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Office of Environmental Management

Office of Technology Development

Technology Catalogue

First Edition

MASTER

February 1994

ACKNOWLEDGMENTS

As a result of discussions with various program officials within the Office of Environmental Restoration and Waste Management (EM), and the recognized need to enhance communication between technology developers and potential end users, the EM Office of Technology Development developed the FY93 Technology Catalogue. The development of the Technology Catalogue is the result of a team effort by a number of individuals. The project was initiated and managed by Joe Paladino, DOE Program Manager. The work was contracted to Sandia National Laboratories (SNL), New Mexico and managed by Nancy Prindle, SNL Principal Investigator. Applied Sciences Laboratory, Inc. (ASL) of Albuquerque, New Mexico supported SNL in developing the Technology Catalogue. Critical roles were performed by Richard Jimenez, Charlene Esparza-Baca, John Reardon, John Smith, and Mike Lyons of ASL in developing the prototype and technology profiles. Thanks to Patricia Trujillo of ASL for the wonderful editing.

Special thanks goes to Jeff Lenhert, DOE Albuquerque Operations Office; Stephen Warren, Bill Schutte, Tom Crandall, and Skip Chamberlain of EM; and Margaret Chu of SNL; for their invaluable comments and support. Others are thanked in particular for providing technical data and support: Gretchen McCabe, Steve Stein, Ann Lesperance and Paul Zakian of Battelle Seattle Research Center for providing ProTech Database information, and the following principal investigators and engineers of the DOE national laboratories or management and operations contractors: Roger Aines, Scott Couture, Terry Hazen, Eric Lindgren, Brian Looney, Jerry Mercer, Jim Phelan, Chester Shepard, John Tixier, Bob Wemple, and Cecilia Williams.

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Introduction

Section 1.0

1.0 INTRODUCTION

The Department of Energy's Office of Environmental Restoration and Waste Management (EM) is responsible for remediating its contaminated sites and managing its waste inventory in a safe and efficient manner. EM's Office of Technology Development (OTD) supports applied research and demonstration efforts to develop and transfer innovative, cost-effective technologies to its site clean-up and waste management programs within EM's Office of Environmental Restoration and Office of Waste Management. The purpose of the Technology Catalogue is to provide performance data on OTD-developed technologies to scientists and engineers assessing and recommending technical solutions within the Department's clean-up and waste management programs, as well as to industry, other federal and state agencies, and the academic community.

OTD's applied research and demonstration activities are conducted in programs referred to as Integrated Demonstrations (IDs) and Integrated Programs (IPs). The IDs test and evaluate systems, consisting of coupled technologies, at specific sites to address generic problems, such as the sensing, treatment, and disposal of buried waste containers. The IPs support applied research activities in specific applications areas, such as in situ remediation, efficient separations processes, and site characterization. OTD works with industries, universities, and other federal agencies, in conjunction with the federal laboratories, to access and advance the best available technologies. Many of the technologies have been successfully demonstrated in the field and now are sufficiently mature to be transferred. The Technology Catalogue is a means for communicating the status of the development of these innovative technologies.

The FY93 Technology Catalogue features technologies successfully demonstrated in the field through IDs and sufficiently mature to be used in the near-term. Technologies from the following IDs are featured in the FY93 Technology Catalogue:

- Buried Waste ID (Idaho National Engineering Laboratory, Idaho)
- Mixed Waste Landfill ID (Sandia National Laboratories, New Mexico)
- Underground Storage Tank ID (Hanford, Washington)
- Volatile organic compound (VOC) Arid ID (Richland, Washington) , and
- VOC Non-Arid ID (Savannah River Site, South Carolina)

Several methodologies were employed to select and prepare technology profiles. Factors affecting the selection of technologies include the availability and quality of technical information, and the maturity of the technology. The primary source of information for the FY93 Technology Catalogue was the ProTech Prospective Technology Database developed by Battelle Seattle Research Center for the DOE. ProTech is a prototype electronic system that describes innovative technologies that are part of IDs. Additional sources of information included technical task plans, conference proceedings, technical journals, environmental permit applications, and data supplied by principal investigators.

Forty-three technologies are featured in the FY93 Technology Catalogue. Of the 43 technologies, 22 are characterization/monitoring technologies and 21 are remediation technologies. Technology entries are three to four pages long and include the following topical areas:

- Technology title and description
- Technical performance and cost data
- Projected near-term performance (1 to 3 years)
- Applicable waste types and forms
- Development status
- Key regulatory considerations regarding the application of the technology
- Potential non-DOE applications
- Baseline comparison technology
- Intellectual property rights, and
- Points-of-contact and references for more information.

The information in each category above introduces the technology to the reader and provides an annual "snapshot" of its status with respect to performance and availability. More detailed information can be obtained from the sources cited in each profile.

HOW TO USE THE DOCUMENT

The Technology Catalogue attempts to match applications with specific technologies in addition to providing profiles on each technology. Section 2 describes the development process utilized to select and prepare technology profiles. Section 3 contains waste applicability tables developed to aid the user in matching applications with each technology. These tables include: Table A which addresses Site Characterization and Monitoring Technologies; Table B which addresses Site Remediation Technologies; and Table C which in the future will contain Waste Management Technologies. Section 4 contains Site Characterization and Monitoring Technologies and Section 5 contains Site Remediation Technologies. Waste Management Technologies will be added in FY94.

For more information, please contact:

The DOE/OTD Environmental Technology Information Service
1-800-845-2096

FUTURE EDITIONS/UPDATES

As illustrated in figure A, future editions of the Technology Catalogue will include updated information, additional technologies being developed under IDs (such as waste management technologies) and information from a broader range of OTD programs. For example, technologies being developed under OTD's Integrated Programs (IPs) may be incorporated. Additional examples include technologies developed under Research Opportunity Announcements (ROAs) and Program Research and Development Announcements (PRDAs).

Also, the Technology Catalogue currently serves as a source of information for DOE's EnviroTRADE Information System. Future plans include applying the Technology Catalogue to the DOE International Technology Exchange Program to enhance the competitiveness of U.S. businesses. In addition, discussions are continuing with the U.S. Department of Defense and the U.S. Environmental Protection Agency to provide information on DOE's emerging technologies for federal environmental databases and other commercially available databases.

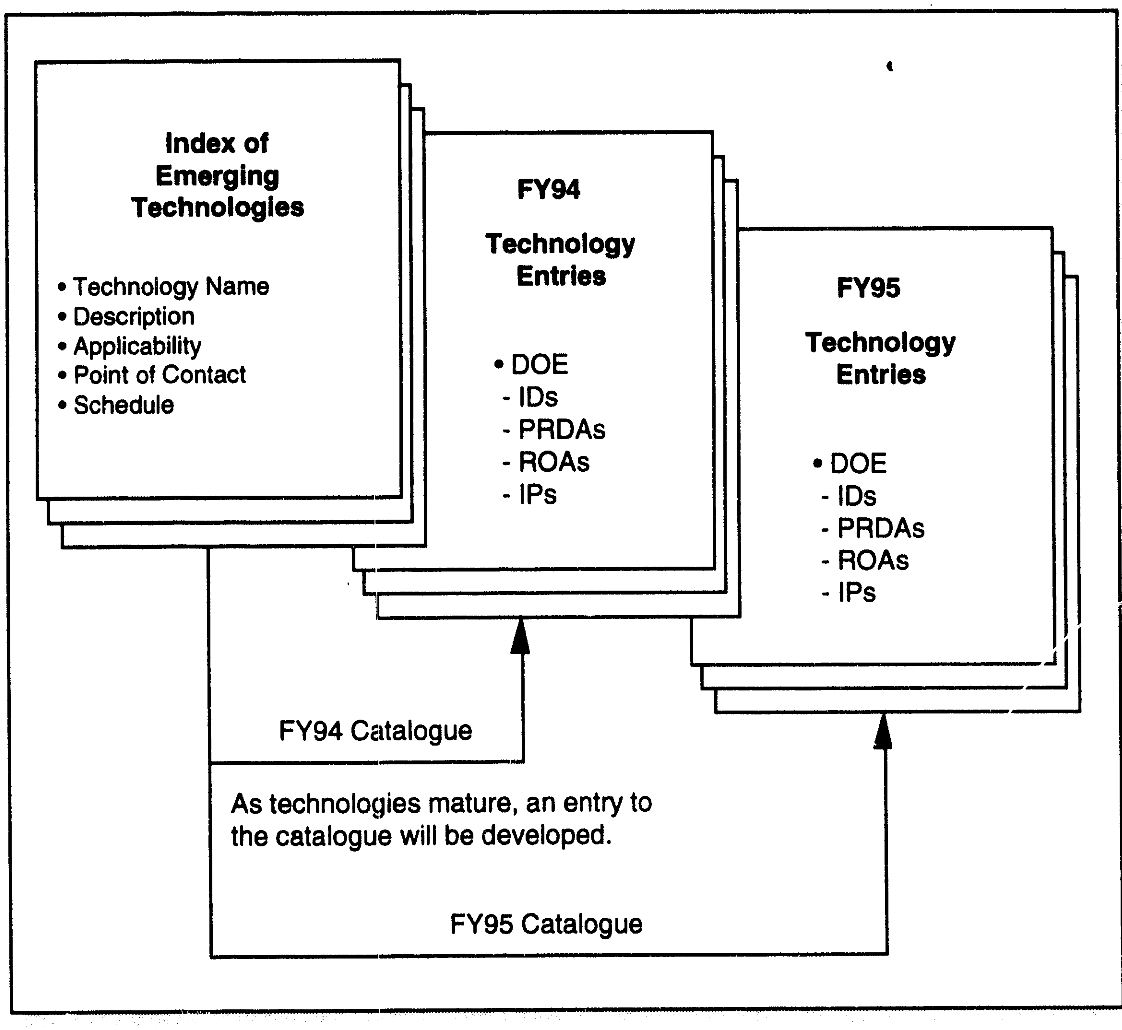


Figure A. Future Development of the DOE-OTD Technology Catalogue.

Development Process

Section 2.0

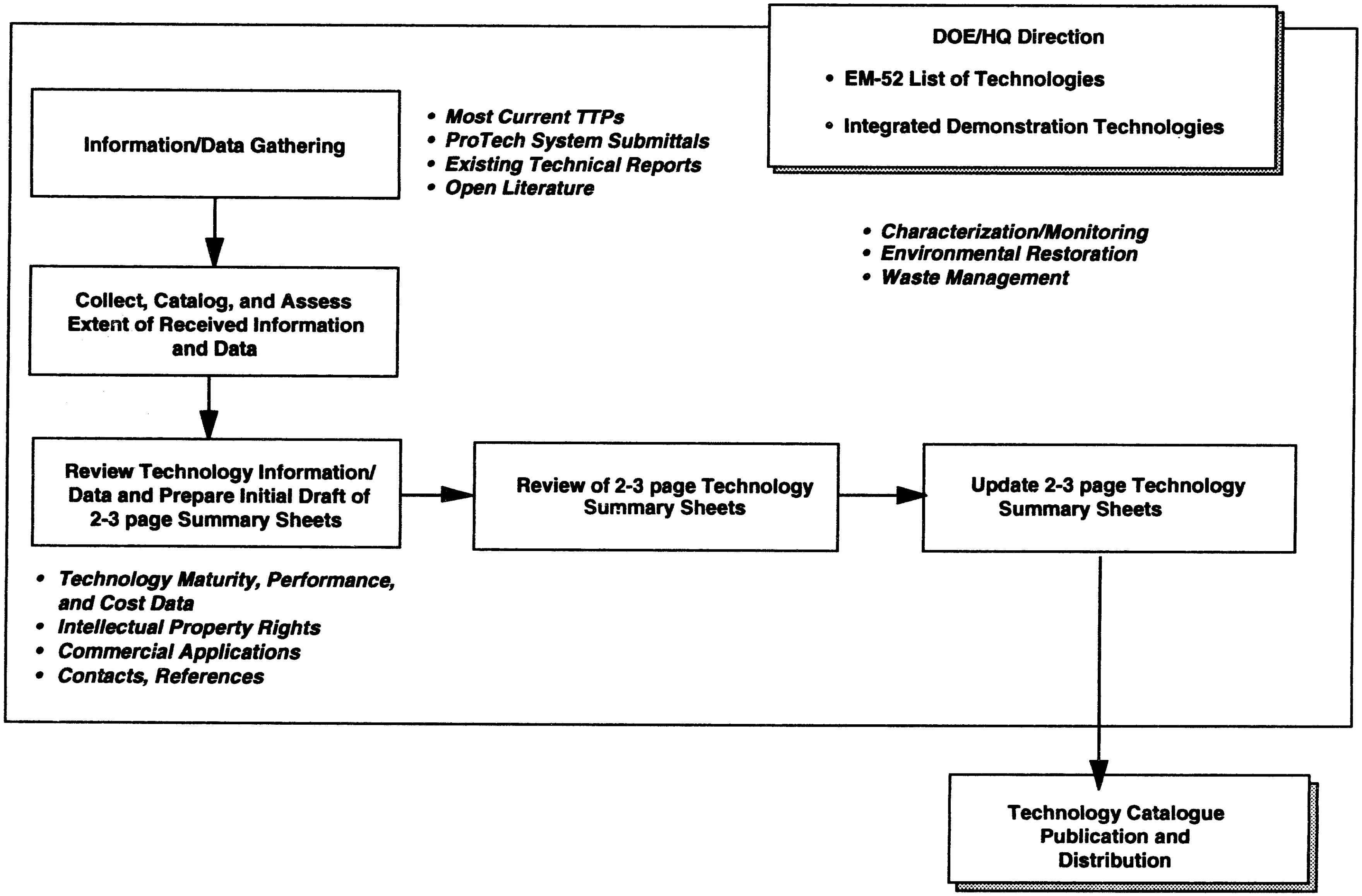
2.0 DEVELOPMENT PROCESS

The methodology applied for selecting technologies to be included in the FY93 Technology Catalogue began with a list of approximately 30 technologies developed by EM-52 in October 1992. Approximately 17 of the 30 technologies are featured in the FY93 Technology Catalogue. The methodology for selection of the remaining technologies featured in the FY93 Technology Catalogue began with a review of the ProTech Prospective Database technology profiles. ProTech developed by Battelle Pacific Northwest Laboratory for DOE is a prototype electronic system that describes innovative technologies of the IDs and was developed for use by the general public. The review was performed to determine which profiles were on the original list developed by EM-52. Those selected were mature (available currently or within the next 2-3 years) and contained sufficient technical detail (performance, cost, etc.). Of approximately 100 technology profiles reviewed, 34 were selected for inclusion in the FY93 Technology Catalogue.

The methodology utilized to prepare the technology entries is illustrated in Figure 1. While the primary source of information and data featured in the Technology Catalogue was ProTech, a number of other sources were utilized. Some of these sources include technical task plans (TTPs), conference proceedings, technical journals, environmental permit applications, and readily available technical documentation.

Once sufficient information was gathered, it was reviewed for clarity, consistency, and quality of technical information. The entry was then technically edited and revised. All entries were then consolidated into the FY93 Technology Catalogue for publication and distribution.

Figure 1. FY93 Technology Catalogue Development Process



Waste Applicability Tables

Section 3.0

Table A. Site Characterization and Monitoring Technologies by Waste Contaminant

TECHNOLOGY	MEDIA	WASTE CONTAMINANT	DESCRIPTION	SPEED	PAGE NO.
METALS					
On-Site Analysis of Metals in Soils Using Stripping Voltammetry	Soils, Sediments	Al, Au, Ca, Cd, Co, Cr, Cu, Fe, Mo, Pb,Pd, Pt, Ni, Ru, Sn, Tc, Th, Ti, U, Va, Y, Zn	An in-field analytical method capable of measuring concentrations of selected trace metals.	Total Cr analysis 8 minutes per sample. Other elements to be determined.	69
Rapid Geophysical Surveyor	Soil	Ferrous contaminants	Provides high resolution geophysical data.	Can collect magnetic data at rates up to 25,000 data points per hour.	81
X-Ray Fluorescence Spectroscopy	Arid soils	Heavy metals, Cr, Ni, Cu, Zn, Hg, Pb	Measures concentrations of heavy metals in soils.	Spectrum takes about 5 min depending on what is being looked for and	109
ORGANICS					
Cone Penetrometer	Soil	Hydrocarbons, chloro-hydrocarbons, carbon tetrachloride	A truck mounted device that rapidly penetrates the ground to collect site data.	Pushes at a rate of 30-40 feet per half hour except in mixed waste environments.	35
Fiber-Optic Sensors	Groundwater, vadose zone, vapor extraction off-gases	VOCs, carbon tetrachloride	Optic fibers transmit probe signals to remotely located sensors to provide a real-time multipoint monitoring capability.	Not available.	43
HaloSnif Fiber-Optic Spectro-chemical Sensor	Air, gases	Volatile chlorine containing compounds TCE, PCE, CFCs	A real-time compound class specific sensor.	Real-time results.	49

Table A. Site Characterization and Monitoring Technologies by Waste Contaminant

TECHNOLOGY	MEDIA	WASTE CONTAMINANT	DESCRIPTION	SPEED	PAGE NO.
ORGANICS (continued)					
Portable Acoustic Wave Sensor	Soil, vapor, water	VOCs, TCE Carbon tetrachloride,	Monitors changes in the speed and power of a wave as it travels across the sensor.	Rapid (2 seconds) and continuous analysis possible.	73
Unsaturated Flow Apparatus Centrifuge	Soil, vadose zone	VOCs	Simulates migration of contaminants of subsurface environments of arid sites to obtain transport data.	Can achieve results in 3 days.	105
RADIOACTIVE					
Cone Penetrometer	Soil	Radionuclides	A truck mounted device that rapidly penetrates the ground to collect site data.	Pushes at a rate of 30-40 feet per half hour except in mixed waste environments.	35
Prompt Fission Neutron Logging System	Soil and rock surrounding a cased borehole	Fissile materials U-235, Pu-239	Provides a near-continuous profile of contaminants as a function of position along a borehole.	Approximately 3 hr are necessary to log and analyze a typical 100 ft borehole.	77
Rapid Transuranic Monitoring Unit	Soil, smears, fallout coupons, filters, air, liquids	Pu, Am, alpha emitters and entire gamma spectrum from X-rays to Co-60 and Cs-137	Provides rapid in-field monitoring	Can analyze 100 samples per day.	85

Table A. Site Characterization and Monitoring Technologies by Waste Contaminant

TECHNOLOGY	MEDIA	WASTE CONTAMINANT	DESCRIPTION	SPEED	PAGE NO.
OTHER/SUPPORT					
Advanced In Situ Moisture Logging System	Arid soils, rock	N/A	Measures moisture content and soil density around access tubing.	Varies. Typically 15 min per 100 ft of tube.	23
Broadband Electro-magnetics for Three Dimensional Site Characterization	Soil	N/A	Three dimensional characterization of buried waste.	A survey requiring detail coverage over 1/2 acre can be performed in one day.	27
Colloidal Borescope	Groundwater	N/A	Direct observation of colloidal size particles and subsequent ground-water flow direction and rate.	30 min to obtain a measurement.	31
Crosswell Seismic Imaging	Soil or rock	N/A	Imaging of goelogy between boreholes non-intrusively.	Data collection 1-3 wk. Interpretation 1-2 mo.	39
Hybrid Directional Boring and Horizontal Logging	Wide range of geologies	N/A	Provides direc-tional access in desired locations.	Dependent on geology. Clays - 200 ft/d Alluvial fills - 100 ft/d.	53
In Situ Permeable Flow Sensor	Saturated, permeable unconsolidated materials	N/A	Measures full three dimensional flow velocity vector.	Velocity measurements in 24-48 h.	57
Light Duty Utility Arm System for Tank Characterization	N/A	Underground storage tank wastes	Provides the capability to gather data on chemical and physical characteristics in undergroundstorage tanks.	N/A	61
Microbial Monitoring	Soil, groundwater bioreactors	N/A	Monitors microbial population changes in soil and ground water samples.	Analysis in complete in 2 days to 1 month depending on technique used.	65

Table A. Site Characterization and Monitoring Technologies by Waste Contaminant

TECHNOLOGY	MEDIA	WASTE CONTAMINANT	DESCRIPTION	SPEED	PAGE NO.
OTHER/SUPPORT (continued)					
Rapid Geophysical Surveyor	Soil containers	Buried ferrous	Provides high resolution geophysical data.	Can collect magnetic data at rates up to 25,000 data points per hour.	81
Remote Characterization System	Soil	N/A	Vehicle remotely delivers several geophysical sensors to a buried waste site to obtain data.	Vehicle can travel 1 to 6 ft/s.	89
SEAMIST Borehole Instrumentation and Fluid Sampling System	Soil, vapor	N/A	Provides multiple vapor sampling/ monitoring locations in a single borehole for unsaturated zone and air permeability measurements.	Up to 30 ft/min.	93
Slant Angle Sonic Drilling	Soil, rock	N/A	A method of rapid access to the subsurface for installation of a sloped well using resonant drilling.	Varies depending on the type of formation. 1 ft/s to 0.5 ft/min. for loose to compact formations respectively.	97
Sonic Drilling	Vadose zone, groundwater	N/A	An advanced and improved drillingtechnology .	Drills holes at double the rate of a cable tool.	101
Unsaturated Flow Apparatus Centrifuge	Soil	Wide range of contaminants, water, microbial nutrients	Simulates migration of contaminants of subsurface envi-ronments of arid sites to obtain transport data.	Can achieve results in 3 days.	105

Table B. Site Remediation Technologies by Waste Contaminant

TECHNOLOGY	MEDIA	WASTE CONTAMINANT	DESCRIPTION	PAGE NO.
METALS				
Arc Melter Vitrification	Soil	Toxic metals	Vitrification	115
Barriers and Post Closure Monitoring	Arid soils	Soluble metals	Containment/ Treatment	119
Biological Destruction of Tank Waste	Supernatents, aqueous streams	Toxic metals	Biosorption	123
In Situ Vitrification of Contaminated Soils	Soil	Heavy metals	Destruction/ Immobilization	163
Polyethylene Encap sulation of Radio-nuclides and Heavy Metals	Aqueous salt and concentrate, saltcake, sludge, ash, ion exhange resin in tanks	Toxic metals, Cr, Pb, Cd	Encapsulation	173
MIXED WASTE				
Arc Melter Vitrification	Soil	Mixed waste (TRU)	Vitrification	115
Dynamic Underground Stripping of VOCs	Soil, groundwater	Mixed waste	Enhanced Removal	139
Fixed Hearth DC Plasma Torch Process	Soil, stored waste	Mixed waste	Waste Form Enhancement	143
In Situ Vitrification of Contaminated Soils	Soil	Mixed waste	Immobilization	163
ORGANICS				
Arc Melter Vitrification	Soil	Organics	Vitrification	115
Barriers and Post-Closure Monitoring	Arid soils	VOCs, organics	Containment/ Treatment	119
Biological Destruction of Tank Waste	Supernatents, aqueous streams	Organics	Biosorption	123

Table B. Site Remediation Technologies by Waste Contaminant

TECHNOLOGY	MEDIA	WASTE CONTAMINANT	DESCRIPTION	PAGE NO.
ORGANICS (continued)				
Dynamic Underground Stripping of VOCs	Soil, groundwater	VOCs	Enhanced Removal	139
Fixed Hearth DC Plasma Torch Process	Soil, stored waste	Organics	Waste Form Enhancement	143
High-Energy Corona	Gas, aqueous liquids, non-aqueous liquids	VOCs, halogenated solvents TCE, PCE, carbon tetrachloride, chloroform, diesel fuel, gasoline	Destruction	147
In Situ Air Stripping of VOCs	Permeable soils, groundwater	VOCs, light hydro-carbons, chlorinated solvents, TCE, PCE	Enhanced Removal	159
In Situ Vitrification of Contaminated Soils	Soil	VOCs	Destruction/ Immobilization	163
Methane Enhanced Bioremediation for the Destruction of Trichloroethylene	Soil, groundwater	Halogenated aliphatic organics, TCA, TCE, PCE	Cometabolic Destruction	167
Six- Phase Soil Heating	Soil	VOCs, SVOCs	Extraction	185
Steam Reforming	Offgas of soil	Halogenated solvents, carbon tetrachloride, chloroform adsorbed on granular activated carbon beds	Destruction	189
Thermal Enhanced Vapor ExtractionSystem	Arid soils	VOCs, SVOCs, VOC -oil mixtures, chemicals with vapor pressures <0.002 atm @ 20°C	Extraction	193
VOC Off-gas Membrane Separation	Gas stream	VOCs, halogentated solvents carbon-tetrachloride, chloroform	Membrane Separation	199

Table B. Site Remediation Technologies by Waste Contaminant

TECHNOLOGY	MEDIA	WASTE CONTAMINANT	DESCRIPTION	PAGE NO.
RADIOACTIVE				
Biological Destruction of Tank Waste	Supernatant, aqueos streams	Various radionuclides, TRU	Separation Volume Reduction	123
Complact Processing Units for Radioactive Waste Treatment	Liquids, sludges, slurries	High-level, low-level, TRU	Biosorption	127
Cryogenic Retrieval of Buried Waste	Soil	TRU	Freezing/Retrieval Containment	131
In Situ Vitrification of Contaminated Soils	Soil	Various radio-nuclides, TRU	Immobilization	163
Polyethylene Encapsualtion of Radionuclides and Heavy Metals	Aqueous salt and concentrate, saltcake, sludge, ash, ion exchange resin in tanks	Various radio-nuclides, TRU	Encapsulation	173
Resorcinol-Form aldehyde Ion Exchange Resin for Cesium Removal	Cs supernate salt streams	Cs	Ion Exchange	181

Table B. Site Remediation Technologies by Waste Contaminant

TECHNOLOGY	MEDIA	WASTE CONTAMINANT	DESCRIPTION	PAGE NO.
OTHER or WASTE INDEPENDENT				
Biological Destruction of Tank Wastes	Supernatents, aqueous streams	Nitrate	Separation Volume Reduction	123
Cryogenic Retrieval of Buried Waste	Soil, buried waste	Hazardous waste	Freezing/ Containment	131
Decision Support System to Select Migration Barrier Cover Systems	Arid and humid soils	N/A	Multi-objective Decision Making Software System	135
Dynamic Underground Stripping of VOCs	Soil, groundwater	NAPLs, DNAPLs	Enhanced Removal	139
Fixed Hearth DC Plasma Torch	Soil, stored waste	Wide variety of solid and liquid wastes, inorganics	Waste Form Enhancement	143
High Pressure Waterjet Dislodging and Conveyance End Effector Using Confined Sluicing	Supenatent, sludge, saltcake in tanks	N/A	Confined Sluicing	151
Hydraulic Impact End Effector	Hard waste forms in tanks	N/A	Fracturing	155
Remote Excavation System	Soil	Buried waste	Retrieval	177

TABLE C. SITE REMEDIATION TECHNOLOGIES BY WASTE CONTAMINANT

RESERVED

Site Characterization and Monitoring Technology Profiles

Section 4.0

ADVANCED IN SITU MOISTURE LOGGING SYSTEM

Sandia National Laboratories

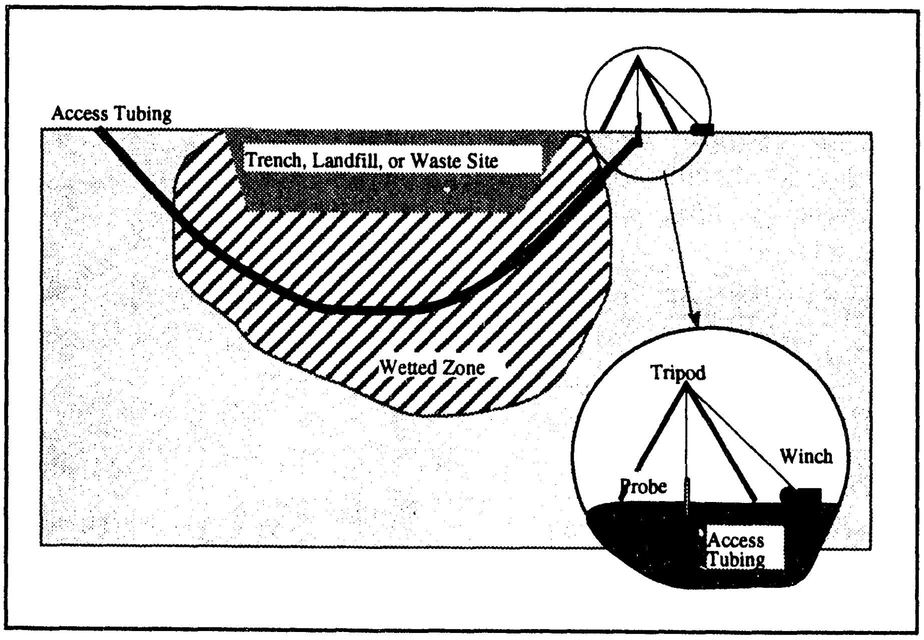
DESCRIPTION

The Advanced In Situ Moisture Logging System measures moisture content and soil density around access tubing within the soil/rock medium. These measurements determine the changes in fluid potential that, in turn, are indicative of leakage/contaminant movement from a waste site. The device is self-contained and programmable, making the application faster and easier, with longer access tubing capabilities than are available in conventional technology. The device provides an alternative for vadose zone monitoring scheme, instead of costly monitor well networks.

The conventional means of deploying such a probe is to lower a logging tool down an access tube to a depth of several meters or possibly tens of meters. The electronics to operate and process data from the probe are in a housing that sits at the top of the access casing. The cable used to lower the probe down the access tube serves to support cabling and to provide electronic communications. The signal/noise ratio may be impaired with the increasing cable length. Therefore, a practical limitation on hole depth exists.

The new Troxler Probe is self-contained. In other words, the electronics required to take a reading and to program subsequent readings of moisture content and soil density are contained within the housing of the device itself. The probe is drawn through an access tube via a support cable that requires no electronic communications to the top of the casing. Therefore, the length of the access tubing is not prohibitive, and long horizontal tubes may be used if a delivery system is properly engineered.

The proposed choice for a delivery system is to employ a constant velocity winch or one that can be hooked up to a datalogger or laptop computer to record cable take-up rate and time and/or length. Such a system has recently become available from Mount Sopris Instrument Co., Inc., Golden, CO. Other devices exist to monitor in situ moisture content and soil density; however, they are general point source devices. The advantage of a downhole logging device is its continuous data collection along the length of the access tubing. Therefore, a greater spatial coverage is obtained.



Moisture Logging System

With the advent of the horizontal/directional drilling technologies, the applications of the downhole self-contained monitoring devices are significantly enhanced. One could envision a network of horizontally drilled access tubes beneath a facility that coupled with the right monitoring technology, could provide an early-warning system for leak detection.

In addition, information from downhole logging devices is essential in evaluating the performance of such remedial alternatives as capping or soil venting strategies and serving as input to risk assessment modeling methodologies. In deep vadose zone regimes, this type of device/monitoring system may be used instead of expensive monitor well installations.

TECHNICAL PERFORMANCE

The neutron source/detector consists of an americium/beryllium combination (10 mCi). The source and detector are in close proximity to each other, and the probe counts thermalized "slow" neutrons that have contacted hydrogen atoms. This technique is significantly different from those used in the mineral and oil industries, where the source and detector are widely spaced and the probe counts "fast" neutrons. This device's count ratio is generally linear with respect to percent moisture. Its configuration allows for quantification of the moisture content to within $\pm$ 2% volumetric water content when calibrated to a given soil and has an approximate radius of influence of about 30 cm. The mineral/oil industry probes integrate soil moisture over much larger volumes, with much less accuracy and precision. The gamma source for measuring soil density is an 8-mCi Cs-137 configuration.

The neutron source/detector can be used in vertical as well as horizontal access tubes. Existing vertical and/or horizontal access tubes are necessary, but beyond that, the device is self-contained.

If the tool becomes stuck inside a hole, there are a number of options to dislodge it. If a surface-to-surface hole is being used, the tool may be dislodged by pulling it from either end. If that fails, the Ditchwitch technology may be employed to retrieve the tool. In the event that the Ditchwitch fails, the last resort would be to excavate the tool, assuming that there are not too many contaminants in the soil. The tool is typically about 30-40 ft below the surface.

The first trials found that the device needed to be more rugged for use in the field; however, subsequent testing showed it to work as intended. The tool is quite reliable and easy to use, but there is always a need for caution when using a device containing nuclear material. There are no user-serviceable parts, but the user can recalibrate the tool if needed.

Cost. The start-up costs are $18,000 for the probe and $16,000 for the winch. Because of these high costs, Troxler Electronics Laboratories, Inc., will lease this tool. No routine maintenance costs are expected.

PROJECTED PERFORMANCE

One major technical challenge is to increase the reproducibility of the results. A second major challenge is to define adequately the accuracy and precision of the method, as well as to further develop the delivery system.

WASTE APPLICABILITY

Since this technology is specifically used to detect the change in fluid concentrations in arid soils attributed to leaks/contaminant migration from a waste site, the technology is waste independent.

STATUS

The technology is currently in the field demonstration and testing stage and will be available at the end of FY93. To date, there are no logging tool manufacturers that have developed a similar tool.

REGULATORY CONSIDERATIONS

Compliance with the Occupational Safety and Health Administration regulations is required for hazardous waste operations and for the protection of occupational workers from electrical power, winch operation, and radiation exposure. In addition, permits may be required for drilling at hazardous waste sites. Since the tool utilizes low-level radioactive materials, it must be stored in a shielded case with the proper security. Transportation of the device must meet Department of Transportation requirements for nuclear materials.

POTENTIAL COMMERCIAL APPLICATIONS

This technology can be used at a wide variety of sites with several different remediation processes. It can be used at any site where monitoring of the vadose zone is needed to detect the potential for contaminant movement from waste sites. Such information is critical to the characterization of waste sites and the monitoring of waste remediation activities and post-closure performance of remediated waste sites. It offers an alternative vadose zone monitoring scheme, instead of costly monitor well networks.

BASELINE TECHNOLOGY

Since most cabled nuclear logging devices are not self-contained, they do not lend themselves to long horizontal access tubing applications.

INTELLECTUAL PROPERTY RIGHTS

The patent owner is Troxler Electronics Laboratories, Inc., #5155356, "Apparatus and Method for Detecting Subterranean Leakage from a Large Storage Vessel."

For more information, please contact:

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REFERENCES

1. DOE-AL, "Technology Information Profile (rev. 2) for ProTech., Technology Name: Advanced In Situ Moisture Logging System," DOE ProTech Database, TTP Reference Number: AL-2211-14, January 12, 1993.

2. TNA-II OTD/OER Crosswalk Worksheet, FY92, "Advanced In Situ Moisture Logging System," TTP Reference Number: AL-2211-14, The 1993 Technology Needs Crosswalk Report, Vol. 3, appendices H and I, Albuquerque, NM.

BROADBAND ELECTROMAGNETICS FOR THREE DIMENSIONAL SITE CHARACTERIZATION

RUST Geotech, Inc.

DESCRIPTION

Broadband Electromagnetic Induction (BBEM) is an advanced geophysical technique applied for three dimensional characterization of a buried waste site. BBEM uses measurements of a secondary magnetic field that is induced in the subsurface following the linear decay of a source magnetic field. Time domain measurements are taken of the secondary magnetic field transient response at various time intervals over a broadband frequency range to locate, identify, and characterize buried waste areas, buried waste forms, buried waste contaminants, underground utilities, and subsurface geology. This non-intrusive technique is a geophysical approach targeted at electrically conductive objects and media (such as metals, saline solutions, and subsurface geology). BBEM development has initially focused on the adaptation of existing hardware and software for shallow, high-resolution problems. Performance assessment of BBEM will continue as part of the Buried Waste Integrated Demonstration (BWID).

Another name for this measurement technique is Time Domain Electromagnetic Induction (TDEM). A source signal is generated using an asymmetric two-coil induction system, which has a large 5-m-diameter transmitting loop. The BBEM system generates the equivalent of a three-decade frequency spectrum (40 Hz to 40 kHz). When the source current flow is interrupted, the current is allowed to decay at a linear ramp. Afterward, a secondary, transient magnetic field may be observed in the subsurface, and broadband (over a wide frequency range) measurements of frequency, amplitude, and time domain signals can be detected. These measurements indicate the depth, the geologic features, and the apparent conductivity of buried conductors in the medium under excitation. The time domain measurements are useful to delineate between the conductivity and penetration depth of a received signal. By using the system in various configurations (transverse, profile, or vertical electric expander), the BBEM system can be used to describe three dimensional subsurface geometries. Collected numerical data is used to generate three-dimensional graphical descriptions of subsurface materials and buried waste.

TECHNICAL PERFORMANCE

Field Demonstration. Performed in 1992 as part of the BWID indicates the utility of this technique. BBEM has located vertical buried waste pit boundaries within 1 m precision and pit depth extent within 2 m. BBEM will be useful to describe any waste environment where conductive targets are sought. A survey requiring detail coverage over 1/2 acre can be performed in one working day. Only two people are required to take readings, to move coils, and to perform initial quality control readings in the field. It is roughly estimated that 5 h of maintenance is required to operate BBEM 50 h/wk. The electrical energy usage is minimal, less than 100 w. The presently available candidate system may be purchased for $75K from Geonics, Ltd. of Mississauga, Ontario, Canada. Other costs are associated with operator and geophysical analyst salaries.

PROJECTED PERFORMANCE

The major technical challenges to be addressed to improve the BBEM measurement system include (1) selecting the best available hardware and software system for waste characterization; (2) developing field procedures to improve target definition; and (3) developing methods of analysis that optimize the interpretation capabilities of the operator/data interpreter. Another desired improvement is to develop data analysis methods to increase the definition of small conductors in a conductive host medium (i.e., component delineation and improved resolution).

WASTE APPLICABILITY

BBEM will be useful to describe any buried waste environment where conductive targets are sought. Applicable wastes include electrically conductive objects, materials, geologic structures, and brine liquid wastes. Examples include ferromagnetic buried material, metal objects, drums, and other containers with conductive contents (saline solutions and other high-ionic content liquids or solids) that may be buried in subsurface soils.

STATUS

The initial evaluation procedure is scheduled for completion on September 30, 1993. The components of the BBEM measurement system are currently available through commercial vendors, but 2 yrs will be required to complete the evaluation of the candidate hardware and software systems.

REGULATORY CONSIDERATIONS

The regulatory considerations are minimal. As BBEM represents a nonintrusive technique, the only input involves the momentary input of a transient electromagnetic field beneath the property surveyed. Nonintrusive BBEM surveys are totally benign and should be completely acceptable to the public.

POTENTIAL COMMERCIAL APPLICATIONS

Commercial applications include geotechnical mining applications and underground geological survey studies.

BASELINE TECHNOLOGY

BBEM is a superior method to measure earth conductivity because of its utilization and analysis of the full transient decay curve over a wide frequency range with one source and receiver. This provides, in effect, the equivalent of three frequency decades of information and, through a single station, scans a section of ground into the third dimension. An interpretation curve is firmly founded on 20 to 30 data points rather than the usual single point for each combination of frequency and coil separation associated with conventional, narrow-band, frequency-domain electromagnetic systems. Although BBEM is more sophisticated and gives a fuller, more accurate description of the subsurface, it also requires a greater investment for instrumentation and operator training.

INTELLECTUAL PROPERTY RIGHTS

Development of the TDEM method for applications in mineral exploration started in 1978, by Newmont Mining and CSIRO in Australia. It is not clear who owns the intellectual property rights.

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Principal Investigator
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Industrial/University Partner
None at present.

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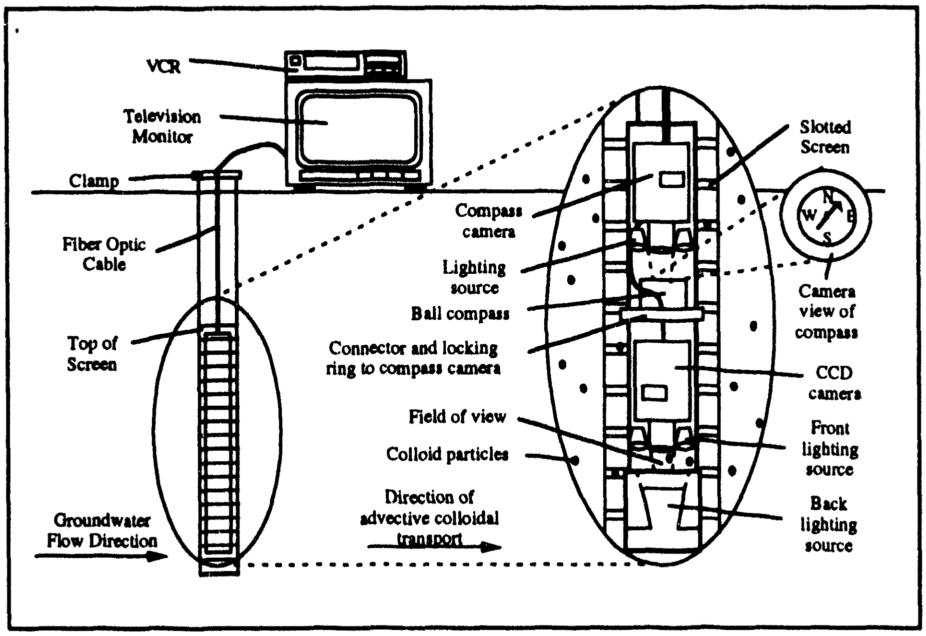
COLLOIDAL BORESCOPE

Oak Ridge National Laboratory

DESCRIPTION

The borescope is used as in situ instrumentation to directly observe colloidal size particles and subsequent groundwater flow direction and rate. Current applications include:

- Site characterization by determining preferential flow paths and fractures;
- Assessing heterogeneities associated with porous media;
- Establishing the existence of immiscible contaminant layers and their associated flow properties;
- Assessing the efficiency of groundwater remediation programs by determining the effective radius of influence of groundwater extraction systems;
- Determining the amount of biological activity present in a bioremediation system; and
- Evaluating the effects of sampling on colloidal concentrations. Potential applications include providing physical observation capabilities necessary to develop and confirm new, more accurate theoretical models of the porous media flow process at the most basic level and assessing the effects of water sampling techniques on natural colloidal concentrations. The instrument could provide the basis for a stochastically based groundwater flow and transport model that accurately describes the movement of contaminants in the subsurface. It could also provide insight to heterogeneity, pore size distribution, flow direction in flat gradient areas, effective radius of pumping, and pressure movement in aquifers.



Cross-Section of a Borescope in a Well

The borescope is inserted into a monitoring well and fixed at the surface with a clamp. The instrument consists of a charge coupled device (CCD) camera, an optical magnification lens, an illumination source, a downhole compass to assess direction of natural flow, and a watertight stainless steel housing. The instrument is approximately 60 cm long, with a diameter of 44 mm. The electronic image is transmitted to the surface by a 33-m fiber optic cable. The image is viewed on a high-resolution 25-cm monitor and recorded on VHS tape for further analysis. The magnified image corresponds to a 1.0 x 0.4 x 0.1 mm field of view.

TECHNICAL PERFORMANCE

Operation of the borescope is not complicated. The instrument is inserted into a well, and the flow is observed on a surface video monitor. The instrument can be used in a well as small as 5 cm in diameter. A measurement is obtained in about 30 min. The stainless steel construction allows for easy decontamination and little maintenance is required. The integrity of waterproof seals is checked periodically.

The colloidal borescope is capable of determining the vertical and spatial distribution of local groundwater velocity, both in magnitude and direction. It is capable of these measurements in low- and high-permeable material. The instrument also permits observation of flow processes at the pore scale. The instrument can assess local flow velocities ranging from 0 to 15 mm/s. Colloidal density is greatly affected by perturbations caused by instrument insertion. A period of 30 min. is generally required for transient turbulence to decline.

Cost. The borescope is more cost effective than conventional methodologies. Since flow velocities are measured directly under ambient flow conditions, unlike measuring in conventional methods, no water disposal is required, thus minimizing water disposal costs. The instrument presently costs approximately $20K. Costs should significantly decrease when production begins.

PROJECTED PERFORMANCE

Continued software development is necessary to address the variability of water flow, and additional work is currently under way to address the variability observed in well bores. The effects of subsurface magnetism on the compass is yet to be determined.

WASTE APPLICABILITY

Since this technology is specifically used for characterization and monitoring of the ground media at problem sites, the technology is waste independent.

STATUS

Prototypes are presently available. An advanced version with associated software are expected to be available in 1994.

REGULATORY CONSIDERATIONS

Compliance with the Occupational Safety and Health Administration regulations is required for hazardous waste operations and protection of occupational workers from electrical power. Also, permits may be required for drilling at hazardous waste sites.

POTENTIAL COMMERCIAL APPLICATIONS

The Colloidal Borescope can be used at any site where information on colloidal size particles and subsequent groundwater flow velocity is necessary. The Colloidal Borescope can be used for site characterization by determining preferential flow paths and fractures. It can also be used for assessing heterogeneities associated with porous media, establishing the existence of immiscible contaminated layers and their associated flow properties, assessing the efficiency of groundwater remediation programs by determining the effective radius of influence of groundwater extraction systems, determining the amount of biological activity present in a bioremediation system, and evaluating the effects of sampling on colloidal concentrations.

BASELINE TECHNOLOGY

The baseline technology is a standard technique used to measure hydraulic head gradients and hydraulic conductivities in boreholes to determine flow velocity. Four holes are required for a measurement using this standard technique as compared to using one hole with the Colloidal Borescope. With the standard technique, information about the hydraulic conductivity of the medium is required and is generally determined using a pump test in which large quantities of water are pumped from the well. Disposal of this purge water can be difficult and expensive.

INTELLECTUAL PROPERTY RIGHTS

The property rights are unknown or do not exist. Contact the principal investigator for further information.

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Industrial Partnership
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REFERENCES

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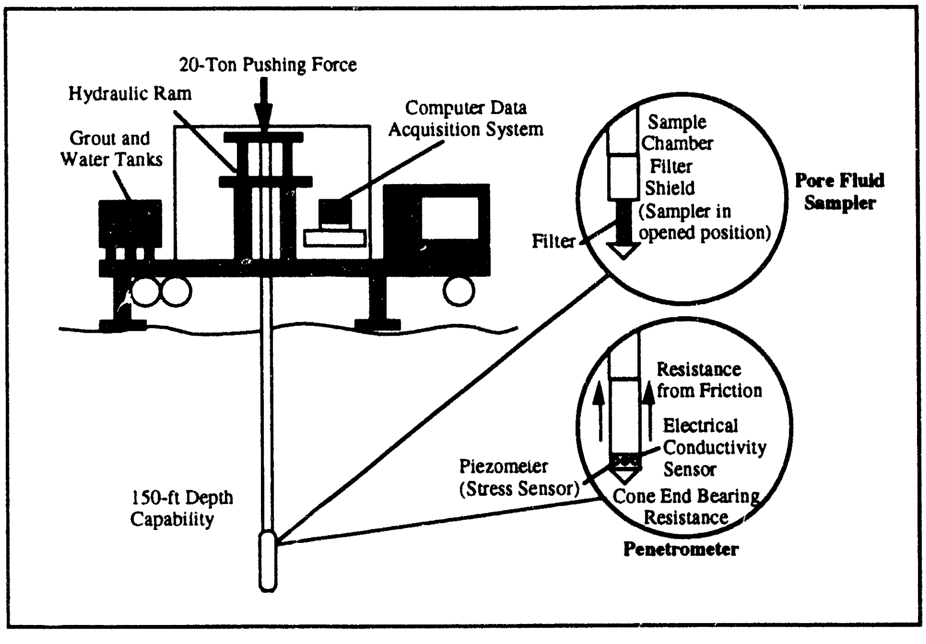
CONE PENETROMETER

Westinghouse Hanford Company

DESCRIPTION

The cone penetrometer is a truck-mounted device that rapidly penetrates the ground to collect site data. It has been used for approximately 50 yrs for geotechnical applications, but its use in environmental restoration is relatively new. The cone penetrometer rod has a conical tip of up to 2 in. in diameter. It is pushed hydraulically into the ground with a maximum pressure of 80,000 lb. The hole generated by the cone penetrometer retains the outside diameter of the rod and can be grouted as the probe is withdrawn to seal the hole and prevent the escape of contaminants. As the rod progresses into the ground, a computer



Cone Penetrometer

reads data from sensors located in both the tip and the side of the probe. The cone penetrometer can monitor for contaminants as the probe is advanced or can leave monitors in place as the rod is withdrawn. It can advance through fine-grained soil at a rate of 40 to 50 ft/h. The cone penetrometer is used to install characterization and monitoring wells and may be able to provide chemical and radiological readings from the subsurface. Successful development, demonstration, and deployment of the system as a source detection tool will provide more cost-effective site characterization and remediation by reducing the number of drill holes required, minimizing secondary waste, and reducing potential worker exposure to contaminated materials.

TECHNICAL PERFORMANCE

The system requires a high level of understanding of soil and hydraulics. The cone penetrometer system functions well in a wide range of soils. It can advance through fine-grained soil at a rate of 40 to 50 ft/h.

Cost. Start-Up costs are \$500K, Operations and Maintenance costs are \$3000/day, and life-cycle depreciation is approximately 10 yrs.

PROJECTED PERFORMANCE

The cone penetrometer will be adapted for full use in the gravel/cobble subsurface common to arid sites and will require upgrading the thrusting capacity of the truck, reinforcing tools associated with the penetrometer to withstand the additional force, and evaluating the use of vibration to facilitate penetration through gravel.

WASTE APPLICABILITY

Target contaminants for this technology are carbon tetrachloride, radionuclides, chloro-hydrocarbons, and hydrocarbons in soil.

STATUS

The status of several different cone penetrometer sensors is given in the table below.

REGULATORY CONSIDERATIONS

Regulatory issues vary, depending on the type waste to be characterized. In general, regulations concerning subsurface access characterization well drilling will apply. Ecological impacts are minimal.

POTENTIAL COMMERCIAL APPLICATIONS

This technology is very applicable for any commercial environmental characterization need. Industries such as the power, fuel storage and distribution, chemical, refineries, and many others that may have soil or groundwater contami-

Standard Penetrometer Probe	
0-40,000 lb Tip Load Cell	AV
0-20,000 lb Sleeve Load Cell	AV
0-500 psi Pore Pressure Transducer	AV
Equal-End-Area Friction Sleeve	AV
Pore Pressures Sensed Behind Tip	AV
Pore Pressures Sensed on Surface of Tip	AV
Two-Axis Tilt Sensor (±15°)	AV
Calibrated Seismic Transducers in Triaxial Configuration	AV

AV = Available
PT = Prototype Tested;
CD = Conceptual Design

Specialty Penetrometer Probe	
Electrical Resistivity	PT
Ground Penetrating Radar (10ft range)	PT
Active Hydrolic Conductivity	PT
Grouting Capability After Probe Withdrawal	AV
Gamma Radiation Detector	PT
Temperture Measurements	CD
In Situ Soil Density	CD
Self-Grouting	AV
Downhole Laser Induced Fluorescence	PT

nation could benefit by this rapid, extensive, visually and economically attractive, contamination site characterization technology.

BASELINE TECHNOLOGY

The baseline technology for site characterization is conventional drilling (auger or mud rotary) and laboratory characterization. The traditional approach lacks detail and precision, is slow in requiring laboratory analysis of contamination, risks cross-contamination, and is potentially hazardous (drilling in waste site). The CPT integrated technique for site characterization is faster, using less costly procedures; has minimum invasiveness, reduced cross-contamination risk; gives greater detail information, except in geophysical logging; and has field analytical ability and real-time data processing.

INTELLECTUAL PROPERTY RIGHTS

There is no patent on this technology, which has been used for the past 50 years for geotechnical applications.

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Industrial Partnership
Applied Research Associates

REFERENCES

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CROSSWELL SEISMIC IMAGING

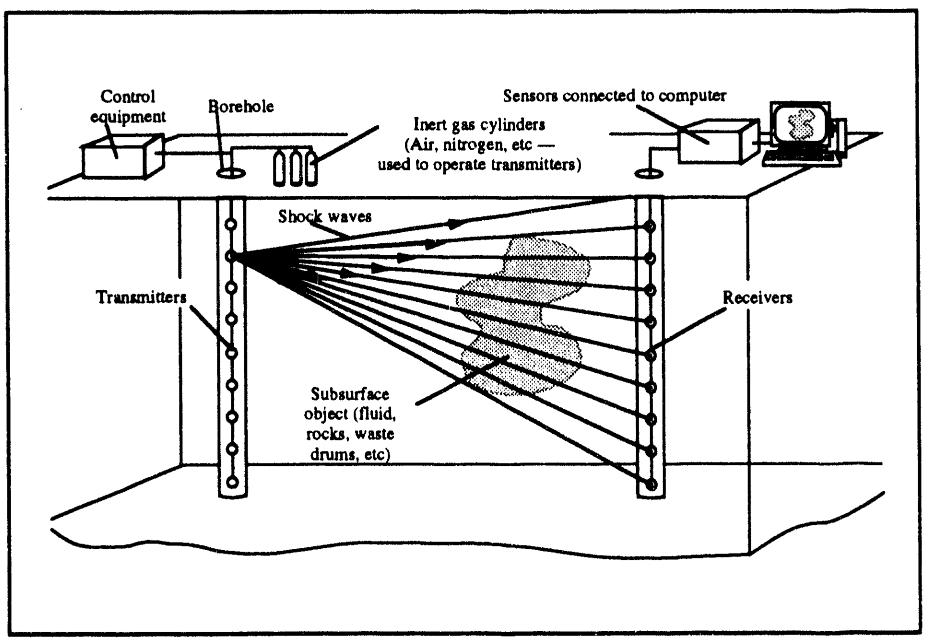
Sandia National Laboratories

DESCRIPTION

For many remediation technologies, a good understanding of the subsurface geology must be obtained to understand contaminant transport and to best devise the proper remediation scheme. Much of this geologic input is presently derived from well log data, which may be scarce, especially in contaminated areas where drilling must be kept to a minimum. Seismic imaging provides a means to image the geology between boreholes nonintrusively.

Crosshole seismic imaging involves the fielding of a downhole source and a downhole receiver in two boreholes, one on each side of the region to be imaged. Seismic travel times are measured between a great number (>300) of source and receiver locations in the two boreholes. These travel times are then inverted into a map of the two-dimensional velocity structure through a method known as tomography. Some of this imaging can be done with surface seismics. However, placing both the source and receiver downhole results in shorter travel paths that preserve higher seismic frequencies and result in better resolution.

For remediation processes where the properties of the subsurface are changed, comparing seismic velocity images before and during the process can provide needed information on where the technology is being effective and to what degree changes are being implemented in the subsurface. The seismic sources used generate primarily shear or primarily compressional waves, depending on the source used. The shear wave source is a controlled vibrator, while the compressional wave source is an impulse source. Comparing the velocity structures for both the compressional and shear waves provides additional information about rock properties and fluid content.



Crosswell Seismic Imaging

The system is reliable and functions well with only general maintenance. Operation of sources requires training of personnel in both source operation and operation of winches for fielding tools. The seismic sources are pneumatic and require compressed gas, usually air, argon, or nitrogen, that is supplied from tanks at the surface. The only physical output will be the vented gas. Effects of failure are restricted to high-pressure hazards and are easily controlled. Components must be periodically pressure tested for continued integrity. Electrical power for running direct current motors and computer control and recording equipment is also required. Some additional site power may be required for winch operation and for appropriately sizing and casing the boreholes that are needed.

TECHNICAL PERFORMANCE

Field Demonstration. Field demonstrations have shown good correlation of imaged velocities with geology interpreted from well logs. Changes in saturation caused by injected air during an air sparging experiment have also been modeled. Resolution of the present system is approximately 1m in size and saturation changes of about 5%.

The seismic method will not provide the spot resolution that well logging can. Also, some a priori knowledge of the geology is needed to interpret the velocity models in terms of geology. The expense of crosshole seismics is greater than surface seismics, although this may change as crosshole seismics become more routine.

Cost. Initial one-time expenditures for equipment needed to field the system include costs for sources and receiver, winches, tripods, PCs for source control, and the seismic recording system. Estimated cost for this full system is $400K. Much of this may be available for rent or lease at a much lower cost. Field operations have been running on the order of 1 to 3 weeks, depending on survey size, for a three-man crew. Processing and interpretation presently take on the order of 1 month, but will probably decrease significantly as software is streamlined. Life-cycle costs should not exceed start-up and operations costs except when additional wells need to be drilled. Data collection takes about 1 to 3 weeks, depending on survey requirements. The interpretation of the data takes about 1 to 2 months.

PROJECTED PERFORMANCE

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

WASTE APPLICABILITY

Since this technology is specifically used for characterization and monitoring of the ground media at problem sites, the technology is waste independent.

STATUS

Although all sources are not commercially available at this time, steps are being taken to transfer the technology. There are several commercially available compressional-wave sources, such as the airgun, that are used primarily for oil and gas exploration, but can be readily modified for use in the environmental arena. No shear-wave sources are commercially available, though there is a poorer quality shear wave generated by the compressional wave sources. The complete fielding system and interpretation software are currently available, though not commercially.

REGULATORY CONSIDERATIONS

Compliance with the Occupational Safety and Health Administration regulations is required for hazardous waste operations and protection of occupational workers from electrical power, pressurized gas, and mechanical hazards associated with operating winches and working under overhead tripods. Personnel should be trained in operating pressurized systems. In addition, permits may be required for drilling at hazardous waste sites.

POTENTIAL COMMERCIAL APPLICATIONS

This technology can be of use at a wide variety of sites and in conjunction with several different remediation processes. Seismic imaging can be used at any site where information on geology between boreholes is necessary. This is especially useful when the number of boreholes that can be drilled is restricted. It can also be used for monitoring any remediation technology that significantly changes the seismic properties of the subsurface such as air sparging, steam flooding, and water flooding.

BASELINE TECHNOLOGY

Although several companies are currently working on downhole seismic sources for oil and gas exploration, no one else is applying these techniques to environmental remediation sites.

For characterization, well logging and surface seismics offer alternatives. Drilling and logging require a large number of wells to be drilled to obtain a continuous picture of the subsurface. This makes this technology relatively more expensive and provides only isolated point information. Surface seismics are relatively limited in resolution. For monitoring imaging, only crosshole electromagnetic techniques being developed are a viable alternative.

INTELLECTUAL PROPERTY RIGHTS

The patent owners are DOE, Sandia National Laboratories, and Richard Hills. Patent Number: 504,317,171 "Advanced Downhole Periodic Seismic Generator."

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Industrial Partnership

Santerra Corporation

REFERENCES

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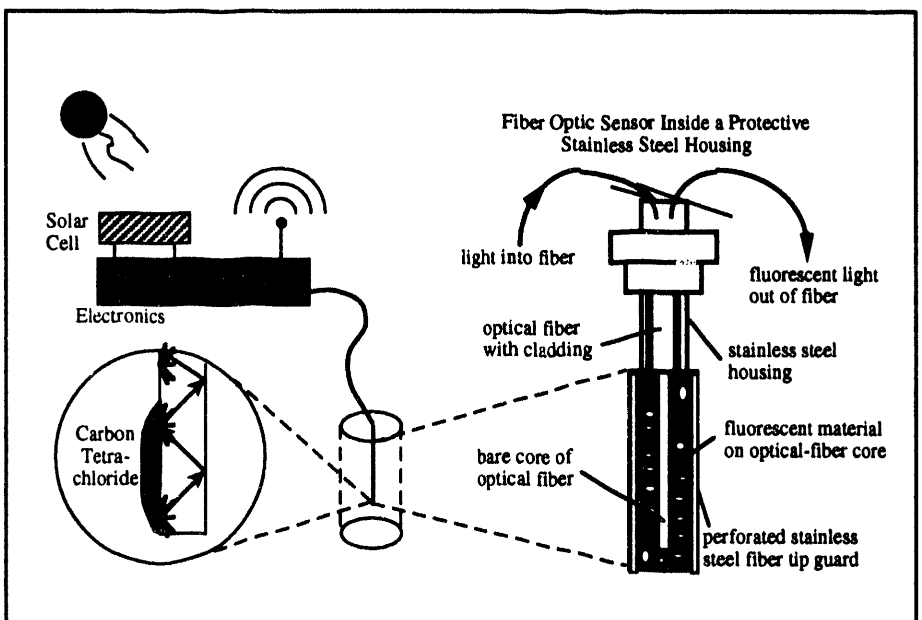
FIBER-OPTIC SENSORS

Lawrence Livermore National Laboratory

DESCRIPTION

A fiber-optic sensor is being developed to monitor carbon tetrachloride (CCl_4) at the Hanford Site. Fiber-optic based sensors are a relatively new type of detection and monitoring technology that facilitates in situ analyses of inaccessible and inhospitable environments. This new technology has already been applied to monitoring and a variety of environmental parameters and toxic contaminants found in the vadose zone and groundwater. The technology is based on the ability of fused quartz optical fibers to transmit probe signals of visible or near infrared light long distances to remotely located sensors. The signals passing through the optical fibers are immune to electromagnetic interferences and can be readily multiplexed to a single optical detector to provide a real-time and multipoint monitoring capability.



Reversible Fiber-Optic Carbon Tetrachloride Sensor

The most common fiber-optic sensors incorporate transduction mechanisms that either monitor a wavelength-dependent optical attenuation of the probe beam or the production of fluorescence emissions in regions of the optical spectrum that are distinct from the probe's frequency. Generally, the chemical species that are targets of environmental analyses do not absorb visible light or produce fluorescence emissions even when they are highly concentrated, so detecting these analytes at the relatively low, parts-per-million levels normally found in contaminated environments requires an indirect method of detection.

The most successful approach to detecting these low analyte concentrations use organic dye molecules that interact reversibly and specifically with the chemical species of interest. The physical-chemical reaction of the analyte with the organic transducer produces a change in the photophysical characteristics of the dye that modulates the probe beam. The magnitude of the optical response is correlated to the concentration of the analyte. When the nature of the analyte-dye interactions is known, specific dye molecules can be selected to detect a narrow range of related chemical species.

The configuration of a fiber-optic sensor system is not complicated and requires a simple light source (a light bulb or a light emitting diode), a detector (silicon photodiode), and simple optics (lens, filter, and mirrors) to focus and guide light into and out of the fiber-optic conduit. The same fiber can be used to transmit the probe beam to the sensor, as well as to carry the modulated signal back to the detector. Consequently, at the proximal end of the fiber is a small calculator-size box of optics and electronics that contains both the light source and signal detection equipment. The electronics box is configured to a small central processing unit (CPU) or a lap-top computer that collects and analyzes the sensor signals and provides useful information on the analyte concentration. At the distal and working end of the fiber is the sensor, normally encased in a protective metal shield to prevent damage.

The efficient transmission qualities of optical fibers, the small cross-sectional area of ruggedized fiber-optic cables and sensors, and the simple and small-scale sensor optics and electronics enlist fiber-optic based sensors as ideal candidates for monitoring vadose zone contaminants in wells, boreholes, and other remote and hard-to-reach locations.

TECHNICAL PERFORMANCE DATA

This technology provides a real-time sensor for monitoring volatile organic compounds (VOCs) in the gas phase. The sensors can be in situ and operate continuously to provide trend data, as well as immediate fluctuations in CCl_4 levels. Fiber-optic sensors can operate automatically and unattended, have sensors placed in remote or hazardous areas, are low in cost and low in maintenance, and can continuously log data for subsequent analysis. The sensors are very small and can be solar powered.

Cost. These units are not yet available; however, a central electronic package that can monitor sensors from several locations may cost approximately $10K. The sensors will be comparatively inexpensive and should cost less than $100. The costs associated with fiber optic based sensors will depend upon the sampling protocols and application for which the technology will be used. The estimated cost for daily operation is negligible. The routine maintenance will involve weekly or monthly checks on the system and should be negligible other than manpower expenditures. Life-cycle costs are estimated at $25K/yr (5 yrs.) and $1.25K/yr (10 yrs.).

PROJECTED PERFORMANCE

The sensors being developed for measuring CCl_4 at the Hanford Site are intended to detect low part-per-million to part-per-billion gas-phase levels of this contaminant. As yet, direct measurement of VOCs dissolved in water has not been accomplished, and all measurements have been made in the vapor phase above contaminated aqueous solutions. However, the issue of direct measurement of VOC's in water will be addressed.

These sensors are not anticipated to satisfy the Environmental Protection Agency's (EPAs) analytical procedures for low level analysis.

WASTE APPLICABILITY

Fiber-optic sensors are applicable to the monitoring of CCl_4 and other classes of VOCs in groundwater, vadose zone, and vapor extraction off-gases. Monitoring is applicable in situ or ex situ.

STATUS

The system is currently available.

REGULATORY CONSIDERATIONS

This technology does not involve any chemical or physical hazards to workers, is inherently safe, and poses no risk to the environment. This technology reduces sample handling, thus further reducing worker exposure to contaminants.

POTENTIAL COMMERCIAL APPLICATIONS

This technology is applicable to the monitoring of CCl_4 and VOCs in wells and at remediation sites. In addition, remote monitoring of waste sites or

on-line process streams may also be possible. The sensors can provide trend data so that changes in contamination levels can be tracked, or the sensors can function as alarms to provide an indication of CCl_4 breakthrough, as in granular activated carbon (GAC) beds or aquifers.

BASELINE TECHNOLOGY

The baseline technology is gas chromatography.

INTELLECTUAL PROPERTY RIGHTS

Patent Ownership: DOE
Other Owners: Patent licensed to Purus, San Jose, CA
Patent Number: 4,834,497 (May 30, 1989)

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Industrial Partnership
None at present.

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[redacted]

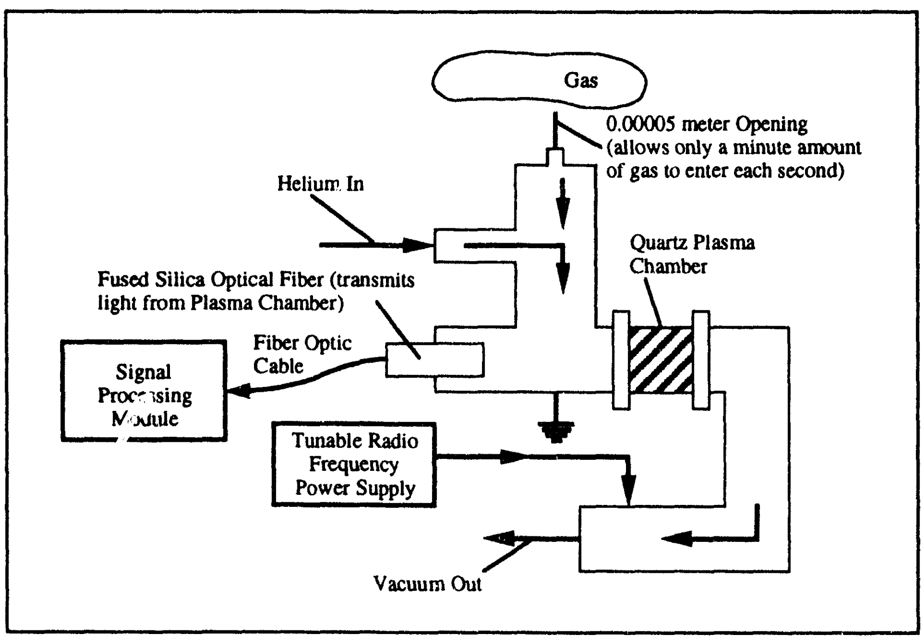
HALOSNIF FIBER-OPTIC SPECTROCHEMICAL SENSOR

Pacific Northwest Laboratory

DESCRIPTION

HaloSnif is a fiber-optic spectrochemical sensor capable of detecting any volatile chlorinated compound in air or gas. During operation, HaloSnif operating at subambient pressure (40 torr) continuously draws an air sample through a critical orifice into the plasma excitation chamber where it is mixed with helium and excited with a radio-frequency signal inductively coupled to the plasma chamber. The plasma chamber is coupled via a fused silica optical fiber to the signal processor unit. The optical emission of the plasma is filtered with a narrow band pass filter designed to monitor the 837.6 nm emission line from the excited chlorine atom. The intensity of the chlorine emission is directly proportional to the concentration of chlorine containing species in the sample gas. The detection sensitivity for carbon tetrachloride is 5 ppmv. The response of the system is linear from the detection limit to 10,000 ppmv. The detection limit for other chlorine-containing compounds can be estimated by calculating the ratio of the percent of chlorine in the compound of interest to that of carbon tetrachloride.

Data acquisition is achieved using a LabView™ data acquisition software package mounted on a Macintosh computer system. The data acquisition system is interfaced to the electro-optical signal processing module via a 1 to 10 V analog output. Real-time concentrations of total chlorinated compounds are displayed on the monitor for observation by on-site personnel. All data are stored in computer memory for post-run processing and analysis.



HaloSnif Fiber Optic Sensor

TECHNICAL PERFORMANCE DATA

HaloSnif's response to chlorinated species is linear from its lower detection limit of 1 to 5 ppmv (for most compounds) in air to approximately 10,000 ppmv. In addition, HaloSnif is not sensitive to moisture or other nonchlorinated compounds present in the sample gas. HaloSnif operates at 40 torr. Equilibration times are normally less than 2 min to reach 90% of full scale. The total weight of the HaloSnif system is 50 lb. HaloSnif also features real-time multipoint environmental field monitoring, small probe size, and the ability to use multiple probes with one central detection and data acquisition system. HaloSnif requires 5 A of 110 VAC power to operate.

HaloSnif can be reconfigured as an element-specific detector for gas chromatography effluents containing chlorine- and fluorine-containing compounds. By simply replacing the critical orifice inlet with an open-face membrane material, HaloSnif is capable of measuring the concentration of total organic chlorine in water samples.

Cost. It is estimated that the final unit will be approximately $10K for the base system and approximately $250 per sensor assembly. Operations and maintenance costs are expected to be minimal.

PROJECTED PERFORMANCE

HaloSnif has the potential to detect gas phase compounds containing bromine, mercury, fluorine, and possibly phosphorus by simply modifying the analytical emission wavelength monitored by the detector.

WASTE APPLICABILITY

HaloSnif is applicable to the detection of any volatile chlorine containing compound including carbon tetrachloride, trichloroethylene, tetrachloroethylene and chlorofluorocarbons in air or gases.

STATUS

All components of HaloSnif are commercially available. Field testing of the new compact unit will be conducted to determine its short-term and long-term maintenance requirements.

REGULATORY CONSIDERATIONS

HaloSnif is considered intrinsically safe, and no environmental impacts are anticipated.

POTENTIAL COMMERCIAL APPLICATIONS

Potential commercial applications of HaloSnif include monitoring at waste sites, chemical storage areas, and process-based manufacturing plants using CFCs.

BASELINE TECHNOLOGY

The baseline technology is the photo ionization detector (PID), or conventional gas chromatography equipped with an electron capture or electrolytic conductivity detector.

INTELLECTUAL PROPERTY RIGHTS

HaloSnif was developed at Pacific Northwest Laboratory (PNL). The patent has been assigned to PNL and the Department of Energy (DOE).

Patent No. 5,085,499, "Fiber Optics Spectrochemical Emission Sensors."

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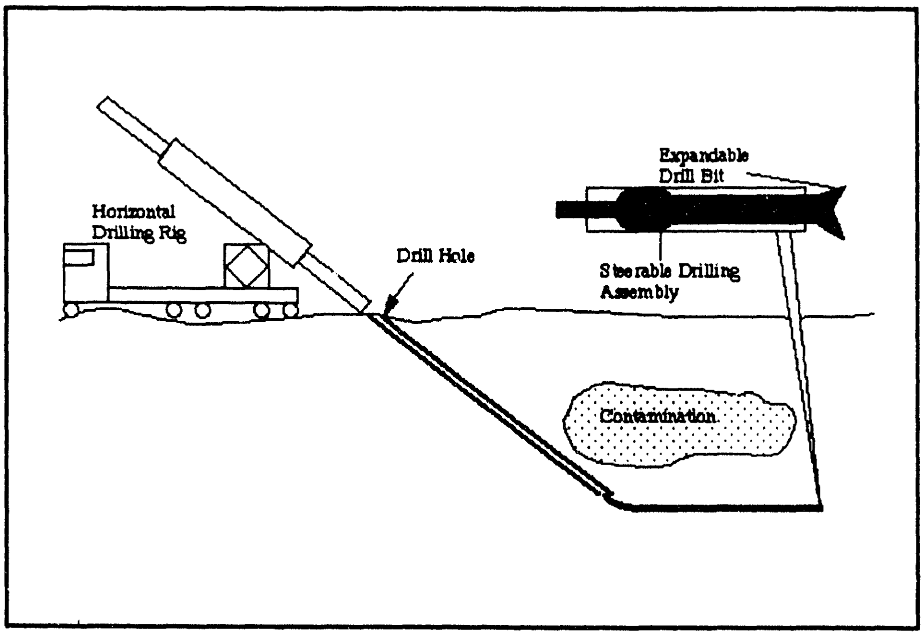
HYBRID DIRECTIONAL BORING AND HORIZONTAL LOGGING

Sandia National Laboratories

DESCRIPTION

The main application of the Hybrid Directional Boring and Logging (HDBL) system is for cost-effective, high-quality access to an otherwise inaccessible contaminated subsurface (see figure below) for site characterization and sensor emplacement. The directional boring technology is an adaptation of existing hardware from various underground industries, primarily from the underground utilities industry. In the short-term development plans, the depths of the boreholes are somewhat shallow (50 ft), but long-term goals include greater well depths (80-100 ft), diameters (~6 in.) and lateral (horizontal) extents suitable for remediation purposes (400-1000 ft).



Horizontal/Directional Drilling

Hardware integrated for the directional boring facet of this technology includes wireline coring rigs, hydraulic thrust systems, electric cone penetrometers, steering tracking hardware, and push coring systems. Hydraulically activated thrust equipment capable of exerting more than 40 tons of thrust are used to push the directional boring heads into the earth. Directional control is obtained by proper positioning of the face of the nonsymmetric boring head. Slow rotation of the boring head will cut and compact the geologic material into the borehole wall. Thrusting a boring head that is not rotating will cause a directional change. The machinery is capable of initiating a borehole, steering down to a desired horizontal depth, continuing at that depth, and then steering back to the surface at a down-range location. This directional boring technology is desirable for environmental applications because the access method requires very minimal addition of fluids and very little soil removal during the drilling process.

Various logging and sampling technologies could be adapted, such as gamma and spectral gamma sensors, resistivity, mass spectrometry, fiber-optic fluorescence, pore pressure, fluid moisture, temperature, volatiles sampling (contaminant vapors), and a sidewall coring/soil sampling apparatus (second generation). In addition, various methods to emplace monitoring equipment are being developed including a pneumatic hammer technology for sleeve emplacement. A key function of the sampling hybrid system is to provide multiple discrete samples per run. It has the potential to recover pristine samples; moreover, it can be used to develop inexpensively a grid of horizontal wells (in an otherwise inaccessible subsurface) for contamination characterization, plume monitoring, and remediation verification.

TECHNICAL PERFORMANCE DATA

The Utilities Industry Rod Pusher is capable of exerting hydraulic, bidirectional thrust in excess of 80,000 lb and can be used in some soils with the standard solid rod and the Hogentogler cone penetrometer hollow rod. Rod diameters are 1.75 in. for both types.

Core Sampler. Provides a core 8-in. long and 1 in. in diameter.

Prototype Boring Machine. Hydraulic bi-directional thrust in excess of 80,000-lb, dry-bore compaction cutting for location/directional control.

Performance. In preliminary field testing, several directional holes were drilled; a depth of 40 ft was achieved with a maximum horizontal extent of 570 ft. Estimated costs were about $20 to $75/ft.

Pilot Scale Testing. Testing was performed as part of the Mixed Waste Landfill Integrated Demonstration at Sandia National Laboratories (SNL), Albuquerque, NM. The technology was also successfully used in the volatile organic compounds (VOCs) in Non-Arid Soils Integrated Demonstration in Savannah River, SC. Testing of directional boring for monitoring equipment installation was performed at the Savannah River Site (SRS) in an actual contamination zone during the summer 1992. The hole was cased with a 3-in. fiberglass casing, in coastal plain sediments. The drilling rate is dependent on the geology.

PROJECTED PERFORMANCE

The project goal is to drill to a maximum depth of 80 ft and to obtain a maximum horizontal reach of 1000 ft. Other goals are to log multiple discrete soil samples per run and to integrate various instrumentation and sensing packages into the boring hardware.

WASTE APPLICABILITY

Practical depth is estimated at 80 ft, and maximum horizontal reach is estimated at 1000 ft. Several geophysical monitoring, fluid characteristics, and contamination analysis tools can be incorporated with the hybrid drilling hardware. Developers state that the drilling method is amenable to a wide range of soil geologies. The developers have also noted that this method may ultimately be limited to compactible soils, although hardrock air drilling may be an option for more difficult media.

STATUS

The hybrid directional drilling system is being developed from modified hardware for existing drilling equipment used in the underground utility industry. The first-generation hybrid equipment may be available from the developer/ manufacturer in 1994. The availability of more advanced, second-generation equipment may follow the first-generation according to demand.

REGULATORY CONSIDERATIONS

The secondary process waste of this drilling technology is kept to a minimum by using only a small amount of water for drilling and electronics cooling. Cuttings are compacted into the formation with very little returned to the surface. Various drilling and safety regulations apply depending on the type of contaminant in the soil.

POTENTIAL COMMERCIAL APPLICATIONS

This technology was developed from existing underground utility installation technologies, so it may also be returned and approved for use in these industries. In addition, the environmental monitoring, sensing, and characterization applications are useful to many industries that may have a shallow contaminant plume. The hybrid technology can be used by many industries economically to characterize, remediate, or monitor the contamination.

BASELINE TECHNOLOGY

A baseline technology might be any larger directional boring and drilling rigs adapted from the oil, gas, and river-crossing industries. The larger equipment technologies are much more expensive ($300/ft of cased well compared to $20 to $75/ft with (HDBL) for directional drilling applications and may not be appropriate for use at shallow depths.

INTELLECTUAL PROPERTY RIGHTS

Both Department of Energy (DOE) and Charles Machine Works, Inc., have patents pending.

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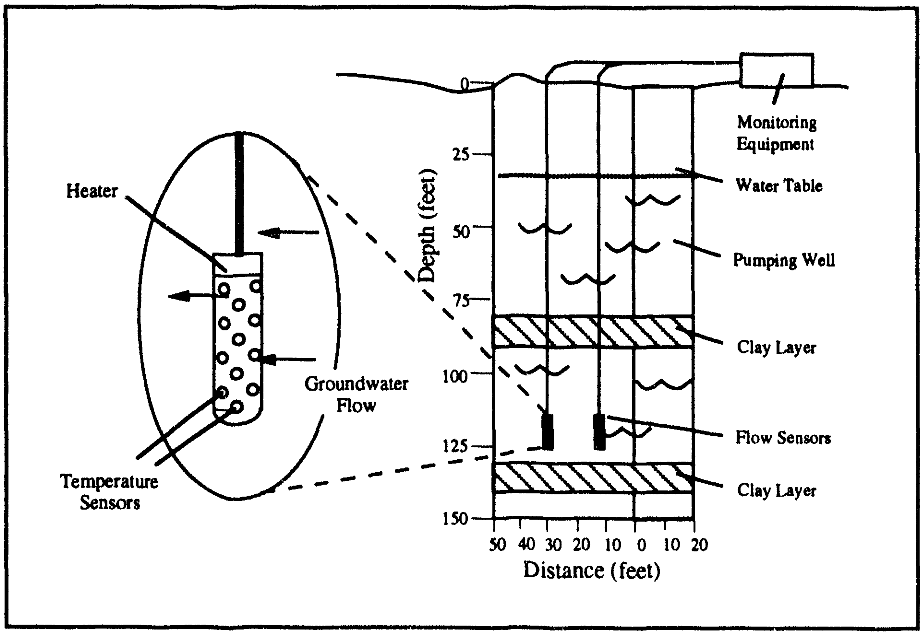
IN SITU PERMEABLE FLOW SENSOR

Sandia National Laboratories

DESCRIPTION

Groundwater flow is perhaps the most important mechanism for the dispersal of many types of toxic waste once they have been released into the subsurface. Accurate information about the groundwater flow field is critical to the characterization of waste sites, the monitoring of waste remediation activities, and the monitoring of the post-closure performance of remediated waste sites. In situ permeable flow sensors can measure the full three-dimensional groundwater flow velocity vector at a point in a saturated, permeable, unconsolidated medium using only one hole. With In Situ Permeable Flow Sensors, information about the hydraulic conductivity is not required. The flow sensors measure the velocity characteristic of a very small volume of material, on the order of 1 m^3. It is easy to set up a flow sensor and monitor it remotely for extended periods of time. Use of this technology at a site does not preclude using any other technology at the same time or at some future date. Shown below is a schematic of the In Situ Permeable Flow Sensor.

The basic operating principle of this technology is to bury a thin cylindrical heater vertically in the ground at the point where the groundwater flow velocity is to be measured. If the heat flux out of the cylinder is uniform over the surface of the cylinder, then the temperature distribution on the surface of the cylinder will vary as a function of the direction and magnitude of the groundwater flow velocity past the cylinder. In the absence of any flow past the device, the temperature on the surface of the probe will be independent of the azimuth and symmetric about the vertical midpoint of the probe. The vertical midpoint will be warmer than the ends of the probe because heat transfer away from the ends of a finite length cylinder is more efficient than from the midsection of the cylinder. Groundwater flow past the device perturbs the surface temperature distribution with the pattern and magnitude of the temperature variations reflecting the direction and magnitude of the groundwater flow velocity. In essence, relatively warm temperatures will be observed on the downstream side and relatively cool temperatures on the upstream side of the instrument as the heat



In Situ Permeable Flow Sensor

introduced into the formation by the heater is advected around the probe.

If the groundwater flow has a vertical component, the vertical temperature distribution on the surface of the probe will no longer be symmetric about the vertical midpoint of the probe, but will be skewed in the direction of the flow. The surface of the downstream end of the probe will be warmer than the upstream end. If there is a significant horizontal component to the flow velocity, the surface temperature distribution will not be independent of the azimuth, but rather the surface temperature will vary approximately as the cosine of the azimuth, with the downstream side of the probe being warmer than the upstream side. The magnitude and direction of the three-dimensional flow velocity vector are determined from the magnitude and the pattern of the temperature variations on the surface of the probe, respectively.

Electric power, either from line power or a generator, is required. For remote monitoring, access to a telephone line or cellular phone service is also desirable (data transfer by radio frequency transmission is presumably possible).

TECHNICAL PERFORMANCE

Field Demonstration. Field tests indicate that flow velocities as low as a few meters per year are resolvable. The probes are simple to install and monitor. Data from a number of probes at the same site can be collected and sent via modem to computers at a remote site. Other than for installation and occasional maintenance, the system can be operated remotely for extended periods of time. Once the heater on the probe is activated, a flow velocity measurement can be obtained after about 24 to 48 h. Current prototype sensors last for approximately one year. Failure occurs when the waterproof coatings ultimately leak, allowing water into the probe where it shorts out the electronics. Failure of the probe does not present any serious consequences other than the fact that useful flow velocity measurements will no longer be available from the probes.

The sensor measures the velocity at essentially a point. Sometimes the average velocity over a wider area is desirable. The standard technique measures a velocity that is an average of the velocity over a much broader region, one whose dimensions are characterized by the separation of the boreholes.

Cost. Purchase of a calibration facility, data acquisition system, and computer for data analysis is estimated at approximately $25K. Each flow sensor is estimated to cost between $500 and $700. In remote monitoring applications, approximately one-tenth of a person's time is required to collect and analyze the data.

PROJECTED PERFORMANCE

The detailed and relatively inexpensive information gained by this technology will enable a greater utilization of time and resources for characterizing, monitoring, and remediating the ground media at problem sites.

WASTE APPLICABILITY

Since this technology is specifically used for obtaining groundwater flow velocity information at problem sites, the technology is waste independent.

STATUS

Virtually all of the components for the sensors and the data acquisition system are available commercially. It is expected that this technology will be commercially available by the end of 1993.

Currently, temperature differences of about 0.01°C can be measured. At this level, flow velocities as low as a few meters per year can be resolved. The probe design needs to be improved to assure long-term reliability of electronics and sensors in groundwater conditions. Flow sensors can monitor groundwater flow for as long as required, until they leak (approximately 1 yr).

REGULATORY CONSIDERATIONS

Compliance with the Occupational Safety and Health Administration regulations is required for hazardous waste operations and protection of occupational workers from electrical power. In addition, permits may be required for drilling at hazardous waste sites.

POTENTIAL COMMERCIAL APPLICATIONS

This technology can be useful at a wide variety of sites and with several different remediation processes. The In Situ Permeable Flow Sensors can be used at any site where information on groundwater flow velocity is necessary. Such information is critical to the characterization of waste sites, the monitoring of waste remediation activities, and the monitoring of post-closure performance of remediated waste sites.

BASELINE TECHNOLOGY

The baseline technology is a standard technique used to measure hydraulic head gradients and hydraulic conductivities in boreholes to determine flow velocity. Four holes are required for a measurement using this standard technique in comparison to only one hole with the In Situ Permeable Flow Sensors. Information about the hydraulic conductivity of the medium is required in the standard technique. This is generally determined using a pump test in which large quantities of water are pumped from the well. At contaminated sites, disposal of this purge water can be difficult and expensive. The flow sensors measure the velocity characteristic of a very small volume of material, on the order of 1 m^3. The standard technique measures a velocity that is an average of the velocity over a much broader region, one whose dimensions are characterized by the separation of the boreholes.

INTELLECTUAL PROPERTY RIGHTS

There is no patent on this technology; it is in the public domain. Sandia National Laboratories has applied for copyrights on engineering drawings and on the software that interprets flow sensor data.

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REFERENCES

1. DOE-AL, "Technology Information Profile (Rev. 2) for ProTech., Technology Name: In Situ Permeable Flow Sensor," DOE ProTech Database, TTP Reference Number: AL-2011-01, July 15, 1993.

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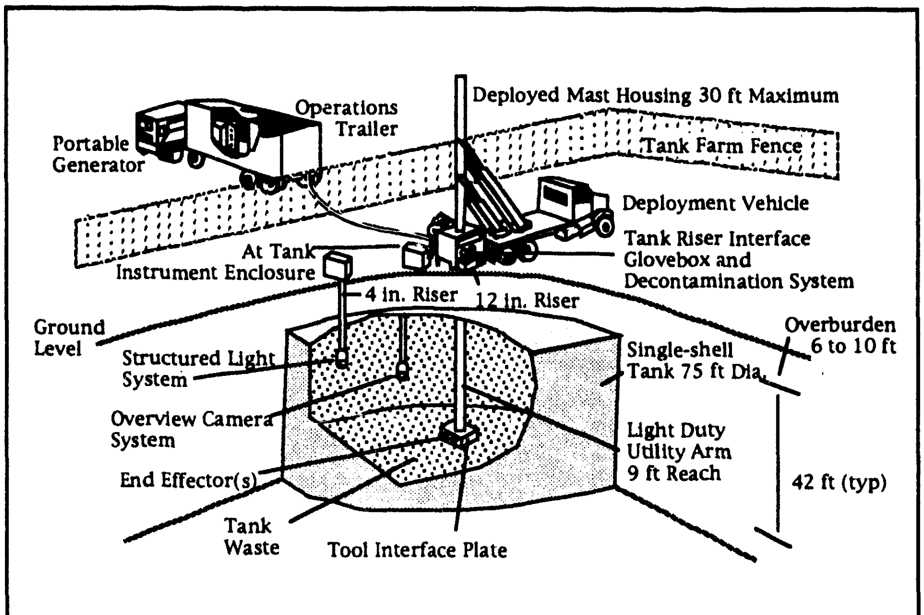
LIGHT DUTY UTILITY ARM SYSTEM FOR TANK CHARACTERIZATION

Westinghouse Hanford Company

DESCRIPTION

The Light Duty Utility Arm System (LUAS), also called the Robotic Tank Characterization System (RTCS), provides a remotely operated, mobile system to deploy end effectors (robotic tools) for waste characterization and tank inspection. This technology will enhance existing capabilities that are limited to single-axis instrument deployment. The current means for performing tank inspection and waste characterization consist of vertical deployment of cameras, instruments, and sampling instruments through risers (openings) on fixed supports. These systems are limited to operation directly below the tank penetration riser.



Light Duty Utility Arm

In contrast, LUAS provides a robotic arm with six degrees of freedom that can position itself at any point within a 9-ft radius hemisphere of the penetration riser. The robotic arm system is designed for deployment through a 12-in. diameter tank riser and reachs to a depth of 48-in. below the waste surface. The robotic arm system will not be able to provide full depth penetration, but it will be able to maneuver other equipment (50-100 lb) above the waste source and provide multiple position samples taken within a 9-ft radius of the riser. LUAS enables some waste characterization, in-tank surveys, and waste topography activities to be performed in-situ to gather data on chemical and physical properties of the waste and information on the structural condition of the tanks. This will not replace laboratory analysis; however, it will provide the capability to gather data in multiple locations within a tank much faster than do current core sampling and laboratory analysis programs.

LUAS consists of various interfaces including an man/machine, graphical user interface; a standardized utility-arm/end-effector interface, called the Tool Interface Plate; and a utility-arm/tank-riser interface for containment. The characterization process would begin by installing the tank riser interface, which includes a containment enclosure. The LUAS mast would then be placed inside the containment enclosure and an appropriate end effector installed. At this point, the mast would be lowered into the tank. The robotic manipulator would be subsequently deployed out of the mast to initiate the characterization or nspection campaign. Data would then be transmitted to data acquisition stations, analyzed, and archived.

Upon completion of data collection, the mast and arm would be retracted out of the tank through a decontamination spray (a pelletized carbon dioxide blast) that removes surface contamination from the mast, manipulator, and end effectors. The pressurized spray decontamination system is mounted just above the tank riser inside the containment vessel.

The graphical user interface can be operated by a single specially trained technician. The graphical control interface includes supervisory control of the robotic system to ease operator fatigue. LUAS also provides a Standard Tool Interface Plate for multiple characterization and inspection end effectors.

TECHNICAL PERFORMANCE

Design. LUAS was designed with a 9-ft multidirectional reach with 6 degrees of freedom of motion. The entire utility arm and end effector was designed for deployment through a 12-in. diameter access riser. It will support instrumentation end effectors that weigh less than 100 lb. As low as reasonably achievable (ALARA) principles were applied to LUAS to minimize human exposure to hazardous environments. The design includes a pelletized carbon-dioxide blast system for high-pressure spray decontamination during retraction.

Laboratory Testing. Detailed reliability analysis is part of the design verification process. Kinematic redundancy analysis has been performed on LUAS to indicate the potential failure modes of the configuration of vendor-proposed designs and to determine whether minor modifications could result in improved performance and reliability. The analytical technique was developed under the Cross Cutting and Advanced Technologies University Program. The results of this analysis have not yet been made available for publication.

Costs. Start-up, operations, and maintenance costs are currently being determined and are not available at this time.

PROJECTED PERFORMANCE

The system is planned for cold testing in FY95 and for a hot testing demonstration in FY96 in the actual radioactive waste environment of a Hanford Underground Storage Tank. Detailed performance and projected performance information will be available after the cold test in FY95.

WASTE APPLICABILITY

This technology is applicable for remote visual inspection of underground storage tank structural conditions. It is also applicable to extract multiple core samples over the lateral positional range (varies with waste level) inside a tank to a maximum penetration depth of 4 ft. The robotic arm would support other chemical and physical property instrumentation tools for in situ characterization of hazardous and radioactive wastes, provided that the total weight of the end effector instrument is less than 100 lb.

STATUS

LUAS is currently in the laboratory testing evaluation and refinement phase of development. Hazards, operability, and regulatory studies are scheduled for late FY93. The system consists of a mix of off-the-shelf and Office of Technology Development developed hardware and software. Development of a complex robotic system is part of this effort.

REGULATORY CONSIDERATIONS

To meet potential regulatory considerations, LUAS includes the pelletized carbon-dioxide blast decontamination system and a containment vessel mounted above the access riser. Clean Air Act requirements are applicable to the containment vessel. Minimal environmental impacts are anticipated from the use of this characterization technology. A detailed regulatory and worker safety analysis will be completed in late FY93.

POTENTIAL COMMERCIAL APPLICATIONS

Potential commercial applications are in the nuclear power industry for Nuclear Regulatory Commission compliance reactor safety inspections, for hot storage tank and spent fuel rod inspection, and for reactor decontamination and decommissioning.

BASELINE TECHNOLOGY

The baseline technology is deployment of cameras, instruments, and waste samplers through risers on fixed supports with their operation limited to vertical-axis motion directly below the riser.

INTELLECTUAL PROPERTY RIGHTS

Patents: None

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Industrial/University Partnership
None at present.

REFERENCES

1. DOE-RL, "Technology Information Profile (rev. 2) for ProTech, Technology Name: Light Duty Utility Arm System," DOE ProTech Database, TTP Reference Number: RL-401203, February 17, 1993.

MICROBIAL MONITORING

Oak Ridge National Laboratory

DESCRIPTION

Many technologies designed to remediate organic contamination either directly depend on increasing populations of bacteria that can degrade the compounds, such as the methane injection, or lead to increases in degradative populations as a secondary result of nonbiological remediation, such as the biological benefits of venting-bioventing. Microbial monitoring is needed to demonstrate the effectiveness of bioremediation and to demonstrate additional bioremediation benefits from other technologies (e.g., bioventing benefits from soil venting). The various advanced monitoring techniques, developed and applied, (e.g., DNA probe analysis, lipid analysis, activity and biomass measurements) all contribute to documenting the necessary changes in microbial populations. In addition, these techniques permit feedback during operation so that procedures may be changed (e.g., changing nutrients) to increase effectiveness of the remediation.

TECHNICAL PERFORMANCE DATA

Microbial population changes were monitored in soil and groundwater samples from the Savannah River Site (SRS). Microbial biomass was evaluated using measurements of colony forming units, MPN techniques for methanotroph and methylotroph population and PFLA analysis. Microbial activity was assessed using the acetate incorporation techniques and by measurement of trichloroethylene (TCE) degradation in enrichments. DNA probes are used to enumerate specific groups of bacteria such as methanotrophs, toluene degraders, and others. Several new probes have been developed as part of this work.

The monitoring has been very effective in documenting significant changes in the microbial community in response to the remediation. The results of this effort indicate that there have been substantial changes in biological activity and biomass with increasingly aggressive measures to promote TCE degration in the subsurface. However, there are some indications of a leveling off or a decrease in some of these measures as the 4% methane injection proceeds. Thus, the data indicate the success in stimulating TCE degrading populations in the subsurface and now may be indicating a limitation of further increases or the potential for decreases in critical populations. Other nutrients may be becoming limiting, and a further phase (methane injection with nutrient addition) may be necessary to increase critical population levels and degradative activity further.

Analysis can be completed in 2 days to 1 month, depending on the techniques used.

Cost. Costs will vary with the intensity of the sampling techniques used. Costs at SRS were high because of the redundancy built into the sampling that was needed to develop the data on the reliability of individual monitoring techniques. Costs for a more focused effort would be lower. Sample costs vary from less than $100 to greater than $500.

PROJECTED PERFORMANCE

This technology is expected to demonstrate the effectiveness of bioremediation and give feedback during operations to increase the effectiveness of bioremediation technologies.

WASTE APPLICABILITY

This technology is applicable to the monitoring of populations that can degrade organic compounds.

STATUS

Materials and equipment are off-the-shelf except for the DNA probes that are not commercially available.

REGULATORY CONSIDERATIONS

Ecological impacts are not anticipated from user of this technology. The potential exists for exposure to solvents and low-levels of radionuclides.

POTENTIAL COMMERCIAL APPLICATIONS

This technology has potential commercial applicatyions at any site undergoing bioremediation.

BASELINE TECHNOLOGY

The baseline technology is mass balance measurements that are limited in monitoring critical changes in the microbial populations.

INTELECTUAL PROPERTY RIGHTS

Patent Ownership: None

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REFERENCES

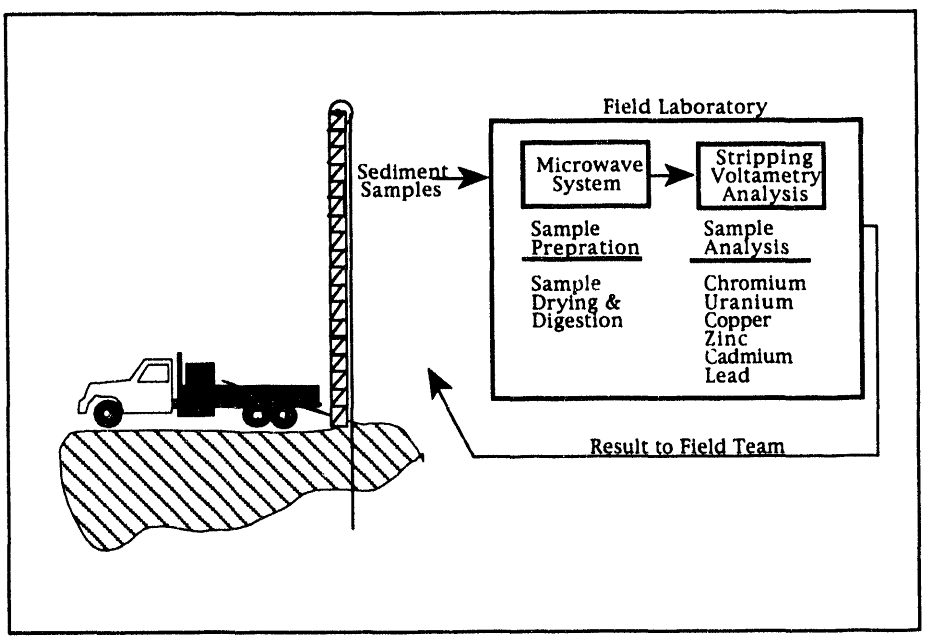
1. DOE-OR, "Technology Information Profile (rev. 2) for ProTech., Technology Name: Microbial Monitoring," DOE ProTech Database, TTP Reference Number: OR-1111-01 (3BAC), March 1993.

ON-SITE ANALYSIS OF METALS IN SOILS USING STRIPPING VOLTAMMETRY

Pacific Northwest Laboratory

DESCRIPTION

Adsorptive Stripping Voltammetry (ASV) has been demonstrated in the field to measure the concentrations of leachable chromium (Cr), lead, calcium, copper, nickel, zinc, and cobalt in soils and sediments. The demonstration is being done at the Chemical Waste Landfill (CWL) at Sandia National Laboratories (SNL) in Albuquerque, NM. Samples are taken from beneath the CWL during drilling operations and analyzed in a portable laboratory at the site. If successful, this technique will allow decisions to be made in the field during characterization and remedial activities by determining the areal and vertical extent of contamination within hours of the sampling.



Adsorptive Stripping Voltammetry

Stripping voltammetry has been used for several decades in the laboratory. Recent advances associated with nonelectrolyte (i.e., adsorptive) pre-concentration schemes and the development of miniaturized electrodes have increased the potential for practical use of the technique in the field.

In this program, the samples are dried with a microwave system and digested with a nitric acid leachate. The resulting solution is diluted with distilled or deionized water and analyzed with the ASV technique. For a particular analysis, an electrode(s), with its surface coated with an agent specifically selected to adsorb the specie of interest, is immersed in the solution. The voltammetric response (potential change) of the adsorbed species during the stripping is a function of the concentration of the specie on the electrode. This, in turn, is directly related to the bulk concentration of the specie in the solution through the adsorption isotherm.

The ASV equipment uses 1 A at 120 VAC (120 W). Ten square feet of bench space and a vent hood are also required for operations in the field. Since a different coating must be used on the electrode for adsorption of a particular specie, ASV is not suitable for screening a site to identify the contaminants, but it does measure the concentration of the contaminants after they have been identified by other techniques or from a priori knowledge.

TECHNICAL PERFORMANCE DATA

The ASV system has a detection limit of 10^{-10} to 10^{-11} moles/L. Concentrations of chromium and uranium have been measured to 1 ppb in both laboratory and field testing.

The concentrations of two of three trace metals may be measured simultaneously from a single sample. Four hours is quoted as typical for obtaining the results in the field for 12 samples. However, the time required for a single analysis is very test specific. For example, 20 to 30 min. were required to determine the concentrations of Cr(III) and Cr(VI) from a single sample in a field test. However, when the Cr(III) was converted to Cr(VI) by the addition of $KMnO_4$ prior to the analysis, only eight min. were required to measure the total concentration of chromium.

Cost**.** Start-up cost depends on the analytical requirements for the specific task. The cost for the stripping voltammetry equipment would range from $5K for single element to $37K for multi-element, multi-sampling capability. A microwave digestion unit is approximately $12K. The operations and maintenance costs are dominated by the need for two operators, one of whom may be a technician. The annual cost for chemicals and supplies ranges from $1K to $2K. Life-cycle costs without labor would vary from $20K to $50K for a single ASV system.

PROJECTED PERFORMANCE

The ASV technique has the potential to measure trace concentrations of approximately 14 metals in addition to those associated with the CWL as shown in the table below. Improvements in the detection limits for some metals may be anticipated.

The following table shows trace metals measured in laboratory and field tests.

Field Tests at CWL	Laboratory Testing[1,2]	
Chromium (Cr)[3]	Aluminum (Al)	Technetium (Tc)
Calcium (Ca)[4]	Iron (Fe)	Thorium (Th)
Cobalt (Co)[4]	Gold (Au)	Tin (Sn)
Copper (Cu)[4]	Molybdenum (Mo)	Titanium (Ti)
Lead (Pb)[4]	Palladium (Pd)	Uranium (U)
Nickel (Ni)[4]	Platinum (Pt)	Vanadium (Va)
Zinc (Zn)[4]	Ruthenium (Ru)	Yttrium (Y)

1. Reference 4.
2. Includes metals tested in the field.
3. Measured at CWL in 1992.
4. Scheduled for measurement at CWL in 1993.

Modifications to the electrodes and processes have also resulted in demonstrated capability of measuring trace levels of electroactive drugs (anti-cancer antibiotics, cardiac glycosides, etc.) and large macromolecules such as insulin and ferritin.

WASTE APPLICABILITY

The ASV technique is being developed specifically to measure trace concentrations of metals in soils and sediments. However, it will probably be extended to make contaminant measurements of radioactive mixed waste materials in the Mixed Waste Landfill (MWL) at SNL. It could also be used to analyze the contaminants in ground and reactor cooling water and in rain.

STATUS

The concentration of chromium was measured to the 1 ppb level, and the ability to distinguish between Cr(III) and Cr(VI) was demonstrated during the field tests in June 1992 at the CWL site. During FY 93, the ASV technique was scheduled for extension to the other six trace metals listed in the table. Shortly thereafter the technology should be transferred to a commercial contractor.

REGULATORY CONSIDERATIONS

Dilute (1%) nitric acid and very small amounts of elemental mercury (50 mL) are contained in the 100 mL sample used for each analysis. Because of these small quantities, no environmental impacts or risks to the public are anticipated for the ASV process.

POTENTIAL COMMERCIAL APPLICATIONS

All the equipment used for the ASV analysis is "off-the-shelf," and at the conclusion of the demonstration it is planned to transfer the technology for an operational system. Thus, the ASV technique should soon be available to the commercial sector for use in measuring the concentration metals in water, soils, and sediments.

The capabilities of the ASV system could also be extended to the metals that have been laboratory tested and are listed in the table. Additional applications in the fields of medicine and pharmacology are possible.

BASELINE TECHNOLOGY

The baseline technologies are acid digestion plus inductively coupled argon plasma (ICAP) or atomic adsorption (AA) analyses; both require the use of an off-site laboratory. In addition to being less convenient for field work than ASV, they are slower. Furthermore, they are less sensitive. For example, experiments with chromium indicated that the detection limit for the ICAP technique was an order of magnitude greater than that for ASV.

INTELLECTUAL PROPERTY RIGHTS

Patent Ownership: None

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PORTABLE ACOUSTIC WAVE SENSOR

Sandia National Laboratories

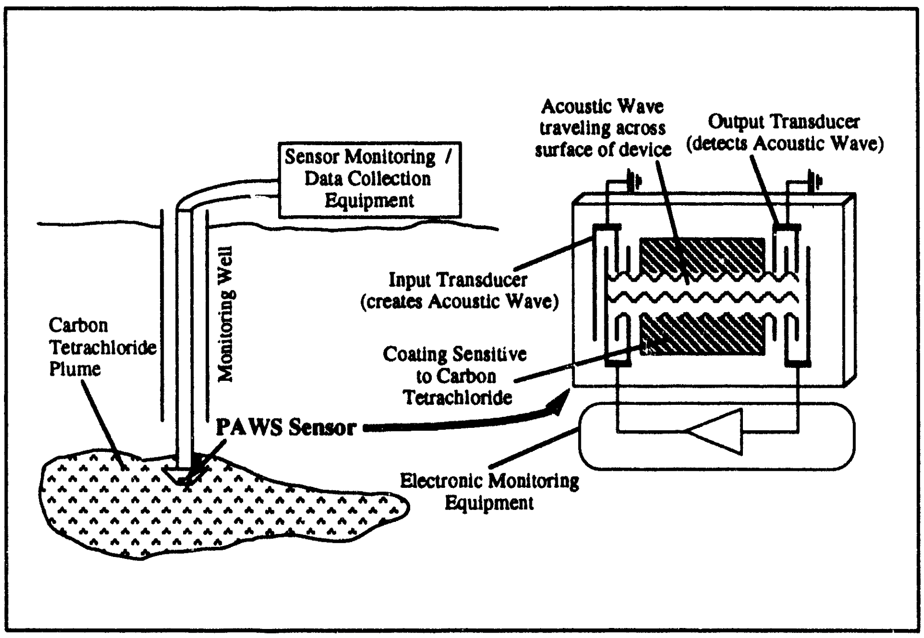
DESCRIPTION

The Portable Acoustic Wave Sensor (PAWS) is a downhole sensor being developed to characterize contamination and monitor contaminant levels of volatile organic compounds (VOCs) at sites in real-time. These sensors will be used with on-site monitoring wells or placed in the ground using a technology such as a cone penetrometer.

The sensor module contains (1) a coated sensor, (2) gas handling equipment, and (3) electronics to operate the device. The PAWS system monitors changes in the speed and power of the wave as it travels across the sensor. These changes occur because a film coating the sensor softens and becomes heavier when it absorbs the contaminant. Coatings have been developed that respond to VOCs. Using one coating material, polyisobutylene, the PAWS system can discriminate carbon tetrachloride from many other contaminants based on a comparison of the two sensor responses. This and other coatings will be tested and used with the probe.

TECHNICAL PERFORMANCE DATA

PAWS can perform continuous in situ monitoring, with rapid and reversible response. In comparison to off-site grab sample analysis, PAWS will perform real-time monitoring of carbon tetrachloride (CCl_4). This technology can identify molecular species and concentrations in dilute gas streams greater than 50 ppm, which can be beneficial during remediation activities. The sensor can be placed down a hole for in situ monitoring and can be automated to provide chemical information to site remediation workers on the distribution and concentration of contaminants. PAWS has capabilities for determining both molecular species and concentration of isolated chemicals. It is faster, cheaper, and as safe as a gas chromatograph (GC) infrared (IR) analyzer.



Schematic of a Portable Acoustic Wave Sensor

For analysis of chemical mixtures, PAWS will not provide all of the information that can currently be acquired with a GC or IR analyzer. When used for real-time analysis, the sensitivity is not as as in some of the alternative techniques. Like most of the alternatives, calibration of PAWS is compound specific. Field demonstrations of above ground and in situ systems have demonstrated an accuracy of better than 10%.

Cost. Vadose zone monitoring unit cost is $10K; operation of the unit requires about 1 h/wk and low maintenance; and life-cycle costs will depend upon use, frequency, and volume of data required.

PROJECTED PERFORMANCE

Future developments include hardware miniaturization for use with the cone penetrometer; development of coatings and pattern recognition for simultaneous characterization of multiple chemical species; decrease in the detection limits based upon improved coatings and environmental sampling techniques; and the development and evaluation of semipermeable membranes for groundwater analysis.

WASTE APPLICABILITY

This field monitoring system is applicable to the quantitative detection of volatile organic compounds in soil, vapor and water. Targeted contaminants are CCl_4 (at Hanford) and trichloroethylene (at Savannah River Site).

STATUS

The PAWS for above ground and in situ vadose zone for a single contaminant is currently available. In situ vadose zone mixture analysis and in situ groundwater analysis with the cone penetrometer will be available in 2 to 3 years.

REGULATORY CONSIDERATIONS

In some situations the sensor may not be sensitive enough. For example the Occupational Safety and Health Administration (OSHA) Permissible Exposure Limit (PEL) for CCl_4 may be lowered to 2 ppm.

POTENTIAL COMMERCIAL APPLICATIONS

This technology has the potential for many industrial applications for real-time, on-line monitoring of exhaust stacks, or work place environments. Sensors can be integrated into on-line process control systems to optimize process operations.

BASELINE TECHNOLOGY

Grab samples and subsequent laboratory or field analysis with a GC or IR analyzer are the baseline technologies.

INTELLECTUAL PROPERTY RIGHTS

Patent Ownership: DOE and Sandia National Laboratories

Patent No: 5,076,094

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PROMPT FISSION NEUTRON LOGGING SYSTEM

RUST Geotech, Incorporated

DESCRIPTION

The Prompt Fission Neutron (PFN) Logging System is also termed Integrated Borehole Geophysical System for Contaminant Identification. This technology is applied for in situ detection of fissile materials, principally U-235 and Pu-239, in soil and rock media surrounding the borehole. It has been reported that PFN probes can also be used as porosity devices or moisture gages. This technology addresses the need for better methods to characterize subsurface geohydraulic features, for in situ methods of characterizing contaminants, and for understanding subsurface contaminant behavior.

The logging system is self-contained and operates as a stand-alone instrument. During field operations, the probe is lowered into a bor[illegible] and data are collected. These data are [illegible] digitally, processed rudimentarily, and di[illegible] to permit quality assurance and initial interpretation. At a later time, the data are processed in detail and interpreted. To generate PFN data, the instrument generates a short burst of neutrons using a linear accelerator in a sealed tube within the probe. The neutrons penetrate the soil and rock surrounding the borehole but are slowed down and eventually captured by other atoms. The atoms that capture neutrons, U-235 and Pu-239 (and other elements with comparable fission, cross sections), spontaneously fission producing additional neutrons. These additional neutrons are counted by a detector that is shielded so that it detects only the energetic neutrons from fission. The observed countrate, which varies as a function of time after each neutron burst, is related to the partial density of fissionable elements in the soil. Epithermal neutrons detected after 200 microseconds are from fission reactions.

An advantage of PFN technology is that it provides a near-continuous profile of contaminants as a function of position along the borehole. Another advantage is that it analyzes some three orders of magnitude larger volume of material than an individual borehole sample. Furthermore, PFN logging provides the opportunity to repeat measurements in the same borehole, year after year, for monitoring purposes. PFN logging can produce in situ assay data in a fraction of the time it takes to submit all of the samples from a borehole to an analytical laboratory and obtain results. With the PFN Logging System, the time needed to log the hole is a few hours, and results are available instantly. On the other hand, the PFN system is not as sensitive in providing assays for waste concentrations as is possible in the laboratory.

TECHNICAL PERFORMANCE

Design. The PFN probe is approximately 11 ft long and is designed to bombard a 2-ft radius immediately around the borehole with a burst of 14 MeV neutrons at a repetition rate of 100/s. A 100-ft borehole could be logged in about 3 hours. PFN logging requires a cased borehole with a minimum inner diameter of 5 in. Vertical direction data point spacings are typically 0.1-0.2 ft. PFN would analyze 1000 times greater volume than borehole sampling. The lower detection limit of the system is about 1 nCi/g Pu-239. (However, some regulatory limits are in the range of pCi/g.)

Cost. It is estimated that a cased, 100-ft deep borehole with an uncontaminated interior could be logged for $1,000 as part of a multiple-hole program. (This is compared to $100,000 for borehole sampling and laboratory analysis of a 100-ft borehole with 20 samples taken at 5-ft intervals.)

PROJECTED PERFORMANCE

The field demonstration scheduled for the Hanford Site in late FY93 will prove or disprove the applicability of this technique. If PFN logging is successful, it should be possible to reduce the required borehole sampling and laboratory analysis costs by 25%, as a conservative estimate, leading to a savings of $24,000 per 100-ft borehole.

WASTE APPLICABILITY

This measurement technique is applicable for in situ detection and quantification of fissile materials, principally U-235 and Pu-239, in soil and rock surrounding a cased borehole.

STATUS

The PFN logger prototype has been constructed and will be demonstrated at the Hanford Site in late FY93. The prototype will be further enhanced in FY94 according to lessons learned and should be available by the end of that fiscal year.

REGULATORY CONSIDERATIONS

Of concern is the potential for human exposure to neutron bursts. Appropriate field procedures eliminate this risk because no radiation is generated until power is applied to the probe. The use of this tool in and around aquifers would be of concern if the tool with the neutron source were lost in the borehole and abandoned.

POTENTIAL COMMERCIAL APPLICATIONS

This technology could be used in mining and exploration activities to log and assay potential uranium deposits.

BASELINE TECHNOLOGY

The baseline technology is borehole sampling and laboratory analysis. While the laboratory analysis could detect fissile materials present in smaller concentrations than the PFN lower detection limit and give a full radiologic spectrum assay, laboratory analysis is much more expensive per data point and analyzes a smaller volume per borehole. PFN logging is not intended to replace requisite sampling and analysis but to reduce the amount of sampling needed. PFN provides an in situ technique that would be useful to provide more data point details to a borehole sampling program. It also provides a relatively inexpensive method for borehole monitoring.

INTELLECTUAL PROPERTY RIGHTS

The Department of Energy owns the intellectual property.

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Industrial/University Partnership

None at present.

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RAPID GEOPHYSICAL SURVEYOR

Idaho National Engineering Laboratory

DESCRIPTION

The Rapid Geophysical Surveyor (RGS) is a passive, nonintrusive geophysical measurement system. This automated system collects high-resolution geophysical data required for economical, accurate buried waste site characterization. The measurement system is based on a magnetometer sensor that can detect anomalies in the subsurface magnetic fields and quantitatively measure natural magnetic fields of buried ferromagnetic waste components.

The RGS system is a hand-pushed, nonferrous vehicle that consists of magnetic sensors, a data logger, data storage hardware, and menu-driven software. The user is required to push a 20-lb cart to collect magnetic data. Magnetic data are automatically collected and stored at user-specified intervals as close as 2-in. apart along survey profile lines. These data form a high-resolution database capable of locating individual objects and potentially determining object orientation, shape, and depth to burial. There is no input required for this passive system, and the output of the RGS is a set of spatially correlated magnetic data. Currently, RGS is limited to sites that are fairly flat with little or no vegetation.

TECHNICAL PERFORMANCE

Field Demonstration. The RGS was field demonstrated in September 1992 and functioned as designed. The magnetometers are sealed by the manufacturer and required no further calibration; however, the distance wheel was calibrated during operations. The RGS collected magnetic data at a maximum rate of 25,000 data points per hour. This is 30 to 300 times faster than the baseline, hand-held magnetometer technologies. The RGS operates on 2 12-volt gel cell batteries and draws about 1/2 watt continuous power. The cost of using the RGS on a waste site is proportional to the size of the site and man-hours required to perform a survey. Maintenance costs are unknown but are expected to be minimal. The complete prototype system cost is under $200K.

PROJECTED PERFORMANCE

It is estimated that a robust positioning system could be incorporated onto the RGS by FY94. This may enable the application of RGS to buried waste sites that are not flat and smooth. The major technical challenges are associated with the effective processing and presentation of large amounts of geophysical data and with interpreting the results of the data processing such that the correlation between data and buried objects is achieved.

WASTE APPLICABILITY

This technique is applicable to buried waste in a soil medium where the buried waste has a ferrous content or where nonferrous waste is enclosed in a ferrous container.

STATUS

The prototype system is available now. A robust positioning system could be available by FY94.

REGULATORY CONSIDERATIONS

Regulatory issues are expected to be minimal. Because this is a nonintrusive characterization technique, there is no subsurface disturbance or process waste, and little or no decontamination of equipment is anticipated by using RGS. There are no health hazards originating from the RGS itself; however, exposure to hazardous materials is possible directly from survey sites.

POTENTIAL COMMERCIAL APPLICATIONS

Commercial applications include underground utility detection (although the cost and level of detail may be impractical), and geotechnical mining applications (especially where mineralized veins carry ferrous components).

BASELINE TECHNOLOGY

Hand-held instrumentation represents the current method for collecting magnetic and electromagnetic geophysical data. A hand-positioned magnetometer system is labor intensive to use. In contrast, the RGS can perform geophysical magnetic surveys more quickly (30 to 300 times faster) and more economically ($.25 versus $5 per data point) than can hand-held instruments. Also, because the RGS is an automated system, it can collect spatially denser data sets than previously thought possible, thereby providing a high-resolution picture of the state of the buried waste site.

INTELLECTUAL PROPERTY RIGHTS

A patent disclosure has been made.

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None at present.

REFERENCES

1. DOE-ID, "Technology Information Profile (rev. 2) for ProTech., Technology Name: Rapid Geophysical Surveyor (RGS)," DOE ProTech Database, TTP Reference Number: ID-121213, July 15, 1993.

RAPID TRANSURANIC MONITORING UNIT

Idaho National Engineering Laboratory

DESCRIPTION

At the Idaho National Engineering Laboratory (INEL), there are 2M ft^3 of transuranic waste commingled with 8 to 10M ft^3 of soil. Retrieval and treatment of this material is one of the final disposition options being considered. The transuranic contaminants, such as oxides of plutonium and americium, can become attached to small soil particles during the excavation process or during internment because of deterioration of the original waste containers, subsidence, and backfill. Since retrieval at INEL and other arid sites would generate considerable dust, control of the potentially contaminated dust spread is mandatory, primarily because of the extremely low levels of uptake allowed (tenths of mg.). A contamination control strategy involves ventilation, dust control, naturally occurring moisture control in the soil/waste mixture, and rapid monitoring to assess the success of the scheme.

A Rapid Transuranic Monitoring (RTM) unit will be demonstrated in the field and will provide on-line monitoring of airborne and loose contamination within the inner building. Hundreds of samples per day of soil, filter, smear, and air samples will be analyzed in an on-line manner for plutonium, americium, and the entire spectrum of gamma emitters. The system utilizes state-of-the-art alpha continuous air monitors (CAMs), a U-L-Shell X-ray measurement system, and a specially designed large-area ionization chamber. The unit has the capability for sample preparation and a separate counting area. The data are assimilated using a VAX 4000 computer and will be continuously displayed and printed out by the computer.

TECHNICAL PERFORMANCE DATA

Analyzed samples can be characterized to tens of pCi/g for soils, smears, and filters, and to 1-DAC (a DAC h refers to the maximum permissable concentration of plutonium in air that can be measured in a one hour sampling time) for continuous air monitoring. The RTM unit can measure isotopic plutonium at 20 pCi/g for 15 min. counts. This rapid in-field measurement allows up to 100 samples of soils/filters/smears to be analyzed per day per trailer. For an environmental restoration project such as a pit retrieval, 100 samples per day should be adequate to track contamination levels, thereby supplying an essentially on-line tracking capability. A true "on-line" tracking of Pu-239 content is presently not possible.

Cost. RMUs can be procured for $500K. Operations and maintenance costs include four technicians and 10% time assistance from scientists. Life-cycle costs have not been estimated.

PROJECTED PERFORMANCE

The RMU will be field deployed in October 1993, when actual field performance will be demonstrated.

WASTE APPLICABILITY

The RTM unit monitors plutonium, americium, any alpha emitter, and the entire gamma spectrum from X-rays to CO-60 and Cs-137 in soils, fallout coupons, filters, air, and liquids.

STATUS

The RTM unit should be field deployable in October 1993.

REGULATORY CONSIDERATIONS

Ecological impacts are not anticipated from use of the RTM unit. Samples for the RTM unit will be standard health physics wrapped and will be prepared under a Class A hood.

POTENTIAL COMMERCIAL APPLICATIONS

Potential commercial applications include monitoring of radioactive contaminated retrieval areas and separation, processing, and storage systems. The RMU could also be applied in accident mitigation.

BASELINE TECHNOLOGY

The baseline for rapid monitoring during retrieval is "in laboratory" analysis and health physics hand-held instruments. Hand-held instruments can provide gross alpha measurements on surface soils at the 5000 - 10,000 pCi/g levels in minutes. Laboratory measurements can provide 4 samples per radiochemist per day at the 0.2 pCi/g level. Alpha CAMs "off the shelf" currently provide about 80 DAC - h sensitivities.

INTELLECTUAL PROPERTY RIGHTS

Patent Ownership: EG&G Idaho, Inc.

Patent Number: S-71-122, "A System to Control Contamination During Retrieval of Buried TRU Waste."

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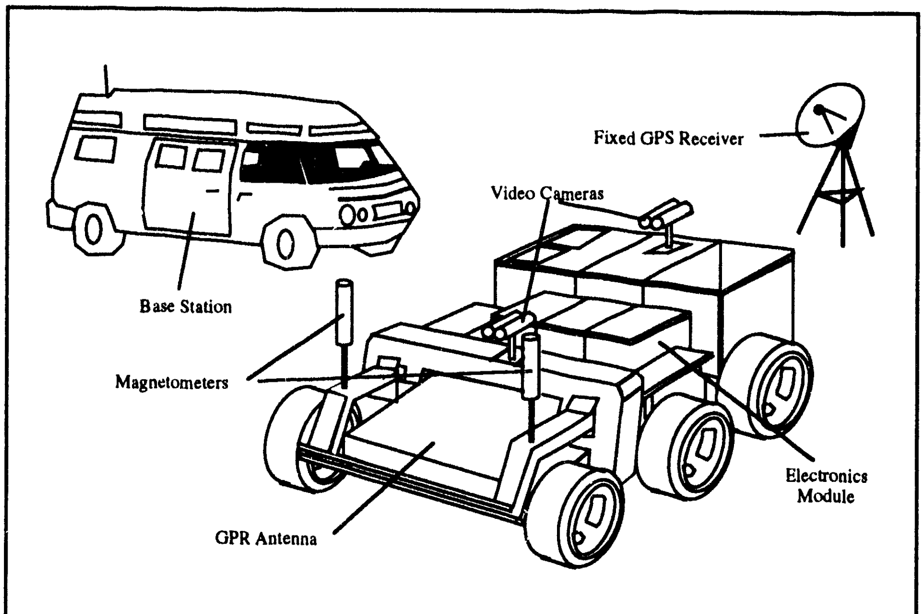
[redacted]

REMOTE CHARACTERIZATION SYSTEM

Idaho National Engineering Laboratory and
Pacific Northwest Laboratory

DESCRIPTION

The Department of Energy (DOE) has developed a Remote Characterization System (RCS) to address hazardous operational problems by using unmanned vehicles and remotely controlled instruments in site characterization surveys. The RCS, which is a hardware system developed under the Buried Waste Robotics Program (BWRP), includes a unique low-signature (nonferrous) survey vehicle, a high-level control station, a satellite-based (navigational/tracking) Global Positioning System (GPS), and a suite of geophysical sensors.



Remote Characterization System

The purpose of the RCS is to deliver several geophysical sensors remotely to a buried waste site on one platform, obtain data from these sensors via a radio-frequency telemetry link, and provide accurate subsurface maps of the waste streams and pit and trench boundaries. The targeted contaminants are metals, volatile organic compounds (VOCs), radionuclides, and other constituents. Initial nonintrusive characterization of buried waste is vital to determine the exact location of pit and trench boundaries, hot spots, radiation levels, and depths to the waste level and the basalt geological layer. This RCS presents an alternative characterization technique to allow improved data quality through automated data acquisition, improved data display for interpretation, and increased safety to personnel.

The Land Survey Vehicle (LSV) is constructed of nonferrous materials to minimize electromagnetic interference with the on-board electronic equipment. The vehicle is self-propelled and guided by a remote base station. The high-level control station includes three 19 in. monitors that provide stereo visual display to the vehicle operator and keyboard- or joystick-operated controls. A qualified geophysicist is part of the two-man survey team. The full range of sensors to be supported by this vehicle and its instrument package has not yet been defined, but it will include ground penetrating radar (GPR), a metal detector, a magnetometer, an induction-type ground conductivity sensor, and a radiological sensor.

A differential, kinematic, GPS-based subsystem has been developed as a primary means of tracking the vehicle. The GPS kinematic system uses a fixed GPS reference antenna and a remote GPS receiver antenna, and it applies acute phase comparison of radio-frequency signals from four or more earth orbiting satellites. GPS navigation enables a real-time three-dimensional coordinate position of the LSV to be calculated with absolute accuracies of ± 50cm (GPS can be as accurate as ±10 cm) at a rate of 2 to 200 measurements per sec.

TECHNICAL PERFORMANCE

Field Demonstration was scheduled for June 1993 at an Idaho National Engineering Laboratory (INEL) buried waste site. The LSV has a 20-hp, gasoline-powered, two-cylinder engine with an average fuel consumption of 1 gal/h; and there is a 12-V, 20-A alternator mounted on the rear section of the chassis. The vehicle has a six-wheel design with modified skid steering. The vehicle was designed to facilitate decontamination. The LSV has an 8-in. ground clearance, except when the GPR antenna is used, reducing the ground clearance to 1 in. The LSV operates at speeds between 1 and 6 ft/s (2/3 to 4 mph) and up to 10 ft/s. The control base requires 12-kW (continuous) electrical power to operate the equipment and to heat or cool the van. The GPS navigation and positioning system can be used to obtain position measurements at accuracies better than 0.1% of the vehicle range. Higher accuracies are possible using phase comparison of radio-frequency telemetry. The prototype system is valued at approximately $550K.

PROJECTED PERFORMANCE

A demonstration at an INEL buried waste pit was scheduled for June 1993. Sensor calibration requirements were assessed at that time. Since the RCS is designed for remote operation from a human engineering control station, a human factors analysis on the control system will be performed.

WASTE APPLICABILITY

RCS is applicable to metals, VOCs, radionuclides, and other types of contamination; any sensor could be mounted on the Remote Characterization System.

STATUS

The prototype RCS has been constructed, and Technical Evaluation Report is scheduled for completion in September 1993. Additional enhancements are scheduled for FY94, including a remote-controlled utility vehicle for refueling and maintenance support. Transfer of this technology to private industry is proposed for FY94.

REGULATORY CONSIDERATIONS

No environmental or ecological impacts are anticipated from the use of this nonintrusive survey vehicle. This characterization system is remote and eliminates worker exposure to hazardous environments.

POTENTIAL COMMERCIAL APPLICATIONS

The potential applications are very broad. It is proposed that this survey vehicle could be incorporated with all stages of a remedial operation. Potential applications include remote support of domestic or foreign hazardous and radioactive cleanup operations (e.g., buried waste landfills, nuclear reactor accidents, and hazardous or physically unstable mine tunnel investigations), rapid property survey, terrestrial topography, and lunar or Mars logging and exploration (if proper GPS satellites were deployed).

BASELINE TECHNOLOGY

The baseline technologies are hand-held instrumentation techniques. The use of remote controlled devices removes operators from hazardous environments and increases the speed of operations, thus reducing overall characterization and remediation costs.

INTELLECTUAL PROPERTY RIGHTS

The Patent is owned by DOE and the Department of Defense.

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Industrial/University Partnership
None at present.

REFERENCES

1. DOE-ID, "Technology Information Profile (rev. 2) for ProTech, Technology Name: Remote Characterization System (RCS)," DOE ProTech Database, TTP Reference Number: ID-332001, July 15, 1993.

2. Sandness, G.A., D.W. Bennett, L. Martinson, D.N. Bingham, A.A. Anderson, "A Remote Characterization System and a Fault-Tolerant Tracking System for Subsurface Mapping of Buried Waste Sites," Spectrum '92 International Topical Meeting on Nuclear and Hazardous Waste Management, August 23-27, 1992, Boise, Idaho; Vol. 1, pp. 86-92.

SEAMIST™ BOREHOLE INSTRUMENTATION AND FLUID SAMPLING SYSTEM

Sandia National Laboratories

DESCRIPTION

SEAMIST™ is an instrumentation and fluid sampler emplacement technique designed for in situ characterization and monitoring. It uses an inverting, pneumatically deployed tubular membrane (impermeable material) to install sampling devices and instruments in boreholes.

The membrane is forced into a drilled or punched well due to by pressure. The membrane descends, everts, and presses against the hole wall, providing wall support and the effect of a continuous packer. After emplacement, the entire hole wall is sealed, thus preventing ventilation of the pore space or circulation of pore water in the well. The membrane can be retrieved from the hole.

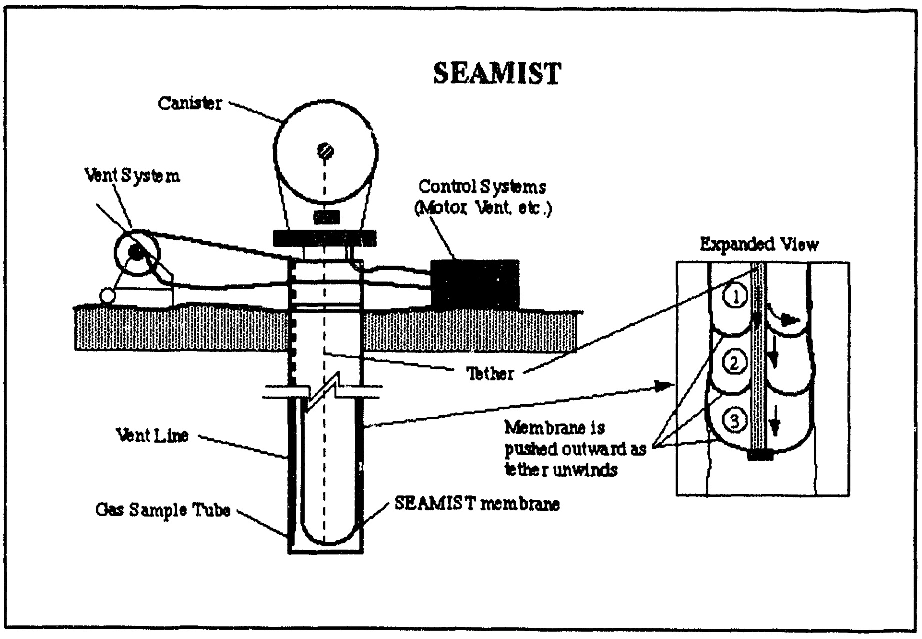
Monitoring instruments and pore fluid sampling devices are placed on the outer surface of the membrane, in contact with the hole wall. The membrane isolates each measurement location. Emplacement has been demonstrated for vertical, horizontal, and crooked or partially obstructed holes. Instruments or samplers are not dragged along the hole wall at any time.

Permanent installation of the membrane is possible by filling the membrane with grout after emplacement. Semi-permanent installation can be accomplished by filling the membrane with sand after emplacement.

The membrane can be applied to perform vadose zone pore and fracture liquid sampling through the use of absorbent pads. Electrical resistance measurements inside the pads indicate moisture uptake. By attaching an array of absorbent pads to the membrane, high spatial resolution of the contaminant distribution is possible.

Extraction of soil gas samples from a hole can be accomplished via tubes to surface sample collectors, or getters, such as activated charcoal absorbers, can be attached to the membrane surface to absorb contaminants. A hybrid concept is to pull a gas sample through a filter positioned at the sampling point.

Air-permeability distribution within a soil matrix can be measured by emplacement of a mem-



SEAMIST™ Emplacement System

brane with several gas sampling ports. As the gas is pulled from one port to the surface, its flow rate and measured pressure response at the adjacent ports imply a local permeability distribution.

Additional instruments can be applied, such as temperature sensors, thermocouple psychrometers, and fiber-optic sensors. Calorimetric materials can be used for visual indications of contaminant distribution.

TECHNICAL PERFORMANCE DATA

Tritium Plume Monitoring. Two systems installed at Lawrence Livermore National Laboratory (LLNL) in 1991 are tracking the movement/concentrations of a tritiated water plume (vapor and liquid water sampling) to 40-ft depths.

Carbon Tetrachloride Monitoring. Two emplacement systems with disposable membrane liners are in use at Hanford for carbon tetrachloride plume monitoring.

Fracture Flow Mapping and Rate Measurement. Membranes coated with liquid-indicating and wicking layers were used to map and measure brine flows underground at the Waste Isolation Pilot Plant (WIPP).

Tritium and VOC Sampling. SEAMIST™ system transported vapor sampling tubes and absorbent collectors 230 ft horizontally beneath an old radioactive waste landfill at Los Alamos National Laboratory (LANL).

SNL Integrated Demonstrations. Transported logging tools and cameras in horizontal boreholes of up to 230 ft length and 1.75 to 4.0 in. diameters. Performed gas sampling and permeability measurements in two boreholes of 11.5 in. diameter and 110 ft depth immediately after augering in SNL's CWL. Installed three borehole liners 110 ft long.

Vapor Sampling/Permeability Measurements. Three membranes were instrumented and installed at SRS in July 1992 for soil vapor, vapor pressure, and permeability measurements. Maximum depth was 130 ft, with ten sampling elevations per membrane.

Neutron Logging Tool Transport. The membrane towed a 3-lb neutron moisture logging tool in horizontal boreholes. Typically, four 4.5-in.-diameter holes (200-250 ft) were logged in one day, with data taken every 2 ft.

Vapor Sampling. A vapor sampling system was installed to 90-ft depths for long-term monitoring.

Borehole Liners. SEAMIST™ liners were installed to support/seal holes while long-term monitoring system is designed. Hole diameter was 8.5 in. and depths were 80 to 100 ft.

High Pressure Borehole Liners. Two Kevlar reinforced membranes were installed to a depth of 155 ft, then filled with water inside cased walls to prevent collapse of polyvinylchloride (PVC) casing during remediation experiments.

Cost. Membrane - $2K to $8K, depending on complexity; emplacement canisters and support sytems - $1K to $5K.

PROJECTED PERFORMANCE

Key performance parameters are listed below, including projections of near-term (1-3 yrs) performance.

Performance Parameter	Demonstrated	Projected
Hole Diameter (in)	1.75 - 11.5	0.5
Hole Vertical Depth (ft)	250	> 300
Hole Horizontal Length (ft)	250	> 300
Vertical Deployment Speed (ft/min)	30	30
Horizontal Deployment Speed (ft/min)	30	30
No. Vapor Sampling Points/Membrane	10	30

WASTE APPLICABILITY

Demonstrated measurement/monitoring of soils contaminated with tritium, carbon tetrachloride, and volatile organic compounds (VOCs).

STATUS

- Demonstrated capability to transport logging tools and cameras in horizontal boreholes up to 230 ft long and 1.75 to 4 in. diameter.
- Performed multilevel discrete gas sampling and permeability measurements at Sandia's CWL in two 11.5-in.-diameter, 110-ft-deep boreholes.
- Installed three 110-ft borehole liners to support holes and protect logging demonstration.

REGULATORY CONSIDERATIONS

Regulatory considerations are a function of where the technology will be used, the nature of contamination, and the intended application of the technology.

POTENTIAL COMMERCIAL APPLICATIONS

SEAMIST™ is commercially available for borehole lining, liquid/vapor sampling, and permeability measurements. Potential near-term applications, include water sampling below the water table; very long (> 300 ft) horizontal deployment for landfill monitoring; pipe inspection, characteri-zation, and monitoring; and large-scale vapor plume movement experiments/ monitoring. The system can be used in both vertical and horizontal pipes and conduits. The membrane can deploy through 45° and long-radius 90° elbows. It can pass over obstructions occupying one-half the pipe diameter. These applications would be useful to utilities; the chemical, mining, oil, and natural gas industries; Environmental Protection Agency (EPA) and Department of Defense (DoD) cleanup operations; and various federal Decontamination and Decomissioning (D&D) programs. SEAMIST™ is also being considered for tritium monitoring in pipes. Duets are being considered for D&D of Department of Energy (DOE) facilities.

BASELINE TECHNOLOGY

SEAMIST™ is a new technology. It replaces the need for ex situ soil sample analysis. The membrane minimizes the likelihood of contamination release from sampling and monitoring boreholes.

INTELLECTUAL PROPERTY RIGHTS

Patent and Trademark Ownership: Eastman Cherrington Environmental, Houston, TX; Patent No. 5176207.

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REFERENCES

1. Lowry, W., C. Williams, "Inverting Membrane Instrumentation and Sampling System (SEAMIST™) for Tritium Monitoring and Characterization," Presentation Material.

2. "Borehole Instrumentation and Fluid Sampling System," Science and Engineering Associates, Inc., Data Sheet, pp. 9-91.

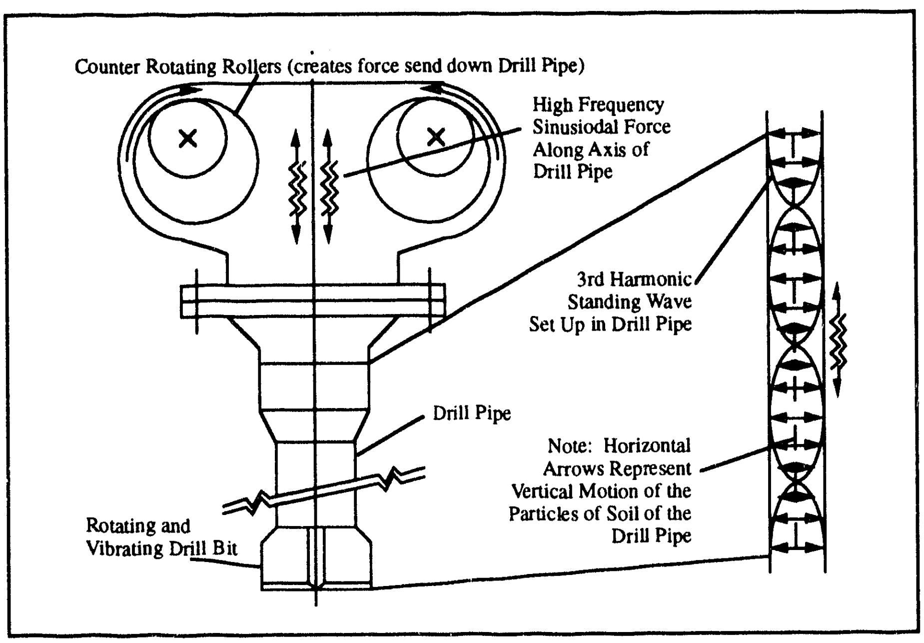
SLANT ANGLE SONIC DRILLING

Sandia National Laboratories

DESCRIPTION

Slant Angle Sonic Drilling (SASD) is a method of rapid access to the subsurface for installation of a sloped well using resonant drilling methods. A high-power hydraulic oscillator containing eccentric, counter-rotating rollers utilizes inertia to effect a high-frequency, third-harmonic, sinusoidal standing wave in the drill pipe and drill head. In addition, to vibration, the resonant drill head also rotates, creating a very efficient cutting action in any geologic formation. Penetration rates are geology dependent, but the sonic drilling method can penetrate any formation including landfills, enabling penetration through boulders, metals, tires, wood, and concrete. The slant angle rig allows a well to be drilled at any angle from vertical to nearly horizontal. A hydraulically activated pull-down mechanism effects penetration into the formation. Below is a schematic of a sonic drill.

Various benefits arise from this drilling technique such as rapid penetration (speed), waste minimization, and high-quality core removal (including alluvial soils). The resulting cutting action of the drill head forces a continuous core of the formation up into the drill string. Moreover, the high forces developed and external flushing nature of the specialized drill string forces excess geologic material into the borehole wall. The result is that no additional cuttings are generated or removed from the subsurface other than the continuous core. This has great economic advantage when applied to an environmental application, such as, sampling below a chemical waste landfill or an application with radioactive soil contamination. The resonant drilling method requires no drilling fluids for lubrication or cutting removal; this contributes to the production of a high-quality continuous core that is useful for both geologic and contaminant analysis of the subsurface formation.



Basic Principles of a Sonic Drill

Technology developments in the form of feedback control and advanced hardware design will improve both the speed of this technique and its component reliability. The advancement of this technology will include an analog or digital feedback control circuit, as well as laboratory and field analysis of bit temperature, bit design, and downhole drill rod temperatures. The developers are in the conceptual stages of incorporating a method of downhole steering into this drilling technology to vary the drill angle during well drilling.

TECHNICAL PERFORMANCE DATA

This technology has been successfully applied to continuous coring, monitoring well construction, and horizontal drilling activities. A demonstration of the improved system, with feedback control and component redesign for improved reliability and more rapid access, is planned.

Drill Head. Dynamic force output is 30,000 lbs at 120 Hz. Power input is 150 hp. Rotational torque is 25,500 in.-lb; rotational speed is 60 rpm.

Drill Rig. Pull down force is 10,000 lb; the pull down rate is 100 ft/min. Angle capacity is 45 to 90° off the truck, and 5 to 45° is off standing mounting plates.

Speed of Drilling. The penetration rate of the sonic drill varies depending on the type of formation being cut. Speeds from 1 ft/s to 0.5 ft/min are encountered when drilling loose to compact formations.

Formations. The sonic drills any type of formation: alluvium, sands, clays, cobbles, boulders, bedrock, permafrost, caliche, and other types of formations including landfills. It is able to drill through metals, garbage, tires, wood, and concrete.

Cost/Benefits. The cost is approximately $100/ft for cased angled hole with continuous core. Drilling requires no fluid, and no cuttings are generated, which eliminates several waste streams and disposal costs. The result is savings of support staffing and cost savings for management of excess contaminated drill cuttings. There is a 95 to 100% core return in alluvial soil versus 60% for conventional drilling. Core sizes range from 2 to 12 in. in diameter depending on the dictates of the drilling program.

PROJECTED PERFORMANCE

The drilling speed and component reliability are expected to improve with the inclusion of feedback control and component redesign.

WASTE APPLICABILITY

This technology is applicable for monitoring wells, vadose zone soil gas sampling, neutron probe pipe installation, core sampling, and injection and extraction wells for bioremediation and/or air stripping/vacuum extraction remediation projects. Additionally, in most conditions, closed-end tubes can be resonated into the ground to significant depths to yield no cuttings or core and to take discrete water samples or in situ cores.

STATUS

Resonant sonic drilling has existed for over thirty years, originating from the work of its inventor, A. G. Bodine. The application of this technology has been well demonstrated by the developers, the Water Development Corporation. There are eleven known U.S. based sonic drill heads and rigs, ten of which are operated by Water Development Corporation. This technology is currently available, with process improvements (feedback control and hardware redesign) expected within 2 to 3 yrs.

REGULATORY CONSIDERATIONS

Drilling and subsurface access regulations may vary depending on the waste site characteristics. Ecological impacts are minimized or eliminated by the absence of secondary waste streams. Occupational Safety and Health Administration (OSHA) regulations apply for drilling equipment operation, high noise levels, and potential contaminant exposure.

POTENTIAL COMMERCIAL APPLICATIONS

This technology can be applied to water well, natural gas well, geothermal well, and oil well drilling. It is also useful to industries that may have soil or groundwater contamination problems. Rapid access to the subsurface, without excess soil removal or secondary waste streams, is economically desirable for such industries to determine the scope of the problem and to remediate the contamination. This method of continuous core removal is useful for other geologic studies and to the mining industry.

BASELINE TECHNOLOGY

This technology is compared to other conventional drilling methods, such as hollow stem auger, air and, mud rotary drill rigs that are traditionally used for oil, gas, and river-crossing applications. Field results demonstrate that the daily output of one sonic drill rig will approximate the daily continuous core output of three to four hollow stem auger rigs.

INTELLECTUAL PROPERTY RIGHTS

U.S. patents for Resonant Sonic Drilling technologies are held by the Water Development Corporation (WDC). Patent numbers are available from the technology developer, WDC.

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REFERENCES

1. Water Development Corporation Brochure, "Resonant Drilling Method," Water Development Corp., Woodland, CA; (800) 873-3073.

2. DOE-AL, "Technology Information Profile (Rev. 2), Technology Name: Slant-Angle Sonic Drilling," DOE ProTech Database, TTP Reference Number: AL2310-05, February 24, 1993.

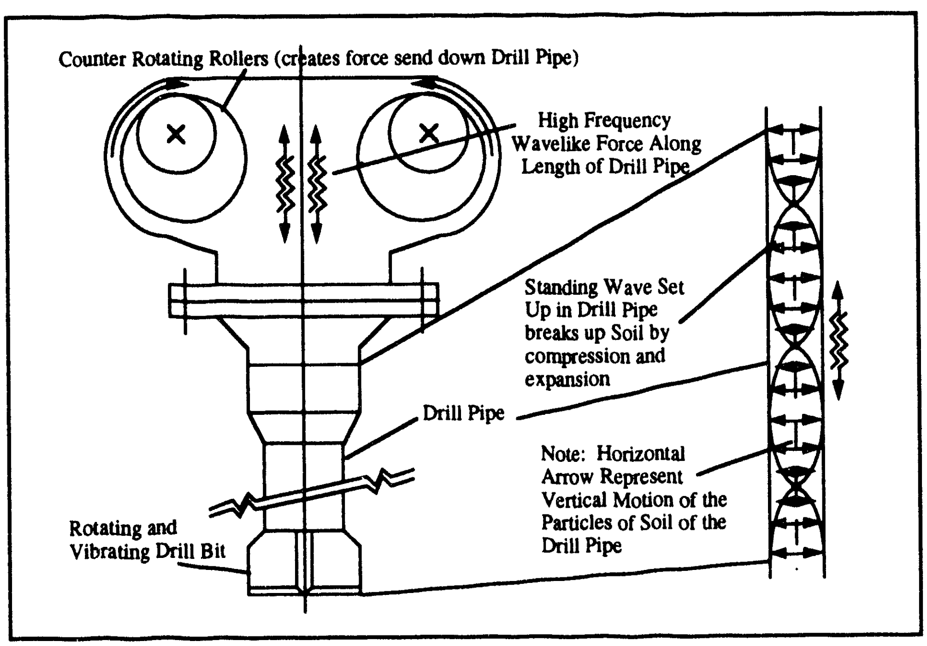
3. DOE-AL, "Directional Sonic Drilling," FY93 Technical Task Plan ; TTP Reference Number: AL-2311-05, Outline for FY 1993.

SONIC DRILLING

Westinghouse Hanford Company

DESCRIPTION

This drilling technology is an enhancement of the sonic drilling method to obtain representative geologic samples that meet data quality objectives and minimize secondary waste generated. It also reduces costs for drilling by means of its increased productivity, while minimizing operational and contamination exposure hazards to personnel. In addition, sonic drilling is utilized for the deployment of instruments, sensors, and other devices to the subsurface for characterization, remediation, and monitoring purposes. Sonic drilling has three major components: (1) a drill rig with the sonic head, (2) a drill pipe, and (3) a drill bit. Two counterbalances in the drill head rotating at high speed impart energy waves down the drill pipe at frequencies up to 150 c/s that are released at the face of the drill bit. The maximum energy delivered varies, depending on the size of the eccentric rollers and the maximum horsepower delivered to the drill head. The most common size sonic system can provide a maximum of 40,000 lb_f. As the drill bit penetrates the soil, the core sample is captured in a tube that rests in the drill bit. Samples are continuously collected and retrieved from the hole using either a wireline retrieval system or by the removal of a sampling string located inside the drill pipe. No circulation medium is required with the sonic method; therefore, the only byproduct from drilling is the core sample. Sonic drilling is a promising method for several drilling applications including characterization borings, groundwater monitoring wells, extraction wells, and barrier installation holes.



Schematic of a Sonic Drill

TECHNICAL PERFORMANCE DATA

Sonic drilling generally produces only the cored sample, and holes are drilled at double the baseline rate. Preliminary testing of sonic drilling at the Hanford Site resulted in a cost reduction of approximately 15-25% over 11 holes, even though downtime from equipment failures was over 45%.

This technology has been successfully applied to continuous coring, monitoring well construction, ing, monitoring well construction, and horizontal drilling activities. A demonstration of the improved system, with feedback control and component redesign for improved reliability and more rapid access, is planned.

Drill Head. Dynamic force output is 30,000 lb at 120 Hz. Power input is 150 hp. Rotational torque is 25,500 in.-lb; rotational speed is 60 rpm.

Drill Rig. Pull down force is 10,000 lb; pull down rate is 100 ft/min. Angle capacity is 45° to 90° off the truck and 5° to 45° off standing mounting plates.

Speed of Drilling. The penetration rate of the sonic drill varies depending on the type of formation being cut. Speeds from 1 ft/s to 0.5 ft/min are encountered when drilling loose to compact formations.

Formations. It drills any type of formation: alluvium, sands, clays, cobbles, boulders, bedrock, permafrost, caliche, and other types of formations including landfills. It is able to drill through metals, garbage, tires, wood, and concrete.

Cost/Benefits. Cost is approximately $100/ft for cased angled hole with continuous core. Drilling requires no fluid, and no cuttings are generated, which eliminates several waste streams and disposal costs. The result is savings of support staffing and cost savings for management of excess contaminated drill cuttings. There is a 95% to 100% core return in alluvial soil versus 60% for conventional drilling. Core sizes range from 2 to 12 in. in diameter depending on dictates of the drilling program. Cost of a high quality rig is $300K; cost of drill strings is undetermined because of further development work needed. Operations and maintenance costs are approximately 20% higher than for a cable tool, but increased productivity will offset the increased maintenance costs.

PROJECTED PERFORMANCE

With the refinement of the sonic head, drill pipe, sampling tools, and core catchers, it is projected that the downtime can be reduced to less than 10%, which results in a substantial reduction in drilling costs.

WASTE APPLICABILITY

This technology is applicable for monitoring wells, vadose zone soil gas sampling, neutron probe pipe installation, core sampling, and injection and extraction wells for bioremediation and/or air stripping/vacuum extraction remediation projects. Additionally, in most conditions, closed-end tubes can be resonated into the ground to significant depths to yield no cuttings or core and to take discrete water samples or in situ cores.

STATUS

Resonant sonic drilling has existed for over 30 yrs, originating from the work of its inventor, A. G. Bodine. The application of this technology has been well demonstrated by the developers, the Water Development Corporation. There are eleven known U.S. based sonic drill heads and rigs, ten of which the Water Development Corporation operates.

Sonic drilling is currently available, with future improvements planned for products/components and substantial reduction of direct drilling costs and durations. Full implementation for vertical drilling is expected in the 1994-1995 time frame. The following represents best estimates on various application time lines: (1) Vertical and Diagonal Drilling: All chemical and low-level radioactive sites - 1 yr; Medium/high level - 2-

3 yrs (2) Horizontal: Feasibility testing - 1 yr; All chemical and low rad - 2-3 yrs; Medium/high rad - 3-5 yrs. For further information on sonic drilling, see the Slant Angle Sonic Drilling technology being developed by Sandia National Laboratories and the Water Development Corporation.

REGULATORY CONSIDERATIONS

Drilling and subsurface access regulations may vary, depending on the waste site characteristics. Ecological impacts are minimized or eliminated by the absence of secondary waste streams. Occupational Safety and Health Administration (OSHA) regulations apply for drilling equipment operation, high noise levels, and potential contaminant exposure.

POTENTIAL COMMERCIAL APPLICATIONS

This technology can be applied to water well, natural gas well, geothermal well, and oil well drilling. It is also useful to industries that may have soil or groundwater contamination problems. Rapid access to the subsurface, without excess soil removal or secondary waste streams, is economically desirable for such industries to determine the scope of the problem and to remediate the contamination. This method of continuous core removal is useful for other geologic studies and to the mining industry.

BASELINE TECHNOLOGY

This technology is compared to other conventional drilling methods, such as hollow stem auger and air and mud rotary drill rigs that are traditionally used for oil, gas, and river-crossing applications. Field results demonstrate that the daily output of one sonic drill rig will approximate the daily continuous core output of three to four hollow stem auger rigs.

INTELLECTUAL PROPERTY RIGHTS

U.S. patents for Resonant Sonic Drilling technologies are held by the Water Development Corporation (WDC). Patent numbers are available from the technology developer, WDC.

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REFERENCES

1. DOE-RL, "Technology Information Profile (Rev. 3), Technical Name: Sonic Drilling," DOE ProTech Database, TTP Reference Number: RL-421103, March 29, 1993.

UNSATURATED FLOW APPARATUS CENTRIFUGE

Washington State University and Pacific Northwest Laboratory

DESCRIPTION

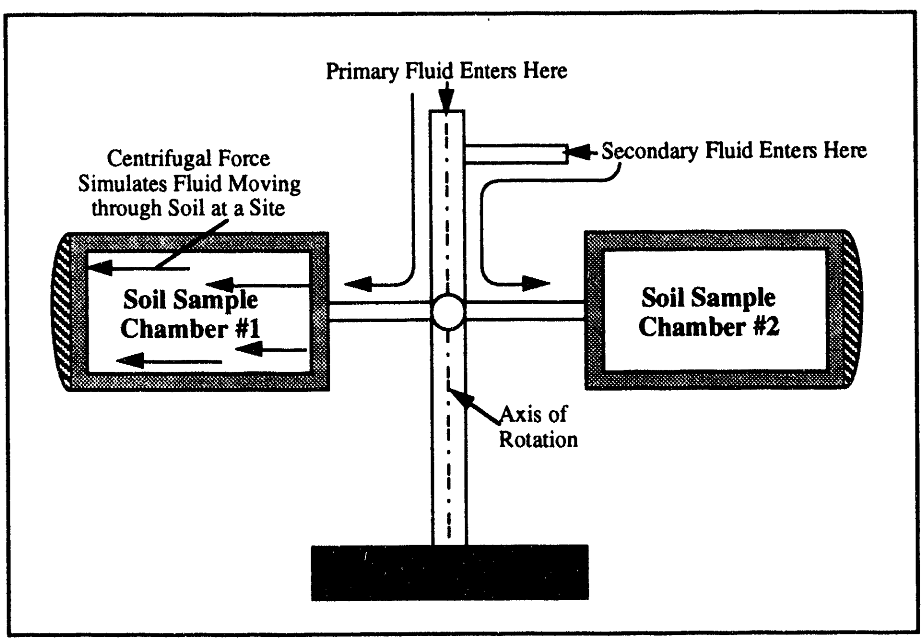
The Unsaturated Flow Apparatus (UFA) Centrifuge is a laboratory instrument that simulates the migration of volatile organic compounds (VOCs), microbial nutrients, and water in the subsurface environment of arid sites, as well as the migration of other contaminants. UFA is based on open-flow centrifugation and provides a technique in which a hydraulic steady-state can be achieved in a matter of hours in most geologic materials at very low water content.

The advantage of using centripetal acceleration as the fluid driving force is that it is a body force similar to gravity and acts simultaneously over the entire system and independently of other driving forces (e.g., gravity or matric suction). The system is a more rapid method for obtaining transport data. The UFA can address any flow transport problem involving any fluid in any porous medium under almost any condition. UFA improves the predictive capabilities of VOC migration and increases the probability of choosing a successful restoration strategy for site-specific conditions. The technology can also be used for quick screening and can provide data to describe field conditions.

TECHNICAL PERFORMANCE DATA

The UFA consists of an ultracentrifuge with an ultraflow constant-rate flow pump that provides any liquid to the sample surface through a rotating seal assembly and microdispersal system.

In the UFA, accelerations up to 30,000g are attainable at temperatures from -10° C to 150°C and flow rates as low as 0.001 ml/h. The effluent is collected in a transparent, volumetrically calibrated container at the bottom of the sample assembly that can be observed during centrifugation using a strobe light assembly. The UFA measures transport parameters at water contents as low as a few percent and hyrolic conductivities down to 10^{-10} cm/s in a few days.



Schematic of an Unsaturated Flow Apparatus

Cost. The present cost of the UFA and support equipment is $100K. An alternate UFA system that can be used only for soil has no temperature capability and does not have a strobe light can be purchased for $50K. The annual operating and maintenance cost is $10K, including the maintenance contract and sample holders. The centrifuge is guaranteed for 5 to 10 yrs.

PROJECTED PERFORMANCE

A new generation UFA is being developed for the VOC Arid Integrated Demonstration. Soil samples will be collected from the Hanford Site using cable tool drilling/split spoon sampler technology. The soil or bedrock samples are transferred to a specially designed titanium canister and subjected to as much as 20,000 g in an open-flow centrifugation device. A rotating seal assembly fitted to the canister allows an ultra-low flow pump to deliver liquid (carbon tetrachloride in this case) or gas to the sample surface during centripetal acceleration. When steady-state conditions are reached (within a matter of hours), three transport parameters will be evaluated; (1) hydraulic conductivity to measure permeability, (2) diffusion coefficient, and (3) breakthrough retardation. Transport data and a compilation of data for Hanford sediments will also be the final output elements.

Modification may need to be made for application of this technology in radioactive environments.

WASTE APPLICABILITY

The UFA can address all flow transport problems involving fluid in any porous media under almost every condition. This technology is applicable VOCs, microbial nutrients, and water in the subsurface.

STATUS

The UFA is available off-the-shelf. UFA was developed and has been deployed in a number of Pacific Northwest Laboratory programs since 1991. Improvements to the UFA are continuing.

REGULATORY CONSIDERATIONS

Environmental regulations are not expected to impact this technology. Proper laboratory procedures will be followed to minimize workers' exposure to contaminants.

POTENTIAL COMMERCIAL APPLICATIONS

UFA supports the development of restoration technologies such as vapor extraction (e.g., estimate vapor migration rates) or bioremediation (e.g., estimate nutrient delivery rates) for unsaturated soils. In addition, the UFA technology is a predictive tool, that is, a "time machine", that can be used (1) to validate the predictive models of subsurface contaminant migration, and (2) to screen the performance of various remediation technologies in the field.

The concrete industry has expressed interest in this technology to test reactivity of concrete aggregate to alkaline solutions. In addition, the movement of pore water through bentonite barriers for waste repository programs is being studied with the Japanese.

BASELINE TECHNOLOGY

The baseline technology is traditional column experiments or in situ analysis such as lysimeter measurements that require months to years to achieve results. UFA data have been shown to be in complete agreement with data generated using traditional column experiments.

INTELLECTUAL PROPERTY RIGHTS

Beckman has the intellectual property rights.

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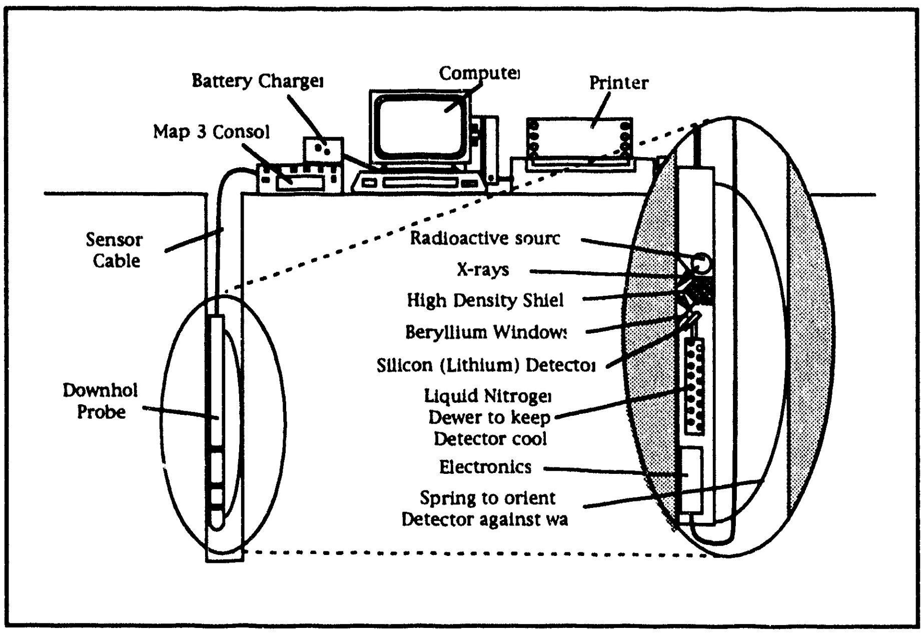
X-RAY FLUORESCENCE SPECTROSCOPY

Pacific Northwest Laboratory

DESCRIPTION

Downhole X-ray fluorescence spectroscopy is a method for detecting and quantifying inorganic (i.e., metal) contaminant concentrations in soils above the water table using a photoelectric process. The X-ray fluorescence (XRF) instrument is a downhole probe consisting of an X-ray source and a photon detector. The instrument probe is placed in a lined borehole. The surrounding soil and the detector are then irradiated with the source X-rays for a specified period of time. The detector receives a combination of Compton backscatter photons, as well as fluorescence photons emitted by certain atoms in the soil. Real-time assays of soil constituents can be performed when the instrument system is properly calibrated. The system also includes an analog-to-digital converter, a multichannel analyzer, and a computer processor.



Scitec XRF System

Calibration of the instrument for a particular element and observation of the number of counts appearing in a specific fluorescence range of the energy spectra results in a quantitative determination of the concentration of the element in the soil.

Fluorescence occurs when the source X-ray energy is greater than the electron binding energy of the K or L shell in the target atom. The source photon collides with the target atom and causes an electron vacancy in the K shell. This vacancy is filled by a transition of an L electron into the K shell and the emission of either a K_a X-ray photon (especially in heavy elements) or an Auger electron (especially in light elements). The competition between the two processes is described by the fluorescence yield. The probability that a K_a X-ray will be emitted approximates unity in high atomic number (Z) elements and approaches zero in low-Z elements. Typically, X-ray fluorescence is useful for elements with a $Z > 20$.

TECHNICAL PERFORMANCE DATA

Several factors affect the minimum detectable concentration of an element. First, the source

X-ray energy must be greater than the electron binding energy in the K or L shell of the target atom. The excitation process is increased when the source and fluorescence energies are closely matched. Second, greater atomic number elements (higher-Z elements) have increased probabilities of K_a (photon) emission compared to Auger electron emission that dominates in lower-Z elements. Third, the detector quantum efficiency depends on the atomic number of the anticipated target atom. Fourth, the energy band resolution becomes increasingly important to achieve signal discrimination when neighboring elements are present in the soil media (e.g., chromium Z=24, iron Z=26). Finally, attenuation of low energy X-rays limits the volume of soil that can be probed, but when the element under consideration increases in Z, then a greater volume of soil can be analyzed with increased accuracy. The accuracy is directly related to the minimum detectable contaminant concentration level.

A field test of an XRF system was conducted at Sandia National Laboratories (SNL) Chemical Waste Landfill (CWL) by Pacific Northwest Laboratories (PNL) in 1992. A commercial downhole probe manufactured by Scitec Corporation was employed for measurements of chromium concentration in three boreholes, 100-ft deep, 9-in. diameter, lined with high-density polyethylene material and a nylon cloth outer liner in a landfill. The X-ray instrument reliably detected chrome and copper. Naturally occurring iron was also detected and shown to overlap with the chrome signal. Therefore, a finer resolution detector is needed (resolution of 0.2 or 0.3 keV) to resolve different elements better and establish a more reliable instrument calibration.

Cost for a commercial instrument is estimated to be $50K.

PROJECTED PERFORMANCE

In 1993, PNL will be testing the XRF system with a new higher resolution detector at Sandia CWL. The instrument will have an outside diameter of 4 in. and a length of 5 ft. The new detector will be a cryogenically cooled SiLi detector that will have an increased quantum efficiency, a better resolution, and an improved count rate. The resolution will be 0.2 or 0.3 keV (full width at half maximum, FWHM). The improved efficiency and increased size of the new SiLi detector will result in a factor of five increase in count rate. As a result, the new system is expected to detect elements in the 50 to 100 ppm range in soil, a ten-fold increase in the minimum detection contaminant concentration limit of the present system.

In 1994 an instrument will be developed that has a diameter of less than 1.5 in. and a length of 3 ft. It will be capable of analyzing any soil type, but boreholes must be bare or lined with thin membranes such as SEAMIST™ (i.e., not steel or PVC cased holes).

WASTE APPLICABILITY

The XRF spectroscopy method of detection and quantification of contamination is appropriate for high-Z metals and all other elements where Z > 20. The penetration thickness into the soil is limited by X-ray attenuation for low-energy radiation. The low-energy X-rays are likely to be used when the target atom has a low atomic number (lower-Z). However, when higher-Z atoms are to be detected, higher energy X-rays will be used and the volume of probed/analyzed soil is increased. The applicability of this technology is largely dependent on the desired minimum detectable concentration, the atomic number of the contaminant, the site characteristics (such as high levels of an element with a similar atomic number), and the resolution of the detecting device.

STATUS

This is a developing technology with respect to low concentration detection (ppm concentrations) and lower-Z element detection such as chromium, Z=24. The technology has been demonstrated on a field scale with some success, but significant improvements have been suggested for the next field demonstration.

REGULATORY CONSIDERATIONS

Compliance with the Occupational Safety and Health Administration regulatons is required for hazardous waste operations and protection of occupational workers from ionizing radiation. In addition, permits may be required for drilling at hazardous waste sites.

POTENTIAL COMMERCIAL APPLICATIONS

This technology could be used to detect metallic contamination near industrial sites. Examples would be Environmental Protection Agency (EPA) required testing, post-closure monitoring, site investigation, or follow-up soil analysis after structural lead paint stripping. XRF could also be used in experimental situations to determine concentrations of metals in an aerosol or aerosol filter (radioactive spent fuel aerosol experiments). In countries that have dated steel processing facilities, such as Poland, the soil surrounding an industrial plant can be analyzed for metallic contamination, specifically lead. Municipal solid waste processing and/or disposal facilities can be monitored for undesirable, toxic, or hazardous metallic waste. Other applications may include decontamination/decommissioning and post-closure monitoring for all types of industrial sites (i.e., nuclear, coal , diesel, natural-gas fired-power plants, decommissioned transformers and others).

BASELINE TECHNOLOGY

The baseline technology for analysis of heavy metals is conventional laboratory analysis such as inductively coupled plasma spectroscopy or atomic absorption. Each require laboratory sample preparation and data evaluation to detect contaminants in soil. XRF has been used previously in the mining industry to detect soil constituents in concentrations greater than 1 percent. The utilization of XRF in environmental site characterization is a recent application. XRF provides a qualitative indication of heavy metal content with minimal sample preparation and data evaluation.

INTELLECTUAL PROPERTY RIGHTS

PNL and Scitec have entered into a Cooperative Research and Development Agreement (CRADA) to develop the probe. All intellectual property rights will be shared between the Department of Energy (DOE), PNL, and Scitec.

Site Remediation Technology Profiles

Section 5.0

ARC MELTER VITRIFICATION

Idaho National Engineering Laboratory

DESCRIPTION

Arc melter vitrification is a high-temperature extractive metallurgy based technology capable of melting soil and metals, pyrolizing or oxidizing residual organics, and melting structural metals from melted slag (silica and metal oxides), and partitioning transuranic (TRU) waste into the slag phase. Depending upon cooling rate and composition, the slag will consist of a glassy phase and several crystalline phases. Suitable composition and heat treatment will partition the TRU into a highly nonleachable, very durable crystalline phase with a probable geologic lifetime. High vapor pressure metals will probably evaporate from the melted phases and be collected in downstream collectors for further treatment. A process technology to recycle or immobilize the collected high vapor pressure metals (HVPM) will need to be developed. Immobilization in a low-temperature final waste form material, such as borosilicate glass, is a possibility.

Vitrification can produce a safe and highly durable final waste material for permanent disposal. Waste volumes can be substantially reduced (up to 65%, depending on waste composition). Selected clean metals may be separable for recycling. High-temperature electric melter technology requires smaller volume off-gas systems, and can facilitate processing of a wide range of materials with less presorting, sizing, and separating. The base arc melter technology has been used for smelting of similar heterogeneous ores for many years, providing a related applications experience base from which to proceed. The glass/ceramic final waste form will likely be suitable for disposal anywhere and may not need to be disposed at a deep geologic repository, such as the Waste Isolation Pilot Plant (WIPP). Further, it would produce a much safer and more compact material to ship.

TECHNICAL PERFORMANCE DATA

The glass/ceramic (crystalline rock) final waste form product will be the most technically effective waste form for long-term encapsulation of TRU. Hazardous organics and materials capable of hydrogen generation will be eliminated from the final waste form material. Buried wastes can be processed essentially as received, along with contaminated soils, with minimal separations, additives, characterization, and pretreatment. However, feed systems will not handle all wastes. Volume of waste and contaminated soils will be reduced. Selected metals may be separable for reuse.

PROJECTED PERFORMANCE

Arc furnace applications for pyrometallurgical processing of heterogeneous materials (ores) are a proven industrial base technology, the operation of which is routinely accepted by the public. Proceeding to design and develop an arc smelter system for mixed waste processing from a strong existing technology experience base should provide a better-performing and more publicly acceptable process technology. The cost of developing and implementing a melting process for the encapsulation of TRU will be a small fraction of the total cost of retrieval and processing. Extensive engineering development will be required for the implementation of a reliable, effective process. A pilot facility will require 3 to 5 years to examine and solve such problems as sealing, remote maintenance, process optimization, fume handling, and encapsulation issues.

A well-designed melting process will incorporate all the TRUs and selected metals in a durable slag and eliminate organics. All TRU elements are expected to be dissolved and retained in the glass/ceramic material formed upon cooling of the molten slag. Volume will be reduced substantially by vitrification (two to five times, depending upon waste soil mix). Selected clean structural metals, such as, iron, may be reduced and tapped. All organics will be pyrolized or combusted, and combustion will be completed in a secondary chamber, possibly in the off-gas system. Fume from the high-temperature melter will require processing by the air pollution control system. Depending upon waste composition, fume may contain acid gases, chlorides, heavy metals, and sulfides. Collected residues from the Air Pollution Control System will require further processing for final disposal.

Buried waste materials and soils are expected to be processable with a minimum of separation, sizing, and precharacterization using a soils buffering approach to ensure a high-integrity final waste form material.

Existing arc melter technology has not been designed for radioactive service; therefore, modifications will be necessary for radiation contamination control.

Cost. The cost to develop and build a system that will process 5 ton/h is estimated at $50-100M.

WASTE APPLICABILITY

Arc melter vitrification is applicable to the treatment and immobilization of TRU wastes, toxic metals, hazardous organics in buried wastes, heterogeneous mixed wastes, and soils.

STATUS

Arc melter technology exists but requires extensive engineering development for alpha-controlled processing and optimization.

The American Society of Mechanical Engineers (ASME) and the U.S. Bureau of Mines (USBOM) had been pursuing the evaluation and demonstration of commercial arc melter furnace technology to the vitrification of municipal incinerator waste ashes. Upon becoming aware of their work in 1992, the present technical task plan to evaluate and demonstrate application of this technology to materials typical of buried mixed wastes was developed. A test series on commercial incinerator waste ash was completed in late 1992 by the USBOM/ASME, showing generally favorable results and identifying some problems to be considered. These results were factored into the test plan for the baseline series of tests for buried waste representative materials in April/May 1993. In parallel with this effort on a three-phase AC melter system, Electropyrolisis Inc., in cooperation with Pacific Northwest Laboratory and Massachusetts Institute of Technology, is evaluating a direct current (DC) arc melter system of somewhat different proposed configuration. Integration of these projects is in progress.

REGULATORY CONSIDERATIONS

The melter system is part of an overall treatment system. All output materials from the process system will either be clean and suitable for reuse or release to the environment (meeting all environmental standards) or will be in a material form suitable for permanent long-term disposal.

High-temperature processing carries with it inherent hazards requiring thorough safety design and analyses. Alpha contamination control and hazardous materials control require further extensive safety considerations typical of any radioactive materials processing facility. Remote operation will protect workers. Potential for pressurization transients, e.g., steam explosion, or combustibles explosion, requires thorough treatment.

POTENTIAL COMMERCIAL APPLICATIONS

Potential commercial applications for the arc melter furnace technology include vitrification of municipal incinerator waste ashes.

BASELINE TECHNOLOGY

There is no accepted baseline technology for treatment of mixed TRU contaminated buried wastes. Preliminary systems design studies for buried wastes identified and compared the most likely treatment options. The highest-ranked process options were those which involved ex situ vitrification in a high-temperature melter. Repackaging of untreated buried waste for disposal storage at WIPP (present baseline plan for stored TRU wastes) is not a probable option. Various arc melter furnace configurations are possible. The baseline configuration for arc melters is standard commercially available three-phase graphite electrode furnace technology. This pilot test system is representative of that baseline electric arc furnace configuration. A number of other similar thermal treatment systems are also under development.

INTELLECTUAL PROPERTY RIGHTS

Patents: None.

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BARRIERS AND POST-CLOSURE MONITORING

Los Alamos National Laboratory

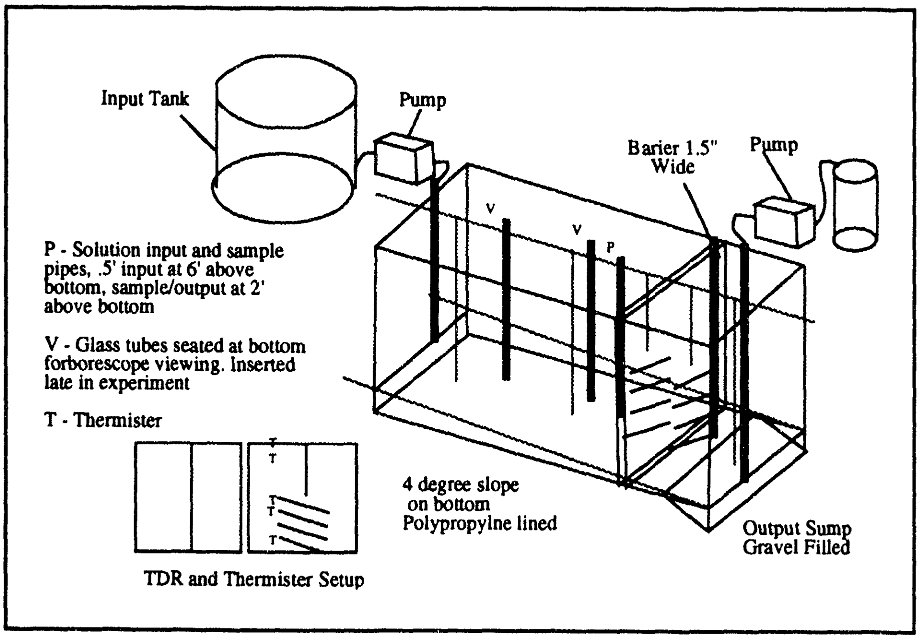
DESCRIPTION

The subject technologies focus on the rapid implementation of near-surface barriers, biotreatment, and post-closure monitoring technology. They integrate water-permeable and biologic barriers that chemically capture and/or degrade contaminants without significantly altering the natural water flow. Specific evaluations are being done for gel barrier materials, enhancement of natural biologic communities, chemical tracer approaches, and remote monitoring of the hydrologic systems.

Two different potential applications of the barrier technologies are being evaluated. The first is the use of barriers for chemical confinement for in-trench treatments with a leach system or an in-place bioreactor. The second is the integration of permeable reactive barriers and petroleum reservoir gel/foam/polymer technology with grout or clay slurry walls to direct horizontal surface and subsurface water flows around a contaminated area.

Barrier and post-closure monitoring tests are being conducted in field-scale demonstration plots and are being designed for actual contaminated sites. The range of materials available for augmenting existing barrier practice is broad. Two types of barriers have been the focus of initial efforts of this program, permeable reactive barriers and in-place bioreactors.

Permeable, Reactive Barriers. These barriers allow the passage of water while prohibiting the movement of contaminants by employing such agents as chelators (ligands selected for their specificity for a given metal), sorbents, microbes, and others. In Department of Energy (DOE) sites where multiple contaminants are ubiquitous, multicomponent barriers need to be evaluated. Field-scale experiments were constructed using natural sand with the permeable barriers consisting of zeolite + silica gel + sand, bentonite + Al crosslink polyacrylimide + sand, and peat + Al crosslink polyacrylimide + sand. The reactive barriers could be designed (1) to remain in place as permanent or semi-permanent installations; (2) to be removed and replaced periodically, thus serving as a component of



Barriers and Post-Closure Monitoring

the remediation process; and/or (3) to be used as part of the post-closure monitoring system in which the appearance of a contaminant in the barrier would then serve to warn of impending contaminant migration.

In-Place Bioreactors. This technical approach uses the capabilities of native bacteria for degrading hazardous organic compounds in a cost-effective, publicly acceptable manner. The capability can be managed to provide prolonged treatment, as well as treatment of relatively short duration. In addition to full-scale site, biodegradation has significant near-term potential as an effective containment strategy. Thus, evaluation of approaches to managing biologic communities on the margins of a site, in combination with other barrier approaches, will provide both significant information for both limitation of contaminant transport and full-site cleanup.

Post-closure monitoring. The field experiments have focused on evaluation of water saturation and chemical transport. Comparison of established neutron probe measurements of water saturation in arid soils with developments in Time Domain Reflectometry probe systems is being used to evaluate opportunities for automated and more detailed characterization. Chemical transport is being evaluated through the use of contaminant and chemical tracer materials. Application of tagged tracers allows evaluation of both barrier system effectiveness and potential contaminant transport pathways or eminent arrival.

Tracers for the permeable barrier experiments included low concentrations of common anions (e.g., bromide), soluble organic acids, semivolatile organic acids, fluorescein, chromium, and EDTA. The tracer/pseudo-contaminant for the bio-barrier experiments focused on toluene, labeled with carbon-13, to allow specific characterization of transport and biodegredation processes as a function of plant cover and fertilization.

TECHNICAL PERFORMANCE DATA

The permeable barriers are being designed to operate unattended with minimal maintenance for long periods of time (i.e., years). However, periodic inspections will be required because these enhanced barriers might fail because of cracking. Since the barriers are passive, no power is required for their operation.

The post-closure monitoring system will be autonomous with minimal energy consumption. Thus, batteries can be used as the power source.

Cost. The field tests at Los Alamos National Laboratory (LANL) that are scheduled for completion in early 1994 had a start-up cost of $1.2M and an operations/maintenance cost of $670K in FY93. Life cycle costs for operational systems have not been estimated, but are expected to be 5 to 10 times less than excavation.

PROJECTED PERFORMANCE

Quantified performance data do not seem to have been estimated for production systems. However, significant improvements are anticipated in both operational costs and acceptance by public and regulatory communities.

WASTE APPLICABILITY

These barrier technologies are primarily intended for in situ treatment/containment of soluble metals and organics in arid soils.

The contaminants will either be degraded or retained in a concentrated form by the barrier material. The barrier could provide permanent containment for the relatively benign residues or provide a decreased volume of the more toxic contaminants for subsequent treatment.

STATUS

Evaluation of the currently installed systems should be completed in early 1994 (Ref. 1). The first barrier and monitoring systems were installed in 1992 and tracer tests, which would include the effects of seasonal changes in the environment, were scheduled for completion in 1993 (Ref. 2). Approximately two additional years would be required to test and evaluate each additional barrier system.

REGULATORY CONSIDERATIONS

Closure and post-closure monitoring will be required under Resource Conservation and Recovery Act (RCRA), Comprehensive Environmental Response Compensation and Liability Act (CERCLA), Superfund Amendments Reauthorization Act (SARA), and Department of Energy (DOE) Order 5820.2A. For hazardous chemical sites, the required post-closure monitoring period is 30 yrs. For radioactive sites that have been closed, DOE Order 5820.2A requires monitoring and maintenance of the site for 100 yrs.

POTENTIAL COMMERCIAL APPLICATIONS

The components of the barrier and monitoring systems that are currently being field tested have all been obtained from commercial vendors. Thus, these technologies can lend to full commercialization.

Furthermore, chemical and petroleum companies are now actively applying the proposed types of permeable barrier and biotechnological technologies in enhanced oil recovery operations.

BASELINE TECHNOLOGY

Baseline technologies currently being used by the DOE include grouts, clay slurries, and cements for pure hydrologic barriers, landfill caps for the biotreatment systems, and monitoring well characterization for water-saturation and contaminants during the post-closure monitoring approaches. However, these barriers are all subject to cracking. In addition, by design, they restrict water transport out of the contained area and often require active treatment and disposal systems to maintain a stability.

INTELLECTUAL PROPERTY RIGHTS

Patent Ownership: To be determined.

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BIOLOGICAL DESTRUCTION OF TANK WASTE

Idaho National Engineering Laboratory

DESCRIPTION

Biological Destruction of Tank Waste (BDTW) is a separation and volume-reduction process for supernatant and sluiced salt cake waste from underground storage tanks. These wastes are usually composed of various radionuclides and toxic metals concentrated in a nitrate salt solution. A BDTW system would be located adjacent to storage tanks applied to the supernatant and sluiced salt cake effluents. The bacteria act as metal and radionuclide adsorbers and also as denitrification catalysts that reproduce themselves at ambient temperature and pressure. Some degradation of organic contaminants may also occur during the process.

Supernatant and sluiced salt cake wastes flow into the BDTW bioreactor, which concentrates hazardous metals through biosorption, separating these hazardous components from the waste salt stream into a biomass product. The radioactive biomass sludge would be incinerated to reduce the volume and suitably stabilized as required for its level of radioactivity. In parallel with the metal sorption process, the microbes also catalytically reduce the nitrate waste salt stream to a bicarbonate solution. The salt solution product could be carefully monitored and, subject to regulatory approval, evaporated and treated (i.e., grouted) as a nonhazardous, nonradioactive waste.

The process uses a mixed culture of natural bacteria isolated from the Great Salt Lake and the Death Valley area. They are able to grow and reduce nitrate in the very high salt concentrations found in the tank wastes. The bacteria are grown in a bioreactor and then recycled to a biosorption tank, where they are mixed with the incoming waste. Agitation is provided by sparging with evolved N_2 and CO_2 gases. The high radioactivity and metals concentration in this tank may kill the bacteria, but dead bacteria biosorb metals equally well. The bacteria and any chemical precipitates that may have formed are removed by filtration to generate a biomass sludge containing nearly all the radionuclides, transuranics, and toxic metals.

The liquid containing the nitrate, organics, and very low levels of metals flows into the bioreactor, where it is mixed with acetic acid as a carbon source for bacterial growth. The nitrate is reduced to innocuous nitrogen gas that is released to the atmosphere after being filtered. Any remaining metal would adsorb on the growing bacteria, but the metallic concentration is now too low to inhibit bacterial metabolism. The effluent from the bioreactor, after filtration, is a concentrated solution of nonradioactive, nonhazardous salts in which nitrate has been replaced, mainly by bicarbonate.

TECHNICAL PERFORMANCE

Design. The field demonstration bioreactor tank size is about 100 m^3, which corresponds to a waste treatment rate of 2 gal/min, sufficient to treat a one million gallon tank in one year. At the 2 gal/min size, the BDTW system is transportable. The current bioreactor is able to process salt solutions having a 4-6 molar nitrate concentration. The maximum salt tolerance is being explored. Power usage is estimated at 20 kW for pumping and agitation.

Laboratory Scale Testing. In 1992, halophilic bacteria capable of operating at salt concentrations of hundreds of grams per liter were isolated. The unique feature is the combination of biosorption and biodenitrification to remove several contaminants at once in highly saline solutions. This process has successfully been demonstrated on the laboratory scale.

Cost. Accurate start-up costs will not be available until developmental experiments are complete. Operational costs should be minimal because of the nature of biological processing.

PROJECTED PERFORMANCE

The volume and status of the biomass sludge product depends on the metals content in the waste and the effectiveness of biosorption (which is currently under study). In most cases, the biomass product would be a low-level radioactive waste that is 1-10% of the feed volume. In some cases the biomass product would be a high-level waste requiring vitrification. The salt solution waste will have approximately the same volume and concentration but the nitrate salts would be replaced by carbonate.

WASTE APPLICABILITY

This biological process is applicable to treat the highly saline underground storage tanks of the Hanford Site, which contain various radionuclides, transuranic and toxic metals, and organic materials. The organic materials are principally salt cake, consisting mainly of nitrate salts and lower levels of metals, and concentrated supernatant whose composition is in equilibrium with the waste sludge and salt cake. It would be applicable to treat similar waste of other tank farms. The process should work on most tank waste, but a bench-scale treatability study would be needed for each tank.

STATUS

The process has been demonstrated in the laboratory. The technology is currently in scale-up design for a field demonstration.

REGULATORY CONSIDERATIONS

No ecological impacts are anticipated. Operation at ambient temperature and pressure enhances worker safety. Full secondary containment is provided to contain leaks. Nitrogen gas release is through high efficiency particulate air filters (HEPA) to prevent any radiation release. Concentrated acetic and phosphoric acids which are brought to the site by tanker trucks are subject to Department of Transportation regulations. The process uses only natural bacteria; no mutant or recombinant strains are used. Consequently, there are no biohazard issues.

POTENTIAL COMMERCIAL APPLICATIONS

This process is versatile and can also treat waste streams from metals reprocessing facilities in addition to those waste streams from nuclear fuels processing and reprocessing facilities. Biosorption is a process that has been commercialized recently for removal of metals from dilute aqueous solutions. It is being used to recover uranium at the Dennisor Mine in Canada at a scale of 90,000 lb/day.

BASELINE TECHNOLOGY

The standard technology consists of ion exchange to remove the radionuclides, followed by calcination and a chromium separation step. The demonstration of this biological process will increase the number of options available for treating supernatants and salt cakes. It is likely that biological treatment is a cost-effective alternative for volume reduction and denitrification of tank wastes.

INTELLECTUAL PROPERTY RIGHTS

A patent has been applied for under the names of G.F. Andrews and A.J. Tien that would be owned by DOE, Idaho National Engineering Laboratory.

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Industrial/University Partnership
None at present.

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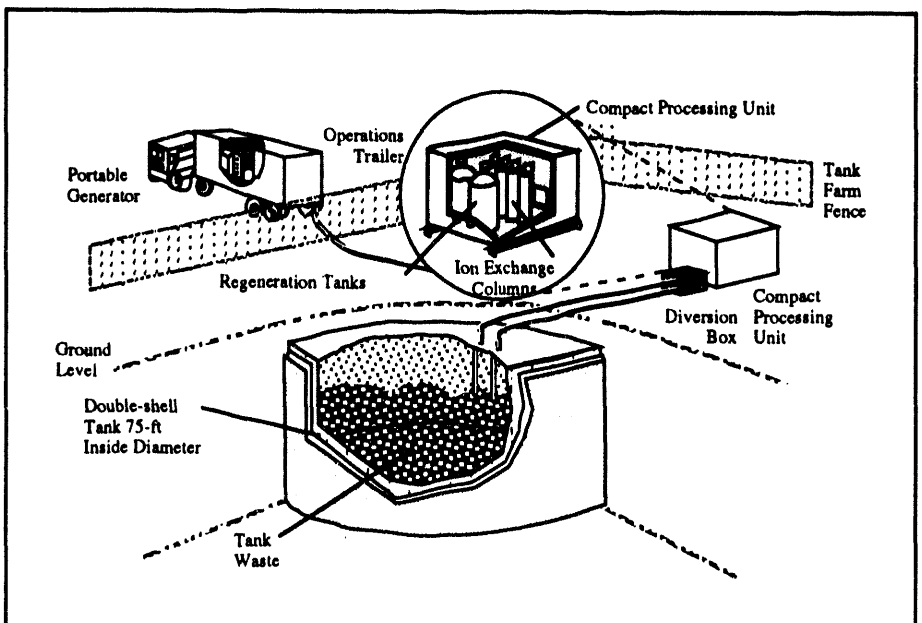
COMPACT PROCESSING UNITS FOR RADIOACTIVE WASTE TREATMENT

Idaho National Engineering Laboratory and Pacific Northwest Laboratory

DESCRIPTION

Compact Processing Units (CPUs), or "Modular Waste Treatment Units," are relatively small mobile equipment modules that would be located near the waste storage tanks or in a conveniently located diversion box in the Hanford waste transfer system. They perform unit chemical process operations. The CPUs allow rapid deployment of technologies for the treatment of radioactive wastes in underground storage tanks. The modules would be manufactured off-site by commercial vendors and moved into place using trucks or special transports. The CPU is designed to permit relocation using a construction crane and a transport trailer. The concept of having standardized modules is based on the notion that various radioactive waste treatment subsystems could be standardized to match the CPU hardware package, leading to more rapid, cost-effective deployment. The cost benefits are realized even when multiple units are deployed to achieve greater processing rates. The modular design concept will also allow for reuse of CPU components for different unit processes or process deployments. The CPU consists of four major subsystems: the containment system (safety), the process system (e.g., ion exchangers), the control system, and the process interface subsystem (which includes solid/liquid separations and waste stream routing).

The ion-exchange CPU will pump undiluted liquid tank waste from an underground storage tank or receive liquid waste from a waste retrieval system for treatment. The CPU will filter this waste to remove solids. The solids removed will be transferred to a holding tank for further analysis and processing. The filtered tank waste will be adjusted to optimize the waste composition and temperature for maximum efficiency of the ion-exchange process. The waste will then be pumped through three ion-exchange columns in series to remove the cesium from the waste. The waste will be returned to the tank farms after the cesium is removed. The ion-exchange columns will use a new formaldehyde resorcinol ion-exchange resin formulation developed at Savannah River Laboratories. The loaded ion-exchange



Compact Processing Unit

resin will be regenerated, using nitric acid to remove the cesium. This high-concentration cesium waste will be neutralized and transferred to the tank farms as a waste feed stream for the vitrification process. The waste stream with the cesium removed will be suitable for disposal as low-level waste.

TECHNICAL PERFORMANCE

Design Specifications. The CPU is a compact volume approximating a cube with 15-ft sides. The process flow rates are restricted by the size of equipment that can fit into a CPU module. The CPU is designed to process tank waste at up to 19 l/min (5 gpm) with an average rate of 9.5 l/min (2.5 gpm). Staffing of the unit for continuous operation is expected to require 18 operators, 12 engineers, and 6 support personnel.

Feasibility Study. In FY92, Westinghouse Hanford Company (WHC) investigated the practicality of using CPUs as an alternative to a centralized pretreatment facility. This investigation consisted of developing the concept to sufficient detail that a cost estimate for deployment could be made.

Cost. The cost estimate performed by WHC showed that deployment of a group of CPUs as a replacement for the initial pretreatment system could result in a capital cost savings of $300M to $500M. The development of this technology, including safety, environmental documentation, and construction of the prototype system, is estimated to be $32M. The annual operating cost of this technology is estimated to be $9.5M/year of operation.

PROJECTED PERFORMANCE

The CPU is designed to treat 1 Mgal of Hanford Double Shell Tank Waste in one year. This would be accomplished at an average process flow rate of 2.5 gpm. The CPU for cesium removal is expected to treat waste streams with concentrations up to 1 Ci/l cesium. It is expected to remove the cesium to levels below the Nuclear Regulatory Commission (NRC) Class A low-level waste standards (1 Ci/m^3). The cesium removal factor is projected to be 10,000.

WASTE APPLICABILITY

This waste treatment technology is targeted for radioactive process liquids, sludges, and slurries. The CPUs are designed to incorporate waste treatment modules that could potentially have application to all Department of Energy (DOE) radioactive liquid tank wastes. The CPU waste treatment hardware system is applicable to high-level, low-level, and transuranic chemical separations technologies. The prototype CPU includes a process module of cesium-specific ion-exchange resin columns that are selective to cesium ions.

STATUS

Pacific Northwest Laboratories developed the compact or modular processing unit concept in FY91. WHC performed a detailed feasibility study with further development in FY92. Deployment of the cesium ion-exchange CPU technology is scheduled for the 1996 calendar year. A radioactive waste treatment demonstration in scheduled for FY97.

REGULATORY CONSIDERATIONS

This process is completely contained and automated, which minimizes worker exposure to hazardous materials and process hazards. No special physical requirements are anticipated for operations personnel. This process will meet or exceed all regulatory requirements imposed by the Environmental Protection Agency and the NRC.

POTENTIAL COMMERCIAL APPLICATIONS

Potential commercial applications include waste treatment, separation, and volume reduction operations for reclamation of radioactive waste liquids, sludges, and slurries stored in underground storage tanks, and process effluent pretreatment before appropriate disposal.

BASELINE TECHNOLOGY

The baseline technologies are large, centralized facilities for supernate waste treatment. The advantages of CPUs over the baseline technology are in four areas: cost reduction, schedule improvement, reduction of technical uncertainty, and reduction of process deployment uncertainty.

INTELLECTUAL PROPERTY RIGHTS

Patents: None.

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REFERENCES

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CRYOGENIC RETRIEVAL OF BURIED WASTE

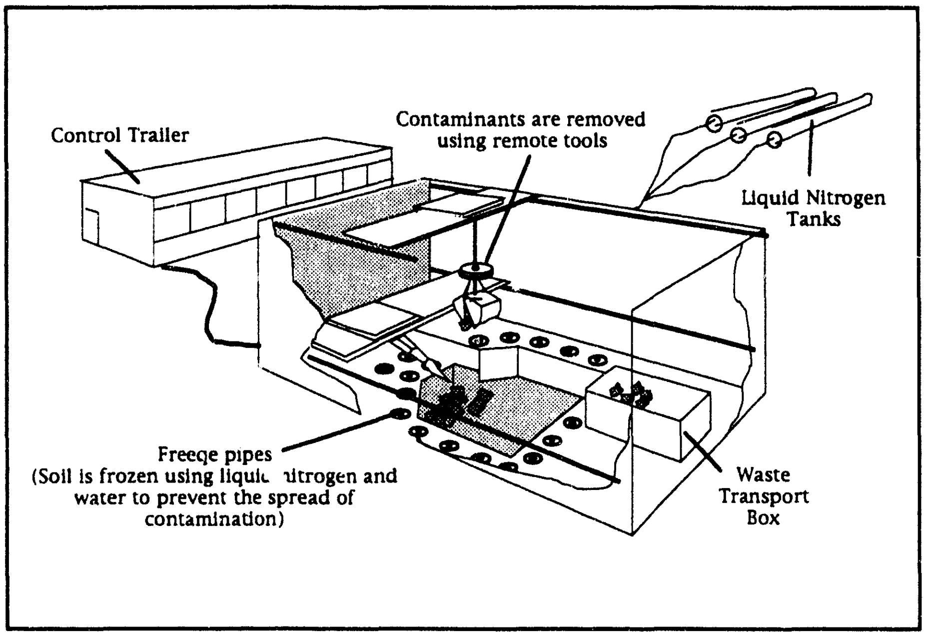
Idaho National Engineering Laboratory and Pacific Northwest Laboratory

DESCRIPTION

Cryogenic Retrieval (CR) of buried waste is a technology that relies on liquid nitrogen (LN_2) to freeze soil and buried waste in order to immobilize hazardous waste and reduce the spread of contamination while the buried material is retrieved with a series of remotely operated tools. CR is proposed for application to any type of radionuclide or hazardous contaminant that may be contained in transuranic (TRU) buried waste. CR has the potential to be used at any buried waste site within the Department of Energy (DOE) complex.

To freeze the soil for the CR process, a series of carbon or stainless-steel small-diameter freeze pipes, approximately 10 to 12 ft in length are driven into an area of soil and buried waste to be frozen and removed. LN_2 is delivered into the pipes and small quantities of water are injected to promote cohesion of the soil and waste particles in the frozen area. While the pit to be excavated is frozen, the perimeters of adjacent pits are also frozen. Once the area to be removed is frozen, the center of an access pit in clean soil is excavated.

The access pit serves to create a dig face from which excavation of the waste can proceed. A gantry with remotely operated tools such as a jackhammer, a hydraulic jack, shears, and a grapple is moved over the frozen area to be retrieved. With the gantry tools in place, the tools are remotely operated, and the frozen soil and waste is broken, chipped, cut, and loaded into transport boxes. The jackhammer chisels and breaks up soil and debris that falls into the access pit. The shears are used to cut and size material, while the grapple picks up the debris and loads it into the transport boxes. The hydraulic jack is used to pry or bend the freeze pipes away from the dig face. During the excavation process, a series of air monitors detect the dispersal of rare earth tracers. The output of the process is the excavated soil and waste material. The principal benefit of this technology is contaminant mobility reduction, since by freezing the soil both airborne and liquid contaminants are immobilized.



Cryogenic Retrieval

A weather shield (a large portable cover or tent) is used with this technology to minimize waste distribution by air motion and to permit operation in all weather conditions. On the other hand, if the freeze pipes cannot be extracted and reused they would require treatment as another buried waste type. If intact containers exist in the waste volume, the drilling of injection pipes might rupture the containers, causing an initial spread of contamination. Furthermore, injection of water to help the freeze process may also contribute to some contamination spread if it were to flow out of the retrieval column.

The major technical challenges for this technology are developing a method for placement of freeze pipes in all types of soil and waste; conservation of LN_2; dispersion of water evenly through the soil and waste matrix; reduction of secondary waste created by the freeze pipes; selecting or developing more productive tools for the removal and handling of frozen waste; and improving methods for the measurement of thermal characteristics and for the detection of moisture migration.

TECHNICAL PERFORMANCE

Field Demonstration. Conducted at Idaho National Engineering Laboratory (INEL) during the summer of 1992 at a cold test pit (i.e., simulated waste). The technology was shown to function as intended. Refinements will be necessary to develop the technology for full-scale, hot-production use. During the field demonstration eight field personnel were used to conduct the demonstration. A detailed estimate of the energy demands has not been made for full scale production; however, during the field demonstration, a 400-kW generator was used to service all field power needs, including running up to three tools simultaneously, plus the hydraulic power unit and the control trailer. The estimated cost for large scale application is \$1250/yd^3 of frozen excavated material.

PROJECTED PERFORMANCE

The production goal for this technology is 80 yds^3/day. It is estimated that 25 to 30 field personnel would be required to set up and operate the Cryogenic Removal equipment in a large-scale application. It is further estimated that an additional 10 to 15 management, safety, engineering, quality, and related technical support personnel would be needed.

WASTE APPLICABILITY

This technology is applicable to the retrieval of TRU buried waste and other types of hazardous buried waste. The technology was developed to mitigate contaminant migration while excavating buried waste.

STATUS

The technology has been demonstrated in a full scale field demonstration in the summer of 1992. The components of this CR technology exist within current industry and have been integrated for the purpose of developing a new method for exhuming buried waste. Approximately four more years are required to develop this technology to a usable level for full-scale hot production. If this technology is developed by 1998, it will be incorporated into the Record of Decision (ROD) for Buried Waste Pits and Trenches at INEL.

REGULATORY CONSIDERATIONS

Minimal ecological impacts are anticipated from use of the proposed technology. LN_2 is not a hazard to the environment. However, while working with LN_2, caution must be used to prevent human contact. Good ventilation is required to assure adequate oxygen concentration. There are no unusual physical requirements for worker safety because the concept relies on remote operation of tools to extract the buried waste.

POTENTIAL COMMERCIAL APPLICATIONS

Potential commercial applications include retrieval of buried wastes that are extremely hazardous and/or radioactive.

BASELINE TECHNOLOGY

A baseline technology has not been established for the retrieval of TRU buried waste. However, a reasonable comparison might be excavation without cryogenic pretreatment to minimize contaminant dispersal during removal with or without remote operation.

INTELLECTUAL PROPERTY RIGHTS

A patent has not been filed for CR.

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REFERENCES

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DECISION SUPPORT SYSTEM TO SELECT MIGRATION BARRIER COVER SYSTEMS

Los Alamos National Laboratory

DESCRIPTION

A Decision Support System (DSS) is being developed to integrate the knowledge of experts from scientific, engineering, and management disciplines to help in selecting the "best capping practice" for a landfill site. Containment technologies, including surface caps, reduce the potential for contaminant migration from the landfill by an alteration of the surface and/or subsurface soils. The process of selecting containment cover technologies for mixed waste landfills requires consideration of many complex and interrelated technical, regulatory, and economic issues.

The objective of this DSS software is to provide risk managers with a defensible, objective way to select capping alternatives for remediating radioactive and mixed waste landfills. The objective will be achieved through a joint project between Los Alamos National Laboratory (LANL) and the U.S. Department of Agriculture, Agricultural Research Service, by developing a multi-objective decision-making software system, with embedded simulation models, to design and/or evaluate engineered surface barriers for mixed waste landfills. The data collected from the migration barrier covers of the Mixed Waste Landfill Integrated Demonstration will be used to evaluate the DSS.

The DSS software ensures that the risk manager uses the best scientific information on barrier design and performance along with other criteria to select the best remediation practice within the constraints of technical performance, regulatory requirements, and cost. The use of the program to design and evaluate barrier cover remediation technology will reduce the likelihood of selecting a barrier cover technology that does not meet performance objectives and the attendant costs of fixing mistakes. Candidate remediation technologies can be evaluated with the DSS before hand to identify technical and regulatory problems inherent in the technologies. It can also be used to evaluate projected long-term performance and the practicality of the designs from a construction and economic viewpoint.

TECHNICAL PERFORMANCE

Field Demonstration. The DSS has been tested at Hill Air Force Base (AFB) in Utah and was found to perform remarkably well. The program is extremely fast and can parameterize and score a site in five minutes.

Since the software is Unix workstation based, it is compatible with many types of computer systems. A PC-based prototype DSS software package, running under Windows 3.1, is being developed. It will be a user-friendly coupling of symbolic processing and numerical near surface hydrologic modeling. The embedded Knowledge Based System (KBS) will integrate confidence limits and exceedence probabilities from stochastic conjectural analyses of hydrologic variables in space and time and the symbolic objects that influence landfill technology. The integration will result in a DSS that should improve long-range predictability of migration barrier performance by incorporating complex environmental processes, along with the management issues, into the decision-making process.

To interpret the output of the KBS applied to landfill design and remediation problems, particularly when multiple and sometimes conflicting objectives exist, requires the aid of decision-analysis tools to simplify the decision-making process. For example, the hydrologic analysis from the KBS might identify a particular barrier design as "better" in controlling runoff and erosion from the site, but at the expense of increasing water infiltration into the landfill. A method is needed to decide whether the increased infiltration will significantly enhance the potential of deep percolation and concomitant migration of solutes toward groundwater and whether this enhanced migration has relevance in light of other factors, such as thickness of the unsaturated zone, potential use of the water, climate, etc.

The DSS will use dimensionless scoring or utility functions parameterized from the quantitative KBS output and expert judgment to convert the range of the decision variables to a unitless common range. This process allows one to combine the decision variables and rank the alternative designs. A major task is to integrate a new decision-making methodology into the existing DSS to eliminate much of the subjectivity in existing multi-objective methods.

Since the DSS requires data to initialize and parameterize the embedded simulation models and the consensus of technical experts in developing the heuristic and scoring function information, there is some inherent subjectivity in the program.

Costs. Software costs have not been estimated. Startup costs include computer hardware and a person to utilize the program. The maintenance cost will be minimal less than $1000/yr to maintain and update the software as improvements are made.

PROJECTED PERFORMANCE

The DSS technology will be adapted and tested for remediation of waste disposal sites with migration barrier cover technology using the designs and database from the existing cover barrier field demonstration at Hill AFB. The multi-objective decision making capability, incorporating a KBS (or expert system) with embedded simulation models and using Hill AFB monitoring data, will be demonstrated.

WASTE APPLICABILITY

Since this technology is specifically used for aiding environmental restoration personnel in the selection of the best capping method for a given waste site, the technology is waste independent.

STATUS

A Unix workstation based DSS software package will be available in FY94. A PC-based prototype DSS software package, running under Windows 3.1, is under development. On completion of the technology, software and documentation will be made available to user groups.

REGULATORY CONSIDERATIONS

There are no regulatory considerations directly associated with this technology.

Current Environmental Protection Agency (EPA) regulations on cap designs focus on the use of the EPA Resource Conservation and

Recovery Act (RCRA) cap, but provide options for the use of alternative designs if equivalency can be shown. There currently is no objective way to develop and evaluate alternative designs. From a technical point of view, the DSS is particularly valuable in supporting a selected design that meets performance criteria.

POTENTIAL COMMERCIAL APPLICATIONS

Since the objective of the DSS technology is to provide risk managers with a defensible, objective way to select the best capping method for a given waste site, all environmental restoration personnel considering the use of capping technologies could potentially be customers.

BASELINE TECHNOLOGY

The alternative to a formal decision support system is to attempt to integrate the large and diverse sources of information in an ad-hoc manner, with the attendant risks of omitting key information needed to make a quality decision. Many examples of selecting cover remediation strategies that exacerbated, rather than resolved, contaminant migration problems at a waste site exist. There is currently no objective way to select landfill capping designs. Current practice is to use EPA guidance for the RCRA cap regardless of the level of risk associated with the site. This results in the use of a costly capping design that often greatly exceeds requirements based on real risks and that have very little field performance data.

INTELLECTUAL PROPERTY RIGHTS

Patents: None.

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REFERENCES

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DYNAMIC UNDERGROUND STRIPPING OF VOCS

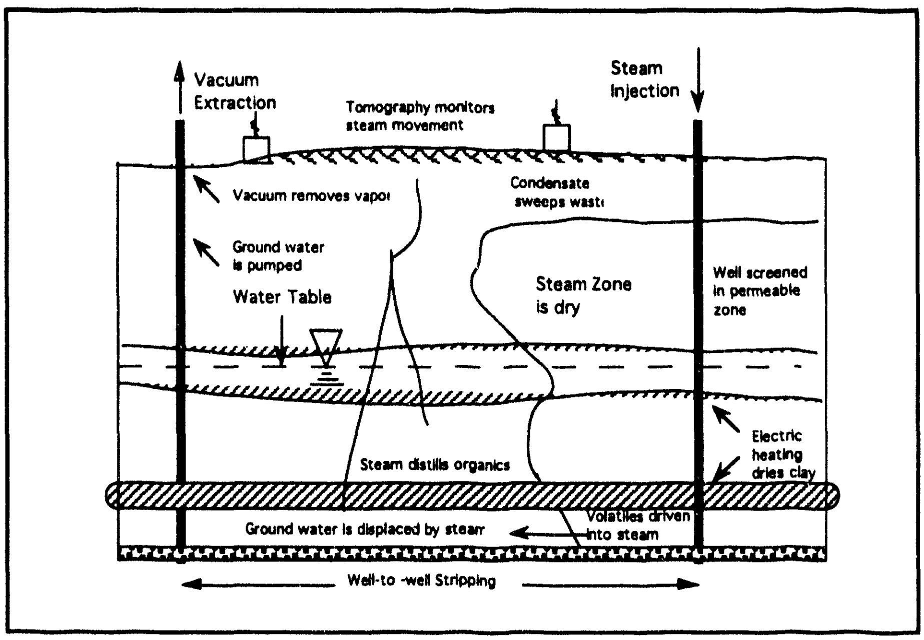
Lawrence Livermore National Laboratory

DESCRIPTION

Dynamic Underground Stripping (DUS) using steam injection is a highly energetic, controllable process for rapid cleanup of localized underground toxic chemical spills. DUS is a technology integration of steam injection, vacuum extraction, direct electric heating, and tomographic geophysical imaging for the remediation of saturated and unsaturated soil zones. Fluid injection wells are located in the periphery of a toxic chemical contaminant plume. Groundwater and soil vapor extraction wells are centrally located in the contaminant region (see figure below). High-pressure steam at about 55 psi (injection pressure will depend on the injection well depth) is injected into soil surrounding a contaminant plume. The resulting dynamic steam-condensate pressure front drives groundwater with aqueous phase and separate phase contaminants nonaqueous phase liquids (NAPLs) toward the extraction well. In addition, the dynamic underground steam cloud heats and strips soil of organic contamination by volatilization (mass transfer of contaminants into the vapor state). The resulting soil behind the moving steam front is dry with a significantly reduced toxic chemical contaminant concentration. A schematic of the process is shown below.

Applicable geophysical techniques for process monitoring and engineering analysis include temperature measurement techniques, electrical resistance tomography, seismic tomography (cross-borehole), induction tomography, and passive seismic monitoring, in addition to conventional geophysical well logging.

To enhance dynamic underground stripping, electrical current is applied to dense soil zones where steam does not easily penetrate. Steam injection is a cost-effective in situ heating method, and when combined with joule heating of dense formations, the entire subsurface can be remediated by this dynamic process, including clay and silt layers. Electrical resistance heating of intermittent or interspersed, low-steam permeable zones will increase volatilization and contaminant mobility in these regions, driving chemical contamination into steam stripped, highly perme-



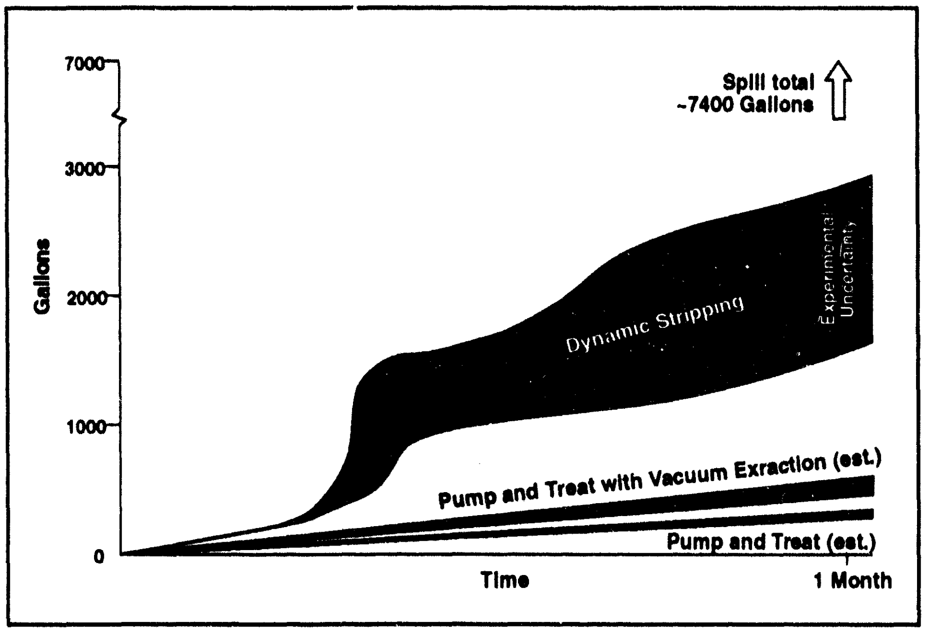
Schematic of the DUS Process

able soil regions. Vacuum extraction and groundwater pumping are continuous. Electrical heating may be followed by one or more additional steam injection phases for contaminant removal and to keep permeable zones "hot."

TECHNICAL PERFORMANCE

Clean Site Engineering Test. This test was completed in 1991 at the Sandia National Laboratories, Livermore Site. Approximately 10,000 yd^3 of soil were heated to the steam temperature (~100° C). A 10-million-BTU, portable, propane-gas-fired boiler was used to heat water. Saturated steam at 50 psi was injected at a rate of 8.5 gpm (as water) to a depth of 135 to 155 ft. Vapor and groundwater were extracted from a well 65 ft away. It took approximately 150 h for the initially injected steam to reach the extraction well. Electrical heating at the Clean Site emphasized electrode design and verification of heating rate predictive models. A six electrode pattern was used, passing a 480-V current at up to 1000 A per electrode.

LLNL Gasoline Spill Remediation. Approximately 17,000 gal of gasoline were spilled at the LLNL gas pad, with an estimated 5000 gal existing in free phase form below the water table. The first pass was completed in March 1993, and these results are given below. 8.6 million kg of steam were injected into the ground in 34 days of operation. Steam that was injected below the water table broke through in 10 days. Large quantities of gasoline were removed, mostly in the vapor state. Fourteen hundred and fifty gallons of gasoline were removed and recycled; between 250 and 1200 gal were destroyed in the treatment system. The gasoline removal rate reached the 100 gal/day limit of the treatment system. The initial removal rate of the DUS system is 25 to 40 times greater than pump and treat alone and 7 to 13 times faster than pump and treat with vapor extraction. Clay layers were heated to a maximum of 70° C. The initial test heated over 85,000 yd^3 (65,000 m^3) of soil by both steam injection and electrical heating. The estimated remediation costs are \$50/yd^3; the energy cost is \$2/yd^3 (steam heating) and \$5/yd^3 (electric heating). The superior performance over the baseline method can be seen from the figure below.



Performance by Cumulative Gasoline Removed

PROJECTED PERFORMANCE

For arid-zone spills with an NAPL core, DUS can reduce operating costs for removal by approximately 50%, principally through the shortening of operational time by the removal of free-phase contaminants. Well-to-well stripping would occur for 1 to 3 months for interwell distances of 60 to 100 ft. The application of dynamic steam stripping is being studied for future application to mixed wastes. A pilot test of a mixed waste application may be performed in the future at the Rocky Flats Site.

WASTE APPLICABILITY

Dynamic stripping is applicable to free-phase organic plumes below 20-ft depths (beyond excavation). It is amenable to all types of liquid contamination including NAPLs and dense nonaqueous phase liquids (DNAPLs), and potentially mixed wastes.

STATUS

The DUS method was demonstrated in March 1993; however, process optimization is continuing, based on experience gained from the first pass remediation at the LLNL gasoline spill site. Continuing process operations will begin in May 1993.

REGULATORY CONSIDERATIONS

Appropriate permits for treatment of off-gases and liquid effluents for specific contaminants must be considered (i.e., the Clean Air Act, Clean Water Act, Resource Conservation and Recovery Act (RCRA), Comprehensive Environmental Response Compensation and Liability Act (CERCLA).

In 1988, LLNL received permission from the Environmental Protection Agency (EPA), the Department of Health Services, and the Regional Water Quality Control Board for conducting a full-scale pilot study at the gasoline spill site. Requirements include Occupational Safety and Health Administration (OSHA) worker safety regulations for boiler/steam injection operations and for in situ electrical heating operations. The Environmental Restoration Program requires National Pollutant Discharge Elimination System (NPDES), Section 402 of the Federal Water Pollution Control Act, Clean Water Act, water discharge permits, and thermal oxidizer discharge permits.

POTENTIAL COMMERCIAL APPLICATIONS

Dynamic steam stripping has application for rapid remediation of deep, concentrated, organic contaminant plumes. Examples of some commercial applications are power plants, fuel pipe lines, chemical plants, refineries, and other fuel, chemical, or solvent storage and dispensing operations. The Electric Resistance Tomography (ERT) monitoring technology is able to detect surface leaks, as well as soil moisture and temperature.

BASELINE TECHNOLOGY

The baseline technology is vacuum extraction with pump and ex situ treatment of groundwater.

INTELLECTUAL PROPERTY RIGHTS

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REFERENCES

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FIXED HEARTH DC PLASMA TORCH PROCESS

Science Applications International Corporation

DESCRIPTION

The Fixed Hearth DC Plasma Torch Process is an ex situ, batch vitrification process to convert nearly all forms of mixed waste into a stabilized, leach-resistant form. This technology is commonly called the Plasma Hearth Process (PHP). The objective of the PHP project is to develop, test, and field-demonstrate a technology that will convert full drums of waste materials directly to an enhanced waste form in a one-step process with little or no need for pretreatment or characterization. The system can be used to treat both the uncharacterized, heterogeneous waste streams resulting from buried waste site remediation as well as entire drums of stored waste that might otherwise require extensive pretreatment with existing technologies.

The PHP is a closed, self-contained system that operates under vacuum. The design was based on concepts developed for vacuum metallurgy, and the result is a highly sealed system. The Plasma Hearth Process uses a transferred arc plasma torch to convert full drums of unprocessed waste material into a vitreous final form in a specially designed refractory hearth. The waste materials are fed into the plasma chamber, where any volatile materials vaporize. These materials are sent to the secondary combustion chamber, where they react at high temperatures to form innocuous products. Solids are retained in the plasma chamber, where they are incorporated into a molten bath. The material in the molten bath forms separable metallic and vitreous phases. When cooled and solidified, the vitrified material forms an extremely durable, leach-resistant slag. In addition, because the PHP will be treating transuranic contaminated materials, the entire system will be enclosed in a containment vessel.

Components of PHP include the primary plasma chamber, waste material feed system, plasma torch, power supply, hydraulic equipment, refractory hearth, secondary combustion chamber, a natural gas burner and support equipment, off-gas monitoring equipment, off-gas cleaning equipment, a control system, and an operator interface. During operation, the PHP requires plasma torch gas, electricity or fuel for generators, air, water, and waste feed materials. The outputs from the system are heat, solidified metal, vitrified slag, salts from the off-gas system, and clean off-gas. The system will process hazardous, transuranic, and mixed wastes without extensive pretreatment and characterization. The ability to process a heterogeneous waste stream without pretreatment or characterization is important because both activities are extremely expensive and time-consuming, and require hands-on involvement by workers. The major technical challenges to development of the PHP are development of material feed systems, product removal and handling systems, off-gas system design, and control system design to handle unknown heterogeneous feeds.

TECHNICAL PERFORMANCE

PHP is designed to vitrify 250-1000 kg/h of contaminated soil and waste material. The plasma chamber achieves a molten bath temperature of 1650 °C. The secondary combustion chamber for destruction of volatilized organic components is designed to maintain reaction temperatures between 1000 and 1400 °C. PHP operates under a vacuum because the system was designed according to vacuum metallurgy concepts.

Pilot Scale Testing. Test indicators have shown an extremely high destruction efficiency. Transuranic components have the tendency to incorporate into the vitreous slag rather than the metallic slag, which is beneficial. Residuals from PHP testing have' been analyzed using EPA's Toxicity Characteristic Leaching Procedure (TCLP) and DOE's Product Consistency Test (PCT) leachability protocols. All PHP residuals analyzed to date have exceeded the Resource Conservation and Recovery Act (RCRA) land disposal restrictions and have shown the slag to be extremely durable.

Cost. Complete procurement, development, construction, testing, and evaluation for a fullscale (1000 kg/h) system are expected to cost about $2M. The largest development cost is expected to be associated with Environmental Protection Agency (EPA) quality trial burn testing and radioactive demonstration testing.

PROJECTED PERFORMANCE

Initiating and maintaining the plasma arc column for the full-scale PHP system is expected to require 1.5-2.0 MW of power. It is anticipated that PHP will operate reliably and with minimal down time. The full-scale melter system is expected to process soil and waste material at a rate of 1000 kg/h.

WASTE APPLICABILITY

The PHP can process virtually all types of solid and liquid waste, including such diverse materials as paper, plastic, wood, soil, concrete, steel, aluminum, and copper. However, it would not be economical to process large volumes of low heating value liquid wastes such as waste water. The PHP is currently not designed for the processing of gaseous wastes, although modification of the system would allow the processing of gases.

STATUS

The final system has not been established. Design, construction, and testing of a full-scale, continuous-operation, prototype system was under way in FY93. Radioactive development testing and evaluation (DT&E) of the prototype system are scheduled to begin in FY94 and to be completed in FY97. Design and construction of the production system is scheduled to begin in FY97 and to be demonstrated on a DOE site in FY98.

REGULATORY CONSIDERATIONS

Pilot-scale analysis has shown the residual slag to be highly durable and leach-resistant according to TCLP and PCT. The implementation of PHP is expected to have negligible environmental impact. Best Available Control Technology (BACT) guidelines will be employed to control stack emissions. The PHP is being designed to process transuranic contaminated materials; therefore, under the regulations governing radioactive processes, no fugitive emissions will be allowed. Residuals from PHP testing have all met the RCRA Land Disposal Restrictions (LDRs).

POTENTIAL COMMERCIAL APPLICATIONS

The PHP system is potentially applicable to industrial process and buried radioactive wastes. It could be used as a component system along with criticality considerations to decommission spent nuclear fuel rods. The engineering design and development may have application for the advancement of vacuum metallurgy.

BASELINE TECHNOLOGY

The baseline technology is vitrification of waste materials after extensive treatment and characterization. PHP will process entire unopened drums of stored waste material and the heterogeneous waste materials resulting from buried waste site remediation. The system will process hazardous, radioactive, transuranic, and mixed wastes with minimal pretreatment or characterization.

INTELLECTUAL PROPERTY RIGHTS

Patent: None.

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REFERENCES

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HIGH-ENERGY CORONA

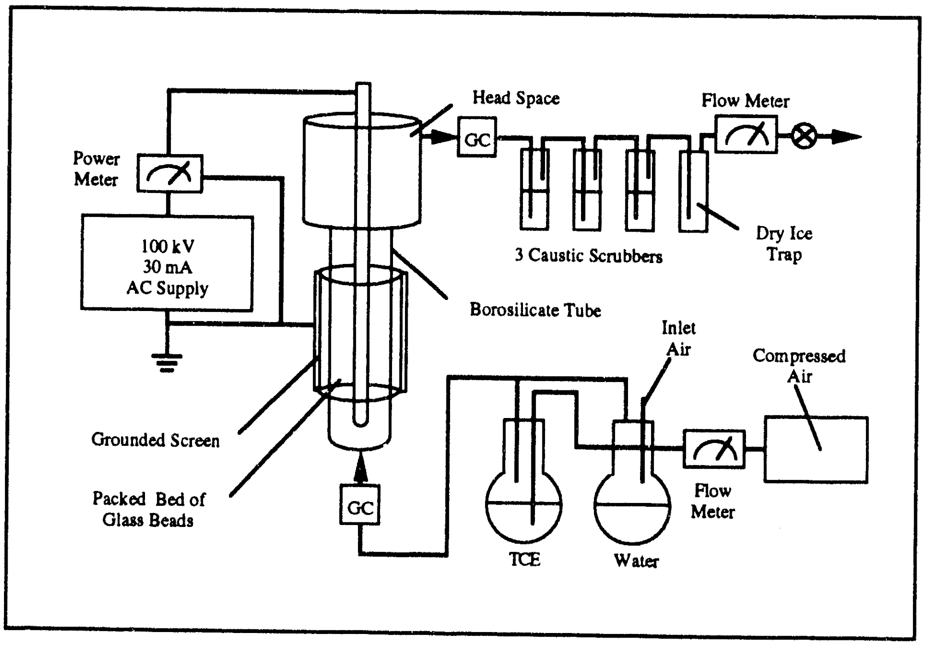
Pacific Northwest Laboratory

DESCRIPTION

Most Department of Energy (DOE) sites have been contaminated with volatile organic compounds (VOCs). Techniques for retrieving these VOCs from soils are being developed and demonstrated at various sites. These techniques generally remove VOCs as vapors (off-gas) from contaminated soil. These vapors must, in most cases, be treated prior to release to the environment. The High Energy Corona (HEC) technology is one of many approaches toward decontaminating soil off-gases prior to atmospheric release. The objective of the HEC technology is to provide a stand-alone, field-portable means of treating soil off-gases produced during soil treatment operations. Contaminants that can be treated include most or all volatile and semivolatile organic compounds. The potential also exists for treating inorganic compounds, such as oxides of nitrogen and oxides of sulfur.

The HEC process uses high-voltage electricity to destroy VOCs at room temperature. As shown in the figure below, the equipment consists of the following: an HEC reactor in which the VOCs are destroyed; inlet and outlet piping containing process instrumentation to measure humidity, temperature, pressure, contaminant concentration, and mass flow rate; means for controlling inlet flowrates and inlet humidity; and a secondary scrubber.

The HEC reactor is a glass tube filled with glass beads through which the prefiltered contaminated off-gas is passed. Each reactor is 2-in. in diameter, 4 ft long, and weighs less than 20 lb. A high voltage electrode is placed along the centerline of the reactor, and a grounded metal screen is attached to the outer glass surface of the reactor. A high-voltage power supply is connected across the electrodes to provide 0 to 50 mA of 60-Hz electricity at 30 kV. The electrode current and power depend upon the type and concentration of contaminant.



Low-Temperature Plasma Reactor

The technology is packaged in a self-contained mobile office that includes gas handling equipment and on-line analytical capabilities. Site power is not absolutely required. Installation consists of connecting inlet and outlet hoses to the HEC process trailer. Training in the use of the equipment can usually be accomplished well within one hour. Failure control is provided by a combination of automated and manually activated means, addressing electrical failure, loss of flow, and loss of VOC containment caused by breakage of the glass reactor vessel. The HEC process can be operated with little, if any, maintenance required. Neither catastrophic failure nor any diminishing in levels of performance have been observed through months of periodic operation in the laboratory. The on-line gas chromatograph and process instruments do require periodic recalibration to ensure data quality.

TECHNICAL PERFORMANCE

The HEC technology appears to destroy more than 99.9% trichloroethylene (TCE). The technology destroys tetrachloroethylene (PCE) to a level of 90 to 95%. In preliminary tests with heptane, destruction levels appear to be extremely high, but have not been quantified. When chlorinated VOCs are treated, water containing either sodium hydroxide or baking soda is recirculated in a scrubber to remove acid gases from the reactor effluent (hydrochloric acid and bleach.) It should also be noted that further contaminant destruction appears likely in this wet scrubber. This is presumably because of strong gaseous oxidants that exit the HEC reactor. Typical outlet properties would be nondetectable concentrations of TCE, ozone, hydrochloric acid, phosgene, and chlorine, with up to 1 ppmv NOx (below regulatory limits.) Air exits the HEC process at temperatures of 100° C or lower or slightly above ambient temperature if a wet scrubber is used. A scrub solution (containing less than 10-wt% table salt in water) is produced when chlorinated VOCs are treated.

One reactor processes up to 5 scfm of soil off gas. The HEC field-scale process that will be demonstrated early in 1993 at Savannah River uses 21 HEC reactors in parallel to treat up to 105 scfm of contaminated soil off-gas. A typical application will involve an inlet stream containing 1800 ppmv of TCE in humid air at 10 to 20° C. Power input is typically 50 to 150 W/scfm being processed. For dry inlet streams, deionized water is added as steam to produce an inlet humidity (hr) of 60 to 80%. Less than 20 mL/min of water is required to humidify a bone-dry stream at a flow of 105 scfm. For water-saturated inlet streams, the stream is preheated (using electric heaters) to lower the inlet humidity (hr) from 100% to 80%. In many cases, the vapor-extraction blower associated with retrieving the VOCs from soil will sufficiently preheat the soil off gas to 80% hr or lower so that no further preheating is required.

Cost. Initial outlay for a 105 scfm process, the prototype field treatment system, is $50K. As with any other technology, large-scale production and customization would significantly reduce costs, perhaps to as little as $20K. Labor requirements are projected as ~0.25 fulltime equivalent (FTE). Energy requirements are $27/day, or roughly $0.35/lb of contaminant. Total cost is roughly $10.00/lb contaminant, including a 25% contingency to account for any unknown additional costs. Although maintenance costs are minimal, the total cost figure assumes 8% downtime and a capital payback period of 6 months.

PROJECTED PERFORMANCE

Continued research & development (R&D) is planned to accomplish the following: fully characterize the reactor emissions to complete mass balances; adapt the HEC process to complete real-time control; better understand the physical and chemical phenomena that make the HEC process work; develop larger reactors; and optimize the hardware and packaging associated with the technology for specific, as well as modular or generic, treatment applications.

WASTE APPLICABILITY

This technique is specifically useful for destroying organics and chlorinated solvents such as TCE, PCE, carbon tetrachloride, chloroform, diesel fuel, and gasoline. Both gas and liquid phase contaminants are treatable.

STATUS

Discussions with manufacturers/licensees have been initiated with the belief that HEC is now ready for commercial availability. The 105-scfm field prototype is available now for commercial testing and evaluation. Pacific Northwest Laboratory (PNL) is continuing R&D to improve and scale the technology. Scaleup to 50 scfm per reactor seems feasible for extremely large applications.

REGULATORY CONSIDERATIONS

Compliance with the Occupational Safety and Health Administration regulations is required for hazardous waste operations and protection of occupational workers from high-voltage electricity.

POTENTIAL COMMERCIAL APPLICATIONS

Since this technology is applicable to treating process off-gases and liquid contaminants in government or industrial settings, the potential commercial applications are very broad. Any remediation or manufacturing process that produces off-gases and/or liquid contaminants that contain organic compounds could possibly be treated with this technology.

BASELINE TECHNOLOGY

The most ubiquitous baseline technology is carbon sorption, in which off-gas contaminants are absorbed onto containerized activated carbon. Once "spent," the carbon is shipped off-site and incinerated, which partially reactivates the carbon for reuse. In many or most cases, the spent carbon must be treated as Mixed Waste because of radon contamination, even if the soil being cleaned has not been contaminated with radioactive wastes. This further increases the cost of baseline carbon sorption use. Some other baseline technologies involve thermal treatment, such as incineration and high-temperature catalysis. Ionizing radiation sources, such as X-rays and electron beams, are also used.

INTELLECTUAL PROPERTY RIGHTS

Pacific Northwest Laboratory has applied for a patent.

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Industrial/University Partnership
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REFERENCES

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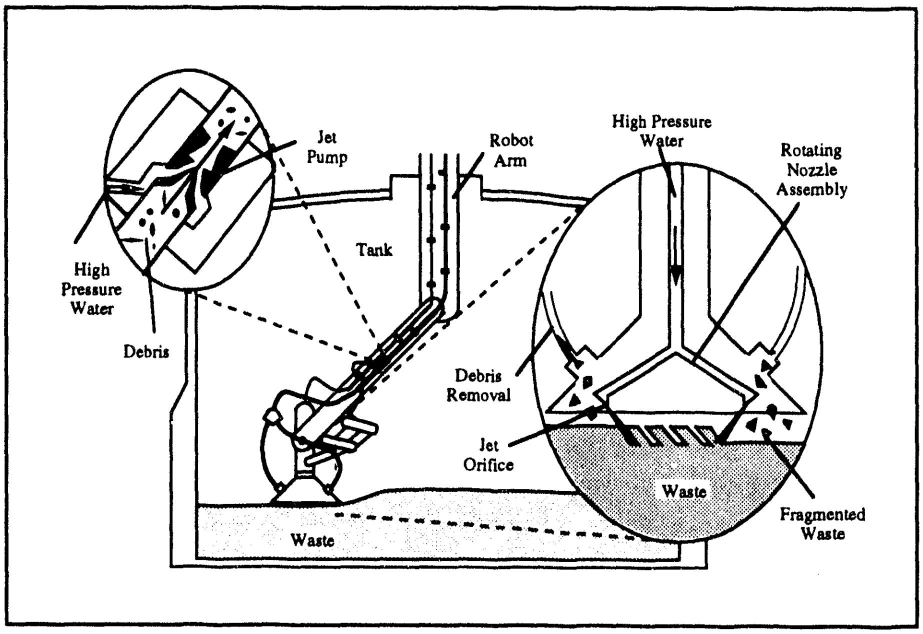
HIGH PRESSURE WATERJET DISLODGING AND CONVEYANCE END EFFECTOR USING CONFINED SLUICING

Sandia National Laboratories

DESCRIPTION

The Confined Sluicing End Effector (CSEF) is a remotely operated tool attached to the end of a robotic manipulator arm. Confined sluicing is applicable for dislodging, mobilizing, and removing all waste forms (hard cake, sludge, and bulk supemate) stored in the Hanford Underground Storage Tanks (USTs). The confined sluicing device is attached as an end effector to an articulated arm that enters the tank through an existing access riser. The CSEF is lowered into a tank containing hazardous waste and is used to dislodge, cut, and remove waste material. It is also used to clean and decontaminate the walls of the tank and any residual hardware that remains in the tank. Confined sluicing uses high pressure (10,000 psi or 70 MPa) waterjets to cut the material in the tank into small pieces, and then sucks the material out using a high pressure (around 7,000 psi or 50 MPa) jet pump. The cutting operations take place in a confining shroud, which leads to an aspirating, high pressure jet pump. Water expelled by the jets and all debris excavated by the process are caught and pumped out of the tank before they can flow into the main body of the tank. Therefore, the injected water and fragmented debris are removed without significant water loss to the tank, and the excavations of mixed waste are carried out of the tank as an aqueous slurry. Conveyance of the waste in a slurry pipeline facilitates feed to downstream waste processors and separators. Although waste processing is external to this waste removal system, the slurry water is captured and separated and then recycled back to the waterjet feed tank, forming an approximate closed loop. Some make-up water may be necessary. Recycling the water results in waste minimization because the volume of waste water generated by the sluicing process is minimized. At the end of the entire tank farm remediation program, the waste water would be treated and reclaimed or suitably disposed of.



Water Jet Cutter

TECHNICAL PERFORMANCE

Design Specifications. The waterjet operates at 10 kpsi, and the jet pump for the pneumatic conveyor develops a 7 kpsi pressure head. The CSEF system is designed to remove all excavated tank waste at a steady flow of 30 gpm or higher. Confined sluicing will break the waste down into a slurry of small particles that are easily processed. It is anticipated that the water-to-solid ratio will be between 2:1 and 4:1. The system will probably require less than 500 hp, but exact requirements are yet to be defined.

Feasibility Study. A feasibility study was conducted in 1992. Feasibility studies have shown that targeted waste removal flow rates of 30 gpm are achievable.

Cost. The cost of this item has not been estimated because of the ongoing refinement of the technology.

PROJECTED PERFORMANCE

It is projected that CSEF will be able to excavate and remove all types of tank waste, including hard cake, sludge, and bulk supernate. The projected removal rate is 30 gpm with a water-to-solid ratio of 2:1 to 4:1. It is projected that the water expelled by the waterjets and retrieved by the pneumatic conveyor will be "close-looped" and recirculated throughout the entire tank farm reclamation process.

WASTE APPLICABILITY

Confined sluicing provides a means to empty and decontaminate the USTs currently used to store radioactive waste. The CSEF is designed for in situ application in the Hanford USTs. The confined sluicing method is applicable for excavation, mobilization, and removal of all the hazardous radioactive material stored in the Hanford USTs, including hard salt cake, sludge, and bulk supernate.

STATUS

Preliminary feasibility studies were conducted in FY92. It is anticipated that this system will be fielded in FY97. Much of the equipment and support systems are commercially available now. However, much of the specific design of the waterjet head required for this application must be developed and validated.

REGULATORY CONSIDERATIONS

No significant environmental impacts are anticipated by the use of this technology. The "closed loop" processing of the waterjet feed water may make this technology more acceptable than other alternatives.

POTENTIAL COMMERCIAL APPLICATIONS

This technology is potentially applicable to radioactive or hazardous excavations in remote settings (such as an underground storage tank). The waterjet cutting technology has applications in advanced manufacturing, material research, and in the mining industry.

BASELINE TECHNOLOGY

There is presently no baseline technology that can break up and remove all types of tank waste. One possible alternative to confined sluicing is flooding of the tanks with water and continuously pumping the water out; such a method is referred to as general sluicing. General sluicing requires large quantities of water, cannot be used in leaking tanks, and cannot deal with hard, insoluble materials.

INTELLECTUAL PROPERTY RIGHTS

Patents: None.

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Industrial Partnership
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HYDRAULIC IMPACT END EFFECTOR

Lawrence Livermore National Laboratory

DESCRIPTION

The Hydraulic Impact End Effector (HIEF) is a remote tool attached to the end of a robotic manipulator arm. HIEF is used to break up monolithic or large pieces of hard cake into smaller fragments. (Hard cake is a solid waste form, typically sodium nitrate or sodium nitrite salts, that has been precipitated out of radioactively contaminated process sludges and stored in underground storage tanks.) After the HIEF tool breaks up monoliths and large waste boulders, the product can be easily handled by other effectors for further size reduction or for pneumatic conveyance out of the waste tank. The HIEF tool has also been called a water cannon or rubblizer. Using brief blasts of ultra high pressure (UHP) water, the water cannon has been shown to be effective in breaking up large monoliths. The HIEF is a beneficial means to dislodge hard waste adhering to various vertical structures within an underground storage tank. Presently, there is no other technology proposed that can break up the monoliths around the risers in a tank as effectively as the HIEF. Another possible means is the water jet technology, but positioning of the device is much more complex and unforgiving.

The HIEF provides a means for continuous high-pressure pulse generation capable of fracturing hard salt cake. The system consists of the end effector tool, the UHP power unit, and the control console. The system uses the energy stored in a volume of water compressed to 40,000 psi to generate a powerful hydraulic shock to fragment monoliths of hard salt cake. The current tool uses water as the working fluid, but evaluation of alternate fluids is in progress. The use of an alternative fluid that vaporizes at ambient temperature would be very beneficial. The control console monitors the pressurization and controls the discharge through the control valve assembly. Fragmentation with the hydraulic impact end effector is comparable to that achieved by explosive charges without the hazards of "fly" rock or toxic fumes. The HIEF system has been designed for either automatic or manual operation. In the manual mode, the operator charges and discharges the tool at his discretion. In the automatic mode, the time intervals for charging and discharging are selected by the operator, and the tool then operates at these settings until shut off. Aiming of the tool is as simple as shooting a rifle. No close tolerances are required.

TECHNICAL PERFORMANCE

The HIEF discharges 200 ml volume of water compressed to 40 kpsi before discharging. The end effector can be fired repeatedly with 5 s between blasts. The UHP power unit is located 100 ft from the end effector and requires 480-VAC electrical power, 7-gpm cooling water, and 90-psi compressed air. The UHP hose has been designed to have a minimum fatigue life of 30,000 cycles. The flexible high-pressure hose is surrounded by a safety shield and has a typical burst pressure of 105 kpsi and a minimum blast pressure of 95 kpsi.

Laboratory Testing. The hydraulic impact end effector was successfully demonstrated in FY92 as a tool capable of fracturing hard salt cake. The hydraulic end effector was effective on a number of different strength simulated hard salt cake compositions. Depending upon the brittleness, cohesiveness, and density of the target, varying degrees of fragmentation result from complete fragmentation with one blast to penetration through the sample. HIEF was very effective in removing salt cake encrusted around pump shafts and pipes. The rubblizer will not damage the steel tank liners, although the hydraulic impact end effector may be limited in use to those tanks known to be structurally intact. Test results have shown that the end effector can be discharged directly into a solid-steel, unsupported plate without noticeable deformation of the plate.

Cost. The cost of the end effector is approximately $90K, including design, and the cost of the UHP power source is $50K.

PROJECTED PERFORMANCE

Currently, the control valve assembly is located at the rear of the effector. In the near term, the control valves will be distanced 75 to 100 ft from the end effector. The rubblizer is expected to break up waste at rate of 12 gpm. Fragments should not exceed a maximum dimension of 14 in. High-pressure, liquid carbon dioxide is being considered as an alternative fluid.

WASTE APPLICABILITY

HIEF is applicable to monoliths and large boulders of the sodium nitrate and the sodium nitrite hard cake form of plutonium processing waste byproduct. The system is designed for applicability to waste stored in underground storage tanks (0.5 to 1 Mgal in size) that may have limited access ports. Hydraulic impact methods have been used to break up natural geologic boulders and rocks in mining applications.

STATUS

The HIEF unit is a modified off-the-shelf commercial unit that has been modified to match the manipulator arm interface. The prototype has been demonstrated on simulated hard cake in 1992. The system with remote maintenance features and alternate fluid usage should be completed in FY95. A pilot-scale waste retrieval demonstration is scheduled for early FY96 and will probably take place in Hanford Tank Number 241-C-106.

REGULATORY CONSIDERATIONS

The HIEF unit was initially developed for use at the Three Mile Island Nuclear Power Plant. The design met all water-jet and decontamination regulations, as well as Environmental Protection Agency (EPA) and Occupational Safety & Health Administration (OSHA) requirements. The HIEF is being designed for deployment by the long reach manipulator arm in the single shell tanks at Hanford. This technology complies with all regulations governing tank farm technologies at Hanford.

POTENTIAL COMMERCIAL APPLICATIONS

The hydraulic impact end effector was initially designed to breakup rubble at Three Mile Island. A hydraulic impact end effector unit is commercially available for use in rock fragmentation to provide powderless gun propulsion shock processing of advanced materials, or for use as a versatile underwater sound source for geophysical applications.

BASELINE TECHNOLOGY

There is currently no baseline technology to break up monoliths around risers in underground storage tanks. The water-jet scarifier is the only reasonable competition to this technology.

INTELLECTUAL PROPERTY RIGHTS

The patent is owned by Quest Integrated, Inc.

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REFERENCES

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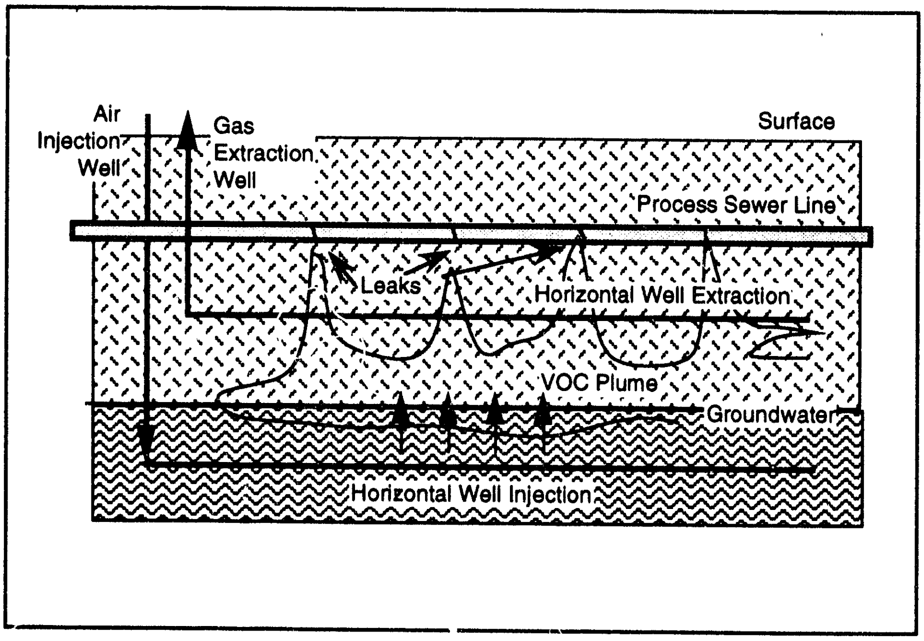
IN SITU AIR STRIPPING OF VOCS USING HORIZONTAL WELLS

Westinghouse Savannah River Company

DESCRIPTION

In situ air stripping (ISAS) is a mass transfer process that utilizes horizontal injection and vacuum extraction wells to remediate sites contaminated with volatile organic compounds (VOCs) within the vadose zone and soil/groundwater in the saturated zone. Air is injected into the saturated zone via horizontal injection wells placed below the water table. As the air passes through the contaminant plume, it volatilizes the chemical constituents. The amount of volatilization and movement of the solute mass into the air stream is a function of the contaminant concentration, temperature, pressure, and Henry's Law constant of the particular solute. Vapors are collected by upper horizontal gas extraction wells. The extracted air stream is then processed to remove or destroy the liquid and vapor toxic chemicals.



In Situ Air Stripping

ISAS performs best in homogeneous soil conditions, while heterogeneities such as formations, fractures, clay layers, and partial clay lenses hinder performance. Clay layers often have high contaminant concentrations, while stratigraphy can cause preferential flow paths and limit the process efficiency. ISAS has been shown to be effective when some interbedded thin and/or discontinuous clays are present.

TECHNICAL PERFORMANCE DATA

A field demonstration of ISAS was conducted during FY90 at the Savannah River Site (SRS). The site featured a pre-existing line source of soil and groundwater based contamination. The soil geology consisted of interbedded soils, silts, and clays, with sands predominating. Vertical-well groundwater and sediment sampling was used to collect multiple samples at various depths. Biomolecular probes were used for laboratory characterization of soil microorganisms. The soil and groundwater at the site have naturally occurring organisms that degrade toxic organic chemicals. Biological monitoring has shown that some contaminant-degrading organisms have flourished at the site during air injection. Geophysical tomography was used to map water saturation distributions in the subsurface; three different geophysical techniques were employed using cross-borehole techniques.

During field testing, two horizontal wells were used, including a 300-ft injection well (165 ft deep, 35 ft below the water table) and a 175-ft long extraction well (75 ft deep). Air was extracted from the upper well at a rate of 55 to 600 scfm for a period of 139 days. Air injection began on day 16 at a rate of 65 scfm. On day 28, the air-injection rate was increased to 170 scfm, and on day 69, it was increased again to 270 scfm. Injection stopped on day 113. A total of 16,000 lb of VOC contamination (trichloroethylene, tetrachloroethylene, and others) was removed through the extraction well.

Soil core samples revealed that an even larger quantity of contamination was destroyed by aerobically activated microorganisms in the soil than was extracted by ISAS. The extraction rate of contaminant removed from the subsurface without air injection (Soil Vapor Extraction or SVE alone) was about 109 lb/day, and the extraction rate increased to approximately 130 lb/day when air was injected through the lower well.

The total cost of VOC removal for the ISAS field experiment at SRS was $15.59/lb. In comparison, an equivalent base technology extraction system, consisting of four vertical vacuum extraction/injection wells and one pump and treat well and processing system, costs approximately $27.07/lb of VOC removed. Although the capital costs are higher for the ISAS system, the higher rate of VOC removal makes it comparatively more cost effective.

PROJECTED PERFORMANCE

ISAS performance with different geometries and/or heating and/or bioremediation nutrient injection is likely to be improved over earlier testing. Future developments will include other geometries, multiple wells, combinations of horizontal wells and vertical wells (giving hydraulic control), and orientation of horizontal injection wells perpendicular to the direction of groundwater flow. The fundamental problems for ISAS are the physical limits of volatilization and requirements of the mass transfer processes. Remaining issues are how to remove the contaminant effectively from the clays and the exponential tail recovery curves. The use of heating, steam injection, and alcohol flooding are possible options to increase volatilization in the clay zones and tight soil pores.

WASTE APPLICABILITY

Geologic Setting. For ISAS to be effective, the geologic setting should have a moderate-to-high saturated soil permeability, homogeneous saturated zone, and sufficient saturated thickness. The vadose zone should have high permeability and homogeneity; coarse-grained soil is most effective. Clay layers have a low permeability, so they are the most difficult to remediate with air stripping.

Contaminant Requirements. Air stripping involves transport between soil, groundwater, and sparged air, so contaminants must be mobile for all phases. Contaminants must have a Henry's Law constant >0.01, vapor pressure >0.1 mm Hg, and soil/water partition coefficient <1000 to be physically removable by air stripping. Most light hydrocarbons and chlorinated solvents satisfy these conditions.

Plume Geometry. Horizontal wells provide better contact with linearly shaped contaminant plumes. Thin plumes are probably more amenable to the air-stripping process. The plume depth affects the cost effectiveness of ISAS.

STATUS

A field demonstration was performed in FY90. A full-scale demonstration, including 4% methane enhancement as a bioremediation nutrient in the injection well, was conducted during FY92, with results to be available in FY93. Better under- ground transport modeling and bioremediation modeling are needed.

REGULATORY CONSIDERATIONS

A state Underground Injection Control (UIC) permit is required because of the active injection of air into the subsurface. ISAS application requires an air permit for discharge of processed off-gases at the surface. This is required to meet Clean Air Act Regulations. The demonstration work at SRS falls under the Resource Conservation and Recovery Act (RCRA) groundwater corrective action permit.

POTENTIAL COMMERCIAL APPLICATIONS

Potential commercial applications include remediation of leaking underground process lines, especially those where chlorinated solvents or other VOC wastes are present; and remediation of VOC contamination, or semi-volatile organic chemical contamination, where the contaminant plume has a linear geometry in the soil or where the contamination covers a large area. In remedial action applications where there is a very large volume of soil contamination spread out over a large area at great depths, both vertical and horizontal wells could be properly used to remediate the contamination zone.

BASELINE TECHNOLOGY

ISAS is an improvement over the vertical well SVE technology or the vertical well air-sparging technology. Broad application of ISAS is possible because of the placement of the lower injection well below the water line, which can remediate both groundwater and soil in the saturated zone. Consequently, ISAS is also an improvement or alternative to a vertical well pump and treat process of groundwater remediation.

INTELLECTUAL PROPERTY RIGHTS

U.S. patent 4660639, "Removal of Volatile Contaminants from the Vadose Zone of Contaminated Ground," was issued on April 28, 1987. The vapor extraction from the upper horizontal well is covered by this patent, and Westinghouse Savannah River Company has paid a one-time license with the assignee, the UpJohn Company, for the use of this process with horizontal wells. U.S. patent 4832122, "In-Situ Remediation System and Method for Contaminated Groundwater," was issued May 23, 1989. This patent is assigned to the Westinghouse Savannah River Company and the Department of Energy (DOE).

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IN SITU VITRIFICATION OF CONTAMINATED SOILS

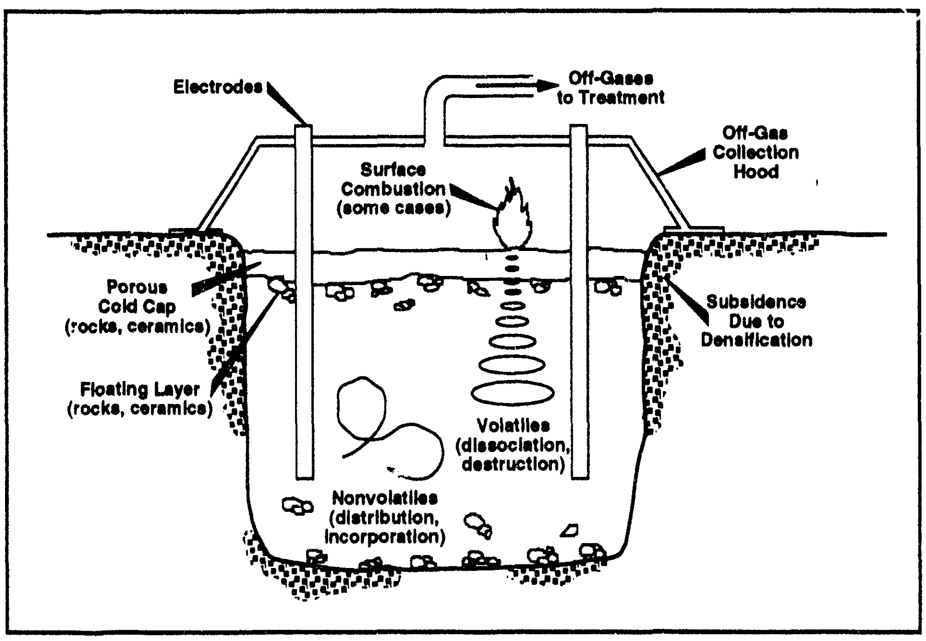
Pacific Northwest Laboratory

DESCRIPTION

In Situ Vitrification (ISV) is a patented thermal treatment process for the in-place destruction and immobilization of contamination in soil. Temperatures of about 1600 °C are achieved using a square array of four graphite electrodes. To initiate the process, a path of conducting material (graphite) is placed on the surface of the soil so that current can flow in the soil beyond the boiling temperature of water (dry soil is not conductive after the conduction path in soil pore water is boiled off) to the melting point of the soil. The joule heating of the starter path achieves temperatures high enough to melt the soil (value is dependent on soil's alkali metal oxide content), at which point the soil becomes conductive. The molten soil zone grows downward and outward. New designs incorporate a moving electrode mechanism to achieve a greater process depth. A vacuum pressurized hood is placed over the vitrification zone to contain and process any contaminants emanating from the soil during vitrification. The vitrification product is a chemically stable, leach-resistant, glass and crystalline material similar to obsidian or basalt rock. The process destroys and/or removes organic materials. Radionuclides and heavy metals are retained within the molten soil.

TECHNICAL PERFORMANCE DATA

Soil Type. ISV is applicable to contaminated soils and sludge, including rocks, sand, silt, or clay. Vapor pressure buildup above the static pressure head of the molten soil is a problem when vitrifying "silty or nonswelling clays" that have low permeabilities ($<10^{-3}$ cm/s) even after drying.



Disposition of Materials During ISV Processing

Soil Moisture Content. This is applicable regardless of moisture content. Soils and sludges were successfully vitrified that had moisture contents of 4 to 50 wt%. Groundwater diversion during processing may be necessary in permeable aquifers.

Soil Composition. It is necessary to have glass forming materials in the soil to process without modification. A minimal alkali content (sodium and potassium oxides) of 1.4 wt% is necessary. The composition of most soils is well within the range of processability.

Depth. Process depths up to 19 ft have been achieved in relatively homogeneous soils. The achievable depth is limited under certain heterogeneous conditions.

Radionuclides. Extremely effective in immobilizing radionuclides, including transuranics and fission products. Criticality limits are conservatively placed at 30-kg plutonium/setting. Typically, there is no volatilization of ^{90}Sr, ^{241}Am, or $^{239,240}Pu$, and measurements indicate greater than 99.993% retention of these isotopes. Rare earth tracers, Ce, La, and Nd, were used as surrogates for transuranic isotopes in an Oak Ridge National Laboratory (ORNL) field test with greater than 99.9995 wt% retention in the melt. Cesium is more volatile than most radionuclides and has been measured with volatilization of 0.029% up to 2.4 wt% of ^{137}Cs in some cases.

Hazardous Inorganic Chemicals. ISV is extremely effective for immobilizing heavy metals and other hazardous inorganics from 70 to 99.99 wt% retention in the vitrified block. Chromium and lead retention at the Hanford Site field test was greater than 99.99 wt%. Nitrates are decomposed, and mercury is removed and collected by the off-gas system.

Hazardous Organic Chemicals. High process temperatures destroy organics by pyrolysis. Concentrations up to 7 wt% in the soil can be processed. The small percentage that is not destroyed, 0.01 to 1 wt%, is removed and collected by the off-gas system. ISV is not applicable to reactive or explosive materials. Limited empirical data suggest that VOCs can be effectively treated; however, treatability studies on a site-specific basis are recommended.

Scrap Metals. Up to 25 wt% has been processed, forming a molten pool at the bottom of the melt. However, electrical short circuiting problems can be avoided by electrode retraction.

Debris and Rubble. Inclusions of high concentrations of concrete rubble, rock, and other debris (up to 50 wt%) can generally be processed by ISV. Monolithic structures that trap moisture should be avoided.

Combustibles. Based on heat removal capabilities of existing equipment, combustible inclusions of up to 7 wt% can be processed.

Sealed Containers. Sealed containers can cause problems as can pocketed liquids or multiple void volumes greater than 0.07 m^3 (2.5 ft^3). This is a focus of current research, the results of which will be applicable to buried waste and underground storage tank vitrification.

Power and Energy Requirements. These requirements will vary with soil geologies and moisture content. They will also vary during the ISV process. Upper current level limits for the 3750 kVA large-scale ISV system are presently at 4000 A. The power available may be limited by the transformer temperature limits.

Cost Data. Treatability Tests - all types $25K + analytical, PCBs and dioxins $30K + analytical; Remedial Design - varies with design firm; Equipment Mobilization and Demobilization - $200K to 300K combined; Vitrification Operation varies with electricity costs, quantity of water and depth of process. Hazardous Waste - $350 to 450/ton; Radioactive waste $400 to 550/ton.

PROJECTED PERFORMANCE

Improved performance includes application to buried waste and underground storage tanks, application to nonalkali soils, increasing the process depth to 30 ft (~9 m), control melt shape, VOC transport modeling, and VOC migration control.

WASTE APPLICABILITY

ISV is applicable to soils containing radionuclides, transuranics, fission products, organic chemicals, metals and inorganic chemicals, and mixed waste. Amenability and achievable depth may be limited by the presence of rock or gravel layers where heat transfer is less efficient.

STATUS

Field-scale demonstrations of contaminated soils have been performed at the Hanford and Oak Ridge Sites. Large-scale demonstrations have been completed at the Hanford Site. Demonstration in acidic soil is planned for the Savannah River Site. The technology is being evaluated for future application to buried wastes and underground storage tanks. Commercial operations will begin during the summer of 1993.

REGULATORY CONSIDERATIONS

Regulatory issues include determination of Comprehensive Environmental Response Compensation and Liability Act (CERCLA)/Superfund Amendments and Reauthorization Act (SARA) and Resource Conservation and Recovery Act (RCRA) requirements as well as state and local requirements. ISV may be considered as an innovative remediation tech-nology by the Environmental Protection Agency (EPA) allowing for treatment of high-level waste.

POTENTIAL COMMERCIAL APPLICATIONS

Geosafe Corporation is offering the technology for commercial applications.

BASELINE TECHNOLOGY

ISV is a new technology to replace retrieve-and-treat technologies. ISV replaces the excavation of soil and above-ground treatment for decreasing toxicity and mobility of hazardous constituents. Other alternatives include grouting and chemical fixation.

INTELLECTUAL PROPERTY RIGHTS

The ISV process was invented by Battelle, Pacific Northwest Laboratory (PNL) for the U.S. Department of Energy (DOE) in 1980. The patent is assigned to DOE, is licensed to Battelle, and is sublicensed to Geosafe Corp. for worldwide rights. Patent No. 4,376,598; issued March 15, 1983.

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magnitude and TCE/PCE concentrations declined to less than 2 ppb; the current drinking water standard is 5 ppb.

Capital investment costs are $150K and 200 man hr for site preparation, setup, and assembly. The operation is low maintenance, requiring only one technician at 25% time (10 hr/wk); other operational costs are for electricity, natural gas, and equipment maintenance. In 429 days of operation, 12,096 lbs VOC was extracted and treated with the CatOx system; less than 726 lbs was emitted, and the remaining amount was destroyed by the CatOx system. Biodegradation was indicated by increased concentrations of carbon dioxide in the extracted vapors and increased concentrations of soluble chlorine in groundwater monitoring wells.

There were four consecutive stages to the demonstration, not including the baseline tests that are vacuum extraction only (240 scfm) and vacuum extraction coupled with 100% air injection at 84% of the extraction flow rate (202 scfm).

The first stage, lasting 3 months, was with 1% (vol) methane added to the injected air flow. Helium conservative tracer tests indicate that more than 50% of the 1,392,774 scf of injected methane was consumed by the indigenous microbes, contributing to biomass growth and contaminant degradation. Initially, biomass grew at an approximate average rate of an order of magnitude every 2 wks. Growth slowed after two months because of the reduction of naturally occurring nitrates and other nutrients. Technical grade methane was also found to be growth-inhibiting because it contains small amounts of acetylene, which is poisonous to methanotrophs.

The second injection campaign was 4% methane added to the injected air stream. Populations of methanotroph bacteria increased while TCE/PCE concentrations decreased. The third stage used pulsing of the injected methane at a rate of 8 hr every 2 days to minimize nutrient competition and optimize growth. However, it was realized that more rapid pulsing produced a more optimum growth rate. Ultimately, the growth and degradation efficiency of the methanotroph bacteria is limited by the paucity of other essential nutrients. The final stage of the demonstration included pulsing of methane with continuous injection of a confluence of air, nitrous oxide at 0.007%, and tri-ethyl phosphate at 0.07%. Rates of mineralization and physiological activity increased dramatically, although nutrient injection had only minor effects on the total biomass. It was concluded that there must be a further deficiency in some other necessary nutrient.

PROJECTED PERFORMANCE

The knowledge gained will enable future applications to have a high quality nutrient injection schedule, approaching an optimum. The results expected are rapid biomass growth, metabolism, contaminant mineralization, and site restoration.

WASTE APPLICABILITY

This technique is specifically useful for destruction of halogenated aliphatic compounds and chlorinated solvents (TCE, PCE etc.); furthermore, the non-specific MMO enzyme has been demonstrated to degrade more than 250 different compounds. It is applicable where the subsurface does not contain significant amounts of copper or azide compounds that either poison the methanotrophs or limit their growth.

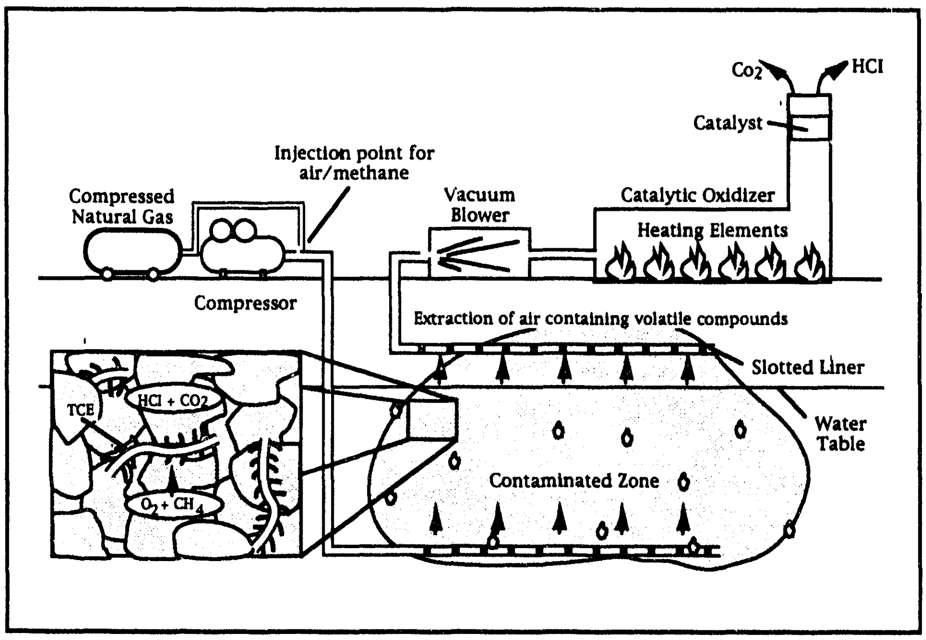
METHANE ENHANCED BIOREMEDIATION FOR THE DESTRUCTION OF TRICHLOROETHYLENE USING HORIZONTAL WELLS

Westinghouse Savannah River Company

DESCRIPTION

Methane Enhanced Bioremediation (MEBR) using horizontal wells is an in situ method to stimulate cometabolic destruction of halogenated aliphatic chemical contamination in the sub-surface, such as trichloroethylene (TCE) and tetrachloroethylene (PCE). This destruction is achieved by enzyme-catalyzed reactions brought on by the methane monooxygenase enzyme (MMO) of indigenous methane utilizing bacteria (methanotrophs). The process has the capacity to degrade the contaminants into carbon dioxide, water, and soluble chlorine.

Horizontal wells provide better contact for nutrient delivery and more efficient aerobic stimulation of the subsurface microflora. A methane and air mixture (<5 vol %) is injected through a horizontal well into an aquifer below the contaminant plume to stimulate microbe biomass growth above the well. One strategy to optimize growth and degradation is pulsing of the methane air mixture and another is injection of nitrogen and phosphorous rich nutrients with concomitant methane treatments. The gaseous nutrients will flow upward through the contamination plume to an upper duty vacuum extraction well. The upper parallel, horizontal, vapor extraction well is located in the vadose zone above the linear contamination plume. A thermal catalytic oxidation (CatOx) system, operated at 825 °C, is used to treat extracted soil vapors. The figure below is a general schematic of the process.



Nutrient Enhanced Bioremediation System

TECHNICAL PERFORMANCE DATA

Pilot Scale Demonstration. Performed at the Savannah River Site, M area, abandoned seepage basin and process sewer line employed for disposal of solvents used to degrease nuclear fuel target elements. Contamination is mostly TCE and PCE with concentrations of 10,000 ppb in soil and 1,000 ppb in groundwater. Extensive soil and groundwater monitoring has demonstrated that methanotroph densities increased 5 orders of

STATUS

This is an emerging technology, but it is available for application now. The knowledge base gained will be applied to future designs for full-scale demonstrations and applications at the Savannah River Site (SRS) and other sites.

REGULATORY CONSIDERATIONS

Resource Conservation and Recovery Act (RCRA) permits and compliance with the Clean Air Act and Clean Water Act for injection control may be required. Comprehensive Environmental Response Compensation and Liability Act (CERCLA), as amended by the Superfund Amendments and Reauthorization Act (SARA), provides the mandate for implementing the demonstration tests to remediate the contamination of soils and aquifers at the SRS.

POTENTIAL COMMERCIAL APPLICATIONS

The use of horizontal wells for microbial stimulation makes restoration of soils and aquifers in otherwise inaccessible areas (e.g. under structures) possible. It is applicable for remediation of organic chemical spills, chemical process sewer leaks, and storage tank leaks. The enhanced bioremediation technology is useful for timely remediation of contaminant plumes that are attributable to the transportation fuel industry, chemical industry, uranium purification, and other activities that may produce, utilize, store, or dispose of chlorinated solvents.

BASELINE TECHNOLOGY

The baseline technology is vacuum extraction alone with effluent treatment or in situ air stripping with effluent treatment but without biomass or nutrient injection. In contrast, the MEBR technology is based on biological destruction of contaminants in situ. Nutrient injection for enhanced bioremediation has the potential to enhance the performance of in situ air stripping, as well as offering stand-alone remediation. The use of horizontal wells gives an increased surface area and contact efficiency for better delivery and distribution of nutrients, for easier recovery of soil-gas and water, and for minimization of formation clogging and plugging phenomena. This technology is capable of decreasing contaminant concentrations to drinking water standards (5 ppm) in heterogeneous environments. Few pump-and-treat technologies are comparable.

INTELLECTUAL PROPERTY RIGHTS

The Department of Energy (DOE) applied for a patent for methane and gaseous nutrient injection through horizontal wells. Patent US 4713343, was issued December 15, 1987, for biodegradation of halogenated aliphatic hydrocarbons and for water purification using microorganisms capable of aerobic degradation of low molecular weight alkanes; the assignee is US EPA. Patent US 4832122 was issued May 23, 1989, for In Situ Remediation System and Methodology for Contaminated Groundwater; the assignee is U.S. DOE.

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Industrial Partnerships
ECOVA, Gas Research Institute, Auigas, Heritage Environmental, and Groundwater Technologies.

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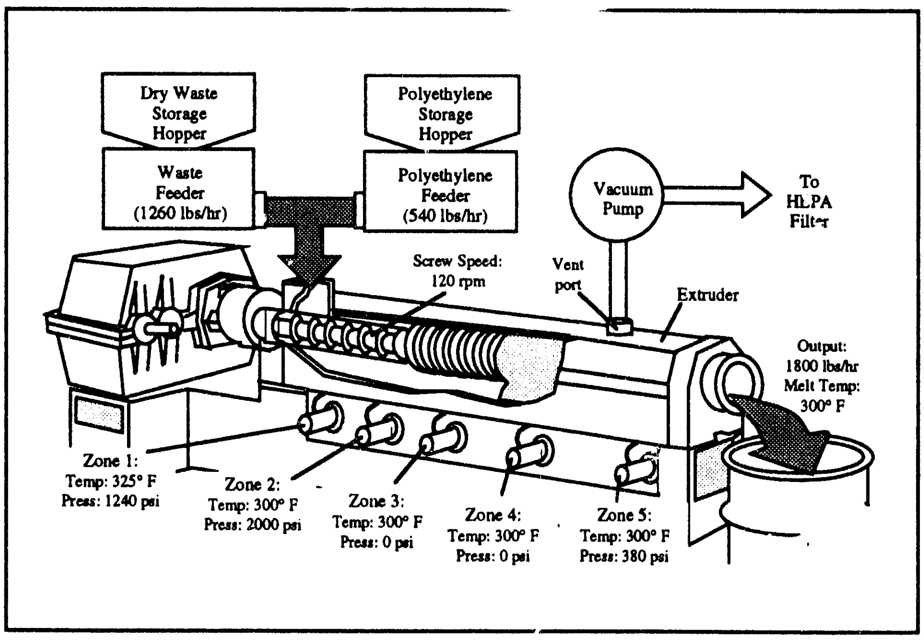
POLYETHYLENE ENCAPSULATION OF RADIONUCLIDES AND HEAVY METALS

Brookhaven National Laboratory

DESCRIPTION

Polyethylene Encapsulation of Radionuclides and Heavy Metals (PERM) is a waste treatment and stabilization technology for high-level mixed waste. Specific targeted contaminants include radionuclides (e.g., cesium, strontium, cobalt), and toxic metals (e.g., chromium, lead, cadmium). A polyethylene encapsulation process was developed several years ago at Brookhaven National Laboratory (BNL) for solidification of low-level radioactive waste (LLW) such as evaporator concentrate salts and ion-exchange resins. Recently, it has been successfully applied for treatment of hazardous and mixed waste streams such as sodium nitrate salts and sludges. Polyethylene, which has a processing temperature of about 150 °C, is an inert thermoplastic; as such, it is not susceptible to chemical interactions between the waste and binder matrix, which could adversely impact solidification. In general, polyethylene encapsulation can be accomplished with greater efficiency (more waste encapsulated per volume of product) and with better waste form performance than is possible using conventional cement-based grout encapsulation technologies.

The PERM process begins by optimizing the polymer matrix for the given waste stream by adjusting property parameters such as the density, molecular weight, and melt index. Aqueous salts, sludges and salt cake are pretreated to remove residual moisture efficiently and prepare the waste for polyethylene processing by extrusion. The dehydrated wastes and polyethylene binder are then precisely metered at predetermined ratios by a loss-in-weight volumetric feed system. The process extrudes a molten, homogeneous mixture of waste and polyethylene binder into a suitable mold (e.g., large metal drum or cube), where it cools to form a monolithic solid waste form. It can then be removed from the mold for transport and disposal or disposed using the mold as a storage/disposal container. The PERM system can be operated in continuous or batch mode.



Polyethylene Encapsulation System

PERM has an integrated system control, including computerized feed control with an output feedback loop that reduces the demand on the operator's attention. Key process parameters are monitored constantly, including feed rates for waste and binder, extruder zone temperatures and pressures, final melt temperature and pressure, extruder screw rotational speed, motor load, and output mass flow rate. A Transient Infrared Spectrometer (TIRS) system developed by Ames Laboratory will be used to provide real-time monitoring and confirmation of waste loading. All controls can be operated remotely to minimize operator exposure. Key process systems are connected to an audible alarm and can trigger automatic, efficient, and orderly shutdown of the system under failure conditions.

TECHNICAL PERFORMANCE

Production Scale Feasibility Study. Scale-up from bench scale tests have demonstrated the feasibility to process waste at approximately 2000 lb/hr. The scale-up feasibility tests have successfully demonstrated the potential to encapsulate at least 60 wt% nitrate salt in polyethylene. A production scale system would fit on a pad about 3 m x 6 m and would be about 4 m high. Polyethylene waste forms have been demonstrated to exceed Nuclear Regulatory Commission, Environmental Protection Agency, and Department of Transportation waste form criteria. Waste forms containing up to several parts per million of toxic metal contaminants have passed the EPA's Toxicity Characteristic Leaching Procedure (TCLP).

Cost. The extrusion processing system would cost $250K, and the integrated treatment system (including pretreatment) would cost $1000K. Operation costs are associated with energy costs for the required thermal input, the salaries for the operator technicians and engineers, and the polymer binder feed material costs.

PROJECTED PERFORMANCE

PERM is projected to achieve production-scale waste processing rates between 1 to 3 metric tons/hour with 60 wt% nitrate salt loading in the polymer matrix. The use of recycled polyethylene is being considered for material cost savings and petroleum resource conservation.

WASTE APPLICABILITY

PERM is applicable for stabilization of high-level radioactive and heavy metal waste components that may be in media such as aqueous salt concentrates, salt cake, sludge, fly ash, and ion exchange resins. Some specific contaminants this technology is designed to encapsulate and stabilize are radioisotopes of cesium, strontium, cobalt, and toxic heavy metals, including chromium, lead, and cadmium.

STATUS

The process should be ready for implementation by FY95. Following "cold" pilot testing at BNL and "hot" testing at a DOE facility (Hanford Underground Storage Tank Integrated Demonstration), the PERM process will be ready for implementation. Full-scale implementation is anticipated by the end of FY95. Installation, start-up and testing of the prototype facility can be accomplished by FY94. A parallel technology development effort that has had favorable results is being conducted in Japan.

REGULATORY CONSIDERATIONS

No ecological impacts are anticipated because no gaseous or liquid effluents will be released as a result of this process. Extensive waste form performance testing has been completed, including compressive strength, water immersion, thermal cycling, radioactive and hazardous constituent leachability, radiation stability and biodegradation. In each case, waste form performance exceeded regulatory criteria by a wide margin.

POTENTIAL COMMERCIAL APPLICATIONS

Potential commercial applications include waste stabilization in the nuclear power industry and other commercial nuclear waste generation sites.

BASELINE TECHNOLOGY

Cementation by grout is the current baseline treatment technology for low-level waste. Vitrification into a glass form is the baseline for stabilization of high-level, concentrated waste streams. Although glass processing is an excellent waste stabilization option, it is not compatible with some waste constituents and requires sophisticated off-gas capture and secondary waste treatment. For low-level waste, a PERM provides 5 times greater volume reduction, while reducing contaminant mobility by more than 100 times compared with baseline grout formulations. Microencapsulation of individual contaminant particles results in leachabilities measured 100 to 1000 times lower than the equivalent grout waste form.

INTELLECTUAL PROPERTY RIGHTS

A patent application is being prepared for submission.

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Industrial/University Partnership
None at present.

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REMOTE EXCAVATION SYSTEM

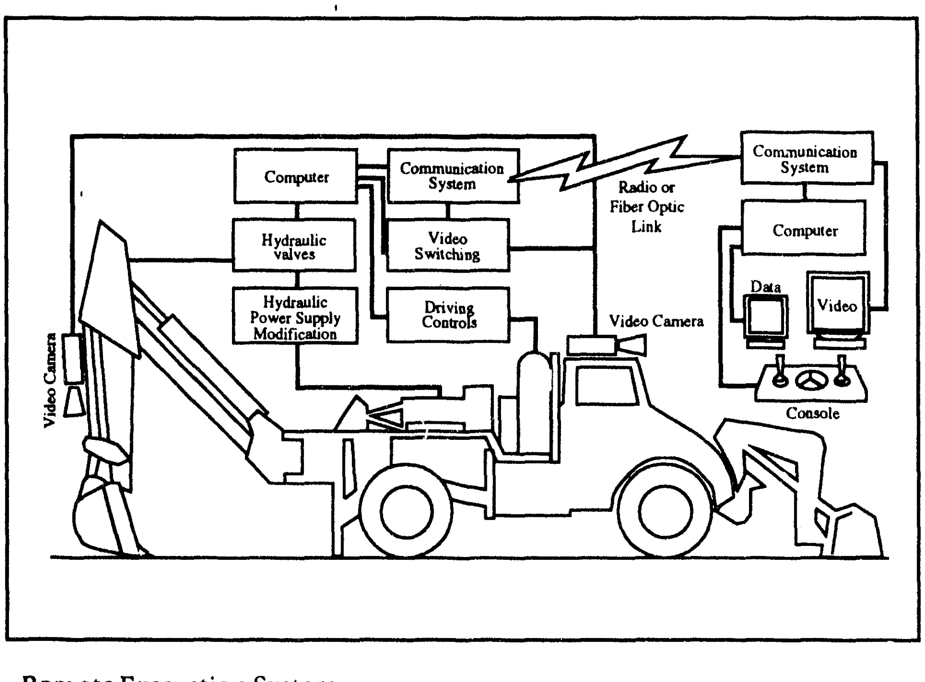
Oak Ridge National Laboratory and Idaho National Engineering Laboratory

DESCRIPTION

The Remote Excavation System (RES) is a military tractor, the Small Emplacement Excavator (SEE), which has been modified for tele-robotic operation by the Oak Ridge National Engineering Laboratory (ORNL). The primary applications for this remote excavation technology are buried waste retrieval for the Department of Energy (DOE) and unexploded ordinance retrieval for the U.S. Army. The hazards of buried waste retrieval are significant if performed by conventional manned operations. The potential hazards include exposure to radiation, pyrophorics (capable of spontaneous ignition when exposed to air), toxic chemicals, and explosives. Consequently, it is highly desirable to excavate and retrieve these wastes by using remotely operated equipment. The RES will be used to excavate and remove buried waste and contaminated soil for ex situ treatment.

The SEE is a multiuse vehicle developed for the U.S. Army that has been configured with a backhoe and a front-end loader. The backhoe is an adaptation of the Case 580E commercial backhoe, and the vehicle is a modified Mercedes Benz Unimog truck. The SEE is not necessarily the excavator of choice for large-scale waste retrieval campaigns; however, the controls technology developed for the RES/SEE shall be readily transferable to other mechanical systems.

The ORNL alterations to the vehicle center around modifying the hydraulic systems for computer control. High-performance servovalve components will be used to greatly improve the dexterity over the existing manual valves. Hydraulic pressure sensors will provide limited indications of force exerted by the backhoe. The backhoe and front-end loader will also be outfitted with position encoders for use in robotic operations. Remote viewing will be provided by two color television cameras with pan and tilt mechanisms mounted on the truck body and a camera mounted on the backhoe boom. In the second phase of the project, the vehicle drive system will be modified for remote driving. A hydraulic motor system is being considered for propelling the vehicle during remote driving operations. Options for remote steering are still being investigated.



Remote Excavation System

The computer system for RES is composed of a SUN workstation host (for the base station) networked to VME-based Motorola 6840 target computer (for the excavator truck) running the VxWorks operating system. The communications system between the vehicle and base station consists of two microwave video channels and an Ethernet data radio. Current microwave systems perform well, but are susceptible to multipath distortion and are poor in over-the-hill performance. Digital radios are being considered as a possibility for digitizing and compressing video to deliver over a digital link. Technology is advancing in this area, and it is anticipated that digital video transmission will soon become practical at a lower cost.

TECHNICAL PERFORMANCE

A 110/220 V, 25 kW power supply is required to run the control station. The SEE operates on diesel fuel. The 110 hp, 6 cylinder engine consumes approximately 30 gal of fuel/day. Monthly oil changes are anticipated as part of a regular maintenance program. The front end loader has a 75 ft^3 capacity, a lift height of 8 ft 2 in., lift capacity of 3,000 lbs, and a breakout force of 6,000 lbs. The backhoe has a bucket capacity of 7 ft^3, loading height of 11 ft, digging depth of 14 ft, digging radius of 17 ft 8 in., a swing arc of 180°, and a digging force of 10,000 lbs.

Field Demonstration. A field demonstration was scheduled for June 1993 at an Idaho National Engineering Laboratory cold test site that includes remote controlled excavation and remote driving. Information on the waste retrieval rate, system reliability, human factors analysis, and equipment cost for the RES will be determined during the demonstration. A Technology Assessment Report is scheduled for completion September 30, 1993.

PROJECTED PERFORMANCE

The primary objective of the demonstration is to demonstrate the feasibility of remote excavation. The supporting objectives are to determine the precision and accuracy, the system reliability, the usability, the factors that affect the system performance, and to develop a knowledge based on remote excavation to assist in future improvements.

WASTE APPLICABILITY

This technology is applicable to any buried waste, excavation, or material handling task.

STATUS

The prototype has been completed and was scheduled for demonstration in June 1993. The SEE currently has remote digging and driving capabilities. The Technology Evaluation Report is scheduled for completion in September 1993.

REGULATORY CONSIDERATIONS

The equipment should be acceptable to regulators because it is tele-operated and removes the operator from hazardous environments. Operation of the vehicle and excavator pose no hazard to personnel as long as prescribed safety procedures are followed. On-board sensors are available to monitor the safety status of the system and to prevent accidents. Decontamination of equipment may be required if the excavator becomes contaminated during operation in a hazardous environment. The use of this technology results in disturbance of buried wastes, as does manual excavation, that may result in the spread of contamination.

POTENTIAL COMMERCIAL APPLICATIONS

The RES could be used for excavation around buried waste or decommissioning sites, for soil excavation, and for handling of bulk hazardous materials. The control technology being developed may be adaptable to other excavation and construction equipment.

BASELINE TECHNOLOGY

The primary alternative to the use of tele-robotics in excavation is to perform the operations using conventional excavation techniques and equipment, though the operator may be in a protective cab or bubble suit. Tele-operated equipment allows the worker to be removed from the potentially hazardous environments, increasing operator safety.

INTELLECTUAL PROPERTY RIGHTS

Patent Ownership is assigned to DOE and the Department of Defense.

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Industrial Partnership
None at present.

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RESORCINOL-FORMALDEHYDE ION EXCHANGE RESIN FOR CESIUM REMOVAL

Westinghouse Savannah River Company

DESCRIPTION

The Resorcinol-Formaldehyde Ion Exchange (ReFIX) resin is applicable to high-level waste streams containing cesium-supernate salt solutions. Radioactive cesium is a fission product found in waste produced by reprocessing fuels from nuclear power reactors. The highest concentrations of this isotope are found in alkaline high-activity wastes, a mixture primarily of sodium nitrate and sodium hydroxide that is called the supernate. This technology is a selective ion-exchange resin (specific sorption of cesium ions) that has 10 times the capacity of the baseline Duolite™ CS-100 phenol-formaldehyde resin. Columns of ReFIX resins will be packaged in a standardized module to fit the Compact Processing Unit (CPU) waste processing module specifications. One specific benefit of ReFIX resin is that it is essentially unaffected by changes in temperature. However, high concentrations of competing sodium and potassium ions reduce the cesium sorption capacity and diffusion efficiency of the ReFIX resin.

High-level supernate from a Hanford waste tank will be processed through an appropriate number of ion exchange columns in a CPU processing module. (See the catalogue entry for CPU.) Cesium will be removed by sorption onto the ReFIX resin in the processing columns. When a column becomes saturated, it will be temporarily removed from service so that the cesium can be eluted from the resin with acid (most likely nitric acid) in a concentrated stream that can be sent for vitrification. Once eluted, the newly regenerated column will be placed in service when another column is removed for elution. The treated streams from these columns may have to be processed with another series of columns containing resin specific for strontium removal before the stream can be incorporated in cement for final storage. Spent resin can be subjected to rigorous elution before disposal to lower its radionuclide content. Carefully eluted resin can then be stored or disposed of by incineration or chemical destruction before incorporation into cement.

TECHNICAL PERFORMANCE

Design Specifications. The column volume is approximately 5000 gallons. The ReFIX resin supports a cesium capacity of approximately 200 column volumes of throughput.

Laboratory Testing. Laboratory scale testing results were published in 1990. Elution of the filled resin columns with 10 column volumes of 0.1 M nitric acid removes 99% of the sorbed cesium. After six feed-elute cycles have been completed, approximately 20% of the resin capacity is lost, requiring either partial reconstitution or replacement of the column resin. This resin appears to be useful for a large variety of concentrations of feed streams over a wide range of temperatures. Preliminary results have shown that the diffusion kinetics of Cs^+ to the sorbing medium is quite slow, and high concentrations of potassium cations may reduce the throughput. Recent analysis suggests that ReFIX resin may have a short shelf life.

Cost. The cost of ReFIX resin is estimated at $1,000/ft^3.

PROJECTED PERFORMANCE

If operated properly with columns in series, the resin is capable of removing Cs-137 to any level desired. The ReFIX waste treatment module for the CPU system is expected to treat the liquid waste at an average flow rate of 2.5 gpm. The ReFIX resin is expected to have a shelf life for optimum performance of one year, at which point the cesium capacity and diffusion efficiency would have decreased by a factor of 10 or more. Failure of the resin can be averted by setting tight specifications on receipt of the resin and distribution coefficient tests (diffusion efficiency) before use.

WASTE APPLICABILITY

This technology is applicable for cesium removal in high-level liquid waste streams, such as the Hanford Underground Storage Tank supernate salt solutions.

STATUS

A prototype is being developed for demonstration at the Hanford Site in FY97. A module of ReFIX resin columns will be demonstrated and optimized with waste from Hanford tank number 241-101-AW. The ion exchange process equipment could use any resin, should a better material be developed at a later date.

REGULATORY CONSIDERATIONS

No ecological impacts are anticipated from the use of this technology. The only safety consideration is radiolytic products, especially benzene derivatives, that are produced when the resin is placed in a radioactive environment. However, preliminary radiolysis studies indicate that no volatile organic compounds (i.e., benzene derivatives) are formed, but a small amount of hydrogen gas is formed in the presence of organic materials. An off-gas treatment system will be required. The hydrogen concentration in the ventilation system is expected to be below the lower explosive mixture.

POTENTIAL COMMERCIAL APPLICATIONS

The ReFIX polymer matrix resin could have applications in the nuclear power industry with cesium removal from both active coolant water and spent fuel storage tank water. In addition, potential applications include decontamination and decommissioning operations and domestic (DOE) or foreign spent fuel reprocessing effluents.

BASELINE TECHNOLOGY

The baseline technology is ion-exchange using Duolite™ CS-100 phenol-formaldehyde resin, which has approximately one-tenth the capacity of the resorcinol-formaldehyde resin.

INTELLECTUAL PROPERTY RIGHTS

Westinghouse Savannah River Company applied for a patent in the names of R.M. Wallace (now deceased) and Jane P. Bibler. The DOE would also be a patent owner. The patent is pending.

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Industrial/University Partnership
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SIX PHASE SOIL HEATING

Pacific Northwest Laboratory

DESCRIPTION

Six-Phase Soil Heating (SPSH) is an innovative technique based on the ability to split conventional three-phase electricity into six separate electrical phases. Each phase is delivered to a single electrode, requiring six electrodes placed in a circle surrounding a single vent. Because each electrode is at a different phase, each one conducts to all the others. This approach produces more uniform heating. Soil heating raises the contaminant's vapor pressure, increasing the removal rate. Heating adds further benefits if temperatures are raised to the soil's moisture content boiling point. A source of steam is then created to strip out the less volatile organic compounds that venting does not remove. In addition, applied electrical fields avoid heat- and mass-transfer limitations by heating soils internally, where the soil itself acts as the heat source.

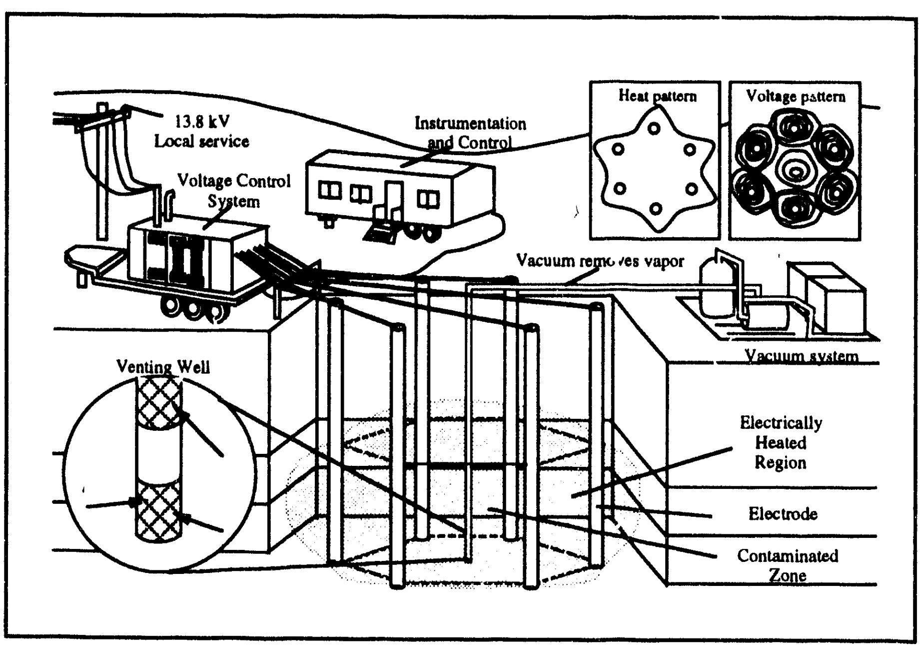
TECHNICAL PERFORMANCE DATA

Effectiveness and efficiency depend largely on uniformity of heating, the sites stratigraphy, and the soil's permeability. There is no inherent depth limit, but it is generally accepted that it can reach down to the water table.

Pilot Scale. Tests of SPSH have achieved temperatures of 100 °C with only 1 °C of variation when measured near electrodes, in bulk soil, and at the center of the heated volume. Tests also demonstrated uniform heating and drying of bulk soils to 1.2 wt% moisture content, producing maximum steam for stripping difficult organic compounds from soil and increasing permeability.

Other Laboratory Tests. Tests resulted in more than 99% removal of volatile organic compounds (VOCs) from sand, a silty loam, and a clay.

Cost. Capital is $200-$300K; Operations and Maintenance is dependent on soil and moisture content, approximately $30 to $60/cy soil. Life-cycle, the equipment can be disposed of as sanitary waste at the end of its useful life, which is estimated at 5 yrs. Based on capital equipment and energy costs SPSH is four to ten times less expensive than other soil heating technologies.



Six Phase Soil Heating

PROJECTED PERFORMANCE

In developing SPSH, Pacific Northwest Laboratory discovered that oxidizing conditions could be created in places that may decompose nonvolatile and bound organic contaminants. Strong electrical fields at particle surfaces produce a nonequilibrium (low temperature) plasma in the presence of air and moisture, without requiring extremely high applied voltages. The technique may be extended to nonvolatile compounds such as heavy oils, greases, industrial compounds such as acrylimide and vinyl, pesticides, chelators, organic acids, and polychlorinated biphenyls (PCBs). In addition, an in situ destruction system will be developed and build on the on-going in situ heating and off-gas destruction tasks and will focus on the effective production of high-energy corona in the subsurface to destroy organics, particularly carbon tetrachloride.

WASTE APPLICABILITY

Target contaminants are VOCs in soils. SPSH is being developed for maximum applicability to complex stratigraphies, impermeable soils such as clays and silts, and semivolatile contaminants.

STATUS

SPSH has been laboratory tested. The system will be demonstrated at the Savannah River Site from September through October 1993. A finite element code has been adapted to calculate spatial and temporal variations in soil temperature, pressure, moisture content, and electrical properties during combined SPSH and soil venting.

REGULATORY CONSIDERATIONS

The 1990 Clean Air Act Amendments must be considered for VOC emissions. Application of the technology is covered under Resource Compliance and Recovery Act (RCRA) Part A Interim Status and a National Environmental Protection Act (NEPA) categorical exclusion.

POTENTIAL COMMERCIAL APPLICATIONS

This technology has potentially wide spread commercial applications, such as in cleanup of gasoline spills, etc.

BASELINE TECHNOLOGY

The baseline technology is soil vapor extraction.

INTELLECTUAL PROPERTY RIGHTS

On November 14, 1991, a patent application was completed. Patent Number: 4,957,393

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Industrial Partnership

None at present.

REFERENCES

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STEAM REFORMING

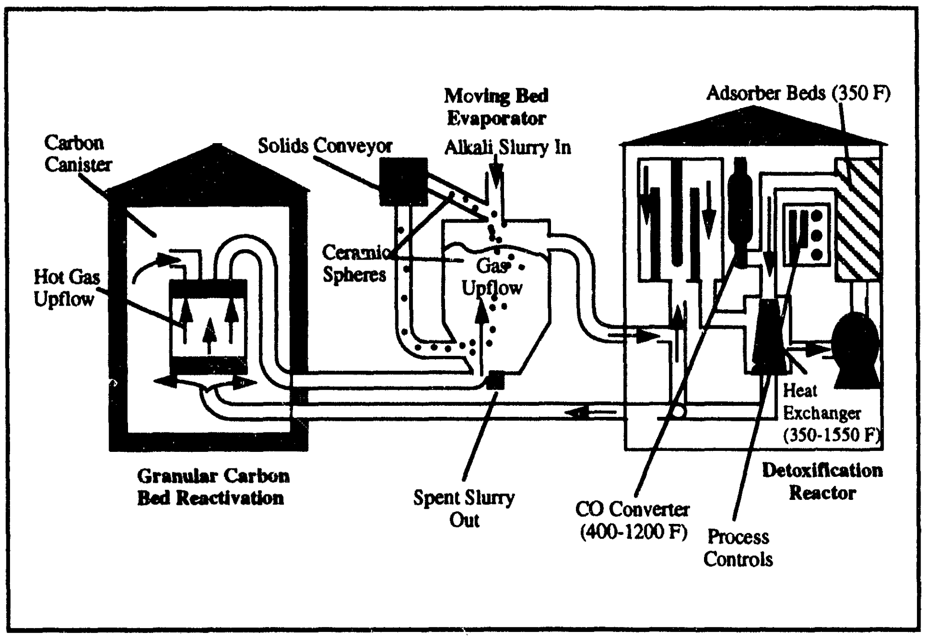
Sandia National Laboratories

DESCRIPTION

Steam reforming is a technology designed to destroy halogenated solvents (such as carbon tetrachloride, CCl_4, and chloroform, $CHCl_3$) adsorbed on activated carbon by reaction with superheated steam (steam reforming) in a commercial reactor (the Synthetica Detoxifier).

Drums of granular activated carbon (GAC), previously loaded with CCl_4 and $CHCl_3$, are desorbed by exposure to 300 °C steam using an experimental thin film sensor to follow the desorption. The CCl_4- and $CHCl_3$-laden steam is then passed through a moving bed evaporator, which consists of a bed of ceramic spheres coated with alkali base. At the 600 °C operating temperature of the evaporator, the chlorocarbons are efficiently decomposed, releasing hydrochloric acid (HCl), which is neutralized by the alkali base coated spheres. As the spheres settle to the bottom of the evaporator, spent base and chloride salts formed by the neutralization of HCl are mechanically scraped off of the spheres. At the bottom of the evaporator, spheres are removed and transported to the top of the evaporator by a bucket elevator, where they are coated with fresh base and reinjected into the evaporator.

The effluent steam stream from the evaporator is fed to a high-temperature (1200 °C) reaction chamber of the Synthetica Detoxifier, where any organic fragments released in the evaporator are destroyed. Any HCl released in the detoxifier is removed by adsorption and neutralization by Selexsorb, a commercial adsorbent. Finally, the effluent from the reactor is passed through a catalytic converter, where carbon monoxide (CO) and hydrogen (H_2) are converted to carbon dioxide (CO_2) and water.



Steam Reforming for Granular Activated Carbon Regeneration

TECHNICAL PERFORMANCE

This technology can be used with multiple feed streams and can destroy any organic that can be gasified by exposure to 600 °C steam.

Drum Feeder. Liquid and solid wastes in drums are gasified in the drum feeder at an operating temperature of 300 °C.

Moving Bed Evaporator. Liquid waste streams are flash vaporized at 600 °C operating temperature.

Detoxifier. The detoxifier can handle a wide variety of waste forms. Operation is completely automated and the unit (4 ft x 5 ft x 7 ft) is easily transportable. Effluents are expected to consist principally of CO_2 and water, traces of H_2, ethane (CH_4), CO, nitric oxide (NO), and nitrogen dioxide (NO_2). The high-temperature reaction chamber of the detoxifier operates at 1200 °C.

Destruction efficiencies are greater than 99.99% and GAC reactivation has been demonstrated for the Synthetica system. One ton/day of chlorocarbons can be processed.

Because steam reforming is not a combustion process, fuel and air are not used, and products of incomplete combustion are not generated.

Cost. The estimated cost breakdown is the detoxifier, $325K; the drum feeder, $50K; and the moving bed evaporator, $165K. The cost of other peripherals is estimated to be $150K. Daily operating and maintenance costs are estimated at $600. Life cycle costs are $340K (5 years) and $270K (10 years). Steam reforming is approximately 75% less expensive than offsite thermal regeneration of GAC.

PROJECTED PERFORMANCE

A Cooperative Research and Development Agreement between Synthetica Technologies and SNL will support studies of alternative heating methods (e.g., microwave heating) for the detoxifier, use of steam reforming catalysts in the detoxifier, and the conversion of the Synthetica gas effluent from the detoxifier into light hydrocarbons using Fischer-Tropsch catalysts.

WASTE APPLICABILITY

Steam reforming is applicable to the treatment of halogenated solvents adsorbed on GAC.

STATUS

The system is currently available. An improved moving bed evaporator will be available in 1994.

REGULATORY CONSIDERATIONS

The spent slurry and salts generated in the moving bed evaporator would be regulated as wastes if toxic or inorganic materials are constituents of these wastes. In such cases, further treatment of the spent slurry and salts may be required prior to disposal. Because of the emissions from the detoxifier, air permits for its operation are routinely obtained. Resource Conservation and Recovery Act (RCRA) and Nuclear Regulatory Commission (NRC) permits may also be required for treatment of radioactive or hazardous wastes.

POTENTIAL COMMERCIAL APPLICATIONS

This technology has wide application for destruction of a wide variety of wastes, such as paint residues, epoxy explosives, benzene, and low-level radioactive wastes.

BASELINE TECHNOLOGY

Offsite thermal regeneration of GAC.

INTELLECTUAL PROPERTY RIGHTS

Patent Ownership: Synthetical Technologies, Inc. Patent No.: 4,874,587

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Synthetica Technologies, Inc.

REFERENCES

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THERMAL ENHANCED VAPOR EXTRACTION SYSTEM

Sandia National Laboratories

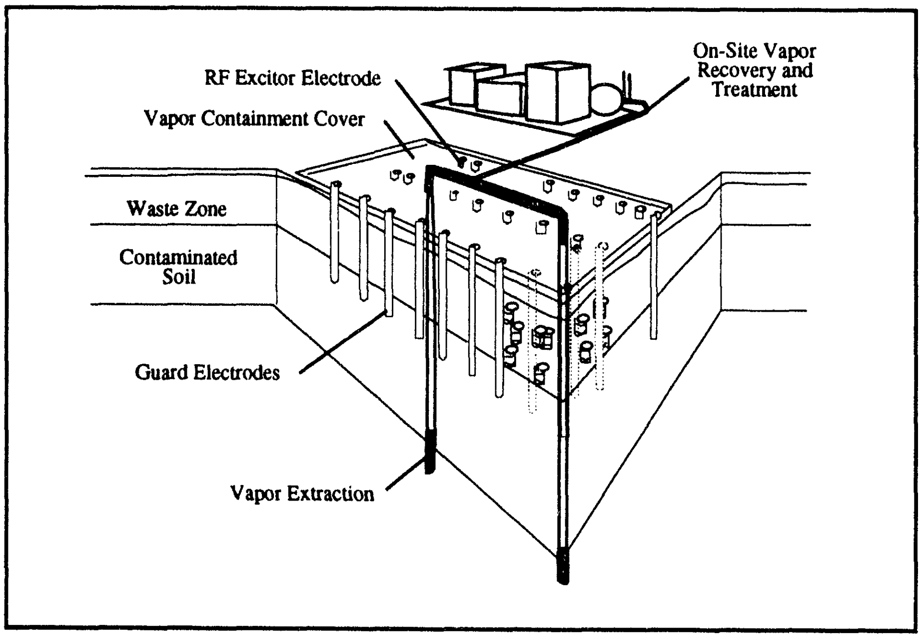
DESCRIPTION

The Thermal Enhanced Vapor Extraction System (TEVES) combines conventional vacuum vapor extraction with both powerline frequency (PLF) soil heating and radiofrequency (RF) soil heating to accelerate the removal of contaminants typically found in hazardous waste landfills.

TEVES will demonstrate and evaluate the effects of temperature on the waste-soil system. The principle effects of temperature on the waste-soil system are increased mass removal rates, especially for lower volatility constituents.

The two types of heating will be demonstrated in series. The first type of heating is powerline frequency heating that is characterized by resistive heat generation by 60Hz alternating current carried by the soil water between two electrodes. As the soil is heated, and as vacuum extraction removes contaminants and soil water, electrical conduction between the electrodes diminishes, and uniform heating declines. Soil heating by powerline frequency heating is limited to 100 °C. The second type of heating, known as radiofrequency heating, is then initiated to heat the soil past 100 °C. Radiofrequency (RF) heating uses radiowaves to provide dielectric soil heating. In contrast to electric resistance soil heating, RF heating does not require the current conduction path of soil water.

TEVES is part of the Mixed Waste Landfill Integrated Demonstration (MWLID). Testing will be performed in six phases at the Sandia National Laboratories (SNL) Chemical Waste Landfill (CWL) as follows: Phase I - Site Investigation; Phase II - Off-Gas Treatment System Design; Phase III - Vacuum Venting and In Situ Heating System Design; Phase IV - Vacuum Venting and Off-Gas Treatment Systems Operation; Phase V - Powerline Frequency Heating and Venting Operation; and Phase VI - Radio-Frequency Heating and Venting Operation.



Artists Rendition of the TEVES System

TECHNICAL PERFORMANCE

Temperature Effects on Vapor Pressure. The vapor pressure of most organic chemicals increases strongly with temperature. The relationship between vapor pressure and temperature is exponential.

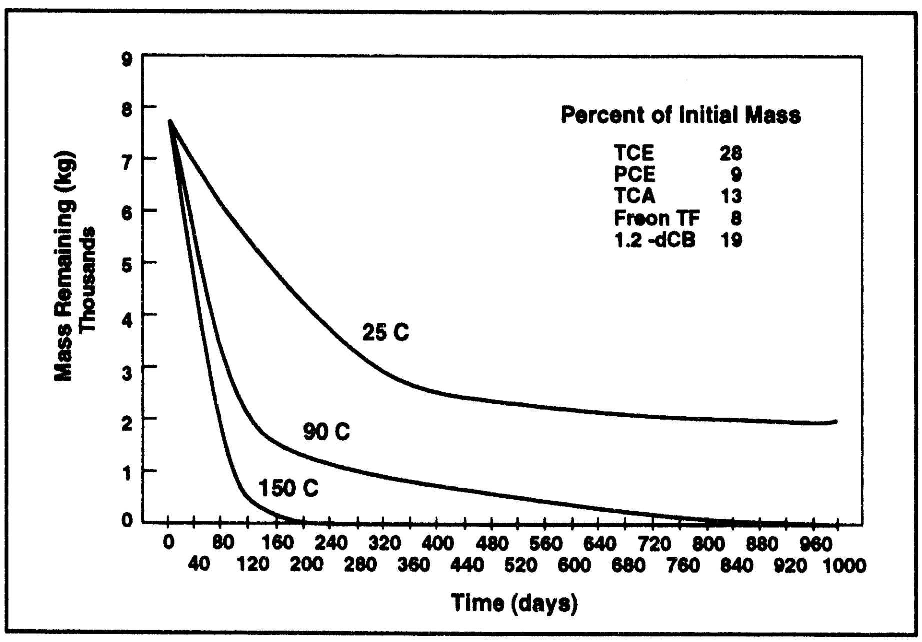
Effects of Heat on Vapor Extraction. The figure below shows the effects over time of soil heating on the soil contaminant mass remaining during vacuum extraction for a mixture of volatile and semivolatile organics present at the CWL. The slope is more precipitous for the higher soil temperatures, indicating higher removal rates.

Powerline Frequency Heating and Venting Operation. Utilizes 60 Hz PLF heating up to a maximum of 100 °C. Hardware includes a transformer, electrical control equipment, cables, vapor extraction wells, and off-gas treatment system. System operation anticipated to be 14 to 35 days. Parameters to be evaluated are mass removal rate and distribution of contaminant species.

TheRadiofrequency Heating and Venting Operation utilizes 2 to 20 MHz of radiofrequency energy and can heat up to a maximum of 250 °C. Additional hardware includes a radiofrequency generator, matching network, electrical control equipment, and cables. System operation is anticipated to be 10 to 30 days. Parameters to be evaluated are increase in mass removal rate and change in distribution of contaminant species (additional lower volatility species are expected to be removed).

Treatment Limitations. 1000 to 3000 yd^3/ treatment. Large quantities of buried metal objects influence the efficacy of resistive and dielectric heating.

Cost. Costs of electricity for the soil heating are a small part of the remediation effort. For example, the CWL demonstration requires 85,000 kWh energy at a nominal cost of $7,000 (at $0.10/kWh). Of the total energy required, 61% is required to heat the subsurface volume to 90 C (and evaporate soil water from 7% to 2% moisture) using PLF heating; whereas 39% of the total electrical energy is required for RF heating to raise the temperature from 90 to 150 °C. RF heating is less efficient because 6 Hz of electrical energy must be converted to RF energy. RF generator efficiencies range from 40 to 60%.



Effects of Soil Heat on Mass Removal by Vacuum Extraction

PROJECTED PERFORMANCE

Soil cleanup of 95+% is possible depending on the contaminant profile. Phase III of the TEVES demonstration will utilize the extent of contamination and air permeability measurements from Phase I to estimate the expected mass removal rates with increased temperatures (see Table below).

Component Mass Removal Rates for TEVES Demonstration			
Component	Removal Rate (lbs/hr)		
	25°C	90°C	150°C
Trichloroethylene (TCE)	0.28	0.97	0.97
1, 1, 1 -Trichloroethane (TCA)	0.12	0.33	0.33
Tetrachloroethylene	0.11	1.76	3.76
Freon 113	0.14	0.15	0.15

WASTE APPLICABILITY

Volatile organic compounds (VOCs), semi-VOCs, and VOC-oil mixtures. Organic chemicals having a vapor pressure less than 0.002 atm, at 20°C that are difficult to remove with ambient temperature vacuum extraction.

STATUS

Thermal enhancement is a near-term technology. There have been previous field tests at Volk ANG Base, Rocky Mountain Arsenal, and Kelly AFB. Phases I-III have been completed. Phases IV-VI are expected to be initiated in the fall of 1993, pending approval of the Resource Conservation and Recovery Act (RCRA) Research Development and Demonstration (RD&D) Permit. Final data analysis, applications analysis, and presentation of results is scheduled for FY94.

REGULATORY CONSIDERATIONS

The primary regulatory issues/requirements are for the RF spectrum to be approved by the Federal Communication Commission (FCC) and the Department of Energy (DOE)/NTIA and for the off-gas treatment system to meet the Clean Air Act requirements. The Comprehensive Environmental Response Compensation and Liability Act (CERCLA)/ RCRA waste treatment permits are also needed.

POTENTIAL COMMERCIAL APPLICATIONS

RF heating can be used near the surface, but PLF heating can be used at almost any depth and has been applied to oil field stimulation projects at great depths (several 1000 ft). TEVES can be used for remediation of industrial waste facilities with organic chemical contamination or other landfills with organic chemical contamination; industrial process sewage leaks, storage tank leaks, etc.

BASELINE TECHNOLOGY

TEVES is an improvement over the ambient-temperature vacuum vapor extraction technology. Ambient-temperature vacuum vapor extraction has been successful in pilot scale demonstrations for compounds with high vapor pressures (above 0.001 atm at 20 °C, such as trichloroethylene, jet fuel, and gasoline). Thermal augmentation of vacuum vapor extraction will promote volatilization of a wider spectrum of soil contaminants and increase contaminant mobility.

INTELLECTUAL PROPERTY RIGHTS

Patent Ownership: Bridges, J.B., Park Ridge, IL; Harsh Dev, Chicago, IL; Richard H. Snow, Bartelville, OK; Allen Taflove, Willamette, IL, Assignee: IIT Research Institute.

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VOC OFF-GAS MEMBRANE SEPARATION

Westinghouse Hanford Company

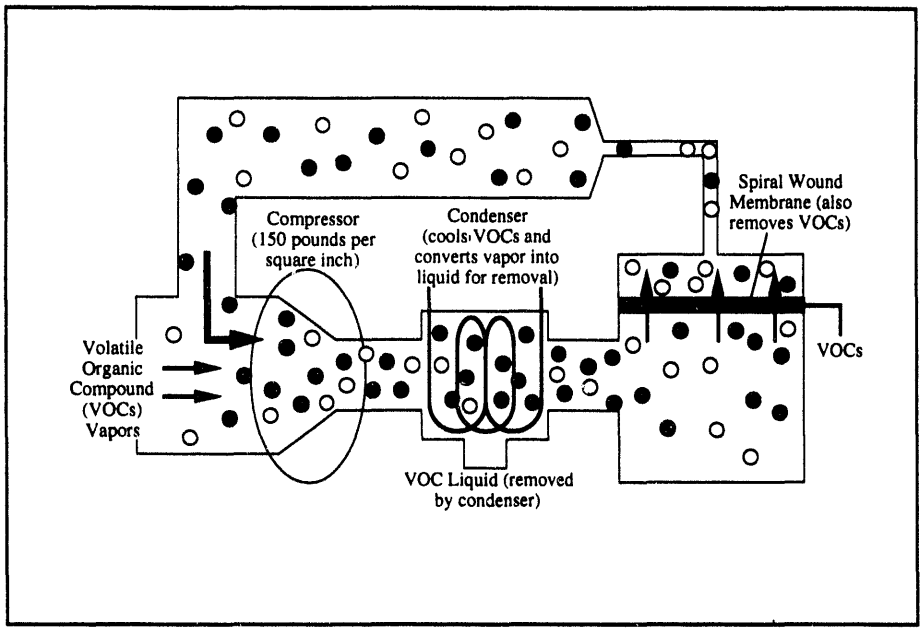
DESCRIPTION

Vacuum extraction will remove the volatile organics from the contaminated soil. A high pressure system has been designed to treat feed streams that contain dilute concentrations of volatile organic compounds (VOCs). The organic vapor/air separation technology involves the preferential transport of organic vapors through a non-porous gas separation membrane (diffusion process analogous to putting hot oil on a piece of wax paper). In this system, the feedstream is compressed and sent to a condenser where the liquid solvent is recovered. The condenser bleed stream, which contains approximately 5000 ppm of the VOC, is then sent to the membrane module. The membrane module is comprised of spiral bound modules of thin film membranes separated by plastic mesh spacers. The membrane and the spacers are wound spirally around a central collection pipe. In the membrane module the stream is further concentrated to 3% VOC. The concentrated stream is then returned to the compressor for further recovery in the condenser.

TECHNICAL PERFORMANCE

Cost. Capital Equipment (7000 scfm) is $2.5M; Operations and Maintenance is $6K (replacement every 3 yrs); Information on life-cycle will be available upon completion of testing; and Emissions Treatment is $2 to 5/lb of VOC recovered.

One of the limitations of this technology is its ability to handle foulants (e.g., lard oil) that are in soil. Radon will not effect the functionality of the membrane separation unit.



High-Pressure Gas Membrane Separation

PROJECTED PERFORMANCE

Based upon a VOC effluent concentration of 1000 ppm, there is a 95% removal efficiency. The remaining 5% is polished using granulated activated carbon (GAC).

Future work involves sizing the pilot plant to handle fluctuations in the

VOC flows from the well field, and fouling of the membrane with other constituents.

WASTE APPLICABILITY

The targeted contaminants are VOCs, carbon tetrachloride, and chloroform in gas streams.

STATUS

This technology is being tested at a Hanford site where VOCs will be obtained by vacuum extraction. Carbon tetrachloride and chloroform will preferentially be removed from the gas stream. This technology and system are available immediately. Testing will be complete before the end of FY1993.

REGULATORY CONSIDERATIONS

The 1990 Clean Air Act Amendments must be considered when treating VOCs.

POTENTIAL COMMERCIAL APPLICATIONS

This technology is applicable to the treatment of any waste stream emitting VOCs and presents a cost-effective alternative to treatment by GAC adsorption currently used by industry.

BASELINE TECHNOLOGY

The baseline technology for treatment of VOCs is GAC adsorption. GAC adsorption generates a secondary waste that requires disposal or regeneration on a regular basis. The membrane system would minimize the secondary waste stream while providing a recyclable product.

INTELLECTUAL PROPERTY RIGHTS

Membrane Technology and Research, Inc. owns several patents.

For more information, please contact:

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REFERENCES

1. DOE-RL, "Technology Information Profile (Rev. 3), Technical Name: VOC Offgas Membrane Separation," DOE ProTech Database, TTP Reference Number: RL-9740, March 25, 1993.

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Section 2.0

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Site Characterization and Monitoring Technology Profiles

Site Remediation Technology Profiles

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4/21/94

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