, including ground water flow and contaminant migration.

STATUS

This technology has been developed and demonstrated at more than six sites. All of the materials, equipment, computer software and related items for application of either the permanent or portable systems are currently available from the technology developer.

REGULATORY CONSIDERATIONS

There appear to be no regulatory or public acceptance issues which are of significance with regard to the application of this technology in the United States.

POTENTIAL COMMERCIAL APPLICATIONS

Potential commercial applications include chemical companies and other industries which utilize storage and disposal ponds for chemicals and industrial waste. This technology could also be applied to the chemical sewer systems and pipelines used to deliver or transport chemicals and industrial waste. The extent of the world-wide market is potentially very large. The developer has a representative in France who will be marketing this technology in Western Europe and Scandinavian Countries.

The developer has also recently entered into a licensing agreement with Gundle Lining Systems, Inc. of Houston, Texas.

Specific DOE needs for which this technology applies include monitoring the physical integrity of contained structures, process sewer lines, pipelines and lined landfills within the DOE complex.

BASELINE TECHNOLOGY

There are a number of US and foreign baseline technologies which are used in leak detection; however, it is the accuracy of this technology, in addition to its ability to graphically locate and describe the leak, which makes it unique.

INTELLECTUAL PROPERTY RIGHTS

This technology has a patent pending filed in the Slovak Republic under the name of "Damage Detection System".

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Treatment and Separation Technology Profiles

Section 3

Section 3.0

ADSORPTION TECHNOLOGY FOR DECONTAMINATION OF LOW AND MEDIUM LEVEL AQUEOUS SOLUTIONS FROM LONG-LIVED RADIONUCLIDES

Institute of Physical Chemistry
Russia

DESCRIPTION

The Institute of Physical Chemistry at the Russian Academy of Sciences has been investigating the use of various ion-exchange technologies for treating aqueous solutions containing low-level or intermediate-level radioactive waste. The technologies are based upon adsorption of radionuclides on organic ion-exchange resins, natural minerals, organic materials, and synthetic inorganic absorbents. The following list of materials (although not comprehensive) are representative of the type of materials currently used in Russia for remediation purposes:

- industrial manufactured ion-exchange resins, such as KU-2x8 (strong acidic sulfocationite),

KB-4P2 (weak alkaline carboxylic anionite), ANKB-2 (aminocarboxylic polyampholite), ANKB-35, AB-17, and KU-1 (phenolphormaldehyde sulphocationite);

- natural and modified aluminosilicates and zeolites, such as bentonite (white clay), vermiculite, clinoptilolite, shabasite, and Selex-KM (modified natural clinoptilolite);
- synthetic zeolites, such as CFB-10 (type A zeolite, caolinite clay modified with phosphoric acid), CMP (type A zeolite), NaA (sodium form of type A zeolite), CaA (calcium form of type A zeolite), NaX (sodium form of type X zeolite), and CaX (calcium form of type X zeolite), KG-13 (synthetic shabasite, potassium form), fluorine-montmorillonite, 5AZ, Mordenite (synthetic zeolite with 7% clay as a binder);
- hydrous oxide based adsorbents, such as ISMA-3 (modified manganese dioxide based cationite), pyrolusite (natural manganese dioxide), SKK-3 (antimony-silicon cationite), Termoxid-5 (hydrated titanium dioxide based adsorbent), and ASKM (silica gel of mesoporous structure);
- polyvalent metal salt based adsorbents, such as FT (titanium phosphates), FZ (zirconium phosphates), and CuS (copper sulfate);
- metal oxide impregnated ion-exchange resins (MOIR), such as chelating polyvinylpyridine or iminodiacetic acid based ion exchange res-

Mobile Water-Treatment System

ins impregnated with titanium or zirconium dioxides;

- ferrocyanide based inorganic sorbent, such as FS-10 (potassium-copper ferrocyanide supported by silica gel), NGA (nickel ferrocyanide supported with aluminosilicate), Ferrocyn, and HG-10;
- coal-based adsorbents, such as BAU (activated charcoal), SK-1 (sulphonic coal), TEC, and SKNO (nitrogen containing activated coal); and,
- other natural and modified natural material, such as wood (sawdust of birch, pine, and aspen wood), oxidized wood (carbonized or oxidized sawdust), phosphorylated wood (sawdust modified with phosphoric acid and urea), peat, and Chizit-03 (chitine-containing adsorbent, fabricated from shrimp shells).

In addition to the sorbents, the Institute of Physical Chemistry has also developed a mobile unit for treating low- and medium-level aqueous solutions. The unit is comprised of three sub-units: (1) a filter system; (2) a cementation unit; and (3) an incinerator. The figure below illustrates in block-diagram form the mobile unit system.

TECHNICAL PERFORMANCE

The table below lists the technical performance of some of these sorbent technologies. The sorbents are used to extract the contaminants from waste streams.

The mobile unit for treating low- and medium-level aqueous solutions is comprised of three different sub-units. The filtering system unit consists of a mechanical filter and three successive

Table of Technical Performance for some Sorbent Technologies.

Sorbent	Contaminant	Capability and Disposal
phosphorylated wood (sawdust)	uranium adsorption from wastewater	ion-exchange capacity of 3-4 mg/g; decontamination factor of 40-80; incineration of the sawdust yields a volume reduction factor of 100
hydrous manganese dioxide	co-precipitation of heavy metals from wastewater	disposal of sorbent
FS-10 (potassium-copper ferrocyanide supported by silica gel)	cesium adsorption from Purex waste	ion-exchange capacity of 100-160 mg; 98% Cs recovery from waste; 99% Cs recovery from the sorbents into a cesium concentrate; concentration factor of 100; disposal of sorbent
NGA (nickel ferrocyanide supported with aluminosilicate)	cesium adsorption from wastewater	a decontamination factor of 400 and 30-40 for Cs and total b-activity (produced by Sr, Ru, Pr, Ce, Th, and Sb), respectively; disposal of sorbent
MOIR (metal oxide impregnated ion-exchange resin; up to 10% Ti/Zr dioxide)	Sr, rare earth, and transplutonium radionuclides from Purex waste	MOIR loaded with radionuclides are subjected to a two-hour process that produces a microspheric-shaped ceramic waste which is suitable for long term storage or disposal.
natural clinoptilolite	Cs adsorption through soil mixing	1000 g/m ² reduced the transfer of Cs into plants by a factor of 1.5;
Ferrocyn (ferrocyanide containing sorbent)	Cs adsorption through soil mixing	20 g/m ² reduced the transfer of Cs into plants by a factor of 35;
HG-90 (ferrocyanide containing sorbent)	Cs adsorption through soil mixing	250 g/m ² reduced the transfer of Cs into plants by a factor of 3.3;
KU-2x8, ANKB-35, AB-17, NaA zeolite, and CuS	Ru, Co, Cs, and Sr adsorption from groundwater	removal percentages range from 5% to 96%; disposal of sorbent

filters for the removal of Cs, Sr, and heavy-element radionuclides. The sorbent is easily removed from the filtering system and unloaded into the cementation unit for encapsulation or into the incinerator unit for incineration. The incinerator unit is equipped with a highly efficient off-gas treatment system. Ashes remaining in the incinerator unit can be easily removed by use of a special bin to load the ashes into the cement mixer of the cementation unit.

WASTE APPLICABILITY

Principal applications of these technologies are in-situ and ex-situ waste treatment of contaminated water and/or soil for the removal and concentration of heavy metals (including radionuclides). Some of the elements removed and concentrated by these technologies are U, Pu, Cs, Sr, Ru, Co, Pr, Ce, Th, Sb, Ca, Mg, Zr, Ci, Mn, Cd, Cu, and Zn. In-situ treatment of soil can be accomplished by applying sorbent directly to the soil.

STATUS

Applications and capabilities of the various sorbents for remediation purposes have been studied and documented. Many of these sorbent technologies have been applied for remediation purposes within Russia. Availability of the mobile remediation unit is indicated.

REGULATORY CONSIDERATIONS

Use of some of the sorbents (e.g., ferrocyanide-based sorbents), as well as incineration, is governed by strict U.S. regulations. Disposal of certain wastes (e.g., radioactive) is also strictly governed.

POTENTIAL COMMERCIAL APPLICATIONS

Potential commercial applications are very wide ranging. Any industry that needs to decontaminate low- and medium-level aqueous solutions through the removal of long-lived radionuclides and heavy metals could benefit from the use of these technologies. Specific application of these technologies include waste water treatment from mining operations, nuclear materials processing, and water and/or soil remediation. These technologies could be applied to help remediate sites throughout the DOE complex.

BASELINE TECHNOLOGY

The combination of various ion-exchange technologies with pump and treat technologies is the baseline for treating water containing heavy metals (including radionuclides). Currently, soils contaminated with heavy metals are excavated and stored in a landfill or contained by use of barriers. If radionuclides are present in excavated soil, the soil may have to be treated first (e.g., leaching) to remove them. Grout barriers (including slurry walls) are baseline for containment.

INTELLECTUAL PROPERTY RIGHTS

None.

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BIOCHEMICAL TREATMENT OF HEAVY METALS

TNO Institute of Environmental Sciences
The Netherlands

DESCRIPTION

This technology is a biochemical version of acid leaching for on-site treatment of large volumes of solid materials which have contaminants with heavy metals including soils, industrial sludges, fly ashes, and possibly mill tailings from mining operations. Sulfur, air and specific microbial cultures (e.g., *Thiobacillus ferrodoxidan*) are mixed

with contaminated material in a bioreactor to produce sulfuric acid which, in turn, dissolves the heavy metals. The liquid mixture containing the heavy metals is collected. Afterward, remaining solids are separated from the liquid mixture in a solid/liquid separator. The dissolved metals are precipitated out of the resulting solution in a sul-

fate reduction bioreactor, possibly producing hydrogen sulfide (H_2S). The heavy metals can then be recovered, and the processed soil can be washed and reconditioned.

The use of this technology requires services for the bioreactors, for sulfate production and reduction, and for the solid/liquid separator. This technology requires excavation and handling of contaminated soil (or other material), soil washing and re-use, and handling and processing of recovered heavy metals.

Bioreactors for sulfate production and sulfate reduction have been successfully demonstrated under laboratory conditions. A pilot test, with a planned capacity of one ton of contaminated soil per day, is planned for 1994, and a field demonstration is expected in 2-5 years following the pilot test. Bench-scale tests have demonstrated this technology's 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 uranium-contaminated soils because uranium can be dissolved in sulfuric acid. This technology should be relatively inexpensive, since it does not need expensive growth media and because sulfur is relatively inexpensive com-

Schematic for Biological Treatment of Heavy Metals Contamination

with contaminated materials in a bioreactor to produce sulfuric acid which, in turn, dissolves the heavy metals. The liquid mixture containing the heavy metals is collected. Afterward, remaining solids are separated from the liquid mixture in a solid/liquid separator. The dissolved metals are precipitated out of the resulting solution in a sul-

linity, high ionic concentrations and other biota (weeds). It is expected that this technology would also be effective for uranium-contaminated soils because uranium can be dissolved in sulfuric acid. This technology should be relatively inexpensive, since it does not need expensive growth media and because sulfur is relatively inexpensive com-

pared to sulfuric acid. Although the reaction rate may be slow for a biological process, it should be safer.

TECHNICAL PERFORMANCE

Laboratory Testing. As demonstrated in the laboratory results presented in the table below, the process is relatively effective for removing most metals (especially Zn, Cd, As, and Ni) from a variety of contaminated soils, depending on the alkalinity of the soil.

Laboratory Test Results. (TNO, 1993) The process is not as effective under high alkalinity or high ionic strength conditions. For example, in laboratory tests, it was not effective for high concentrations of chromium (because of toxic effects on the microbes) or for low pH with lead (because resulting $\text{Pb}(\text{HSO}_4)_2$ salt is insoluble). It should be noted that it may be difficult to maintain and control the appropriate conditions in the bioreactors, especially if other biota (e.g., weeds) are present in the contaminated soil. Applications for removal of radionuclides have not been tested.

Cost. The cost and rate schedule is unknown because of the laboratory status of the process and the plant size dependency of costs. However, the technology should be relatively inexpensive because it does not need expensive growth media and because sulfur is relatively inexpensive compared to sulfuric acid. The cost of the bioreactor is not known.

It is projected that this technology will be applicable to radionuclides, but it has not been tested.

WASTE APPLICABILITY

This technology can treat large amounts of solid materials (e.g., soils, industrial sludges, incinerator fly ash, etc.) moderately contaminated with heavy metals (including radionuclides). High soil alkalinity and high ionic strengths should be avoided. Some pre-treatment of the soil may be

required (e.g., to remove other biota which may interfere with the sulfate production process).

STATUS

The bioreactors for sulfate production have been successfully demonstrated under laboratory conditions. However, the interaction of other contaminants on the biological processes and the application to radionuclides has not been demonstrated.

REGULATORY CONSIDERATIONS

United States regulatory issues are not known.

POTENTIAL COMMERCIAL APPLICATIONS

This technology is potentially applicable to community incinerator plants, mining operations and a wide range of other industrial applications which produce heavy metal waste in soils or other solid materials.

Specific DOE needs for which this technology is applicable are waste treatment and on-site treatment of soils contaminated with heavy metals including possibly radionuclides.

BASELINE TECHNOLOGY

The comparable US baseline technology is soil washing without biochemical treatment or acid leaching without secondary treatment. The candidate technology appears to be specific to certain types of contaminants; whereas, the baseline technologies may handle wider ranges and combinations of contaminants.

Compared to soil washing alone, this technology is (1) more effective in removing and ultimately separating (possibly for reuse) heavy metals from contaminated soils, thus reducing the secondary waste stream; (2) more expensive in terms of operating cost, but less expensive in total cost be-

cause less secondary waste disposal/treatment costs and increased recycle credits for the recovered heavy metals; (3) slower with small plants, but larger plants may also be used; and (4) more acceptable because of waste minimization and reutilization.

Compared to acid leaching alone, the candidate technology is (1) marginally less expensive and safer because sulfur replaces sulfuric acid (sulfuric acid is produced and reduced captively in the bioreactors; therefore, no H_2SO_4 handling is required); (2) slower because the biochemical reaction times required to generate sulfuric acid are on the order of 1-2 wks; and (3) more acceptable because of waste minimization and reuse through sulfate reduction, although secondary treatment of H_2S would be similar.

INTELLECTUAL PROPERTY RIGHTS

The Dutch government provides 30 percent of the project funding with an industrial partner providing the rest. Technology can be transferred to the industrial partner with no obligation to the Dutch government or to the EC. No pending patents are known.

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BIOLOGICAL DEHALOGENATION OF CHLORINATED ETHYLENES

TNO Institute of Environmental Sciences
The Netherlands

DESCRIPTION

This technology is a biological treatment method for treating ground water and soil vapors containing chlorinated ethylenes. The primary use is for ex-situ treatment of chloroethylene contaminated soil, groundwater, or air. A secondary use of this technology is for in-situ treatment of chloroethylene contaminated soil. The system, being primarily an ex-situ system, requires

anaerobic dehalogenation of perhalogen compounds, which is a function of temperature; followed by (2) aerobic complete dehalogenation and mineralization through microbial co-oxidation. The remediated groundwater is usually returned with some biomass to the soil. For contaminated soils, microorganisms from a mixture of granulated anaerobic sludge are mixed with the soil in-situ or ex-situ. Any air used or that has escaped during the process is treated in a biofilter to re-

move the volatile chlorinated compounds. The system needs a small placement area and services, such as air, water, and sludge, for the reactors and filters. In addition, monitoring of the remediation process is necessary in order to determine when acceptable levels have been reached.

Biological Dehalogenation of Chlorinated Ethylenes

groundwater/soil vapor extraction (including possibly reinjection). This would preclude in-situ bioremediation or other ex-situ treatment technologies.

For groundwater or soil vapor, the process uses a two-step sequential biological process: (1) the

anaerobic dehalogenation of perhalogen compounds, which is a function of temperature; followed by (2) aerobic complete dehalogenation and mineralization through microbial co-oxidation. The remediated groundwater is usually returned with some biomass to the soil. For contaminated soils, microorganisms from a mixture of granulated anaerobic sludge are mixed with the soil in-situ or ex-situ. Any air used or that has escaped during the process is treated in a biofilter to re-

TECHNICAL PERFORMANCE

Laboratory Testing. In laboratory studies, groundwater containing perchloroethylene and trichloroethylene (PCE and TCE) was decontaminated in anaerobic reactors using granulated, anaerobic, digested, domestic sludge. PCE (3 mmole/l)

water contaminated with perchloroethylene are presented in the Table. It should be noted however, that anaerobic conditions are difficult to maintain.

Table of Laboratory Test Results.

Reactor	Initial	Effluent			
	PCE	PCE	TCE	1,2 cis DCE	1,2 trans DCE
A	573	<1	19	88	245
B	506	<1	27	101	143
C	370	<1	151	86	44
D	388	<1	5	75	207
E	442	<1	6	108	36

(Concentrations are mg/l)

Laboratory Studies. (1) Air contaminated with PCE and TCE was effectively dehalogenated into DCE within several days, using heather compost inoculated with granulated anaerobic and aerobic sludges; and (2) soil contaminated with PCE (1.5 mol/l) was effectively dehalogenated into TCE within about twenty days, using microorganisms from a mixture of granulated anaerobic sludge at 20°C. The further aerobic complete dehalogenation and mineralization of DCE is the second step in the process. However, the effectiveness of this important process is currently unknown, although it is being studied in the US and remains to be investigated.

Cost. Data not available due to immature status of the technology.

WASTE APPLICABILITY

This technology is applicable to chlorinated ethylenes in groundwater, soil and air.

STATUS

This technology is in a laboratory demonstration phase of development. Currently the focus is

studying aerobic complete dehalogenation and mineralization of TCE and DCE, which is a significant issue. Also, the interaction of other contaminants on the biological processes need to be evaluated.

REGULATORY CONSIDERATIONS

Bioremediation methods are generally preferred because there are minimal secondary byproducts and the process destroys the waste as opposed to simply concentrating it.

POTENTIAL COMMERCIAL APPLICATIONS

A market survey has not been done in the United States, so the market potential is currently unknown. Specific DOE needs include on-site treatment of chlorinated ethylene contaminated soils, groundwater and soil vapor.

The developer, TNO, is only interested in research. Once the development of the technology is complete, it will be transferred to TNO's industrial partner (unknown), who has provided about 2/3 of the funding. Negotiations (e.g., for licensing agreements) would be conducted with the industrial partner.

BASELINE TECHNOLOGY

The baseline technology for this application is air stripping in conjunction with carbon filtration (which only separates and concentrates the contaminants) or oxidation processes (which destroy the contaminants). In comparison to air stripping with carbon filtration or air stripping with oxidation, the candidate technology is potentially (1) more effective in some cases, although not as widely applicable to various contaminants, but it does not result in secondary wastes (e.g., it destroys rather than concentrates the contaminants); (2) marginally cheaper, safer and more acceptable because it minimizes secondary waste, al-

though the advantages are reduced if additional treatment technologies are required; and (3) significantly slow (due to biological process). In both cases, the candidate technology is specific to PCE/TCE whereas the baseline technologies may handle combinations of contaminants.

INTELLECTUAL PROPERTY RIGHTS

The process has no pending patents at this time. The Dutch government provides 30 percent of the project funding, with an industrial partner providing the rest. Technology can be transferred to the industrial partner with no obligation to the Dutch government or the EC.

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BIOPUR® BIOLOGICAL SOIL AND GROUNDWATER TREATMENT SYSTEM

TAUW Milieu bv
The Netherlands

DESCRIPTION

BIOPUR® is a biological treatment for groundwater and soil vapor contaminated with organic

Since BIOPUR® is an ex-situ treatment system, groundwater extraction and soil vapor extraction (and possibly reinjection) is needed. The use of this system would preclude in-situ bioremediation or other ex-situ treatment technologies. The system also needs a small placement area and services such as air, water, nutrient solution, and pH control chemicals. In addition, monitoring of the remediation process is necessary in order to determine when acceptable levels have been reached. Although the effectiveness 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. The system is commercially available, cheaper than strippers/AC filters, and case studies exist.

Generic BIOPUR® Application

compounds. BIOPUR® is an aerobic, plug flow, fixed film, trickling filter bioreactor system, in which groundwater and soil vapor contaminated with organic compounds is passed through a reticulated polyurethane (PUR) packing material with a high specific contact area. The high specific contact area of the PUR growth media results in high biomass concentrations and, thus, high reaction rates at short retention times. In contrast to most bioreactors, the soil vapor and groundwater are treated simultaneously to prevent stripping/volatilization of the volatile components. Operation of the system involves simply reading meters and refilling nutrient solutions.

TECHNICAL PERFORMANCE

The system is relatively effective in degrading a variety of organic compounds, as summarized in the table. The effectiveness varies with flow rate, retention time, and original concentration.

Performance Levels for Various Waste Types.

As shown on the following table, tests with BTEX (benzene, ethylbenzene, toluene, and xylene), mineral oil, and naphthalene where the rate varied up to 15 m³/hr and the retention time varied from 1/4-1 hr. For example, in limited tests, BTEX was degraded with greater than 96 percent effi-

ciency in five cases where concentrations were equal to or above 650 mg/l, but the efficiency was

Table of Performance Levels for Various Waste Types

Compound	Biodegradability	Treatment Efficiency (%) ¹
Benzene	++	95
Toluene	++	95
Xylenes	++	95
Ethylbenzene	++	95
Mineral Oils	+	>90
Benzine	++	>90
Kerosine	+	>85
Diesel	+	>80
Naphthalene	+	90
PAH (heavy)	+/-	±50
Epsilon-HCH	-	<20
Beta-HCH	-	<30
Gamma-HCH	+	±70
Delta-HCH	+/-	±50
Alpha-HCH	+	±70
HCB	+/-	±30
chlorobenzene	+	>98
dichlorobenene	+	±90
trichlorobenzene	+	20-80
tetrachlorobenzene	+	10-50
1,2 - dichloroethene	+	70-80
TRI	u.i.	80
PER	u.i.	80
1,1 - dichloroethane	u.i.	10-20
1,1,1 - trichloroethene	u.i.	80
Phenol	++	>80
Cresol	+	>70
Dimethylphenols	+	>70
m,p - Ethylphenol	+	>65
¹ = dependent on organic load u.i. under investigation ++ = readily degradable +/- = somewhat degradable + = degradable - = not readily degradable		

only 79 percent in the one case where the concentration was 500 mg/l. The efficiency in degrading mineral oil, on the other hand, increased from 62-92 percent and then decreased to 55 percent as the concentration increased from 300 to 1,300 to 18,000 mg/l. The effectiveness of degrading chlorinated hydrocarbons is uncertain at present.

Cost. Depends on flow rates through the bioreactor. At slow flow rates (10 m³/hr.) the cost is about 0.50 DM (Dutch Marks)/m³, which is about 30% less cost than for stripper/activated carbon filtration. As the flow rate increases, the cost decreases (i.e., about 0.35 DM/m³ at 40 m³/hr flow), which is about the same as for stripper/activated carbon filtration.

WASTE APPLICABILITY

This technology is applicable for a wide variety of organic compounds over a wide range of concentrations in groundwater and soil vapor. See the table in the Technical Performance section regarding effectiveness for specific compounds. Concentrations of iron greater than 20 mg/l can cause clogging of the filters. Floating layers cannot be treated and should be removed before treatment. Typically, biodegradation of chlorinated hydrocarbons is difficult.

STATUS

This technology is commercially available, and case studies exist (17 plants since 1989). However, the applicability to chlorinated hydrocarbons is being studied at the pilot scale.

REGULATORY CONSIDERATIONS

There appears to be no US regulatory issues restricting the use of this technology. The foreign regulatory issues are not available for comparison since most of the previous applications have been conducted under Dutch regional or federal government supervision.

Bioremediation methods are preferred because there are minimal secondary byproducts and the process destroys the waste as opposed to simply concentrating it.

POTENTIAL COMMERCIAL APPLICATIONS

Potential commercial applications are very wide ranging. Any industry which has polluted groundwater or soil with contaminants which are degradable by known microbial strains. Specific DOE needs for which this technology is applicable include treatment of groundwater and soil vapor contaminated with various organic compounds.

BASELINE TECHNOLOGY

U.S. baseline technologies include (1) Air Stripping of volatile organic compounds in groundwater, which simply separates the contaminants for further treatment; (2) UV oxidation of contaminated groundwater; (3) thermal or catalytic oxidation of primary or secondary contaminated vapors; (4) carbon filtration or contaminated groundwater or vapors (which concentrates the contaminants in the filter medium); or (5) other trickling bioreactors not supported on polyurethane padding (for groundwater only).

Compared to the other technologies (e.g., oxidation), the candidate technology potentially can treat groundwater and soil vapor simultaneously, with little subsequent treatment required. Specifically, compared to air stripping/carbon filtration, the candidate technology is potentially (1) more effective in some cases, although it is less widely applicable to various contaminants, but it does not result in any secondary wastes (i.e., it destroys rather than concentrates the contaminants); (2) marginally cheaper, safer, and more acceptable because it results in no secondary

wastes; and (3) somewhat slower (due to biological process) and more difficult to operate reliably. Compared to other trickling filter bioreactors, the candidate technology is potentially (1) more effective in removing contaminants from vapors simultaneously with groundwater; (2) quicker to setup due to its mobile containers; and (3) more stable and less sensitive to iron clogging.

INTELLECTUAL PROPERTY RIGHTS

This technology has been patented in the US and Europe, and there has been no known foreign government investment in the development. US Patent No. 5,080,793, granted 1/14/92. Europe Patent No. 0385555 granted 7/28/93.

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CHROMPIK VITRIFICATION PROCESS FOR DRIED LIQUID, SPENT NUCLEAR FUEL WASTE

Czech Nuclear Research Institute
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DESCRIPTION

The Chrompik Vitrification Process is a waste treatment process for waste minimization and stabilization of liquid radioactive wastes through evaporation and subsequent inductive vitrification. Liquid radioactive waste is concentrated by a factor of 20, mixed with a glass frit, transported into an induction furnace, dried at a low temperature, and melted at 1150°C. The vitrification process is based on medium-frequency induction heating and operates batchwise with the amount of 20 kg product per batch. The product is cast into stainless steel cylindrical shaped cases, transported into the intermediate storage areas and then on to a final repository. The exhausted vapors and contaminated air are treated using a series of filters, and the condensate is recycled to the evaporator.

The Nuclear Research Institute in Rez, Czech Republic, Laboratory of Vitrification Processes (LVP) has developed the technology and appropriate equipment for the solidification of high level liquid wastes which have resulted from the decommissioning of the Slovak Nuclear Power Plant A-1 in Jaslovské Bohunice. The primary problem at the facility site is the high concentrations of chromium compounds in wastes and the incorporation of the chromium into the glass matrix. This process is capable of incorporating up to 8 percent of chromium into the glass matrix, reaching 20 to 30 percent load factor for other waste constituents. This result is possible due to the properties of the glass frit which has been developed for this specific need in cooperation with the Research Institute of Glass in Hradec Králové. During the vitrification process, part of the chromium becomes incorporated into the glass ma-

trix and the remaining chromium is incorporated in the form of chromium oxide particles in the bulk of the glass.

TECHNICAL PERFORMANCE

General. The LVP has a wide and long-term experience base in the field of glass-related research, determination of various glass properties (including long-term behavior and properties) and in the technical aspects of these processes. This knowledge base is the result of extensive research activities both within the LVP as well as in conjunction with key university centers within the Czech Republic. Also in recent years, the LVP has maintained close contacts with Russian research centers, cooperated in the development of vitrification processing of defense-related wastes, cooperated in the development of "dry re-processing" of spent nuclear fuel as well as the vitrification of wastes from nuclear power reactors. The LVP works in conjunction with the Czech Nuclear Power Utilities and has close cooperation with the French Research Centers of the CEA.

Pilot Scale Demonstration. During the pilot-plant experiments more than 100 runs were accomplished with the total solidification of about 15,000 liters of the simulated waste. The resulting glass totaled more than 2,000 kg. The corrosion resistance of the crucible material was satisfactory and the entire process exhibited acceptable performance for industrial and large-scale applications.

Full-Scale Demonstration. The processing of pool water from spent nuclear fuel storage areas in the A-1 Nuclear Power Plant in Jaslovské Bohunice involves the treatment of waters con-

taining alkaline metals, such as macrocomponents, and relatively high concentrations of hexavalent chromium. The radionuclides contained in these waters include ^{134}Cs , ^{137}Cs , ^{90}Sr and small amounts of U and Pu. This waste consists of approximately 40 m^3 as a result of a nuclear power plant shutdown after an accident which occurred in 1977. The vitrification process is based on the high temperature processing of a dried waste and glass frit mixture which results in a high quality glass product. Melting conditions aid in the chromate reduction to the insoluble Cr_2O_3 during the melting process. The chromium sesquioxide partly forms the glass lattice, and partly is fused into the glass because the property of glass to absorb Cr^{3+} is small. The vitrification apparatus is based on a medium-frequency induction heating and operates batchwise with the amount of 20 kg of product per batch.

Cost. Cost data are not available at this time.

WASTE APPLICABILITY

This technology is applicable for the processing of limited amounts of a typical, high-level radioactive waste in the presence of tri- or hexavalent chromium salts.

STATUS

The technology and associated equipment is beyond proof-of-principle and pilot plant scale testing. This equipment is in use and is constructed for operation under "hot" conditions" at the NPP A-1 Reactor site located in Jaslovské Bohunice. Potential problems associated with any further development of this technology involves the financial constraints of the Czech Nuclear Power Utilities (the entity which finances the operations of the Czech Nuclear Research Institute). There is no history of application of this technology within the DOE complex or the US.

REGULATORY CONSIDERATIONS

There appear to be no regulatory or public acceptance issues which are of significance with regard to the implementation of this technology at sites in the United States.

POTENTIAL COMMERCIAL APPLICATIONS

The extent of the worldwide market for this technology is not known. A market analysis was not provided by the technology developer. Specific DOE needs include treatment of high-level liquid radioactive wastes within the DOE complex. The technology developer is interested in discussing the possibilities associated with establishing foreign partners for purposes of further demonstrating and commercializing this technology. The interests of the technology developer include transferring the technical aspects of this vitrification process through a contractual arrangement and participating in a joint development program to orient the technology to meet specific DOE needs.

BASELINE TECHNOLOGY

Currently there are a number of technologies which exist for the vitrification of these types of wastes; however, many of the commercially available technologies are reported to be for high level activity radioactive wastes without significant concentrations of chromium salts.

INTELLECTUAL PROPERTY RIGHTS

The proprietors of the research results and equipment are the Slovak Power Works and the Jaslovské Bohunice Nuclear Power Plant.

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COBALT DICARBOLLIDE SEPARATION TECHNOLOGY FOR RADIOACTIVE WASTE

Khlopin Radium Institute
Russia

DESCRIPTION

Russian Scientists, in a joint effort with Czech scientists, developed and utilize a solvent extraction process for recovering cesium and strontium from acidic highly radioactive waste. The process uses cobalt dicarbollide (CDC); a compound first created (1965) in the U.S., but never produced or used commercially. The Czech scientists observed that CDC dissolved in suitable solvents can be highly selective in removing cesium from concentrated and complex solutions of radioactive waste. The Russians developed a process and constructed a facility that successfully uses the technology. Although CDC is not produced in the U.S., it is produced in industrial quantities in Russia. CDC is very stable and exhibits high stability in a radioactive environment. CDC is soluble in polar organic solvents, such as nitrobenzene, and can remove or exchange cations with aqueous wastes. It has a particularly high selectivity for cesium and by using appropriate additives in the process, CDC can also remove strontium with high selectivity. Implementation will require associated surface treatment facilities. Disposal/processing of the CDC after use must be provided.

TECHNICAL PERFORMANCE

The ability of CDC to extract cesium and strontium from simulated Idaho National Engineering Laboratory (INEL) waste was proven in experimental tests. The results are summarized in Table 1 and show that the distribution coefficients (K_d) for cesium increase with an increase in concentration of CDC in the solvent (nitrobenzene). Strontium distribution coefficients, though not as high as cesium, increase much more rapidly with increasing CDC concentration in the solvent. Diluting the waste resulted in similar trends to increasing the concentration of CDC. The effects of nitric acid and sodium nitrate concentrations on the distribution coefficients were investigated. The results are listed in Table 2 and Table 3. Increasing concentrations of sodium nitrate and nitric acid cause the distribution coefficients of both cesium and strontium to decrease, but the mechanism of the effect is presently unclear. Even so, moderate distribution coefficients remain even at acid and salt concentrations of up to 1.5 M.

Costs. No cost information was provided.

Table 1. The effects of CDC concentration on the distribution coefficient (K_d) for removal of cesium and strontium from simulated INEL waste.

Concentration of CDC (moles/liter)	K_d , Cs	K_d , Sr	Waste Diluted 1.5 times K_d , Cs	Waste Diluted 1.5 times K_d , Sr
0.1	6.9	0.72	16.6	1.2
0.2	10.6	3.2	26.8	4.4
0.3	20.1	7.6	41.2	12.8

Table 2. The effects of nitric acid concentration on distribution coefficients for cesium and strontium.

HNO ₃ Concentration (moles/liter)	0.1 M CDC Kd, Cs	0.1 M CDC Kd, Sr	0.3 M CDC Kd, Cs	0.3 M CDC Kd, Sr
0.3	19.7	1.37	44.0	14.9
0.5	11.6	1.3	43.2	13.5
0.7	11.3	1.2	41.8	12.9
1.0	8.4	1.0	28.5	9.9
1.3	6.1	0.91	21.1	7.8
1.7	5.4	0.62	19.9	5.8

Table 3. The effects of sodium nitrate concentration on distribution coefficients for cesium and strontium.

HNO ₃ Concentration (moles/liter)	0.1 M CDC Kd, Cs	0.1 M CDC Kd, Sr	0.3 M CDC Kd, Cs	0.3 M CDC Kd, Sr
0.5	14.5	1.0	25.4	14.0
0.7	10.4	0.98	22.2	9.3
1.0	8.6	0.72	19.6	9.0
1.2	8.0	0.61	18.8	7.3
1.5	7.2	0.54	16.7	5.5

New diluents for CDC are being investigated for their affects on the extraction of various elements from highly radioactive wastes. Investigations on the use of CDC for extraction of additional metals (e.g., barium, americium, cerium) from radioactive waste are being conducted. The investigators hope to increase the number and degree of metals extracted from highly radioactive waste.

WASTE APPLICABILITY

The cobalt dicarbollide separation technology is primarily applicable in recovering cesium and strontium (and possibly additional metals) from acidic, aqueous, highly-radioactive waste.

STATUS

The cobalt dicarbollide separation technology has

been successfully used at production scale in Russia. However, a good deal of work remains to optimize and demonstrate the process for U.S. applications.

REGULATORY CONSIDERATIONS

Since the CDC technology is used to treat highly-radioactive waste, permits will be needed to utilize the technology. Disposal of any radioactive waste is strictly regulated.

POTENTIAL COMMERCIAL APPLICATIONS

Any institution that needs to decontaminate acidic, aqueous, highly-radioactive waste containing cesium and/or strontium could benefit from the use of this technology. Specific application of this

technology includes waste water treatment from nuclear materials processing and water and/or soil remediation. This technology could be applied to help remediate sites throughout the DOE complex.

BASELINE TECHNOLOGY

There is no current baseline technology for comparison.

INTELLECTUAL PROPERTY RIGHTS

None.

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COMPOSITE INORGANIC-ORGANIC ION-EXCHANGE MATERIALS

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DESCRIPTION

This technology involves a new composite inorganic-organic ion exchange preparation method. The technology is applied to the separation and treatment of liquid radioactive waste. Many of the disadvantages normally associated with inorganic ion-exchange materials for the treatment and separation of waste have been overcome by a new universal composite preparation process. The small size and low granular strength of the inorganic particles are no longer problems with the composite materials. The advantage of an inorganic ion-exchanger's high selectivity for the capture of certain ions is not diminished when the inorganic, active component is incorporated into the modified Polyacrylonitrile (PAN) polymer matrix. Moreover, the composite ion-exchanger can be utilized for continuous, flow-through systems, whereas baseline ion-exchangers are typically utilized only in relatively small capacity batch processes.

This technology uses remotely-operated columns, piston pumps and the ion-exchanger material. The contaminated water is circulated through the column containing the ion-exchanger material. Using this technology, water is circulated through the columns to separate out and concentrate targeted radionuclides. The concentrate can then be solidified for appropriate disposal.

The composite ion-exchange material can be shaped as grains, beads, fibers, felt, fabric membranes, tubing, etc. In addition, the content of the active component in the composite exchanger can be varied in a very broad range depending on the targeted application. In this way the mechanical and granulometric properties of the prepared ion-

exchange materials can be modified to suit the application. A schematic of the composite ion-exchange preparation process is shown in the figure that follows.

Preparation of PAN-Based Composite Ion-Exchangers

Composite ion-exchangers have been developed using the following active components: ammonium molybdophosphate (AMP-PAN), potassium-nickel hexacyanoferrate (NiFC-PAN), sodium titanate (NaTiO-PAN), titanium dioxide (TiO-PAN), manganese dioxide (MnO-PAN), magnesium oxide (MgO-PAN), barium sulfate activated by calcium (Ba[Ca]SO₄-PAN), copper sulfite (CuS-PAN), and synthetic mordenite (M₃₁₅-PAN) or zeolite (Na-Y-PAN). The various types of ion-exchangers have the ability to separate and con-

centrate targeted radionuclides. Many have been demonstrated to separate cesium, cobalt, radium, strontium, and uranium. Additional composite ion-exchangers containing other active components are currently being prepared and tested by the technology developer. A composite absorber is currently being tested to separate plutonium from liquid wastes.

TECHNICAL PERFORMANCE

Laboratory Experiments. Based on experiments involving pond water taken from a long-term fuel storage pond, the resulting reduction in ^{137}Cs contamination was three orders of magnitude (10^3). Relatively high removal rates for ^{137}Cs , ^{134}Cs , ^{60}Co , and ^{54}Mn have been demonstrated in laboratory experiments.

Other Laboratory and Field Scale Demonstrations.

- Concentration of cesium from fresh and sea waters for the radioanalytical determination of the concentration of ^{137}Cs and ^{134}Cs .
- Separation of cesium from neutral and alkaline solutions (where AMP-PAN ion-exchanger is unstable). The NiFC-PAN composite exchanger was tested.
- Concentration of cobalt from groundwater and surface water using MnO-PAN and NaTiO-PAN ion-exchangers.
- Collection of radium from mining waters using the $\text{Ba}(\text{Ca})\text{SO}_4$ -PAN composite ion-exchanger.
- Removal of cesium and strontium from water contained in a long-term storage pool of spent nuclear fuel elements.
- Removal of cesium, cobalt and strontium from water used for biological shielding at a nuclear power plant.
- Removal of radium from waste acids associated with the underground leaching at uranium mines.

Pilot Plant. Based on the results of the laboratory and field-scale demonstrations, a pilot plant has been proposed to verify the decrease of radioactivity of the water in the long-term storage pool at the A-1 Nuclear Power Plant which is being decommissioned in Jaslovske Bohunice, Slovak Republic.

Cost. There are many factors which will influence the price associated with the preparation of the absorbers. It has been estimated that the cost should not exceed \$200-\$300/liter of swollen absorber. This estimated cost is comparable with the costs for non-composite inorganic ion-exchangers which are currently available in the market place. These prices could be considerably lower if the composite ion-exchangers are produced in the Czech Republic for export to the U.S. or when industrial intermediates are used as the active components.

WASTE APPLICABILITY

The applicable waste types are radionuclides and non-volatile metals. The applicable waste forms are particulate solids in solution, liquid wastes, and other liquid wastes contained in lined ponds, underground tanks, as well as surface water and groundwater.

STATUS

This technology is developed beyond proof-of-principle and is at the "demonstration stage". The lead scientist involved in developing this technology, Dr. Sebesta, is prepared to meet with appropriate DOE officials to discuss demonstrating this technology at a DOE site in the United States or to demonstrate the technology at a site in the Czech Republic which has problems of a nature similar to those at DOE sites.

REGULATORY CONSIDERATIONS

There appear to be no regulatory or public acceptance issues of significance with regard to the implementation of this technology at sites in the United States. One issue that needs clarification involves the toxicity of the PAN materials upon chemical or radiation decomposition.

POTENTIAL COMMERCIAL APPLICATIONS

Once commercially protected in the United States, this technology could be commercialized and marketed to address a wide variety of water-related environmental contamination problems. Commercial applications include treatment of spent fuel storage tank waters at nuclear power plants.

The specific DOE needs include the treatment of water contaminated with radioactive constituents, heavy metals and other inorganic constituents. The extent of the market potential beyond DOE/EM needs has not been evaluated in detail but is believed to be very large.

BASELINE TECHNOLOGY

Current U.S. baseline technologies involve the use of inorganic absorbers, some of which lack the structural strength advantages of the composite materials. For many specific applications, the use of these absorbers will be cheaper and easier to perform when compared with classical separations technologies.

INTELLECTUAL PROPERTY RIGHTS

The procedure for the preparation of the composite absorbers has been patented in the Czech and Slovak Republics.[2]

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ELECTROCHEMICAL DEHALOGENATION OF TOXIC ORGANIC COMPOUNDS

TNO Institute of Environmental Sciences
The Netherlands

DESCRIPTION

This technology is intended for the destruction of chlorinated-phenols in waste water or contaminated groundwater. The toxicity and biodegradability of chlorinated compounds is in part determined by their chlorine content. Therefore, removing chlorine atoms from organic molecules prior to their discharge in waste water may facilitate the subsequent biological treatment of the toxic waste water. One process for accomplishing this is electrochemical dehalogenation. This process provides several advantages over other methods including:

- treatment of waste water is performed at ambient temperature
- no additional chemicals are required
- the process provides selective removal of chlorine while the organic skeleton remains which can be digested by biological means (microbes)
- the process yields a less toxic compound in contrast to concentration methods such as carbon filtration, membranes, etc.

An electrolysis treatment is applied to chlorinated organic compounds utilizing a platinum gage anode and a carbon fiber bundle cathode. The electrolysis reactor also has a cation permeable separator to prevent electrical and hydraulic short circuiting. Sodium hydroxide and/or disodium sulfate electrolytes are added to the contaminated water prior to entering the electrolysis reactor. In addition, a small amount of organic solvent (e.g., methanol or acetonitrile) is added to increase solubility of the organic compound. A constant current is applied to the reactor to selectively remove halogens from halogenated organic compounds.

Electrochemical Flow Through Reactor

Application of this process requires groundwater extraction or a discharge source of waste water, an electrical power supply, and processing of residual phenols (e.g., microbial degradation).

TECHNICAL PERFORMANCE

Laboratory Scale. A laboratory-scale system was successfully demonstrated using an electrochemical cell consisting of a fiber bundle cathode containing 50,000 single fibers (8-mm diameter) and a Pt-gage anode. The electrodes were separated by a cation permeable membrane to prevent electrical and hydraulic short circuiting. Laboratory experiments were performed with 1 liter batch samples of pentachlorophenol (PCP) contaminated water with NaOH and Na₂SO₄ electrolytes added. A constant current of 10 amps was applied to the electrodes. A small amount of

organic solvent (methanol or acetonitrile) was added to increase the solubility of the phenol contaminants. The initial concentration of PCP was in the range of 30-500 mg/l. After 20 minutes of electrolysis, the PCP concentration was reduced from 50 mg/l to about 1 mg/l. All five Cl-atoms were removed from the PCP leaving phenol residual. During the processing period, intermediate chlorophenols were formed (tetrachloro-, trichloro-, dichloro-, and monochlorophenol). While the intermediate compounds typically have low toxicity, the process was allowed to proceed until all the Cl-atoms were removed.

Small-volume laboratory tests suggest 98 percent reduction in the PCP concentration. Additional research is necessary to determine performance under field-scale conditions.

Cost Data. Field-scale performance has not been demonstrated, although, a continuous flow through system has been given some design consideration. The expected cost is estimated at \$6/m³ waste water.

WASTE APPLICABILITY

This technology is applicable to the dehalogenation of chlorinated organic compounds in industrial waste water, with no restriction on concentration. The use of this process requires secondary treatment (such as biological destruction) of dehalogenated, detoxified organic compounds.

STATUS

The technology is in the laboratory demonstration phase of development. Amount of funding and schedule required to complete development is not known. Potential problems include scale up to industrial-scale, durability of the membrane, and interactions of various contaminants.

REGULATORY CONSIDERATIONS

United States regulatory issues restricting the use of this technology have not been identified.

POTENTIAL COMMERCIAL APPLICATIONS

A market survey has not been done in the United States, so the market potential is currently unknown. However, PCP contamination in waste water is a common problem. Specific DOE needs include on-site treatment of chlorinated ethylene contaminated soils, groundwater and soil vapor. The developer, TNO, is only interested in research. Once the development of the technology is complete, it will be transferred to TNO's industrial partner (unknown), who has provided about 2/3 of the funding. Negotiations (e.g., for licensing agreements) would be conducted with the industrial partner.

BASELINE TECHNOLOGY

This technology may be compared with carbon filtration, oxidation techniques (O₃, UV and other oxidants), high temperature catalytic hydrogenolysis, and bacterial techniques. This electrochemical process produces a less toxic compound which can be eliminated using standard biological treatment methods. The most commonly used alternative methods (e.g., carbon filtration) rely on concentration processes which do not eliminate the contaminants, where as other alternatives (e.g., oxidation and biological methods) are generally not as effective. Estimated costs for the technology are similar to alternative methods such as carbon filtration although life cycle costs may be less since the toxicity of the waste water is reduced and the disposal costs could presumably be less.

INTELLECTUAL PROPERTY RIGHTS

No patents are pending.

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ELECTRO-RECLAMATION

Geokinetics
The Netherlands

DESCRIPTION

Electro-reclamation employs one or more electrode array(s) which, when electrically charged, cause one (or several) of the following effects:

Electro-osmosis: the movement of soil moisture or groundwater from the anode (+) to the cathode (-),

Electrophoresis: the movement of soil particles within the soil moisture or groundwater,

Electrolysis: the movement of ions and ion complexes within the soil moisture or groundwater.

The core of an electrokinetical installation con-

sists of the electrode array(s) and their housing. 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 de-

vices and monitoring devices (see section 5 for schematic diagram). 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 can be applied to both in situ remediation of contaminated soil (also groundwater) and for on- or off-site ex situ remediation of excavated soil, river sludge, and industrial or sewage sludge. For ex situ applications, a more permanent installation may be most effective.

When evaluating the applicability of an in situ installation, the following conditions should be considered:

- contaminants should be soluble at pH 4-5,
- soil should not contain conductive objects or insulating objects, and
- the contamination should not occur as concretions (e.g., paint residue).

If these conditions are not satisfied, the contaminated material can be pretreated to improve the result but such pretreatment may require excavation. Pretreatment can consist of:

- sieving, sorting and homogenizing the soil,
- mixing the soil with organic or inorganic acid or with complexing agents, or
- treatment of the soil to neutralize pH.

Depending on the availability of electrical power, the pretreated material can then be remediated ex situ either:

- in depot: large volumes during long time periods, using a relatively low energy supply, or
- in batch installation: small volumes during short periods using a relatively high energy supply.

The advantage of the latter is that it allows for almost immediate intervention when deviations in the process occur, resulting in more efficient control of the electro-reclamation process.

Electro-reclamation can also be used to create electrically charged subsurface barriers (i.e., subsurface fencing). These subsurface barriers could be installed at sites polluted, for example, by leakage from storage tanks, spilling during industrial processes, leaching of agricultural lands, landfills, and mine tailings. Currently, this is only a conceptual application and no demonstrations have yet occurred. It is important to note that such a barrier would not only contain but remediate as well. The contaminants to be contained can be: organic or inorganic or both; electrically charged or neutral; and soluble, insoluble, colloidal or suspended in water (Lageman, et al., 1993).

An electrical power source must be supplied. In the ex situ application, the excavated soil can be mixed with an acidified solution to enhance performance; in this case, tilling/mixing equipment is needed. Excavation/drilling is required for installation of the electrode array(s). Space is needed for the surface facility. The treated solution (i.e., the concentrated contaminant) must be disposed of.

The candidate technology would replace other in situ or ex situ remediation methods (e.g., pump and treat), and would require disposal of the concentrated contaminants. As a barrier, the technology would supplement other remediation methods.

TECHNICAL PERFORMANCE

Table 1 lists results published by Lageman, et al., (1989), on a variety of electro-reclamation laboratory tests, from which several inferences can be drawn. For example, it appears that the electro-reclamation process is less efficient for some metals, such as Pb and Hg (generally < 75%), than

others, such as Cd, Ni, Zn (generally > 80%). Although the overall performance of this technology may fall short of U.S. cleanup standards, in certain soil types (e.g., clay) it could be the only viable alternative to landfills. With appropriate pretreatment, the removal efficiencies can be improved.

Table 1. Results of Electro-Reclamation Laboratory Tests (Lageman, et al., 1989).

Soil Type	Metal	Conc. before (ppm)	Conc. after (ppm)	Decrease (percent)
Peat	Pb	9000	2400	73
	Cu	500	200	60
Pottery clay	Cu	1000	100	90
Fine argillaceous sand	Cd	275	40	85
Clay	As	300	30	89
Fine argillaceous sand	Cd	319	<1	99
	Cr	221	20	91
	Ni	227	34	85
	Pb	638	230	64
	Hg	334	110	67
	Cu	570	50	91
	Zn	937	180	81
	Average:			83
River sludge:	Cd	10	5	50
	Cu	143	41	71
	Pb	173	80	54
	Ni	56	5	91
	Zn	901	54	94
	Cr	72	26	64
	Hg	0.5	0.2	60
	As	13	4.4	66
	Average:			69

Tables 2 and 3 are the published results of electro-reclamation in several field tests (Lageman, et al., 1989). Table 2 contains the results of the first field test, held at a former paint factory in The Netherlands. This site was along the side of a water filled ditch bordered by sediments dredged from the ditch. The sediment was contaminated with heavy metals (e.g., Pb and Cu) from paint residuary and was 20-50 cm in height, 70 meters long and 3 meters wide. Underlying the dredging spoils was a peat soil contaminated by leaching of the heavy metals from the dredgings. This first field-test was conducted for 430 hours, after which the changes in heavy metal concentrations were measured at 20 locations varying in depth (10, 20, 30, 40 and 50 cm). The values in Table 2 are some of the results for Pb and Cu within the underlying peat soil (sampled at depths of 30-40 cm), and are the only results published for this

case (Lageman, et al. 1989). In general, these results support the observations made from the laboratory test showing a substantial decrease in the concentrations of heavy metals with a great deal of variability in the performance over the area sampled.

Table 2. Electro-Reclamation, Field Results, site 1 (Lageman, et al., 1989).

Sample point (30-40 cm depth)	Metal	Conc. before (ppm)	Conc. after (ppm)	Decrease (percent)
1	Pb	440	110	75
	Cu	185	35	81
2	Pb	3900	700	82
	Cu	540	220	59
3	Pb	>5000	560	89
	Cu	1150	580	50
4	Pb	>5000	2450	51
	Cu	475	250	47
5	Pb	>5000	610	88
	Cu	1170	230	80
6	Pb	>5000	300	94
	Cu	580	45	92
7	Pb	3780	285	92
	Cu	410	30	93
8	Pb	380	180	53
	Cu	35	15	57
9	Pb	340	90	74
	Cu	50	15	70
	Average:			74

Table 3. Electro-Reclamation, Field Results, site 2 (Lageman, et al., 1989).

Sample point (30 cm depth)	Metal	Conc. before (ppm)	Conc. after (ppm)	Decrease (percent)
1	Zn	5120	4470	13
2	Zn	2030	1960	3
3	Zn	1600	800	50
4	Zn	2320	2320	0
5	Zn	2450	2450	0
6	Zn	4390	2360	48
7	Zn	1960	940	52
8	Zn	3250	1960	40
9	Zn	2400	2000	17
10	Zn	70	30	57
11	Zn	150	120	20
	Average:			20

Table 3 lists the results of a second field test, performed at a galvanizing plant in The Netherlands. An area 15 meters long, 6 meters wide and 1 meter deep was selected for this test. The soil was a sandy clay contaminated with Zn to a depth of 40 cm. In the upper 10 cm the average pretreatment Zn concentration was 3000 ppm and at 40 cm the concentration averaged 500 ppm. Lageman, et al., (1989), indicates that two horizontal cathode drains were placed at a depth of 50 cm and were installed along the length of the site. In addition, Lageman specifies that 33 1-meter long anodes

were placed horizontally at a 1.5 meter spacing (in three rows). The anode to cathode spacing was also 1.5 meters. The test ran for eight weeks and was monitored at 12 sampling locations, each sampled at 10, 30 and 50 cm. Results for the 30 cm interval are presented in Table 3 and, as shown, the removal of Zn is limited. The low Zn mobility in this case was attributed to the high buffering capacity of the soil caused by the presence of NH_3 and NH_4Cl (remnants of the galvanizing process).

The first "official" electro-reclamation remedial action took place from January - May 1989 at the site of a former timber impregnation plant in The Netherlands. Two hundred and fifty cubic meters (250 m^3) of heavy clay soil were polluted with arsenic (As) at concentrations averaging 115 ppm. The contaminated clay was up to 2 meters thick over an irregular shaped area. Described as two adjacent sections, the contaminated area measured 10 meters long, 5 meters wide and 1 meter deep in the first area and the adjacent area measured 10 meters long, 10 meters wide and 2 meters deep (see Figure 1).

Three pairs of cathodes were installed, the distance along each pair was 24 meters and each of these pairs was 3 meters apart. Fourteen anodes were placed between the cathode pairs along their 24 meter length. A fourth pair of cathodes spaced 15 meters apart made up the last row with eight anodes along this line (see Figure 1). In all cases, the anodes were spaced 1.5 meters apart.

What makes this case interesting is not the performance of the remediation, which was similar to the previous demonstrations (summarized in Table 4), but that there was an anomalous region over which the As concentration would not appreciably decrease (see right side of Figure 1).

Table 4. Results of the first "Official" Electro-Reclamation Remedial Action (Lageman, et al., 1993).

Pretreatment	Treated volume of soil	250m ³
	Weight of soil	450 tons
	Average pre-treatment As-concentration in soil	115 ppm
	Amount of As in soil before remediation	52 kg
Electro-reclamation	Total amount of As removed by electro-reclamation	34 kg
Excavation	Weight of excavated soil	71 tons
	Average As concentration of excavated soil	200 ppm
	Amount of As in excavated soil	14 kg
Post treatment	Total amount of As removed after remediation	48 kg
	Amount of As remaining in the soil	4 kg
	Average As concentration of remediated soil	10 ppm

Figure 1. Pre- and Post Treatment Arsenic-Concentrations at Remedial Action Site (Lageman, et al., 1993).

It became apparent that this region would not respond to the electro-reclamation process and was subsequently excavated and treated off site. During the excavation, many metal objects such as barrels and iron re-bar (in concrete) were discovered. It was apparent that these objects functioned as preferential flow paths for the electrical current thereby impeding the remediation of the soil in their vicinity. This was not anticipated and, had it been known in advance, these objects would have been removed before the remediation was conducted.

It is apparent from these examples that the electro-reclamation process has the potential to remediate heavy metals in some of the most difficult problem areas, including those with clay based soils.

However, an accurate and complete site characterization would be necessary to determine the applicability, and predict the success, of any in situ electro-reclamation project.

Limitations. From the charts and discussions presented in Lageman, et al., (1989, 1993), it is clear that the performance of in situ electro-reclamation is variable and is dependent upon many factors, including:

- pH of the contaminated material (contaminants should be soluble and at a pH compatible with the circulating solution);
- type of heavy metal;
- physical soil characteristics (permeability, porosity, resistivity, moisture content);
- presence and distribution of highly conductive material (e.g., buried metal containers) that act as preferential flow paths;
- presence and distribution of insulating materials (e.g., buried wooden beams) that restrict the flow of current;
- distribution of the contaminant (i.e., locally high concentrations or concretions of the pollutants can decrease the performance).

Lageman, et al., (1989, 1993), indicates that these problems can be largely mitigated by soil pretreatment or by performing the process ex situ following sieving and/or other pretreatment steps. However, the presence of these limitations on the in situ applications stresses the need for accurate and complete site characterization to determine the applicability, and predicting the success of an in situ electro-reclamation project. The alternative process, ex situ electro-reclamation, may be more feasible and more cost effective in some cases.

It should be noted that the process is nonselective. For example, it will remove large amounts of all ionic metals in solution, including those occurring naturally (e.g., calcium). This may in-

hibit performance and result in high treatment costs, and may cause some amount of subsidence as a side effect.

Cost & Schedule Re/Implementation. Figure 2 shows the typical decrease in cost (US\$/ton) of the electro-reclamation process as the duration of the remediation is increased (and the energy level decreased).

Figure 2. Electro-reclamation cost (\$/ton) per time period (days) (Lageman, 1993).

Figure 3 shows the typical decrease in cost (US\$/ton) of the electro-reclamation process as the soil resistivity increases for the same application, with a duration of 60 days.

It is clear from these two examples that the duration of the remediation and the soil resistivity, in conjunction with the layout, determine the power requirements (and thus cost) to achieve specific performance efficiencies.

Figure 3. Electro-reclamation Cost (US\$/ton) versus soil Resistivity (ohm).

Safety Re/Implementation. The electrical current used in this process is high but the potential is low so there is really no high voltage danger. The developer indicates that there are no unusual safety concerns, although the process may result in uncontrolled gas emissions (e.g., H_2S).

WASTE APPLICABILITY

Principal application is in situ or ex situ waste treatment of soil (including clay soils) and/or groundwater contaminated with heavy metals (including radionuclides). Secondary application is containment of a wide variety of subsurface contaminants.

The technology is applicable to treatment of heavy metals in liquids and solids, with certain limitations (e.g., no concretions). Specific applications include: clay, peat and fine argillaceous sand polluted with As, Cd, Co, Cr, Cu, Hg, Mn, Mo, Ni, Pb, Sb, and Zn. Other combinations of soils and pollutants (including radionuclides, especially ionic and in solution) may be feasible. The technology is also applicable to containment of a wide variety of contaminants. There are no limit on

Figure 4. Electro-reclamation Field Unit (Lageman, et al., 1989)

Figure 5. Some Conceptual Applications of In Situ Electro-fencing (Lageman, Et. al., 1989)

depth or volume of waste. Typically, the process remediates about $2,500m^3$ for a single installation but multiple installations are possible at a single site.

As discussed in the Technical Performance section (limitations), alkali soils and the presence of anomalous materials cause some problems, which can be largely mitigated by soil pretreatment or

by performing the process ex situ following sieving and/or other pretreatment steps. The process is most applicable to low permeability soils. The proposed application of an electro-fencing subsurface barrier has not yet been demonstrated.

STATUS

Commercially available and demonstrated at several sites with published results on remediation projects for heavy metals (see below). This has not been demonstrated for radionuclides or contaminants other than heavy metals.

Development is complete for the remedial applications but the application to radionuclides and contaminants other than heavy metal, as well as the application of an electro-fencing subsurface barrier must be demonstrated. No problems are anticipated.

PREVIOUS APPLICATION (REFERENCES):

Electro-osmosis has been used effectively for many years to speed consolidation of clay soils for civil engineering purposes. In part, this is a different application of that process. Lageman, et al., (1993), provides several examples of completed applications, which are summarized in the following tables.

Project:	In situ field trial electro-reclamation "Ooerbosch"
Year:	1987
Commissioned by:	Provincial authorities of Groningen, The Netherlands
Locality:	Site of a former paint factory in Groningen
Volume of soil:	300m ³ peat and clay soil
Size:	Length 70m, width 3m, depth 1m
Type of contaminants:	Copper (Cu) and Lead (Pb)
Concentration at beginning:	Cu: 5000 mg/kg, Pb: 500-1000 mg/kg
Concentration at end:	Cu: 80% reduction; Pb: 70% reduction
Test period:	43 days of 10 hours/day
Energy consumption:	39 kWh/ton

Project:	In situ field trial electro-reclamation "Braat"
Year:	1988
Commissioned by:	Bammensgroep B.V. Maarssen
Locality:	Site of a galvanizing plant in Delft, The Netherlands
Volume of soil:	50 m ³ clay soil
Size:	Length 15m, width 6m, depth 0.5m
Type of contaminants:	Zinc (Zn)
Concentration at beginning:	Zn > 7000, average 2,400 mg/kg
Concentration at end:	Zn (average): 1,620 mg/kg, reduction 33%
Test period:	53 days of 16 hours/day
Energy consumption:	160 kWh/ton

Project:	In situ electro-reclamation "Loppersum"
Year:	1989
Commissioned by:	Kwint B.V. and municipality of Loppersum, The Netherlands
Locality:	Site of a former timber impregnation plant
Volume of soil:	250 m ³ heavy clay soil
Size:	length 25m, width 15m, depth 1 to 2 m
Type of contaminants:	arsenic (As)
Concentration at beginning:	max: 500 mg/kg, average: 115 mg/kg
Concentration at end:	max: 30 mg/kg, average: 10 mg/kg, Reduction: >90%
Test period:	80 days of 18 hours/day
Energy consumption:	150 kWh/ton
Use after remediation:	residential area

Project:	On site electro-reclamation "Stadskanaal"
Year:	1990-1992
Commissioned by:	Provincial authorities of Groningen/Municipality of Stadskanaal, The Netherlands
Locality:	Site of a temporary soil deposit
Volume of soil:	Total deposit 7,200 m ³ fine argillaceous sand. During first phase: remediation of 1,500 m ³ . The remaining soil will be cleaned in 3 to 4 additional phases.
Size:	Length 70m, width 40m, depth 2.6m
Type of contaminants:	Cadmium (Cd)
Concentration at beginning:	max: Cd > 2,000, average: Cd = 250 mg/kg
Concentration at end:	Cd ≤ 20 mg/kg
Test period:	2 years
Energy consumption:	~400 kWh/ton

Project:	On site electro-reclamation "Woensdrecht"
Year:	1992 to 1993
Commissioned by:	Ministry of Defense, The Netherlands
Locality:	Site of a soil deposit on the air-base of Woensdrecht
Volume of soil:	Total deposit 2,500 m ³ clay and moor to be remediated in 2 phases.
Size:	length 90m, width 20m, depth 1.4m
Type of contaminants:	Zn, Cu, Pb, Cd, Cr, Ni
Concentration at beginning:	Zn: 2,600, Cu: 700, Pb: 730, Cd: 660, Cr: 7,300, Ni: 860 (mg/kg)
Concentration at end:	
Remediation period:	one year
Energy consumption:	200-300 kWh/ton
Use after remediation:	

1. Post remedial concentrations not published, these may be available from the developer.

REGULATORY CONSIDERATIONS

It is not clear that electro-reclamation will remediate to U.S. standards, but in some cases it may be acceptable. This technology has been demonstrated to remediate at a level that meets Dutch standards. Institutional/Public acceptance should not be a problem.

POTENTIAL COMMERCIAL APPLICATIONS

DOE needs include: in situ, as well as ex situ waste treatment for clay soils contaminated with heavy metals (possibly including radionuclides) at various sites; and subsurface barriers at various sites to minimize transport and enhance cleanup efforts.

The non-DOE market should be very large as heavy metals are a wide spread problem. In addition, there are few in situ technologies which are effective in clay soils, and there is a large need for effective and inexpensive barrier. There is a U.S. patent.

BASELINE TECHNOLOGY

Currently, clay soils contaminated with heavy metals are excavated and stored in a landfill. If radionuclides are present, the soil may have to be treated first (e.g., leaching) to remove them. In more permeable soils, pump and treat is the baseline. Grout barriers (including slurry walls) are baseline for containment.

Electro-reclamation appears to be the only viable technique available for in situ remediation of low permeability clay soils containing heavy metals. The technology should be cheaper, safer, and more acceptable, although slower, than excavation and disposal. In more permeable soils, it is probably not cheaper or faster than pump and treat. As a subsurface barrier, it is probably cheaper in the short-term and more expensive in the long-term, but has the benefit of remediating as part of the same effort.

INTELLECTUAL PROPERTY RIGHTS

The extent of foreign government investment in the development of the technology is unknown. There are pending patents in Canada. It was difficult for the developer to acquire a patent in the U.S. because of similarities with research on this technology being done at MIT and LSU (ref. personal contact with developer). There is no indication that these research groups have a commercially competitive product; however, continued research in the U.S. may result in the development of a similar technology provided by a U.S. vendor.

This technology is patented in the EC with an extended patent that covers some non-member European countries, as well. This is also patented in the U.S.

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EX SITU BIOREMEDIATION OF HEAVY METALS USING SULFATE REDUCING BACTERIA

Paques B. V.
The Netherlands

DESCRIPTION

Principle application of this technology is for the ex situ remediation of groundwater contaminated with both heavy metals and sulfates. No secondary applications have been identified. This tech-

proximately 200 gallons per minute (Bonkoski, pers. comm).

2. The contaminated water is then pumped to a mixing tank where nutrients such as H_3PO_4 and $NaOH$ are added to aid the biological process

Figure 1. Schematic for Biological Treatment of Groundwater Contaminated with Heavy Metals.

nology uses sulfate reducing bacteria in a process to simultaneously remove sulfate and heavy metals from contaminated groundwater. This process includes the following steps (Figure 1):

1. Groundwater contaminated with heavy metals and sulfate is pumped from the subsurface into a buffer tank. This buffer tank facilitates regulation of the flow rate through the plant, ap-

in future steps. Ethanol is also mixed with the influent and will act as the electron donor/substrate in the sulfate reduction reaction.

3. The groundwater then enters an Upflow Anaerobic Sludge Blanket (UASB) reactor (Figure 2), where the sulfate is reduced to sulfide by sulfate reducing bacteria. The reactor consists of the following parts:

- An influent system which is designed to spread the incoming water evenly over the active biological bed. The hydraulic capacity of the influent system is such that the sludge bed is gently mixed to avoid the channeling problems of a compact sludge. Mixing is also improved by the gas bubbles that are produced.
 - A reaction chamber where the bacteria convert sulfate to sulfide (including metal sulfides). Additionally, ethanol is partly converted to acetate, which is then converted to methane and carbon dioxide by methanogens. For short residence times to be achieved bacteria must attach to the sludge blanket.
 - A three-phase separator is located at the top of the reactor. It is comprised of three levels of V-shaped hoods. The gas produced in the reactor is trapped by these hoods. The separator is located below the surface of the water and, after sufficient pressure has built up, the gas is released.
4. The byproduct gases (CO_2 , H_2S , CH_4) are vented to a scrubber where the CO_2 and H_2S

are removed followed by flaring of CH_4 (methane).

5. The effluent from the UASB is transferred to a Submerged Fixed-Film (SFF) reactor where sulfide oxidation occurs. This step removes excess sulfide (HS^- , H_2S) produced in the UASB. The SFF reactor consists of a water-inlet system at the bottom, a reaction chamber, and an air-inlet system. In this reactor, aerobic bacteria convert sulfide to elemental sulfur by oxidation.
6. Following sulfide oxidation in the SFF, the process water flows into a tilted-plate settler where solids such as sulfur and metal sulfides are collected.
7. As a final polishing step, the process stream flows through a sand filter that strips off any remaining solids.

An appropriately designed and implemented system of withdrawal wells is needed to provide an

Figure 2. Detail of UASB and SFF Reactors.

adequate inflow rate to the process plant. Facilities for the removal and disposal of the recovered materials (sulfur and metal sulfides) are required. The technology could be incorporated with conventional pump and treat methods.

TECHNICAL PERFORMANCE

The Budelco zinc refinery at Budel-Dorplein, The Netherlands, is presently the only site where this process has been demonstrated on a commercial scale. The groundwater at the site was contaminated with high concentrations of heavy metals and sulfate resulting from approximately 100 years of active zinc refinery activities. The zinc and cadmium concentrations were as high as 200 and 0.2 mg/l, respectively. Published results from the pilot plant at Budel-Dorplein show that the process is very effective at removing Zn, Cd, Fe, Pb, Cu, Co, and Ni (Table 1).

Table 1. Average influent and Effluent Concentrations for UASB Reactor (Scheeren, 1992).

Component Concentration, mg/l*	Influent	Effluent
Zn	250	<0.05
Cd	1.10	<0.001
Fe	33	0.03
Pb	13	<0.02
Cu	2.2	<0.02
Co	0.2	<0.02
Ni	0.3	<0.01
Mn	35	20
Mg	40	35
Ca	300	290
Na	60	370
As	0.010	<0.005
NH ⁴⁺	12	19
SO _{2/4} -	1.4	0.120

Limitations. Process requires efficient recovery of contaminated groundwater. May not work if contaminants are sorbed or coupled with formation material.

Cost & Schedule Re/Implementation. The operating cost of the plant is related in large part to the amount of ethanol used in the bioreactor. The zinc is reprocessed in the refinery and thus helps to offset some of the cost. Specific cost esti-

mates and efficiencies of the commercial scale plant are unavailable. However, results of the commercial plant were presented in the proceedings of the Zinc Conference in Australia in October 1993.

Safety Re/Implementation. Part of the plant is treated as an explosive zone because of the type of gas produced. Equipment is supported by computer safeguards that monitor process parameters. In case of major deviations from parameter set points the computer will intervene to maintain safety.

WASTE APPLICABILITY

Application is designed for groundwater contaminated with both heavy metals and sulfates. Typical sites would involve metal refining. Process requires efficient recovery of contaminated groundwater. May not work if contaminants are sorbed or coupled with formation material.

STATUS

This technology is mature and has been demonstrated at the Budelco zinc refinery, Budel-Dorplein, The Netherlands. A commercial scale plant was put on-line in May 1992 at this site and has successfully treated heavy metal and sulfate contaminated groundwater to comply with Dutch environmental standards.

Background & Previous Application (references). As stated in previous sections, the Budelco zinc refinery at Budel-Dorplein, The Netherlands, is presently the only site where this process has been applied on a commercial scale. Approximately 5000 m³/day are processed at the plant. Table 2 summarizes the process parameters at the plant.

Table 2. Design Parameters for Commercial-Scale SRB Plant.

Influent flow, m ³ /h	300
Temperature, °C	25
Residence time in USAB, h	6
Residence time in SFF, h	0.55
Residence time in tilted-plate settler, h	0.4
Filter surface area, m ²	30
Flow through 1 m ² of filter, m ³ /h	10

Budelco reports (Scheeren, 1993) that the system is performing according to design goals. Waste stream solids consists of approximately 90 percent zinc sulfide (ZnSO₂) and 10 percent organic metals.

REGULATORY CONSIDERATIONS

None known.

POTENTIAL COMMERCIAL APPLICATIONS

Commercial applications would include industries which require ex situ treatment of groundwater contaminated with both heavy metals and sulfate. No assessment is currently available. May be applicable in states that contain large or numerous metal refineries.

Several parts of the process train involve patented products. The Upflow Anaerobic Sludge Blanket (UASB) is patented by Paques, a Dutch company with experience in anaerobic water treatment systems, the trade name is "BIOPAQ". Shell's Sittingbourne Research Centre (SRC) in the United Kingdom hold patents on the other components.

BASELINE TECHNOLOGY

Pump and treat technologies are commonly used to remediate heavy metal contamination in groundwater, using chemical processing to remove contaminants. Soil washing can be used if heavy metals and sulfates are sorbed on soil particles. This process may be cheaper and more efficient than physical and chemical remediation, if the sulfate reducing bacteria can be maintained at sufficient levels.

INTELLECTUAL PROPERTY RIGHTS

Paques B.V. holds a patent for the UASB reactor. Additional patents are held by Shell's Sittingbourne Research Centre (SRC) in the United Kingdom. This technology is patented in the EC. Patent status in other countries is unknown.

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EX SITU EXTRACTION OF ORGANIC BROMINE COMPOUNDS FROM SOILS USING NaOH

TNO and HWZ Bodemsamering
The Netherlands

DESCRIPTION

Ex situ physical/chemical extraction of organic bromine compounds (or perhaps other halogenated VOCs) from soils using NaOH. The extraction of organic bromine compounds using NaOH solution consists of the following process steps:

1. Soil pretreatment to separate large objects (e.g., stones) and reduce the size of large pieces of consolidated soil (crushing and wet sieving).
2. Intimate mixing of soil with extracting agent (approximately 0.2 percent NaOH solution); the soil-to-water ratio is about 3 to 1 on a weight basis.
3. Extraction and washing of the soil with clean extracting agent in counter-current flow in two modified in line screw classifiers.
4. Dewatering of soil before redeposition. The remaining alkalinity of the soil will be largely neutralized by absorption of CO₂ from the ambient air.
5. The overflow of the first modified screw classifier is passed through a settling tank to collect fine mineral particles entrained in the extracting liquid. The particles that settle have diameters between approximately 35 mm and 60 mm (approximately 1 percent of the total soil). This material is collected from time to time and washed separately with a NaOH solution.
6. Sludge is formed in the effluent by adding lime as coagulant and polyelectrolyte as flocculant.

The sludge formed can be separated in a tiltable plate separator.

7. Dewatering of the sludge in a solid 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.
9. HCl neutralization.

Equipment necessary for excavation of the contaminated soil and transportation to the pretreatment facility will have to be provided. The pretreatment process will require a conveyer system, sieves, and/or other separation equipment. Aside from the screw classifiers, several tanks and conveyance systems will be needed for the mixing, washing, and settling phases of the remediation process. For nearly all aspects of the processing, ample supplies of water, air, and electricity must be available. Provisions must also be made for monitoring/sampling of the remediation process to determine when acceptable levels have been met. Furthermore, a means for the disposal of the waste sludge and spent activated carbon filters must be provided. This technology may replace or improve other ex situ physical/chemical extraction technologies.

TECHNICAL PERFORMANCE

Experiments showed that it is possible to remove the bromine compounds from the soil down to a level of 1 mg Br/kg or less. The cleaned extract-

known whether the process has been applied in a full-scale environment. However, experiments indicated that successful remediation using this process is highly probable. Contact TNO for further information.

REGULATORY CONSIDERATIONS

None known.

POTENTIAL COMMERCIAL APPLICATIONS

Potential commercial applications include industries which would require the destruction of organics from complex concentrated wastes. The commercial market is potentially very large, depending on the relative importance or occurrence of organic bromide contamination in the relevant commercial industries. A market survey was not performed.

BASELINE TECHNOLOGY

The baseline technologies are pump and treat, soil washing, and thermal treatment remediation technologies. This technology is more expensive than simple pump and treat methods; however, the remediation process is more complete and not limited to relatively permeable materials. On the other hand, thermal processes are likely more expensive than the proposed technology, and are likely even more complete. The proposed technology is most comparable to soil washing, yet more enhanced. Therefore, depending on the relative costs associated with the process materials and the duration of remediation, the proposed technology may either be cheaper or more expensive.

INTELLECTUAL PROPERTY RIGHTS

None known.

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IN SITU REMOVAL OF CADMIUM AND ON-SITE TREATMENT BY ION-EXCHANGE

TAUW Milieu BV and MORIK BV
The Netherlands

DESCRIPTION

The principal application is in situ remediation of soils contaminated with cadmium (Cd) and other heavy metals. This process consists of two principal steps. In the first step, 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 (10 cm dia.) recovers the percolate which is then pumped through vertical wells to the surface.

In the second step, a 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 system consists of five filters containing 3 m³ of resin each. The filters are arranged in two parallel series, each containing two filters. A polishing filter containing 1 m³ of resin is used in a final step of Cd removal. The fifth filter is held in stand-by and is used during regeneration.

The regeneration of the ion exchange resin is performed with upflow flushing of 5 percent hydrochloric acid, followed by flushing with fresh water. The hydrochloric acid is then discharged to an industrial cleaner (precipitation and ion-exchange). The regeneration of the resins yields a CdCl solution that must be further treated off-site or removed to a controlled waste dump (Urlings, 1993). The cleaned acidic water is then infiltrated again into the polluted soil.

Urlings, et al. (1993) stressed the importance of close interaction between the hydrologist, environmental engineers, water treatment engineers

and soil scientists to develop an effective remedial plan. Implementation will require drilling contractor and associated surface treatment facilities. Must be coupled with a containment technology to control mobility of contaminants during the leaching process. Must provide for disposal of CdCl solution.

TECHNICAL PERFORMANCE

This technology has been successfully demonstrated at a photo-paper producing plant in the province of Utrecht, The Netherlands. In this application, the soil was characterized as fine to coarse sandy soil with a very low adsorption capacity. The concentration of Cd in the soil was reduced to 1 mg/kg (the detection limit) in 90 percent of the soil samples. A total of approximately 400 kg Cd was removed from the soil. Figure 1 (Urlings, 1989) shows the Cd concentration in one of five areas remediated at this site. The site was divided into five zones based on the capacity of the groundwater treatment installation (approximately 250 m³/h) and the hydraulic properties of the soil.

The water treatment process operated to design criteria; however, the pH, and Ca-, Al- concentrations in the influent must be carefully controlled to optimize the efficiency of the ion exchange process. Levels of pH greater than 5.5 resulted in flocculation, while at low pH levels (<5.0) the pH of the resin decreased. The average removal efficiency from the influent was estimated to be about 96 percent.

Figure 1. Cd concentration in one of five areas remediated at photo-paper producing plant in the province of Utrecht, The Netherlands.

Initially, freezing of the in situ installation during winter was an issue of concern. However, a combination of a mild winter and the thermal mass of the earth prevented in situ freezing.

Limitations. Several limiting factors were found during previous applications of this technology. It was discovered that:

- the escape of air from the soil limited the discharge flow rate of groundwater which increased the start-up time;
- minor low permeability lenses within the soil were shown to inhibit the infiltration and therefore prevent adequate circulation;
- it may be more efficient to excavate these low permeability areas;
- during the water treatment process, the pH, the Ca- and the Al- concentrations need to be carefully controlled to maximize the exchange of Cd with ions in the resin; and

- the mobilization of the heavy metals during this process must be carefully contained by a properly designed drain and well field, since an inadequate design could lead to contamination of surrounding areas.

Cost & Schedule Re/Implementation. This process was estimated to be approximately 20 percent less expensive than conventional soil washing. A site with the following characteristics would cost US\$83/m³ (Urlings, 1993):

- volume of contaminated soil 30,000 m³ over an area of 6,000 m²;
- soil characterized as middle fine to middle coarse sand soil; and
- soil has generally low adsorption capacity.

In addition, the resin's commercial value is quite high and can be sold after the remedial action.

Illustration of key components, or system-level flow charts:

Safety Re/Implementation. No hazards known.

WASTE APPLICABILITY

Can be used on many types of heavy metal in soil and groundwater, with no restrictions on amounts (Urlings, personal communication). In sub-freezing climates, the surface treatment facility should be covered to prevent freezing.

STATUS

The process has been demonstrated on a commercial scale, and development is complete. This process was demonstrated at a site where the remedial action covered an area of 6,000 m² with a volume of 30,000 m³ and an estimated pre-remediation Cd concentration of 725 kg (Urlings, 1988). Of five target areas at the site, the first area was successfully cleaned between August and December of 1987. By October 12, 1987, all the soil samples showed Cd concentrations equal or less than 0 mg/kg dry soil and the Cd concentration in the percolate was 10 micro-grams/L. At this point, acidification was stopped and re-neutralization of the soil was started with NaOH at a pH of 8.5. When the percolate Cd concentration of every drain was below the detection limit (<10 micro-grams/L), neutralization was stopped.

Further development is in progress to produce a magnetized resin with even higher affinity to heavy metals. This development is still currently proceeding in the laboratory with a magnetized resin (Urlings, pers. comm.). At the demonstration site (Urlings, 1993), the system circulated groundwater at approximately 250 m³/hour (this is limited by the permeability of the soil at any given site).

This technology has been demonstrated with Cadmium. Sites containing combinations of other heavy metals should consider a laboratory-scale demonstration before full-scale.

REGULATORY CONSIDERATIONS

None known. There may be some concern of flushing the contaminants in previously uncontaminated aquifers. This can be addressed with containment technologies but the acceptance may be effected. Level of remediation is generally high which would permit subsequent uses of site.

POTENTIAL COMMERCIAL APPLICATIONS

Commercial applications would include industries for which in situ treatment of cadmium (and other heavy metals) contaminated soil or groundwater is required. The commercial market potential is unknown, but could be very large (i.e., heavy metal contamination in soil is a common problem). A market survey has not been conducted. TAUW is interested in marketing this technology in the United States and are willing to consider partnerships with U.S. companies.

BASELINE TECHNOLOGY

The baseline technology is soil washing (with/without biochemical treatment) or acid leaching (without secondary treatment). This technology has been demonstrated at a commercial scale to be approximately 20 percent cheaper than soil washing. In one of the applications, the method was selected over precipitation techniques because precipitation tends to increase the salt content in the recirculated water.

INTELLECTUAL PROPERTY RIGHTS

None known. The process and resin are not patented.

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IN SITU REMOVAL OF WEAK ACID BY FLUSHING WITH NaOH

Delft Geotechnics and BMS Environmental Soil Systems
The Netherlands

DESCRIPTION

This technology involves in situ remediation of highly viscous, low solubility, weak acids. The method is based on the principle that the dissociation (and the solubility) of a weak acid is highly dependent on pH. Therefore, flushing soil that is contaminated by a weak acid with an alkaline solution (instead of water) may considerably reduce the remediation time. The basic steps involved in the process are to:

1. Identify the contaminated zone;
2. Install groundwater extraction wells;
3. Flush the contaminated soil with an alkali solution (e.g., NaOH);
4. Pump the groundwater and the dissociated pollutant from the extraction wells into a treatment facility comprised of an acid mixing unit and a flotation separation system; and,
5. Return the cleaned groundwater to the aquifer and properly dispose of the remaining sludge.

A means of identifying the contaminated zone within the soil will be required. A driller and/or excavator would be hired to install the extraction wells and pumping pit. In addition, a pumping and wastewater treatment facility would have to be installed. Therefore, a supply of fresh water, air, and electricity will be necessary. A field monitoring program should be established to evaluate performance and identify when an acceptable level of contamination has been achieved. Activated carbon filters (and any other process residuals) will have to be disposed of properly.

A preliminary assessment of the site hydrologic characteristics is required to determine the feasibility of mixing and displacing weak acid with

alkaline solution. Potential for cross contamination from drilling of extraction wells must also be considered along with compatibility of alkaline solution with other contaminants present.

TECHNICAL PERFORMANCE

This remediation technology has been applied at a petrochemical site in The Netherlands to remove decanoic acid. Of an estimated 16 tons of spilled waste, nearly complete recovery was reported.

Figure 1. Cumulative Amount of Removed Decanoic Acid (Visser, 1993).

Figure 2. Flushing System for the Removal of Decanoic Acid.

Limitations. As in any injection/withdrawal system, the technology will only be applicable to situations where the contaminated soils are transmissive.

Cost & Schedule Re/Implementation. Costs estimates not available. Scheduling requirements would be a direct function of the size of the contaminated region, the number of injection and withdrawal wells, the hydrologic properties of the soil and the capacity of the water treatment facility.

WASTE APPLICABILITY

The technology is applicable in remediation problems involving weak acid contamination of relatively permeable soils. If other contaminants are present at the site, some additional treatment (pre or post) may be required. The site must be comprised of relatively transmissive materials.

STATUS

The technology has been successfully applied in the field for a relatively small site (Visser, 1993). The method has been used to remediate a decanoic acid spill below a storage tank (Visser, 1993). The storage tank, located at a petrochemical site in The Netherlands, had been leaking for approximately seven years. Over this time, an estimated 16 tons of acid leaked from the tank contaminating the groundwater.

The reaction between decanoic acid (HDe) and an alkali solution can be represented as:

Because of the completeness of the reaction 1 m³ of 0.25 m NaOH solution will dissolve 43.75 kg of decanoic acid.

Following the installation of 12 extraction wells around the leaking tank, a sodium hydroxide solution was allowed to infiltrate from the surface

above the contaminated region and mix with the decanoic acid. The contaminated groundwater was then pumped from the formation and transferred to a treatment plant comprised of an acid mixing unit and a flotation separation system. The treated water was then returned to the groundwater at the site.

The circulation system started on September 28, 1990 and continued until May 30, 1991; however, there was a 3 week hiatus due to equipment failure in November 1990. During the remediation, the infiltration process operated 5 days a week at 20 m³ per day of 0.25 m NaOH solution. The groundwater was pumped 7 days per week at 50 m³ per day. At the end of the remediation period, 16.8 tons of acid had been removed. Therefore, based on the estimated amount of the spill, it appears as though this method completely remediated the contaminated soil (Visser, 1993).

REGULATORY CONSIDERATIONS

There may be concern regarding the spread of the contaminants through the flushing process. This concern can be addressed by coupling the technology with an appropriate containment system.

POTENTIAL COMMERCIAL APPLICATIONS

Potential commercial applications are currently being assessed. Applications would include remediation of decanoic acid spills (or other weak acids) for commercial petrochemical companies. Removal of other weak acids from contaminated soils by the same process.

BASELINE TECHNOLOGY

Pump and treat methods and excavation/soil washing methods. The process of lowering the groundwater pH to increase the solubility of weak acid contaminants should decrease the remediation time compared to simple pump and treat technologies.

INTELLECTUAL PROPERTY RIGHTS

None known.

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IN SITU TREATMENT OF VOCs BY RECIRCULATION TECHNOLOGIES

University of Karlsruhe
Germany

DESCRIPTION

The project described herein was conducted by Oak Ridge National Laboratory (ORNL) to identify processes and technologies developed in Germany that appeared to have near-term potential for enhancing the cleanup of volatile organic compound (VOC) contaminated soil and groundwater at DOE sites. Selected German technologies developed at or in association with the University of Karlsruhe (UoK) for in situ treatment of VOC contaminated soils and groundwater were identified and evaluated. The two processes identified as having near-term potential for DOE were: (1) the vacuum vaporizer well/groundwater re-

circulation well (German: Unterdruck-Verdampfer-Brunnen/Grundwasser-Zirkulations-Brunnen, or UVB/GZB) and (2) the porous pipe/horizontal well (PP/HW). Figure 1 shows the major components of the systems.

The UVB/GZB technology shown below with an ideal capture zone demonstrated significant potential. The UVB/GZB consists of a vertical well with screened sections below and above the water table, a treatment section, and an above ground air blower. These vertical wells use an airlift effect (UVB) or electric pump (GZB) to remove groundwater through the bottom section, move it vertically, and reinject it. The upper and lower screened sections can be in different layers but the layers need to be hydraulically connected to form a circulation cell. The system has proven application for inducing recirculation in relatively homogeneous aquifers and under ideal conditions can encompass the entire aquifer thickness. A blower, mounted on the outlet, moves air from the ground surface, through the well, and back to the well head. A separation plate prevents mixing of treated with entering water. Soil air receives treatment by entering the UVB/GZB at the second screened section due to a vacuum developed by the blower. The gaseous is treated above ground prior to release. No water is brought to the surface, eliminating some problems associated with treatment, disposal or reinjection.

Figure 1. Major Components of the UVB/GZB Vertical Well for In Situ Recirculation and Treatment of Groundwater

The PP/HW consists of horizontal well pairs (for withdrawal and injection of subsurface fluids) connected to a caisson that houses treatment and pumping equipment. Groundwater (and/or soil air) enters one well, passes through the caisson connecting the wells, and then is reinjected into the aquifer through a second well.

TECHNICAL PERFORMANCE

The UVB/GBZ is well demonstrated at full-scale for air stripping of VOCs (trichloroethylene, trichloroethane, perchloroethylene, benzene, toluene, and xylene) in Germany (Herrling et al., 1991) and the process performance is reported as good. Capital and operating costs are reported to be significantly less than for traditional methods. The PP/HW lacks significant testing. The well configurations of the PP/HW may more significantly affect circulation geometry than the UVB/GZB. Also, short-circulating problems (between injection and extraction wells) are expected to be less significant with the PH/HW system. Extensive field testing in different hydrogeological settings, computer simulations, and detailed cost comparisons to other methods need to occur before these recirculation technologies can be implemented on a broad scale.

KSK Microtunneling Technologies in Rastatt, Germany is the manufacturer of the porous pipe horizontal well and FlowTex Directional Drilling installs the horizontal wells. The technology has been demonstrated at the Frankfurt airport using a horizontal, radial system for soil vapor extraction of jet fuel. The KSK technology was not complicated and attractive because it was up-scaled from the utility industry, rather than down-scaled from the oil industry. The German drilling technique was demonstrated in fine soils (rock and gravel may cause problems). KSK/FlowTex demonstrated horizontal well installation rates of 80 to 120 m/d at a cost of \$100 per meter (10-m depth). Schumacher Environmental in Crailsheim has developed a porous plastic pipe (pore sizes of 10 to 100 μm).

WASTE APPLICABILITY

The UVB/GZB technology enables simultaneous treatment of aquifers and unsaturated zones. The technology also has potential for inducing strong vertical and horizontal gradients for aiding in removal of nonaqueous phase liquids (NAPLs).

Because of the flow fields created, the method may also be applicable to recovery of dense nonaqueous phase liquids (DNAPLs).

The PP/HW technology offers potential for VOC treatment at sites with thin aquifers or heterogeneities. However, there has been limited testing of this PP/HW technology.

Although the principal applications of the technologies to date are for VOCs within saturated, moderately permeable sites, they are potentially applicable for destroying other organics and inorganics.

STATUS

Project activities were conducted between the fall of 1991 and February of 1992. Some of the treatment technologies are currently in the foreign field-demonstration stage.

The goal of a three year project funded by the Office of Technology Development, within the DOE's Office of Environmental Management, under the In Situ Remediation Integrated Program is to package one or more unit processes for in situ treatment of VOCs and radionuclides in groundwater, as modular components in vertical and/or horizontal recirculation wells. The project builds on previous accomplishments outlined above. This effort will include (1) evaluation of horizontal wells for inducing groundwater recirculation; (2) development of belowground treatment modules for simultaneous removal of VOCs and radionuclides; and, (3) demonstration of a coupled module-recirculation system.

Preliminary research activities conducted during the first year (1994) included identification and screening of applicable technologies, hydrodynamic modeling, bench scale experiments, and field tests. Part of the technology screening involved the selection of horizontal well materials and installation methods. Building on results of the investigation of German technologies de-

scribed above, the flexible porous pipe, installed with utility-industry equipment will be used. This work is being conducted in collaboration with investigators from UoK and KSK/FlowTex of Germany. It is anticipated that the drilling and installation methods will achieve significant cost savings and provide greater flexibility with respect to site access than conventional horizontal well drilling. An uncontaminated location at DOE's Portsmouth facility was selected as a preliminary test location. Although the Portsmouth facility was the location selected, discussions are continuing with personnel from the DOE Hanford and Paducah sites.

REGULATORY CONSIDERATIONS

Safety Issues. There are no safety issues known beyond those normally associated with drilling in contaminated sites. In fact, hazards may be reduced by in-situ treatment. From a regulatory point of view, in-situ treatment of VOCs is generally accepted, although verification will be necessary. Since no groundwater treatment discharge is required, permitting is simplified. Any enhanced site emissions will have to satisfy NEPA.

POTENTIAL COMMERCIAL APPLICATIONS

These technologies could be applied by any organization (public or private) with the need to in-situ treat VOCs at contaminated sites. The technology can be used in conjunction with other technologies (horizontal drilling, containment, etc.) and be used to treat not only VOCs, but also other organics and inorganics. The use of the technologies would preclude other ex-situ soil and groundwater VOC treatments. These technologies could be applied at many sites throughout the DOE complex.

BASELINE TECHNOLOGY

For favorable conditions, the baseline technology is the conventional pump and treatment methods (for example, extraction wells and interceptor

trenches). For less favorable conditions, excavation/thermal treatment (or excavation/safe disposal) and containment are the baseline technologies.

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PLASMA FURNACE TECHNOLOGY FOR VITRIFICATION OF TRU CONTAMINATED WASTES

PLASTECH Corporation
Russia

DESCRIPTION

This technology involves a new approach for treating compacted transuranic (TRU) waste by use of a plasma/induction furnace (PIF) technology. The researchers developed and tested a multipurpose PIF process and associated equipment for continuous processing of steel cylinders (57.0-cm in diameter, and 87.0-cm in height) filled with compacted wastes of various types: organic sludge, metallic sludge, combustibles (paper, plastics, wood, cloth, etc.), or any combination of the previous.

The main component of the system is the induction furnace tank. The furnace is actually made

up of an initial heating furnace (IHF) powered by a 300-kW/2400-Hz generator and a plasma/induction furnace with cooled pot (PIFCP) powered by a 1-MW generator. Water flowing through copper pipes attached on the outside of the furnace prevents the furnace surfaces from melting. The magnetic field produced in the furnace actually aids in preventing contact of the melt with the furnace surfaces and aids in the agitation of the melt. A plasma torch system comprised of four plasmatrons (each at 100 kW) is also used in the process to achieve overheating of the metal and slag (metal oxides, etc.), which is needed to obtain a good separation of these two products.

First, the PIFCP is turned on to melt the metal ingot in the bottom, which was leftover from previous processing. Next, a waste cylinder is lowered into the IHF by a special loading apparatus. The bottom of the cylinder is initially melted with the plasma torch system. After the bottom of the cylinder starts to melt, the IHF is turned on and the cylinder is slowly lowered into the melted ingot in the PIFCP. Further heating by the furnace and plasma torch system brings the melt up to the desired temperature. In order to oxidize various compounds, air is flowed into the furnace. Due to the high temperatures, all organic compounds are destroyed. Metal oxides that are produced end up as part of the slag melt. The slag melt which separates out to the top is continually drained off into a slag tank. As soon as the cylinder is melted, the system is ready for the next cylinder.

Operation Scheme of the Plasma/Induction Furnace Technology

The bottom of the furnace is actually a water cooled, independent, movable surface that can be lowered from the bottom of the furnace. An apparatus attached to the furnace bottom lowers the bottom and the partially solidified metal ingot slowly from the furnace. Only when the ingot reaches a limiting length must the process of feeding cylinders into the furnace stop, so that the ingot can be removed.

TECHNICAL PERFORMANCE

The developers conclude that the primary advantage of the technology is its ability to treat unsorted waste. In addition, they conclude that the process allows a continuous (for the most part) operation cycle, in-drum processing, the production of homogeneous final products that may be disposed of without additional processing, greater volume reduction, greater energy efficiency, the collection of radioactive metals (oxides) in the slag, the complete decomposition of organic wastes without producing toxic gasses, and the prevention of dust from exiting the furnace with the effluent gas stream.

The ingot has a final diameter of approximately 70 cm and a height of approximately 100 cm. The density of the ingot is approximately 8.1 g/cm³. Therefore, an ingot will weigh a little over 3 metric-tons (1 metric-ton equals 1,000 kg). A single

standard steel drum filled by only metallic wastes weighs about 60 kg and adds a thickness of about 1.9 cm to the ingot. Therefore, about 52 drums of this type can be processed before the ingot has to be removed. The actual number of drums that can be processed before removing the ingot depends on the amount of metallic waste in the drums.

The Table 1 below lists the process steps to vitrify one drum of waste and the time needed to complete each step in the process.

The total time to produce a full size ingot is about 26 hours (52 drums * 0.5 hours/drum). The time needed to unload the ingot, inspect the system, and prepare the system for further operation takes approximately 6 hours. Therefore, the total cycle time between ingot production is about 32 hours. For a 240-day working year, approximately 9360 drums could be processed. The average power consumed by the process is on the order of 500-700 kW.

PROJECTED PERFORMANCE

Future developments includes refinements in system design and construction of a new system to process standard drums filled with real compacted radioactive wastes. The new system will be used for pilot-scale demonstrations.

Table 1. Process Steps to Vitrify One Drum of Waste and Time Needed to Complete Each Step

<u>Process Step</u>	<u>Time</u>
1. Waste drum loading into the IHF	2 minutes
2. Initial drum melting with the plasma torches	2 minutes
3. Initial heating in the IHF	2 minutes
4. Lowering and melting of the drum in the PIFCP	15 minutes
5. Final heating and air sparging in the PIFCP	5 minutes
6. Pulling of the metal ingot	1 minute
7. Miscellaneous	3 minutes
Total Time	30 minutes

WASTE APPLICABILITY

The PIF technology is applicable to minimizing wastes contained in waste drums. Targeted contaminants include various hazardous and radioactive wastes (especially transuranics).

STATUS

The technology and associated equipment are beyond proof-of-principle testing (although drums containing actual radioactive material have not been processed). There is no history of applications of this technology within the DOE complex or elsewhere in the US.

REGULATORY CONSIDERATIONS

Detailed US regulatory considerations have not yet been determined. Proposed NRC and DOT regulations will require shipment in a Type B cask for containers with radiation fields greater than 1 rem/hr.

POTENTIAL COMMERCIAL APPLICATIONS

This technology is applicable by any industry (hospitals, nuclear power generation, etc.) that produces drums filled with hazardous and/or radioactive waste. This technology could be useful in support of waste volume reduction efforts at the DOE complex cleanup sites and at US commercial nuclear power facilities.

BASELINE TECHNOLOGY

Currently there are a number of technologies which exist for the vitrification of radioactive and heavy-metal bearing wastes. However, none of these technologies are specifically designed to process contaminants contained in drums.

INTELLECTUAL PROPERTY RIGHTS

None.

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PLASTIC SOLIDIFICATION PROCESS FOR RADIOACTIVE WASTES

JCG Corporation
Japan

DESCRIPTION

This technology reduces the volume of radioactive liquid wastes by dehydration into a powder and then stabilized by embedding the powder into a thermosetting resin matrix. Low-level radioactive wastes, such as evaporator concentrates, spent ion-exchange resins, and others are received into

revolutions per minute (rpm). In the dehydrator, water is evaporated from the waste while flowing downward in the form of a thin film on the heated cylindrical surface. An unsaturated polyester resin binder is fed into a pre-mixer where a specified quantity of powdered waste is fed from the hopper to the pre-mixer. After a thorough and uniform mixing step, the powder and binder are

drawn out of the pre-mixer into a drum where the components are mixed again with the addition of hardening agents. Various safeguards have been considered in this process to prevent splashing during the in-drum mixing. For example, a variable speed, vertical motion mixer which has uniquely designed mixer blades has been utilized to minimize splashing. After mixing is completed, the mixer is removed from the waste-binder mixture. The drum is subsequently transferred

Schematic of the Plastic Solidification Process

the waste feed tanks and subsequently fed continuously and quantitatively into a drying unit to be dried into a powder. The powdered wastes are received into a hopper, and the evaporated water is condensed (in a condenser) and transferred to a liquid waste treatment system.

A vertical thin-film evaporator is used as a dehydrator. This dehydrator consists of a steam-jacketed, cylindrical body stator and a bladed shaft rotor which rotates at a speed of several hundred

to the intermediate storage area and allowed to set. During this time, polymerization proceeds in the drum resulting in a hardened final product.

TECHNICAL PERFORMANCE

General. The plastic solidification process is a new process established by combining JGC's own technology with the process developed by the Grenoble Nuclear Research Center (CENG) of the French Commissariat for Atomic Energy (CEA). The technology was further improved to produce

solidified products with high volume reduction and excellent physical properties.

Full-Scale Demonstration. A plastic solidification plant is now being constructed by JGC at Fukushima No. 2 nuclear power plant site, a facility of the Tokyo Electric Power Company, Inc. No other technical performance data was supplied.

Design Data. Design information on the amount of waste that the full-scale plastic solidification process must handle can be developed from waste production rates from nuclear reactors.

Table 1. EPRI Design Basis for Reactor Produced Waste Volumes (five year period).²

Waste Stream	Container Size (ft ³)	Approx. Container Dimensions (ft)	Approx. Rad Field (R/hr)	Qty. of Containers	Stack Height	Waste Volume (ft ³)
NSSS resin	120	5Dx6H	2,500	10	1	1,200
Radwaste Resin	190	6Dx6.5H	5	50	2	9,500
Very-low activity resin	215	4x6x4H	0.005	25	2	5,375
High Activity DAW	96	4x6x4H	0.05	50	4	4,800
Very-low-activity DAW	96	4x6x4H	0.001	200	4	19,200
Total						40,075

The Table 1 represents conceptual design basis data from estimates of the LLW that could be expected from either a multi-unit pressurized water reactor (PWR) either moderate waste quantities or a single- or dual-unit boiling water reactor (BWR) with relatively low waste quantities. Low-level waste volumes and costs for DOE Weapons Complex site cleanup activities need to be determined.

WASTE APPLICABILITY

This technology is applicable to liquid low-level radioactive wastes. It is possibly applicable to mixed wastes or other hazardous wastes depending on the leachability of the waste.

STATUS

This technology was developed with plans to establish full-scale production facilities at Japan's nuclear power plants.

REGULATORY CONSIDERATIONS

Detailed U.S. regulatory considerations have not yet been determined. Some of the containers listed in the Table 1 may be difficult to ship after mid-1992. Proposed NRC and DOT regulations will require shipment in a Type B cask for containers with radiation fields greater than 1 rem/hr. The upper size limit is approximately 5-ft in diameter and 140-ft³ in volume due to size limits on currently available Type B casks.

POTENTIAL COMMERCIAL APPLICATIONS

This technology is applicable to power companies which have nuclear powered generating stations. The technology could be useful in support of low-level waste volume reduction efforts at the DOE complex cleanup sites and at U.S. commercial nuclear power facilities.

BASELINE TECHNOLOGY

The United States is developing a technology called "Polyethylene Encapsulation of Radionuclides and Heavy Metals (PERM)." Full scale-implementation of PERM is expected in FY95 following "cold" testing at the Brookhaven National Laboratory and "hot" testing at the Hanford Underground Storage Tank Integrated Demonstration. PERM is projected to achieve production-

scale waste processing rates between 1-3 metric tons/hr with 60 percent nitrate salt loading in the polymer matrix. Although the Japanese technology is closer to be implemented in full-scale applications, comparable technical performance data has not been made available.

INTELLECTUAL PROPERTY RIGHTS

The JGC corporation owns the intellectual property rights.

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POLLUTED WATER CLEANING WITH TWO-STAGE HETEROGENEOUS DISCHARGE

Science Applications International Corporation, Inc.
Russia

DESCRIPTION

This innovative water cleanup technology involves the successive application of pulsed electric discharges (stage-1) in a heterogeneous air-water mixture of contaminated sludge water, followed by biodegradation (stage-2) to reduce the toxicity to acceptable standards. The development of this two-stage approach involves a collaborative effort between three institutions. The first two, located in Tomsk, Russia, are the Institute of Electrophysics at the Ural Branch of the Russian Academy of Science and Aquapulse Ltd. The third is the Center for Bioengineering and Pollution Control at the University of Notre Dame. Aquapulse Ltd. has successfully developed and commercially manufactured one-stage pulsed power modules for sludge water treatment. These modules have been demonstrated at various sites in Russia. The chosen approach is an alternative to the well-known water purification techniques of using chlorine and fluorine and/or processing with ultra violet radiation with the addition of ozone.

The first stage device was developed in Tomsk Russia for removing pollutants from sludge water such as dissolved heavy-metal salts and organic compounds. Since pulsed electric discharge treatment alone does not guarantee complete degradation of refractory organic compounds, a second stage is being added to the cleaning process which utilizes biological processing techniques.

TECHNICAL PERFORMANCE

General. The electric pulsed discharge devices for water cleaning (stage-1 equipment) have been developed and demonstrated in Russia. For ex-

ample, tests using one prototype device conducted by the World Laboratory Branch in the USSR under the Auspices of the Western Siberian Center of Ecology in 1991 and 1992 showed that processing of the polluted river water resulted in the decrease of organic compounds concentrations by two times, phenols from 10-15 times, halogenated compounds from 3-4 times and heavy metals (e.g., Fe) from 3 mg/l - 0.2 mg/l. The average polluted water flow rate treated by this discharge device (first stage only) is 25 m³/h, with a typical device energy consumption of 0.1 to 0.2 kWh/h-operation.

Laboratory Testing. The VL-15 C Pulsed Discharge Water Cleaning Device was tested with 15 m³/h sludge water flow rate. Its application reduced the concentrations of phenols and organic amines (monomethylamine, diethylamine, and the like) by a factor of 10 to 15. The initial contents of the original water was in excess of 30 MAC (from 0.03 to 0.0015-0.0010 mg/l for phenol). The concentrations of chloroorganic compounds were reduced by a factor of 3 to 4 for the same conditions (from 0.1-0.01 mg/l for chloroform). Adjustments were made to decrease the iron content in conformity with the Drinking Water State Standard; for example, the concentration in the original water was up to 7 mg/l and was decreased to 0.1-0.2 mg/l. With the operation mode specially adjusted for a given parameter, the efficiency of purification can be significantly increased. The ozone concentration of more than 5 mg/l generated by the process assures the safe use of treated water from an epidemiological standpoint.

In the period from November 12-28, 1991, the VL-15 installation was located near the river port

of Tomsk. During testing, several water parameters were monitored including concentrations of phenols, chloroorganic compounds, volatile amines, iron and hydrogen sulfide and biological characteristics such as the coli-index and the total microbe number (TMN). The testing demonstrated reduction of organic compound concentrations from 20 to 10 percent; the iron concentration was reduced from 3 to 0.2 mg/l; the coli index was reduced from 380 to 1 or smaller, and the TMN was reduced from 10-4.5 to slight traces. During the tests, the installation produced ozone concentrations from 20 to 40 mg/l which are in excess of the recommended by sanitary standards (6 mg/l). Biotests not only showed no possibility of forming other toxic compounds, but actually decreased toxicity by 20 to 30 percent of the initial toxicity.

Innovative collaboration between the United States biological processing (secondary stage) and the Russian pulsed power (first stage) research approaches could provide significant enhancement of final water quality, up to the total absence of residual toxicity.

WASTE APPLICABILITY

This technology is applicable to polluted sludge and waste waters contaminated with iron, toxic organic compounds (phenols, gasoline, phosphates, methylamines, etc.) and chlorinated organic compounds.

STATUS

Pulsed electric discharge devices have been developed and commercially applied in Russia, and bioremediation technologies for sludge and polluted water treatment are well-demonstrated at the University of Notre Dame (and other research facilities). The operational coupling of both techniques for an engineering demonstration remains to be accomplished (1993-94).

REGULATORY CONSIDERATIONS

Regulatory issues have not been determined.

POTENTIAL COMMERCIAL APPLICATIONS

Commercial applications include numerous municipal and industrial cleanup sites throughout the U.S. and the world. The specific DOE needs for this type of technology are related to its numerous contaminated groundwater and surface water sites as well as sludge effluents throughout the DOE weapons complex requiring treatment and/or remediation .

BASELINE TECHNOLOGY

This U.S.-Russian collaborative program will have to be compared with standard U.S. waste water treatment techniques; however, such comparisons have not been made at this time.

INTELLECTUAL PROPERTY RIGHTS

Aquapulse, Ltd., Tomsk, Russia owns rights to the pulsed power water treatment devices. There are a variety of Russian patents including: SU patent n.1069314, 1075596, CO 2F 1/46, July 9, 1982; SU patent n. 12563384, CO 2F 1/46, Nov 5 1984; SU patent n. 1151512, CO 2F 1/48, 1985. And other patents have been filed with the University of Notre Dame patent office for bioremediation technologies.

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VITRIFICATION OF LIQUID RADIOACTIVE WASTE WITH LOW AND MEDIUM LEVEL ACTIVITY FROM NUCLEAR POWER STATIONS

SVUS a.s.
Czech Republic

DESCRIPTION

Vitrification, a process of transforming components into a vitreous phase by heat treatment, may be applied to liquid radioactive wastes with low or medium level activity. The glass, as a carrier matrix, bonds the radionuclides contained in the waste. The final product has properties which allow it to be disposed for long periods without concern for contaminant migration.

components are formed by a natural aluminosilicate which is, by its composition, a suitable additive for melting purposes. The formed suspension, kept in a homogeneous state by stirring, is sufficiently stable for controlled discharging by a pneumatic feeder onto the glass melt surface at the melting end of an electrically-heated furnace. A schematic of the technology is presented in the figure below.

An effective melting aggregate operation depends

Schematic of SVUS a.s. Vitrification Technology

The technology is based on a one-stage vitrification process. The liquid radioactive wastes are re-pumped from a container to the evaporator where they are partially dehydrated. From the evaporator they are shifted to a mixing apparatus for mixing with glass forming components. These

nitrogen oxides, carbon dioxide, alkalies, boric acid, flue dust, portions of the unbounded active components - cesium and strontium) are exhausted from the melting furnace. These contaminants are captured using a system of filters, cooling devices and absorbers.

on regular feeding and a uniform distribution of charged, semi-liquid mixture ("melt") on the glass melt surface. This operation uses a furnace with ceramic lining, heated by metal electrodes immersed into the melted material. The furnace has a melting end and a suitable spout adapted for additional treatment of the melt in the forming machine. In the final phase, the automatic deposition equipment adjusts the formed vitrified product prior to storage and disposal. Water vapor and other air contaminants (e.g.,

TECHNICAL PERFORMANCE

The proposed system is capable of processing approximately 1,300 liters of treated waste per day yielding 500 kg of melted product. The cost to construct the equipment associated with this vitrification process is estimated to be approximately \$500,000 (USD). The following is additional technical and cost-related information for the vitrification of low and medium level radioactive wastes and hazardous wastes:

Vitrification of Low and Medium Level Rad Waste.

Amount of rad waste	30-43%/batch
Melting temperature	1050-1200°C
Final product	Borosilicate glass
Type of operation	Continuous
Output/day	200 kg-experiment 500 kg-designed 1000-1500 kg-mathematical modeling

Cost Data.

Output (t/day)	0.2	0.5	1.0	1.5
Construction (\$USD)	400k	500k	670k	850k
Operation (\$USD/kg)	0.85	0.55	0.35	0.27
Energy (kwh/kg)	4.5	3.6	3.0	2.8

Vitrification of Hazardous Wastes.

Amount of rad waste	50%/batch
Glass-forming comp.	waste cullet, zeolite

Types of inorganic wastes tested include waste cullet, zeolite ashes, sedimentation from industrial filters, lime and fluoride sludge, and glass grinding slurry.

Cost Data.

Output (t/day)	0.8	1.5	3.0
Construction (\$USD)	150k	200k	300k
Operation (\$USD/day)	0.7	0.4	0.25
Consumption (kwh/kg) Projected Performance	3.3	2.0	1.2

WASTE APPLICABILITY

This technology is applicable for treating low and medium level, liquid radioactive wastes as well as liquid wastes contaminated with other hazardous constituents (e.g., Pb, Cr, Cd, Ag, As, Se). The glass product formed in processing non-radioactive constituents is reported to result in a stable matrix and may be used, in some cases, as a secondary raw material for further applications.

STATUS

This technology is beyond proof-of-principal. Recently, two long-term pilot plant tests were completed using a model waste and yielded a melted product of 150 kg per day. Further development work for this technology was interrupted in 1989 (at the beginning of the political transition). There is no history of application of this specific technology within the DOE complex or elsewhere in the U.S.

REGULATORY CONSIDERATIONS

There appear to be no regulatory or public acceptance issues which are of significance with regard to the implementation of this technology at sites in the United States.

POTENTIAL COMMERCIAL APPLICATIONS

Extent of the worldwide market for this technology is not known. A market analysis was not provided by the technology developer. Specific DOE needs include treatment of low and intermediate liquid radioactive wastes within the DOE complex.

The technology developer is interested in discussing the possibilities associated with establishing foreign partners for purposes of commercializing this technology. The interests of this technology developer include transferring the technical aspects of this vitrification process through a contractual arrangement and participating in a joint development program to orient the technology to meet specific DOE needs. Ultimately, the goal of the technology developer is to commercialize the technology for international distribution.

BASELINE TECHNOLOGY

Currently there are a number of technologies which exist for the vitrification of radioactive and heavy metal bearing wastes - however, many of the commercially available technologies are reported to be for high level activity radioactive wastes (e.g., Monsanto, Pacific Northwest Laboratory, firms in Germany, France, Belgium, Japan).

INTELLECTUAL PROPERTY RIGHTS

This technology has a patent under the name of "Method of Vitrification of Liquid Radioactive Wastes with Low Activity Level" in the Slovak Republic. The patent number was not provided.

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Containment Technology Profiles

Section 4

Section 4.0

ECOSOL® CONTAMINANT ABSORBING GROUT

Soletache
France

DESCRIPTION

ECOSOL® grout has a primary application as a subsurface containment barrier. Secondary application is the treatment of contaminated groundwater with an ECOSOL® filtering trench. Another secondary application is the stabilization/solidification of hazardous wastes. ECOSOL® grout was designed specifically for constructing

Precipitation is mainly used for retaining acidic industrial wastes containing metallic ions in solution, like iron, zinc, nickel copper, lead, cadmium and tri-valent 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 physiochemical reaction depending on the specific surface area of porous material, typically clays and activated charcoal in this case (which have been added to the grout). These materials adsorb pollutants as the pollutants pass within close proximity, allowing for one or more binding mechanisms to take place. These binding mecha-

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.

nisms 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, depending on the equilibrium thermodynamics and kinetics. The design and performance assessment of barriers using this technology is carried out through numerical simulations.

A conservation of mass partial differential equation forms the basis for the simulations. In order to carry out a simulation it is necessary to specify:

- hydraulic characteristics of the site,
- the initial concentration of the pollutant,
- the temperature of the system, which must be constant, and
- the barrier thickness.

In addition, the following laboratory derived barrier parameters must be specified:

- diffusivity,
- porosity,
- permeability,
- coefficient of dispersion, and
- Freundlich coefficients.

The numerical simulations, suggest that conventional barriers begin to break down after 2-3 years, at which time solutions with effluent concentrations of nearly 57 percent emerge from the downstream side of the barrier. In contrast, ECOSOL® lasts nearly 120 years with a maximum effluent concentration of less than 4 percent. Some support may be required for laboratory and field test necessary to acquire modeling parameters. Also, support for barrier installation is required. This would replace standard barrier technologies and would support remediation efforts by controlling the migration of contaminants.

TECHNICAL PERFORMANCE

The numerical simulations, suggest that conventional barriers begin to break down after 2-3 years, at which time solutions with effluent concentrations of nearly 57 percent emerge from the downstream side of the barrier. In contrast, ECOSOL® last nearly 120 years with a maximum effluent concentration of less than 4 percent.

Limitations. This technology concentrates contaminants in the matrix of the barrier. Further

processing would be very difficult since it would entail removal of the barrier. However, in some cases this may be acceptable where the level of performance offsets the limitations. Some designs incorporate the use of a removable cartridge that facilitates secondary processing of collected contaminants.

Cost & Schedule Re/Implementation. No information available at this time on specific costs.

Safety Re/Implementation. None known.

WASTE APPLICABILITY

As a containment barrier this technology could be applied to a large variety of waste types. As a treatment method, this technology applies only to groundwater.

Installation requires access for heavy equipment, such as drilling and trenching equipment. Once the barrier is installed there are no special requirements.

STATUS

Fully developed and applied in several projects. None known.

Contact the developer for case histories and performance data based on several projects.

REGULATORY CONSIDERATIONS

No issues or problems are foreseen.

POTENTIAL COMMERCIAL APPLICATIONS

Potential commercial applications would include industries where containment of all types of wastes to control migration of contaminants is required in support of the industry's remediation

efforts: Treatment of groundwater contaminated with heavy metals and organics. Commercial market is potentially very large as the range of applicable waste types is also large.

BASELINE TECHNOLOGY

Standard grout technologies are the baseline for containment. Pump and treat and bioremediation methods are the baseline for groundwater treatment.

This technology exceeds the retention properties and life span of conventional grouts, but may do so at a higher cost. The advantage with this technology in groundwater treatment is that it contains and treats simultaneously, which provides a performance advantage that may (if used in place of conventional methods) save money over the life of the project. If used in conjunction with baseline treatment methods, the cost would be greater but the performance of the remediation project may be substantially increased.

INTELLECTUAL PROPERTY RIGHTS

Patented in the U.S. and Europe. No patent numbers provided at this time.

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HYDROFRAISE® SUBSURFACE CONTAINMENT WALL CONSTRUCTION

Solentanche
France

DESCRIPTION

Hydrofraise® is a commercially available drilling machine for constructing containment walls in soils. The 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. The device creates a slot 2.4-m long and 0.6- to 1.5-m thick. A pump placed just above the drums evacuates the loosened soil which is carried to the surface as 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. The design of the system makes it possible to drill diaphragm wall elements in a wide range of soil conditions from cohesionless soils to hard rock. The equipment is capable of installing containment walls up to 125-m in depth.

The Hydrofraise device has been used successfully in Europe and Japan to construct low-permeability barriers around contaminated soils and landfill sites. All required equipment and support are available from the technology developer (Solentanche), including barrier material, a mixing plant, and injection pumps. The barrier material is typically ECOSOL slurry with a geomembrane insert. Cement-based and bentonite-based material have been applied in Europe and the USA.

Hydrofraise can operate only in a vertical mode. Applications requires existence of natural horizontal barrier at depth and possibly a cover to prevent recharge and contaminant transport within the contained region.

TECHNICAL PERFORMANCE

General Specifications.

The system is capable of installing low permeability containment walls in a very wide range of media from cohesionless soils (silt, sand, gravel

Generic Hydrofraise Application

and cobbles to 10 cm) to hard soil. Vibration and shock are minimal; overbreak is less than 10 percent, and can be vertically controlled to within 0.2 percent. Excavation rates are inversely proportional to soil hardness, ranging from more than 20 m³/hr (for cohesionless soils) to 1 m³/hr (for the case of hard soil). Performance of the wall is also a function of the barrier material to be used. Cement-based and bentonite-based materials, as well as ECOSOL slurry with geomembrane inserts, have been applied in Europe and in the United States.

Full-Scale Applications. Solentanche has constructed numerous cutoff walls associated with building construction sites around the world since 1976. Hydrofraise® was successfully used to construct a diaphragm wall for the Sizenell B nuclear power plant in England (1987). The wall was 1260-m long, 55-m deep, and 0.8-m thick. The wall was constructed in 20 weeks.

Cost Data. The cost and implementation schedule depends on the size of barrier and site conditions. Solentanche states that its costs are competitive with other available methods. Detailed cost estimates are available from Solentanche.

WASTE APPLICABILITY

Hydrofraise subsurface barrier construction is applicable to landfills, buried waste sites, contaminant spills, and above-ground and underground storage tanks to contain virtually any type or amount of contaminants. However, Hydrofraise is limited to operation in the vertical mode, and its application requires existence of natural horizontal subsurface barrier such as a rock or clay layer.

STATUS

The development of this technology is complete, and it has been applied numerous times in full-scale industrial applications.

REGULATORY CONSIDERATIONS

No regulatory restrictions of this technology are known.

POTENTIAL COMMERCIAL APPLICATIONS

Industrial applications include chemical companies, industrial waste landfills, refineries, and fuel storage facilities. Specific DOE needs and applications include in-situ, lateral containment of virtually any type or amount of contaminant such as around leaking tanks where lateral transport dominates or where a cover would reduce recharge. Currently, Solentanche has no U.S. partner although the company has conducted operations in the United States. Solentanche may be interested in licensing agreements.

BASELINE TECHNOLOGY

The baseline technology is conventional slurry wall technology. Compared to conventional slurry wall technology, Hydrofraise tends to provide a higher quality wall with less construction interference, at similar costs, schedule, etc. A similar technology has been developed in Japan: the Seiko SMV technique and Taiser "Trust" technique.[2]

INTELLECTUAL PROPERTY RIGHTS

A patent is held by Solentanche (a French owned company), and Hydrofraise has no government investment.

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IN SITU BARRIER CONSTRUCTION WITH MONTAN WAX EMULSION

Vereinigte Mitteldeutsche Braunkohlenwerke AG (MIBRAG)
Germany

DESCRIPTION

Montan wax is the primary component of a mineral wax emulsion developed in Germany by Vereinigte Mitteldeutsche Braunkohlenwerke AG (MIBRAG), a large industrial company with headquarters in Bitterfeld, Germany. The montan wax emulsion is currently being evaluated as a grout for construction of subsurface barriers for remediation of contaminated sites. MIBRAG was responsible for lignite coal mining operations in the eastern portion of the former German Democratic Republic and operates a number of coal gasification plants in the area. Within the lignite coal fields operated by MIBRAG are the world's largest known deposits of montan wax. A plant in Amsdorf has produced most of the world's supply since the early 1900s. Montan wax is a fossil plant wax with properties similar to natural plant waxes such as those found in carnauba palms. The wax is a hard, high-melting point, non-toxic material used in carbon inks, emulsions, polishes and lubricants. It is comprised of a mixture of waxes, resins, and asphaltene-like materials composed of C-24 to C-32 carbon chain esters of long chained acids and alcohols.

The idea to use montan wax to construct containment barriers came about because of the serious environmental problems in the Bitterfeld area. There are several industrial waste disposal pits where leachates are entering the local aquifer contaminating the drinking water supply. Site remediation may take many years to accomplish because of the large volume of material involved and the associated costs. In an attempt to address this problem, MIBRAG began testing the feasibility of creating containment barriers with mon-

tan wax emulsions in several field demonstration projects in the area. The sites contained unconsolidated soils with relatively high hydraulic conductivities (e.g., 10^{-3} cm/s). After permeating the soils with a mixture of montan wax, water and bentonite, the conductivity of the soil was reduced by as much as five orders of magnitude.

Montan wax grout is a particulate-type grout consisting of a stable emulsion of montan wax, water and surfactant. The grout is formed by injecting a stream of melted wax into water at near boiling temperature where the wax solidifies into small particles. The size of the wax particles can be controlled to some extent by varying the temperature of the wax and water or by mechanically shearing the particles after they are formed. A small amount of surfactant is added to the mixture to create an emulsion. Immediately prior to injection of the grout, a small amount of bentonite clay is added to the emulsion. The surfactant sorbs to the added bentonite, breaking the emulsion and allowing the wax particles to begin to adhere to one another. Inside the soil matrix, the wax particles continue to aggregate, thereby increasing in size, move through void spaces in the soil until they bridge an opening and become fixed. The blockage of interconnected pores reduces the permeability of the soil and the rate of advective transport of contaminants.

Emplacement of the subsurface grout barrier can be performed with several technologies. The work performed employs permeation grouting, a standard grout emplacement method. Vertical boreholes have been used for the permeation grouting in this test program, but directional (inclined) boreholes can also be employed. Jet grouting is another possible placement method.

TECHNICAL PERFORMANCE

Laboratory Scale. Grout permeation experiments and chemical compatibility tests have been performed to assess the performance of the montan wax grout. The grout permeation experiments included characterization and testing of soils from three sites: the Hanford Site, Sandia National Laboratories, and the Idaho National Engineering Laboratory (INEL). Hydraulic conductivities of soils from each site were measured to establish pre-grouting permeabilities. The soils were then permeated with grout and post-grouting hydraulic conductivities were measured.

The laboratory tests indicated that the montan wax grouts can be successfully permeated into sand and gravel type soils from Hanford and Sandia. Grout permeation into silty clay samples from INEL was not possible with the grout, because of the high percentage of fine material in the samples. The grout significantly reduced the hydraulic conductivity of the Hanford and Sandia soil with one Hanford sample showing an estimated reduction of six orders of magnitude. The grout appears to be compatible with most of the common types of hazardous waste, with the exception of glycols which rapidly degrade the grout. Radiation compatibility testing has not yet been performed.

Field Scale. A field study involving a series of single-borehole injection tests was performed at Sandia to evaluate the penetration characteristic of the montan wax grouts over a range of soil conditions and formulations. Four grout injection boreholes were prepared, and geophysical boreholes were located between the injection boreholes at 1-m intervals to track the movement of the grout front. The injection boreholes at the test site were spaced 3-m to 4-m apart in an effort to create overlapping grout fronts between adjacent injection boreholes.

Grout injection was accomplished using the tube à manchette method, a standard grout emplace-

ment technique. Grout was injected at specific depths through perforations located at regular intervals in the casing. Downhole geophysical methods for measuring electromagnetic resistivity, moisture content, and temperature were useful for tracking the arrival of the grout in the vicinity of a borehole. The penetration distance of the grouts from the injection borehole typically ranged between 1 and 2 meters.

The single-borehole tests indicated that the montan wax grout can be emplaced in unconsolidated soils with conventional grout permeation methods, provided the soils have sufficiently high permeability. Grout injection was attempted in a number of soil types and depths in each of the injection boreholes, but grout permeation was limited to the higher permeability zones. Attempts to inject grout in the low permeability soils resulted in unacceptable injection pressures (i.e., capable of hydraulically fracturing the soil) or fracturing of the annular region surrounding the grout injection pipe. The minimum hydraulic conductivity for permeation grouting appears to be around 5×10^{-4} cm/s for the montan wax grout.

The second phase of field testing will incorporate multiple-borehole tests performed to evaluate the feasibility of constructing a competent subsurface barrier of sufficient lateral extent and hydraulic integrity to support DOE environmental restoration needs. Site selection for the tests is currently in progress. Post-test characterization will include large double-ring infiltrometer tests of the barrier, followed by excavation and inspection of the barrier.

Cost Data. The montan wax costs between \$0.52 - \$0.82 per liter depending on the bentonite content. The grout is currently manufactured in Germany, and shipping costs to the U.S. are considerable. If demand were sufficiently high, manufacturing of the products could be done in the U.S. Emplacement of the grout requires the same equipment normally used by a grouting contrac-

tor. Assuming installation, shipping, and mark-up costs are comparable with other specialty grouts, the total cost is estimated to range from \$45 - \$80 per m³.

WASTE APPLICABILITY

Subsurface barriers can be used to contain known contamination long enough to allow realistic planning, scheduling, and budgeting for remediation or the development of new technology. Barriers can also be used as a backup measure during other cleanup activities. Grouts are of interest because they provide a means for creating, in situ, a containment system that will limit further movement of contaminants until they can be safely and effectively removed. The montan wax grout appears to be compatible with most of the common types of hazardous waste, with the exception of glycols which rapidly degrade the grout. Radiation compatibility testing has not yet been performed.

STATUS

The technology is in the field stage of development. The second phase of field testing will incorporate multiple-borehole tests performed to evaluate the feasibility of constructing a competent subsurface barrier of sufficient lateral extent and hydraulic integrity to support DOE environmental restoration needs. Radiation compatibility tests and additional durability studies are also planned.

REGULATORY CONSIDERATIONS

U.S. regulatory issues restricting the use of this technology have not been identified.

POTENTIAL COMMERCIAL APPLICATIONS

A market survey has not been done in the U.S., and the market potential is unknown. However, site owners with contaminant sources such as leaking tanks would be likely candidates for use of the technology. Barrier placement would be particularly useful in situations where appropriate final remediation technologies have not yet been developed. The montan wax grout also has potential to enhance other remedial technologies, by providing an in situ method for flow redirection.

BASELINE TECHNOLOGY

This grout may be compared with typical chemical grouts, including sodium silicate grouts. Comparisons with laboratory grout permeation studies using glyoxal-modified sodium silicate grout have indicated that the montan wax results in lower post-grouting hydraulic conductivity values.

INTELLECTUAL PROPERTY RIGHTS

A patent on the montan wax emulsion is held by Vereinigte Mitteldeutsche Braunkohlenwerke AG (MIBRAG) of Bitterfeld, Germany.

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BASELINE TECHNOLOGY

For horizontal containment (up to 30 m deep), slurry wall, interceptor trenches, sheet piles and Withdrawl wells are the baseline technologies. At greater depths, clay-based grouting is the baseline technology.

INTELLECTUAL PROPERTY RIGHTS

STG owns the intellectual property rights.

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Conclusions

Section 5.0

5.0

CONCLUSIONS

The International Technology Exchange Staff of the U.S. Department of Energy (DOE) has been instrumental in identifying and evaluating international technologies that have a high potential for meeting DOE's environmental restoration and waste management technology needs. This International Technology Catalogue is designed to serve as a vehicle for the DOE to facilitate interactions between U.S. businesses and foreign technology developers and to assist with the potential for the import of innovative technologies to the DOE complex.

The International Technology Catalogue contains information that can also be used to identify opportunities for collaborations with U.S. commercial partners and enhance the U.S. environmental industry as a whole. Information cited in each technology description and profile consists of that available at the time of printing of this publication. Interested U.S. businesses are invited to review the information and pursue, with the foreign developer indicated in the technology profile, any interactions that would be appropriate for the technology involved.

The references cited in this publication provide a source of additional information that pertains to the screening, selection and evaluation of applicable foreign environmental technologies to the DOE complex. These references also contain summaries of activities performed by the International Coordination task teams supported by the DOE/EM-52.1 staff and budget allocations.

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