EPA United States Environmental Protection Agency

# The Superfund Innovative Technology Evaluation Program

# Technology Profiles Tenth Edition

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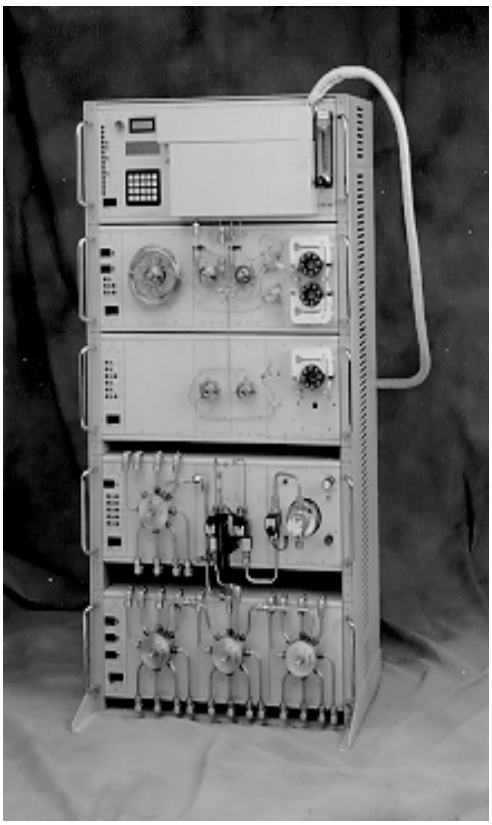
# ANALYTICAL AND REMEDIAL TECHNOLOGY, INC.
## (Automated Sampling and Analytical Platform)

## TECHNOLOGY DESCRIPTION:

Analytical and Remedial Technology, Inc. ($A^+RT$), produces components that can be assembled in various configurations to allow automated sampling and analysis of water streams. The $A^+RT$ components are mounted in a custom case to produce an automated sampling and analytical platform (ASAP). A complete ASAP system consists of the following basic components:

- An ASAP sampling manifold module with internal pump
- An optional module to allow the ASAP to control up to 48 Grundfos 2-inch submersible pumps
- One or more ASAP sample preparation modules
- One or more third-party gas or liquid chromatographs with appropriate detectors
- One or more third-party integrators for processing raw data and producing hard copies of chromatograms
- A Windows 3.X-compatible microcomputer running $A^+RT$ software to control the system, store results in a database, and provide telecommunication capabilities



Sampling and Analytical Platform

The photograph below illustrates an ASAP configured for automated sampling of 29 points using 0.25-inch stainless steel tubing. The $A^+RT$ purge-and-trap concentrator draws a precise volume of water (selectable from 0.2 to 10 milliliters) from the selected sample stream and prepares it for volatile organic compound (VOC) analysis using a gas chromatograph. The $A^+RT$ concentrator differs from the customary batch purging approach in that it uses a flow-through, countercurrent stripping cell.

The $A^+RT$ high performance liquid chromatograph (HPLC) sample preparation module collects a sample in a fixed volume loop and delivers it to the HPLC. With additional components, the module can support a second channel for HPLC analysis along with either automated or manual sample selection. The module can also be configured to process the samples using solid-phase extraction. This process concentrates analytes, which are then backflushed with solvent and extracted for subsequent HPLC analysis.

An optional Grundfos pump interface module (GPIM) allows the ASAP, for a given sample, to select and operate one of up to 48 Grundfos RediFlo-2™ 2-inch submersible pumps connected to the ASAP. Thus, this module allows automatic sampling of groundwater for groundwater depths greater than 15 to 20 feet



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below surface. Control of up to 48 pumps requires only one Grundfos MP1 controller interfaced with the GPIM.

The A+RT components and software are designed to allow continuous (24-hour) monitoring for long periods of time (months to years) with automated continuing calibration checks and recalibration when necessary. The ASAP is designed to be installed with the other system components permanently or semipermanently in a secure, temperature-controlled space on site.

## WASTE APPLICABILITY:

The ASAP is designed for automated sampling and analysis of aqueous samples, such as those obtained from a treatment or process stream or from wells emplaced in a groundwater contaminant plume. The ASAP can be configured for a wide variety of contaminants, including VOCs, polynuclear aromatic hydrocarbons, ionizable organic chemicals, and a range of inorganic substances.

## STATUS:

Several commercial ASAP systems have been purchased by universities for use in groundwater remediation research at U.S. Department of Defense facilities. The ASAP has considerably broader capabilities than the prototype system (the Automated Volatile Organics Analytical System, or AVOAS) evaluated under the SITE Program. The AVOAS was demonstrated in May 1991 at the Wells G and H Superfund site in EPA Region 1. The results of the demonstration have been published by EPA ("Automated On-Site Measurement of Volatile Organics in Water, EPA/600/R-93/109, June 1993").

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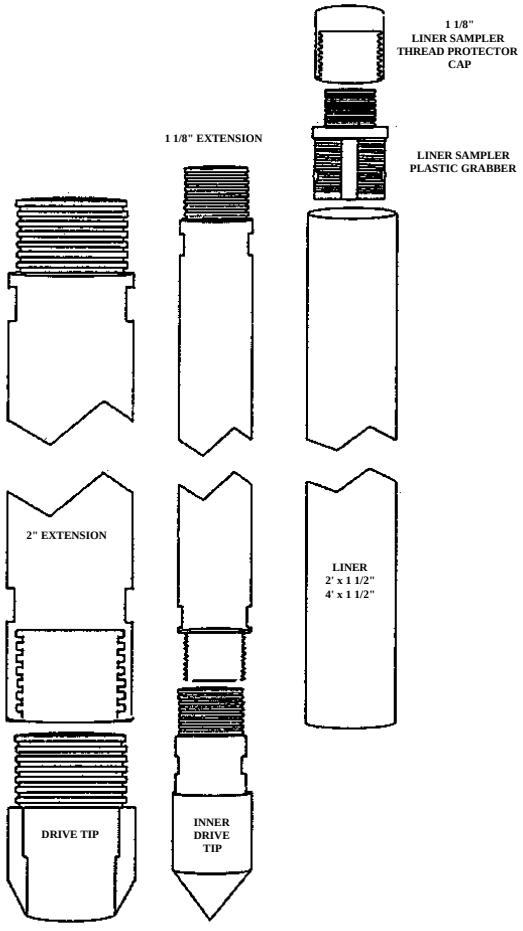
# ART'S MANUFACTURING AND SUPPLY
## (AMS™ Dual-Tube Liner Soil Sampler)

## TECHNOLOGY DESCRIPTION:

The Art's Manufacturing and Supply (AMS™) dual tube soil sampler, shown in the figure below, is designed to work with direct-push sampling rigs. The sampler consists of two steel tubes of differing diameters designed so that the two tubes fit within one another. The outer tube is equipped with a metal drive tip at the lower end and threaded at the upper end to allow additional metal extensions with increasing sampling depth and the addition of a drive head adaptor. The lower end of the inner tube is threaded with a plastic grabber to allow attachment of a polybutyrate liner during sampling or a solid-point metal inner drive tip during sampler advancement. The inner drive tip fits snugly within the outer drive tip, and both extensions and drive tips are held firmly in place by the drive head. Dual tube sampler extensions are available in 1-, 2-, 3-, and 4-foot lengths with wall thicknesses of 0.25 or 0.375 inch. The outer extension serves as a temporary casing so that continuous or discrete soil samples can be collected using the inner extension liner and drive tip assembly. The inner extension by itself can also be used for sampling.




Dual-Tube Liner Soil Sampler



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The direct-push drill rig used to mount the dual tube liner sampler must be a 0.75-ton or heavier pickup truck supplied by the buyer or a custom-made truck assembled by AMS.

The dual tube liner sampler decreases the likelihood of cross-contamination, preserves sample integrity, collects samples chemically representative of the target sampling interval, can collect either discrete or continuous soil samples of unconsolidated materials, and does not generate drill cuttings.

## WASTE APPLICABILITY:

The AMS™ dual tube liner sampler can be used to collect unconsolidated, subsurface soil samples at depths that depend on the capability of the direct-push advancement platform. The sampler has been used to collect samples of sandy and clayey soil contaminated with high concentrations of volatile organic compounds (VOC). It can also be used to collect samples for semivolatile organic compound, metals, general minerals, and pesticides analyses.

## STATUS:

The AMS™ dual tube soil sampler was demonstrated under the Superfund Innovative Technology Evaluation (SITE) program in May and June 1997 at two sites: the Small Business Administration (SBA) site in Albert City, Iowa, and the Chemical Sales Company (CSC) site in Denver, Colorado. Samples collected during the demonstrations were analyzed for VOCs to evaluate the performance of the samplers.

Demonstration results indicate that the dual tube liner sampler had higher sample recoveries in the clayey soil present at the SBA site than the standard methods. Conversely, the sampler had lower recoveries than the standard methods in the sandy soil present at the CSC site. VOC concentrations in samples collected with the dual tube liner sampler did not significantly differ statistically from concentrations in samples collected using the standard methods. Sample integrity using the dual tube liner sampler was preserved in highly contaminated soil. The sampler's reliability and throughput were generally as good as those of the standard methods. Costs for the dual tube liner sampler were lower than costs related to the standard sampling methods. According to the developer, all sampler decontamination was done using the on-board wash station on the AMS direct push platform (the AMS Powerprobe 9600). This significantly reduced the overall time to sample and decontaminate its equipment.

Demonstration results are documented in the "Environmental Technology Verification" report for the sampler dated August 1998 (EPA/600/R-98/093).

Organics were the primary groundwater contaminant at the site, and trichloroethene (TCE) was selected as the contaminant of concern for the demonstration. The Demonstration Bulletin (EPA/540/MR-95/511) and Demonstration Capsule (EPA/540/R-95/511a) are available from EPA.

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# BIONEBRASKA, INC.
## (BiMelyze® Mercury Immunoassay)

## TECHNOLOGY DESCRIPTION:

The BioNebraska, Inc., BiMelyze® Mercury Immunoassay technology measures mercury concentrations in solid matrix samples. The field-portable immunoassay technology provides semiquantitative results based on the activity of mercury-specific monoclonal antibodies. The technology consists of two kits: an extraction kit and an assay tube kit. The kits together can process 16 samples.

The solid matrix samples are first extracted using a 2:1:1 mixture of hydrochloric acid, nitric acid, and deionized water. A buffer solution provided in the extraction kit is then added to the sample pH to 6 to 8, and the samples are filtered.

The extracted and filtered samples are then transferred to mercury assay tubes supplied in the assay tube kit. These tubes are coated with sulfhydryl-rich proteins that trap the mercury ions. After the addition of kit-supplied antibodies, conjugate, and substrate, the presence of mercury can be semiquantitatively determined by comparing the color of the sample tubes to the color of tubes of the mercury standards supplied in the kit. The standards are determined, within limits, by the customer. The limit of detection is 0.5 parts per million (ppm) and the analytical range is 0.5 to 40 ppm. The absorbance of the sample tubes can be measured using a spectrophotometer.The BiMelyze® Mercury Immunoassay technology has been used to analyze soil and sediment samples containing mercury. The technology works best on fine-grained material because of the larger surface-to-volume ratio. The effect of moisture content on the technology's applicability is unknown. The technology can provide semiquantitative or sample screening information and has been found to have a good potential as a Level I analytical method.

## STATUS:

The BiMelyze® Mercury Immunoassay technology was accepted into the Superfund Innovative Technology Evaluation (SITE) program in 1994 and was demonstrated in August 1995 at two sites: the Carson River Mercury (CRM) site in Reno, Nevada, and the Sulfur

Bank Mercury Mine (SBMM) site in Clear Lake, California. Samples collected during the demonstrations were split for analysis in the field using the BiMelyze® Mercury Immunoassay technology and for later confirmatory analysis using standard inductively coupled plasma (ICP) mass spectrometry (MS). A total of 110 soil and sediment samples were collected from the CRM and SBMM sites (55 samples from each site) and split. The demonstration results indicate that the BiMelyze® Mercury Immunoassay technology agreed with ICP MS results for 66 percent of the samples analyzed. Demonstration results are documented in the "Innovative Technology Evaluation Report" from July 1998.



The SITE Program assesses but does not approve or endorse technologies.

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# BRUKER ANALYTICAL SYSTEMS, INC.
## (Mobile Environmental Monitor)

## TECHNOLOGY DESCRIPTION:

The Bruker Analytical Systems, Inc. (Bruker), mobile environmental monitor (see photograph below) is a field-transportable, gas chromatography/mass spectrometer (GC/MS) designed to identify and measure organic pollutants in various environmental media. The MS uses a quadruple mass analyzer similar to most conventional instruments. Like conventional MSs, this instrument can identify and quantify organic compounds on the basis of their retention time, molecular weight, and characteristic fragment pattern. The integrated GC allows introduction of complex extracts for separation into individual components and subsequent analysis in the MS.

The Bruker instrument's design and electronics are specially designed for field use. The instrument is designed to operate with battery power and can be used in various environmental situations with minimum support requirements.

The mobile environmental monitor was originally designed for the military to detect and monitor chemical warfare agents. Environmental samples may be introduced to the MS through the direct air sampler or the GC. Results are collected and stored in a computer, where data is reduced and analyzed. The computer provides reports within minutes of final data acquisition.

## WASTE APPLICABILITY:

The Bruker mobile environmental monitor is designed to detect the full range of volatile and semivolatile organic compounds directly in air and in water, soil, sediment, sludge, and hazardous waste extracts. It provides in-field, real-time support during the characterization and

Bruker Mobile Environmental Laboratory



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remediation phases of cleanup at a hazardous waste site.

## STATUS:

This technology was demonstrated at the Re-Solve, Inc., and Westborough Superfund sites in EPA Region 1. The technology was used to analyze polychlorinated biphenyls and polynuclear aromatics in soil and the full range of Superfund-targeted volatile organic compounds in water. Splits of all samples analyzed in the field were shipped to a laboratory for confirmatory analysis using standard EPA analytical methods.

The SITE demonstration was completed in September 1990, and the final report (EPA/600/X-91/079) is available from EPA. The results of this study were presented at the American Society for Mass Spectrometry Conference in May 1991 and at the Superfund Hazardous Waste Conference in July 1991. A recent survey of regional laboratories identified additional testing of this technology as a priority need.

Bruker has developed an additional system that addresses recommendations made in the project report. This system, designated the EM640, has increased mass range, decreased power consumption, faster sample analysis, and automated report generation. The EM640 was evaluated in July and September 1995 through the U.S. EPA Environmental Technology Verification Program (ETV). The evaluation showed that the EM640 provides "useful, cost-effective data for environmental problem-solving and decision-making." The Environmental Monitoring Systems Laboratory-Las Vegas purchased a Bruker mobile environmental monitor in fiscal year 1992 to pursue other applications and to expand the scope of this project.

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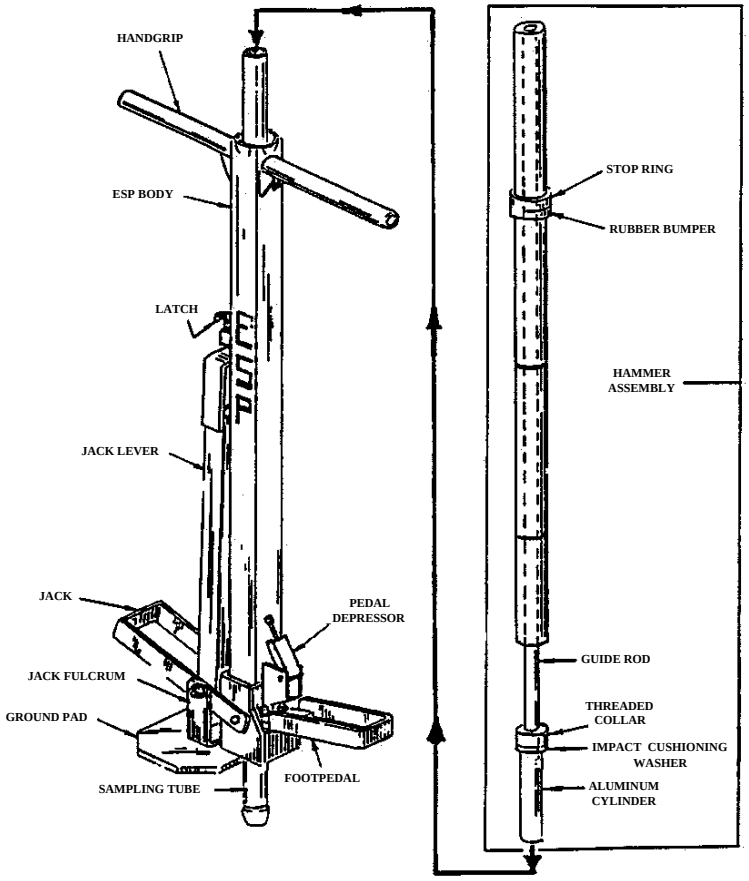
# CLEMENTS, INC.
## (JMC Environmentalist's Subsoil Probe)

## TECHNOLOGY DESCRIPTION:

JMC Environmentalist's Subsoil Probe (ESP) developed by Clements Associates, Inc., consists of a sampling tube assembly, the ESP body, and a jack used to assist in sample retrieval (see figure below). The sampler can be advanced using manual or direct-push methods. The primary component of the ESP body is a heat-treated, 4130 alloy steel, nickel-plated sampling tube. The tube has a uniform 1.125-inch outer diameter and is 36 inches long. The ESP tube comes with three interchangeable stainless-steel tips (a solid drive point, a standard cutting tip, and a wet cutting tip) and inner sample liners that can also be used for sample storage.

The ESP body serves as a base and guide for the sampling tube as it is driven into or retrieved from a borehole. The jack used to retrieve the sample also allows operators to smoothly lower the sampler and tool string into the borehole at a controlled rate, thereby minimizing borehole disturbance.

According to the developer, the ESP sampler is simple to operate and requires no special training to use, is unaffected by variable field conditions, can collect either discrete or continuous soil samples of unconsolidated materials, can be used to characterize subsurface soil contamination, is easily transportable, and does not generate drill cuttings.




Clements' ESP



The SITE Program assesses but does not approve or endorse technologies.

## WASTE APPLICABILITY:

The ESP sampler can be used to collect unconsolidated, subsurface soil samples at depths of 4 feet below ground surface (bgs); however, through the use of extensions, samples from depths of up to 25 feet bgs can be collected. Physical limitations of ESP sampler operation depend on the method of sampler advancement and the nature of the subsurface matrix. The technology is primarily restricted to unconsolidated soil free of large cobbles or boulders. The sampler can also be used in sediment containing gravel-sized material supported by a finer-grained matrix. Originally, the sampler was designed for sampling agricultural residues containing radioactive trace elements. The sampler has been used to collect samples of sandy and clayey soil contaminated with high concentrations of volatile organic compounds (VOC). The sampler can also collect samples for polychlorinated biphenyl, polynuclear aromatic hydrocarbon, pesticides, and metals analyses. The ESP sampler was accepted into the Superfund Innovative Technology Evaluation (SITE) program in May 1997 and was demonstrated in May and June 1997 at two sites: the Small Business Administration (SBA) site in Albert City, Iowa, and the Chemical Sales Company (CSC) site in Denver, Colorado. Samples collected during the demonstrations were analyzed for VOCs to evaluate the performance of the samplers.

Demonstration results indicate that the ESP sampler had higher sample recoveries in both the clayey soil present at the SBA site and in the sandy soil present at the CSC site than the standard methods. VOC concentrations in samples collected with the ESP sampler from the SBA site significantly differed statistically from concentrations in samples collected using the standard methods; however, this difference was not observed for samples collected from the CSC site. Sample integrity using the ESP sampler was preserved in highly contaminated soil. The sampler's reliability and throughput were generally better than those of the standard methods. Costs for the ESP sampler were much lower than costs related to the standard sampling methods.

Demonstration results are documented in the "Environmental Technology Verification" report for the sampler dated August 1998 (EPA/600/R-98/091).

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# ACTIVE ENVIRONMENTAL, INC.
## (formerly EET, Inc. TECHXTRACT® Process)

## TECHNOLOGY DESCRIPTION:

The TECHXTRACT® process employs patented chemical formulations in successive steps to remove polychlorinated biphenyls (PCB), toxic hydrocarbons, heavy metals, and radionuclides from the subsurface of porous materials such as concrete, brick, steel, and asphalt (see figure below). Each formulation consists of chemicals from up to 14 separate chemical groups, and each formulation can be specifically tailored to each contaminated site.

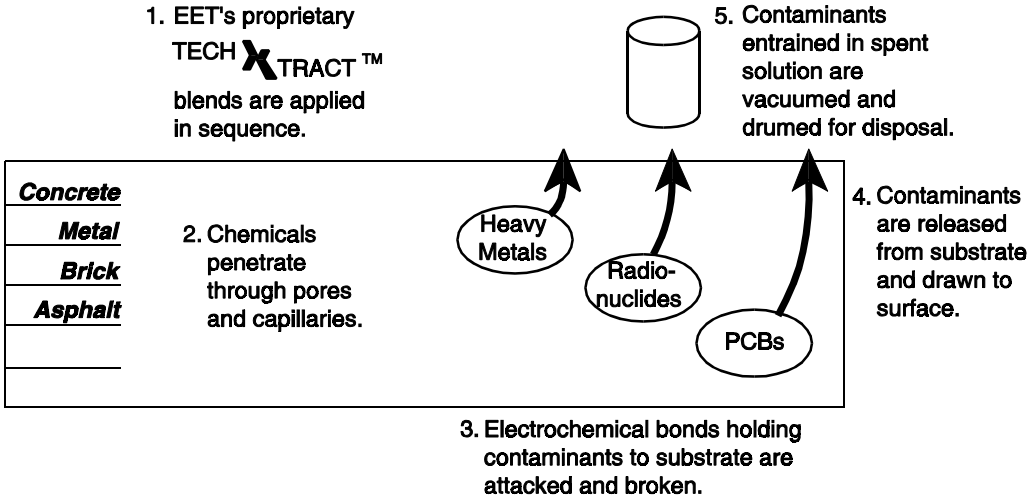
The process is performed in multiple cycles. Each cycle consists of three stages: surface preparation, extraction, and rinsing. Each stage employs a specific chemical mix.

The surface preparation step uses a solution that contains buffered organic and inorganic acids, sequestering agents, wetting agents, and special hydrotrope chemicals. The extraction formula includes macro- and microemulsifiers in addition to electrolyte, flotation, wetting, and sequestering agents. The rinsing formula is pH-balanced and contains wetting and complexing agents. Emulsifiers in all the formulations help eliminate fugitive releases of volatile organic compounds or other vapors. The chemical formulation in each stage is sprayed on the contaminated surface as a fine mist and worked into the surface with a stiff bristle brush or floor scrubber. The chemicals are allowed to penetrate into the subsurface and are then rinsed and vacuumed from the surface with a high-efficiency, particulate air-filtered, barrel-vacuum. No major capital equipment is required.

Contaminant levels can be reduced from 60 to 90 percent per cycle. One cycle can take up to 24 hours. The total number of cycles is determined from initial contaminant concentrations and final concentration target levels.

## WASTE APPLICABILITY:

The TECHXTRACT® process is designed to treat porous solid materials contaminated with PCBs; toxic hydrocarbons such as pesticides; heavy metals, including lead and arsenic; and radionuclides. Because the contaminants are extracted from the surface, the materials can be




Process Flow Diagram of the TECHXTRACT® Process



The SITE Program assesses but does not approve or endorse technologies.

left in place, reused, or recycled. After treatment, the contaminants are concentrated in a small volume of liquid waste.

In commercial applications, the process has reduced PCB concentrations from 1,000,000 micrograms per 100 square centimeters ($\mu$g/100 $cm^2$) to concentrations less than 0.2 $\mu$g/100 $cm^2$. Core samples have shown removals from up to 4 inches deep in concrete. The TECHXTRACT® process has been used on concrete floors, walls and ceilings, tools and machine parts, internal piping, valves, and lead shielding. The TECHXTRACT® process has removed lead, arsenic, technetium, uranium, cesium, tritium, and thorium.

## STATUS:

This technology was accepted into the SITE Demonstration Program in summer 1994. The demonstration was successfully completed at the Pearl Harbor Naval Complex in April 1997. A video tape of that demonstration is available from the Technology Developer.

The technology has been used in over 400 successful decontamination projects for the U.S. Department of Energy; U.S. Department of Defense; the electric, heavy manufacturing, steel, and aluminum industries; and other applications. Active Environmental, Inc. has developed methods for removing or concentrating metals, particularly radionuclides, in the extracted liquids.

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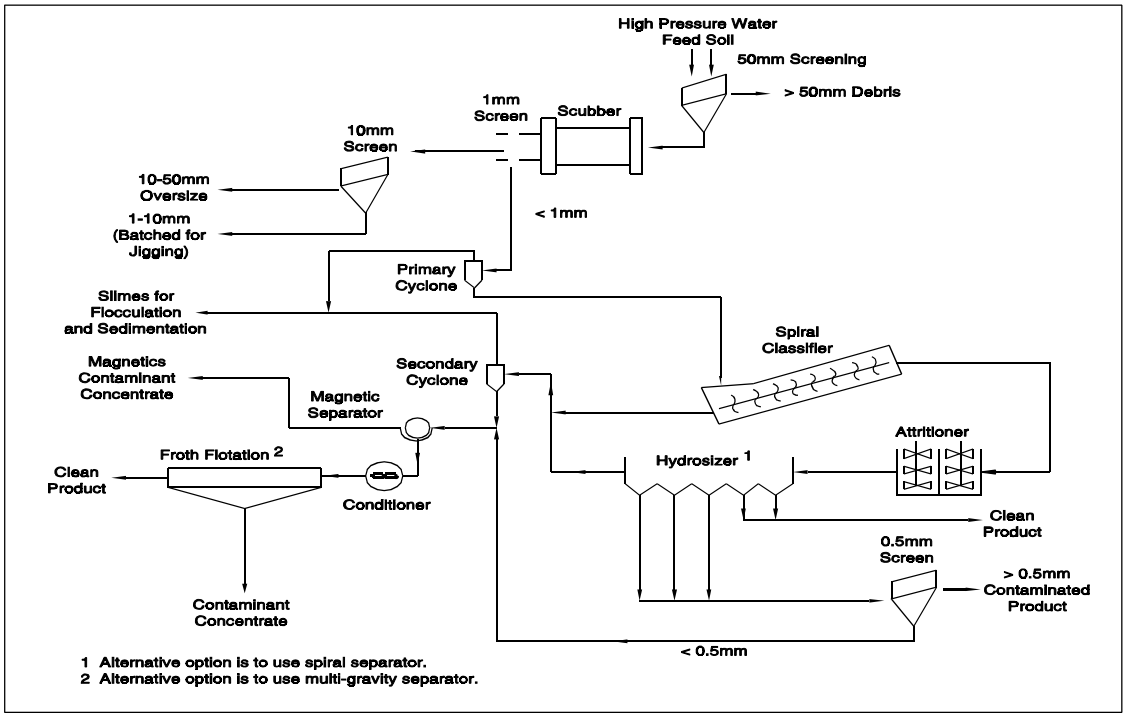
# AEA TECHNOLOGY ENVIRONMENT
# (Incorporating UK National Environmental Technology Centre)
### (Soil Separation and Washing Process)

## TECHNOLOGY DESCRIPTION:

AEA Technology Environment (AEA) has developed an ex situ soil separation and washing process that uses mineral processing technology and hardware. The process can be used (1) as a volume reduction process to release clean soil fractions and concentrate contaminants, or (2) as a pretreatment stage in a treatment train.

Because each contaminated soil is different, AEA has developed a custom physical treatment process for soil using a three-stage process: laboratory-scale characterization, separation testing and assessment, and treatment and data analysis.

AEA is experienced in conducting pilot plant testing programs on contaminated soil and mineral ores. In addition, AEA uses computer software designed to reconcile material flow data. The results of data processing lead to recommendations for full-scale continuous flow sheets with predicted flows of solids, associated contaminant species, and water. Contaminant levels and distributions to the various products can also be estimated. Such data are required to estimate the cost and potential success of the full-scale remediation process plant. Flow sheet configuration is flexible and can be customized to address the nature and contamination of each soil or waste. A typical schematic flow sheet of the process is shown in the diagram on the previous page. The flow sheet involves screening the raw feed at 50 millimeters (mm) under powerful water jets to deagglomerate the mass. Debris greater than 50 mm in size is often decontaminated. Remaining solids and the water are passed through a drum scrubber that deagglomerates the mass further because agitation




Generalized Flowsheet for the Physical Treatment of Contaminated Soil



The SITE Program assesses but does not approve or endorse technologies.

is more intense. It breaks down clay lumps and adhering material into suspension, except for surface coatings of clay and oil on fine particles. The drum scrubber discharge is screened at 1 mm, and the oversize discharge is screened at 10 mm. The 10 to 50 mm size range is often clean debris; if it is not clean then it can be crushed and refed to the system. Material from 1 to 10 mm is often contaminated and requires further treatment.

For all material less than 1 mm, the clay and water are removed by hydrocycloning. The fine product, less than 10 micrometers (m), is flocculated and thickened to recover the process water for recycling. Thickened clay product, usually containing concentrated contaminants, passes to further treatment or disposal. Sands from the hydrocycloning step are further dewatered in a classifier before the third and most intense deagglomeration operation.

An attrition scrubber removes the remaining surface contamination and degrades fine clayballs. Having completed deagglomeration, the soil is fractionated by particle size or separated by specific gravity. A second stream of particles less than 10 mm is removed by hydrocycloning and joins the primary product stream. Finer sands and silt are screened at 500 mm to yield a contaminated sand for disposal or retreatment. A 10 to 500 mm fraction can be separated magnetically, by flotation, by multigravity separation, or by a combination of these methods. These stages produce a contaminant concentrate, leaving the remaining material relatively contaminant free.

## WASTE APPLICABILITY:

The soil separation and washing process is designed to remove metals, petroleum hydrocarbons, and polynuclear aromatic hydrocarbons from soil. The process may be applied to soils from gas and coke works, petrochemical plants, coal mines, iron and steel works, foundries, and nonferrous smelting, refining, and finishing sites. The process can also treat sediments, dredgings, sludges, mine tailings, and some industrial wastes.

## STATUS:

The technology was accepted into the SITE Emerging Technology Program in July 1991 and completed in 1994. A Final Report was delivered to the U.S. EPA in 1994, and work done with this technology was presented the same year at the 87th Annual Meeting and Exhibition of the Air and Waste Management Association, the 20th Annual RREL Hazardous Waste Research Symposium, and the 5th Forum on Innovative Hazardous Waste Treatment Technologies: Domestic and International. Pilot trials were conducted on 30 tons of soil at a throughput rate of 0.5 ton per hour. Several test runs were performed to evaluate different flow sheet configurations. Reports on this technology can be obtained from the U.S. EPA.

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# AMERICAN COMBUSTION, INC.
## (PYRETRON® Thermal Destruction)

## TECHNOLOGY DESCRIPTION:

The PYRETRON® thermal destruction technology controls the heat input during incineration by controlling excess oxygen available to oxidize hazardous waste (see figure below). The PYRETRON® combustor relies on a new technique for mixing auxiliary oxygen, air, and fuel to (1) provide the flame envelope with enhanced stability, luminosity, and flame core temperature, and (2) increase the rate of heat released.

The technology is computer-controlled to automatically adjust the temperatures of the primary and secondary combustion chambers and the amount of excess oxygen. The system adjusts the amount of excess oxygen in response to sudden changes in contaminant volatilization rates in the waste.

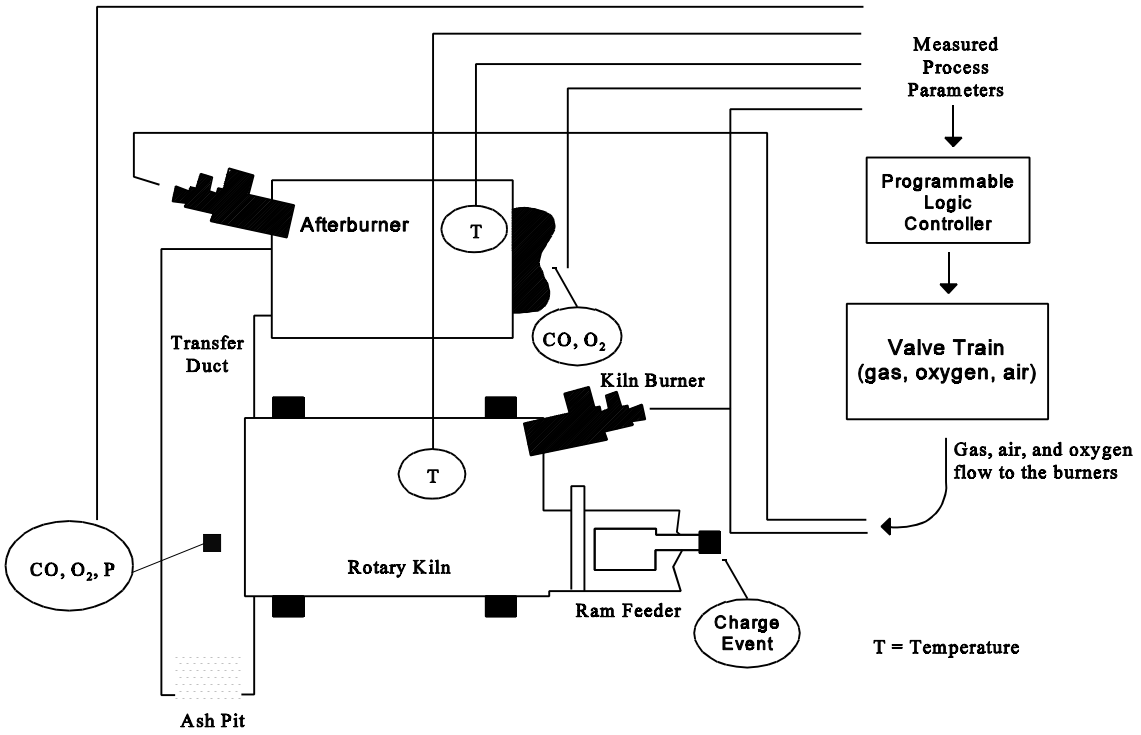
The technology fits any conventional incineration unit and can burn liquids, solids, and sludges. Solids and sludges can also be coincinerated when the burner is used with a rotary kiln or similar equipment.

## WASTE APPLICABILITY:

The PYRETRON® technology treats high- and low-British thermal unit solid wastes contaminated with rapidly volatilized hazardous organics. In general, the technology treats any waste that can be incinerated. It is not suitable for processing Resource Conservation and Recovery Act heavy metal wastes or inorganic wastes.

## STATUS:

The PYRETRON® technology was demonstrated at EPA's Incineration Research Facility in Jefferson, Arkansas, using a mixture of 40 percent contaminated soil from the Stringfellow Acid Pit Superfund site in Glen Avon, California and 60 percent decanter tank tar sludge (K087)




PYRETRON® Thermal Destruction System



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from coking operations. The demonstration began in November 1987 and was completed at the end of January 1988.

Both the Innovative Technology Evaluation Report (EPA/540/5-89/008) and Applications Analysis Report (EPA/540/A5-89/008) are available from EPA.

## DEMONSTRATION RESULTS:

The polynuclear aromatic hydrocarbons naphthalene, acenaphthylene, fluorene, phenanthrene, anthracene, and fluoranthene were selected as the principal organic hazardous constituents (POHC) for the demonstration. The PYRETRON® technology achieved greater than 99.99 percent destruction and removal efficiencies for all six POHCs in all test runs. Other results are listed below:

- The PYRETRON® technology with oxygen enhancement doubled the waste throughput possible with conventional incineration.
- All particulate emission levels from the scrubber system discharge were significantly below the hazardous waste incinerator performance standard of 180 milligrams per dry standard cubic meter at 7 percent oxygen. This standard was in place until May 1993.
- Solid residues were contaminant-free.
- There were no significant differences in transient emissions of carbon monoxide between air-only incineration and PYRETRON® oxygen-enhanced operation with doubled throughput rate.
- Cost savings increase when operating and fuel costs are high and oxygen costs are relatively low.
- The system can double the capacity of a conventional rotary kiln incinerator. This increase is more significant for wastes with low heating values.

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# ARIZONA STATE UNIVERSITY/ ZENTOX CORPORATION

## (Photocatalytic Oxidation with Air Stripping)

## TECHNOLOGY DESCRIPTION:

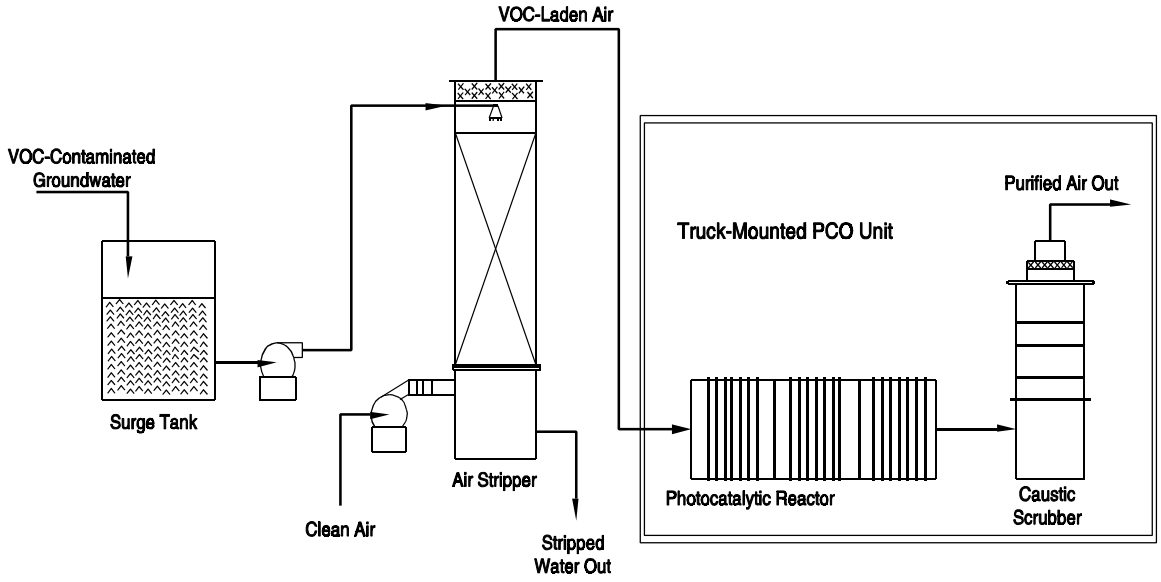
Chlorinated volatile organic compounds (VOC), such as trichloroethene (TCE) and tetrachloroethene (PCE), are readily removed from groundwater and soil using established methods such as air stripping and vapor extraction. However, this solution produces a VOC-contaminated air stream that requires further treatment.

In gas-solid photocatalytic oxidation (PCO), the VOC-laden air stream is exposed to a titania catalyst in near-ultraviolet (UV) light. The UV light activates the catalyst, producing oxidizing radicals. The radicals promote rapid chain reactions that completely destroy VOCs to carbon dioxide and water; these oxidation reactions occur at or near room temperature. The treatment of chlorinated organics also produces hydrochloric acid.

Arizona State University (ASU) is investigating an integrated pilot-scale pump-and-treat system that transfers chlorinated VOCs to an air stream using air stripping. A PCO reactor installed downstream of the air stripping unit treats the contaminated air stream. The figure below illustrates the system. The PCO unit incorporates a flow-through photocatalytic reactor for VOC destruction and a caustic absorber bed for removal of hydrochloric acid. The acid is neutralized to sodium chloride in the absorber bed.

PCO offers the following advantages over conventional treatment technologies:

- The photocatalytic process allows VOCs to be oxidized at or near room temperature.
- Low-temperature operation allows the use of plastic piping and construction, thereby reducing costs and minimizing acid corrosion problems.
- Chemical additives are not required.




Photocatalytic Oxidation with Air Stripping



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- The titania catalyst and UV lamps are inexpensive and commercially available (modified catalyst formulations are available for enhanced performance).
- A variety of halogenated and nonhalogenated organic compounds can be completely oxidized to innocuous or easily neutralized products, such as carbon dioxide and hydrochloric acid.

## WASTE APPLICABILITY:

This technology can treat VOC-contaminated streams generated by air stripping treatment of contaminated groundwater or soil vapor extraction of contaminated soil. The technology is appropriate for dilute VOC concentrations (such as 500 parts per million by volume or less) and low to moderate flow rates. Laboratory data indicate that the PCO technology can also be adapted for industrial facilities that emit dilute VOC-contaminated air streams. Candidates include chemical process plants, dry cleaners, painting operations, solvent cleaning operations, and wastewater and hazardous waste treatment facilities. Air in closed environments could also be purified by integrating PCO units with heating, ventilation, and air conditioning systems.

## STATUS:

The PCO technology was accepted into the SITE Emerging Technology Program in 1993. Under the program, ASU has conducted bench-scale tests to evaluate the integration of a PCO unit downstream of an existing air stripping unit. Results of the bench-scale testing have provided design data for a pilot-scale test at a Phoenix, Arizona, Superfund site contaminated with chlorinated VOCs. ASU's previous laboratory studies indicate rapid destruction to nondetectable levels (98 to 99 percent removal) for various concentrations of TCE and other chlorinated ethenes in humid air streams.

In 1995, Zentox Corporation (Zentox) fielded a prototype PCO system for the treatment of TCE in air. Building on the data gained from that system, Zentox is fabricating a second generation system for use at the Phoenix site. Following tests at the Phoenix site, the 50- to 100-cubic-feet-per-minute pilot plant unit will be available for trials at other locations.

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# ARS Technologies, Inc.
## (formerly Accutech Remedial Systems, Inc.)
## (Pneumatic Fracturing Extraction℠ and Catalytic Oxidation)

## TECHNOLOGY DESCRIPTION:

Accutech Remedial Systems, Inc. (Accutech), and the Hazardous Substance Management Research Center at the New Jersey Institute of Technology in Newark, New Jersey have jointly developed an integrated treatment system that combines Pneumatic Fracturing Extraction℠ (PFE℠) with catalytic oxidation. According to Accutech, the system provides a cost-effective, accelerated approach for remediating less permeable formations contaminated with halogenated and nonhalogenated volatile organic compounds (VOC) and semivolatile organic compounds (SVOC).

The Accutech system forces compressed gas into a geologic formation at pressures that exceed the natural in situ stresses, creating a fracture network. These fractures allow subsurface air to circulate faster and more efficiently throughout the formation, which can greatly improve contaminant mass removal rates. PFE℠ also increases the effective area that can be influenced by each extraction well, while intersecting new pockets of contamination that were previously trapped in the formation. Thus, VOCs and SVOCs can be removed faster and from a larger section of the formation.

PFE℠ can be combined with a catalytic oxidation unit equipped with special catalysts to destroy halogenated organics (see photograph below). The heat from the catalytic oxidation unit can be recycled to the formation, significantly raising the vapor pressure of the

The SITE Program assesses but does not approve or endorse technologies.

contaminants. Thus, VOCs and SVOCs volatilize faster, making cleanup more efficient. PFE℠ can also be combined with hot gas injection (HGI), an in situ thermal process, to further enhance VOC and SVOC removal rates. HGI returns to the ground the energy generated during catalytic oxidation of the VOCs.

## WASTE APPLICABILITY:

The Accutech system can remove halogenated and nonhalogenated VOCs and SVOCs from both the vadose and saturated zones. The integrated treatment system is cost-effective for treating soil and rock when less permeable geologic formations limit the effectiveness of conventional in situ technologies.

According to Accutech, the PFE℠-HGI integrated treatment system is cost-effective for treating less permeable soil and rock formations where conventional in situ technologies have limited effectiveness. Activated carbon is used when contaminant concentrations decrease to levels where catalytic oxidation is no longer cost-effective.

## STATUS:

The Accutech technology was accepted into the SITE Demonstration Program in December 1990. The demonstration was conducted in summer 1992 at a New Jersey Department of Environmental Protection and Energy Environmental Cleanup Responsibility Act site in Hillsborough, New Jersey. During the demonstration, trichloroethene and other VOCs were removed from a siltstone formation. Results of this demonstration were published in the following documents available from EPA:

- Technology Evaluation Report (EPA/540/R-93/509)
- Technology Demonstration Summary (EPA/540/SR-93/509)
- Demonstration Bulletin (EPA/540/MR-93/509)
- Applications Analysis Report (EPA/540/AR-93/509)

## DEMONSTRATION RESULTS:

The demonstration results indicate that PFE℠ increased the effective vacuum radius of influence nearly threefold. PFE℠ also increased the rate of mass removal up to 25 times over the rates measured using conventional extraction technology.

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# ART INTERNATIONAL, INC.
## (formerly ENVIRO-SCIENCES, INC.)
## (Low-Energy Extraction Process)

## TECHNOLOGY DESCRIPTION:

The patented Low-Energy Extraction Process (LEEP®) uses common organic solvents to concentrate and extract organic pollutants from soil, sediments, and sludges. LEEP® can treat contaminated solids to the stringent cleanup levels mandated by regulatory agencies. LEEP® includes pretreatment, washing, and concentration processes (see figure below).

During pretreatment, particles measuring up to 8 inches in diameter are removed in a gravity settler-floater. The settler-floater includes a metal detector and remover, a crusher, and a metering feeder. Floating material often found at remediation sites, such as wood chips, grass, or root material, is also removed.

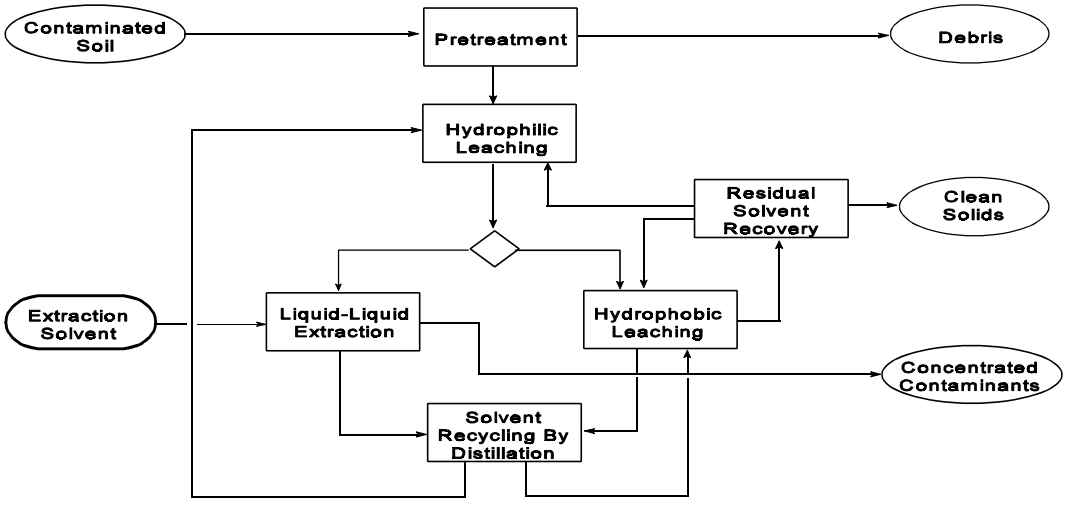
After pretreatment, the solid matrix is washed in a unique, dual solvent process that uses both hydrophilic and hydrophobic solvents. The combination of these proprietary solvents guarantees efficient contaminant removal.

The extracted pollutants are then concentrated in a sacrificial solvent by liquid-liquid extraction or by distillation, before being removed from the process for off-site disposal or recycling. The treated solids can be returned to the site as clean fill.

LEEP® is a low-pressure process operated at near-ambient conditions. It is designed as a closed-loop, self-contained, mobile unit consisting of proven heavy-duty equipment. The relatively inexpensive solvents used in the process are recycled internally. The solvents are applicable to almost every type of organic contaminant, and their physical properties enhance clay and silt particle settling.

## WASTE APPLICABILITY:

LEEP® can treat most organic contaminants in soil, sediment, and sludge, including tar, creosote, chlorinated hydrocarbons, polynuclear aromatic hydrocarbons, pesticides, and wood- preserving chlorophenol formulations. Bench- and pilot-scale experiments have shown that




LEEP® Process Flow Diagram



The SITE Program assesses but does not approve or endorse technologies.

LEEP® effectively treats tar-contaminated solids from manufactured gas plant sites, soils and sediments contaminated with polychlorinated biphenyls and refinery waste sludges, and soils contaminated with petroleum hydrocarbons.

## STATUS:

LEEP® was accepted into the Emerging Technology Program in July 1989. Bench-scale studies for process development were completed in 1994. A draft report that details the evaluation results has been submitted to EPA. The final report will be available in 1997.

In addition, ART International, Inc., routinely conducts bench-scale treatability studies for government and industrial clients, and it has obtained Toxic Substances Control Act, Resource Conservation and Recovery Act, and air permits for the technology. Other developments include the following:

- A 200-pound-per-hour pilot-scale unit has been constructed.
- Tests of the pilot-scale unit indicated that LEEP® can treat soil from manufactured gas plant sites containing up to 5 percent tar.
- Tests to scale up the pilot-scale unit to a commercial unit are complete.
- Commercial design criteria and a turnkey bid package are complete.
- Commercialization activities for a full-scale unit are underway.
- In 1994, Soil Extraction Technologies, Inc., a wholly owned subsidiary of Public Service Electric & Gas, purchased a LEEP® license.

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# ATOMIC ENERGY OF CANADA, LIMITED
## (Chemical Treatment and Ultrafiltration)

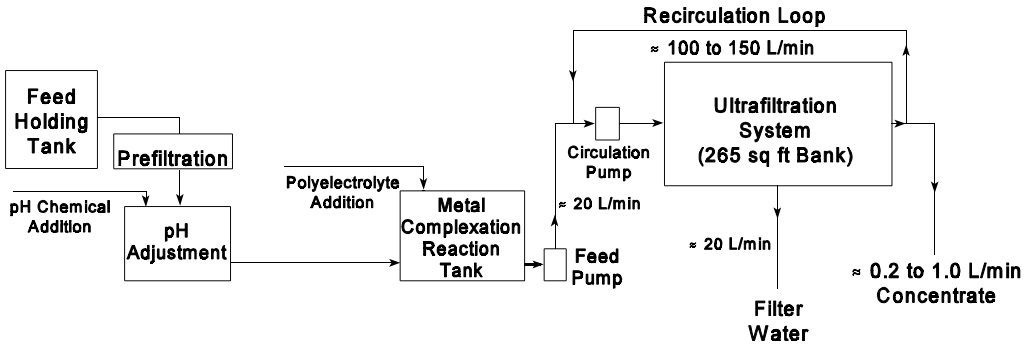
## TECHNOLOGY DESCRIPTION:

The Atomic Energy of Canada, Limited (AECL), process uses chemical pretreatment and ultrafiltration to remove trace concentrations of dissolved metals from wastewater, contaminated groundwater, and leachate. The process selectively removes metal contaminants and produces a volume-reduced water stream for further treatment and disposal.

The installed unit's overall dimensions are 5 feet wide by 7 feet long by 6 feet high. The skid-mounted unit consists of (1) a bank of 5-micron cartridge prefilters, (2) a feed conditioning system with polyelectrolytes and chemicals for pH adjustment, (3) two banks of hollow-fiber ultrafilters, (4) a backflush system for cleaning the membrane unit, and (5) associated tanks and instrumentation.

The figure below illustrates the process. Wastewater enters the prefilter through the feed holding tank, where suspended particles are removed from the feed. The filtered waste stream is then routed to conditioning tanks where the solution pH is adjusted. Water-soluble macromolecular compounds are then added to the wastewater to form complexes with heavy metal ions. Next, a relatively high molecular weight polymer, generally a commercially available polyelectrolyte, is added to the wastewater to form selective metal-polymer complexes at the desired pH and temperature. The polyelectrolyte quantities depend on the metal ion concentration.

The wastewater then passes through a cross-flow ultrafiltration membrane system by way of a recirculation loop. The ultrafiltration system provides a total membrane surface area of 265 square feet and a flow rate of about 6 gallons per minute (gpm). The membranes retain the metal complexes (in the concentrate), while allowing uncomplexed ions to pass through the membrane with the filtered water. The filtered water (the permeate) is continuously withdrawn, while the concentrate stream containing most of the contaminants is recycled until it meets the target concentration. After reaching the target concentration, the concentrate stream is withdrawn for further treatment, such as solidification. It can then be safely disposed of, while the clean filtered water is discharged.




Single-Stage Chemical Treatment and Ultrafiltration Process



The SITE Program assesses but does not approve or endorse technologies.

## WASTE APPLICABILITY:

The AECL process treats groundwater, leachate, and surface runoff contaminated with trace levels of toxic heavy metals. The process also treats effluents from (1) industrial processes, (2) production and processing of base metals, (3) smelters, (4) electrolysis operations, and (5) battery manufacturing. Potential applications include removal of metals such as cadmium, lead, mercury, uranium, manganese, nickel, chromium, and silver.

The process can treat influent with dissolved metal concentrations from several parts per million (ppm) up to about 100 ppm. The process also removes other inorganic and organic materials present as suspended or colloidal solids. The sole residue is the ultrafiltration concentrate, which generally constitutes 5 to 20 percent of the feed volume.

## STATUS:

The AECL process was accepted into the SITE Emerging Technology Program in 1988. During initial bench- and pilot-scale tests, the AECL process successfully removed cadmium, lead, and mercury. These results were used to help designers construct the mobile unit.

The mobile unit has been tested at Chalk River Laboratories and at a uranium mine tailings site in Ontario, Canada. The field evaluation indicated that process water characteristics needed further study; pretreatment schemes are being evaluated. The mobile unit, which is capable of treating influent flows ranging from 1,000 to 5,000 gallons per day, is available for treatability tests and on-site applications. An Emerging Technology Bulletin (EPA/540/F-92/002) is available from EPA.

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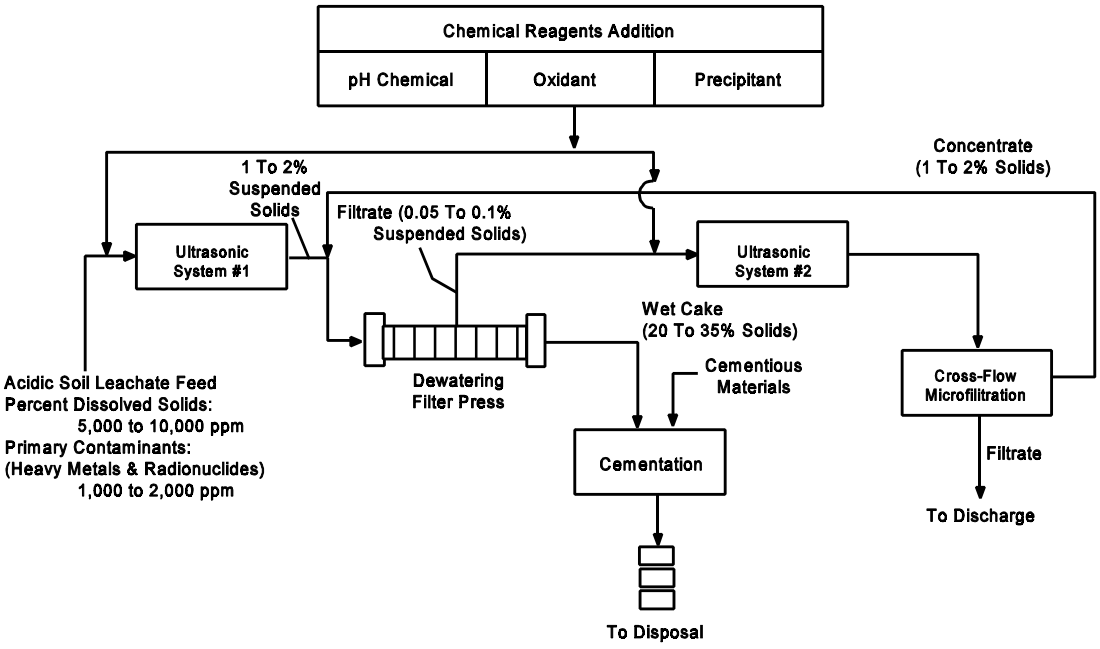
# ATOMIC ENERGY OF CANADA LIMITED
## (Ultrasonic-Aided Leachate Treatment)

## TECHNOLOGY DESCRIPTION:

The ultrasonic-aided leachate treatment process involves enhanced chemical treatment of acidic soil leachate solutions. These solutions, also known as acid mine drainage, are caused by the oxidation and dissolution of sulfide-bearing wastes that produce sulfuric acid. The resulting acidic water leaches metal contaminants from the exposed waste rock and mine tailings, creating large volumes of toxic acidic leachates.

The ultrasonic-aided leachate treatment process uses an ultrasonic field to improve contaminant removal through precipitation, coprecipitation, oxidation, ion scavenging, and sorption (see figure below). These processes are followed by solid-liquid separation using a filter press and a cross-flow microfilter connected in series. The time required for treatment depends on (1) the nature of acidic waste to be treated, (2) the treated water quality with respect to contaminant concentration, and (3) the rate at which the physical and chemical processes occur. The treatable leachate volume is scalable.

The major difference between this technology and conventional processes is the use of ultrasonic mixing instead of mechanical agitation in large tanks. Research indicates that an ultrasonic field significantly increases both the conversion rate of dissolved contaminants to precipitates and the rate of oxidation and ion exchange. Earlier studies by Atomic Energy of Canada Limited (AECL) revealed that the time required to precipitate heavy metals from aqueous solutions decreased by an order of magnitude in the presence of an ultrasonic field.




Single-Stage Chemical Treatment and Ultrafiltration Process



The SITE Program assesses but does not approve or endorse technologies.

The ultrasonic-aided leachate treatment process is compact, portable, and energy-efficient. Safety and process controls are built in as necessary for handling mixed radioactive solutions. The process also generates minimal fugitive emissions and produces a treated effluent that meets applicable discharge limits. The process may also be able to treat waste containing small amounts of dissolved or suspended organics.

## WASTE APPLICABILITY:

The ultrasonic-aided leachate treatment process treats acid mine drainage contaminated with heavy metals and radionuclides. The process can also be combined with soil remediation technologies.

## STATUS:

The ultrasonic-aided leachate treatment process was accepted into the SITE Emerging Technology Program in 1993. Under this program, AECL is developing and testing a pilot-scale unit to treat acidic soil leachate solutions containing low levels of metals and radionuclides.

The quality assurance and test plan was approved in October 1994. Laboratory-scale testing using acidic leachates from the Berkeley Pit in Butte, Montana, and from Stanleigh Mines in Elliot Lake, Ontario, Canada, is complete. The tests were designed to find optimal single and multistage treatment regimes to remove from the leachates a variety of dissolved species (such as iron, aluminum, manganese, magnesium, copper, zinc, uranium, radium, and sulfate), either as contaminants or as reusable resources.

Given optimum process chemistry, low energy (less than 5 kilojoules per liter), and low frequency (20 kilohertz), ultrasonic cavitation fields were sufficient to remove the dissolved species to levels meeting discharge requirements.

The energy input corresponds to a chemical conditioning time of a few seconds to tens of seconds. The underlying principles examined include lime and limestone precipitation, copper cementation, iron, and uranium oxidation, ion sorption, and ion scavenging.

A Phase 1 interim report summarizing the laboratory-scale results was issued in August 1995. A revised Phase 1 report was issued in February 1996. Testing of the pilot-scale system was December 1996.

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# BATTELLE MEMORIAL INSTITUTE
## (In Situ Electroacoustic Soil Decontamination)

## TECHNOLOGY DESCRIPTION:

This patented in situ electroacoustic soil decontamination (ESD) technology removes heavy metals from soils through direct current electrical and acoustic fields. Direct current facilitates liquid transport through soils. The technology consists of electrodes, an anode and a cathode, and an acoustic source (see figure below).

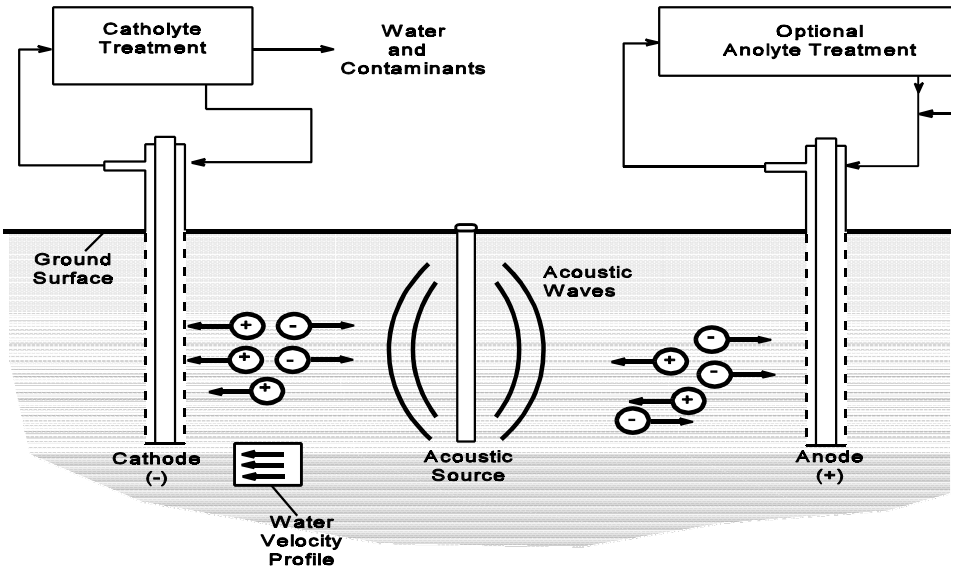
The double-layer boundary theory is important when an electric potential is applied to soils. For soil particles, the double layer consists of (1) a fixed layer of negative ions that are firmly held to the solid phase, and (2) a diffuse layer of more loosely held cations and anions. Applying an electric potential to the double layer displaces the loosely held ions to their respective electrodes. The cations take water with them as they move toward the cathode.

Besides water transport through wet soils, the direct current produces other effects, such as ion transfer, pH gradients development, electrolysis, oxidation and reduction, and heat generation.

Heavy metals present in contaminated soils can be leached or precipitated out of solution by electrolysis, oxidation and reduction reactions, or ionic migration. The soil contaminants may be (1) cations, such as cadmium, chromium, and lead; or (2) anions, such as cyanide, chromate, and dichromate. The existence of these ions in their respective oxidation states depends on soil pH and concentration gradients. Direct current is expected to increase the leaching rate and precipitate the heavy metals out of solution by establishing appropriate pH and osmotic gradients.

## WASTE APPLICABILITY:

This technology removes heavy metals from soils. When applied in conjunction with an electric field and water flow, an acoustic field can enhance waste dewatering or leaching. This phenomenon is not fully understood. Another possible application involves the unclogging of recovery wells. Because contaminated particles are driven to the recovery well, the pores and interstitial spaces in the soil can close. This technology could be used to clear these clogged spaces.




In Situ Electroacoustic Soil Decontamination



The SITE Program assesses but does not approve or endorse technologies.

The technology's potential for improving nonaqueous phase liquid contaminant recovery and in situ removal of heavy metals needs to be tested at the pilot-scale level using clay soils.

## STATUS:

The ESD technology was accepted into the SITE Emerging Technology Program in 1988. Results indicate that ESD is technically feasible for removing inorganic species such as zinc and cadmium from clay soils; however, it is only marginally effective for hydrocarbon removal. A modified ESD process for more effective hydrocarbon removal has been developed but has not been tested. The Emerging Technology Report (EPA/540/5-90/004) describing the 1-year investigation can be purchased through the National Technical Information Service, (PB 90-204728/AS). The Emerging Technology Summary (EPA/540/S5-90/004) is available from U. S. EPA.

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# BERGMANN, A DIVISION OF LINATEX, INC.
## (Soil and Sediment Washing)

## TECHNOLOGY DESCRIPTION:

The soil and sediment washing technology developed by Bergmann, A Division of Linatex, Inc.'s, (Bergman), separates contaminated particles by density and grain size (see photograph below). The technology operates on the hypothesis that most contamination is concentrated in the fine particle fraction (less than 45 microns [$\mu$m]) and that contamination of larger particles is generally not extensive.

After contaminated soil is screened to remove coarse rock and debris, water and chemical additives such as surfactants, acids, bases, and chelators are added to the medium to produce a slurry feed. The slurry feed flows to an attrition scrubbing machine. A rotary trommel screen, dense media separators, cyclone separators, and other equipment create mechanical and fluid shear stress, removing contaminated silts and clays from granular soil particles.

Different separation processes create the following four output streams: (1) coarse clean fraction; (2) enriched fine fraction; (3) separated contaminated humic materials; and (4) process wash water. The coarse clean fraction particles, which measure greater than 45 $\mu$m (greater than 325 mesh) each, can be used as backfill or recycled for concrete, masonry, or asphalt sand application. The enriched fine fraction particles, measuring less than 45 $\mu$m each are prepared for subsequent treatment, immobilization, destruction, or regulated disposal. Separated contaminated humic materials (leaves, twigs, roots, grasses, wood chips) are dewatered and require subsequent treatment or disposal. Upflow classification and

Bergmann Soil and Sediment Washing



The SITE Program assesses but does not approve or endorse technologies.

separation, also known as elutriation, separates light contaminated materials such as leaves, twigs, roots, or wood chips. The process wash water is treated by flocculation and sedimentation, oil-water separation, or dissolved air flotation to remove solubilized heavy metal and emulsified organic fractions. The treated process wash water is then returned to the plant for reuse.

## WASTE APPLICABILITY:

This technology is suitable for treating soils and sediment contaminated with organics, including polychlorinated biphenyls (PCB), creosote, fuel residues, and heavy petroleum; and heavy metals, including cadmium, chromium, lead, arsenic, copper, cyanides, mercury, nickel, radionuclides, and zinc.

## STATUS:

This technology was accepted into the SITE Demonstration Program in Winter 1991. It was demonstrated in Toronto, Ontario, Canada in April 1992 as part of the Toronto Harbour Commission (THC) soil recycling process. For further information on the THC process, including demonstration results, refer to the THC profile in the Demonstration Program section (completed projects). The technology was also demonstrated in May 1992 at the Saginaw Bay Confined Disposal Facility in Saginaw, Michigan. The Applications Analysis Report (EPA/540/AR-92/075) and the Demonstration Bulletin (EPA/540/MR-92/075) are available from EPA. Since 1981, Bergmann has provided 31 commercial systems, treating up to 350 tons per hour, at contaminated waste sites.

## DEMONSTRATION RESULTS:

Demonstration results indicate that the soil and sediment washing system can effectively isolate and concentrate PCB contamination into the organic fractions and the fines. Levels of metals contamination were also beneficially altered from the feed stream to the output streams. The effectiveness of the soil and sediment washing system on the inorganic compounds met or exceeded its performance for PCB contamination. During a 5-day test in May 1992, the Bergmann soil and sediment washing system experienced no downtime as it operated for 8 hours per day to treat dredged sediments from the Saginaw River.

The demonstration provided the following results:

- Approximately 71 percent of the particles smaller than 45-$\mu$m in the input sediment was apportioned to the enriched fine stream.
- Less than 20 percent of the particles smaller than 45-$\mu$m in the input sediment was apportioned to the coarse clean fraction.
- The distribution of the concentrations of PCBs in the input and output streams were as follows:
  Input sediment = 1.6 milligrams per kilogram (mg/kg)
  Output coarse clean fraction = 0.20 mg/kg
  Output humic materials = 11 mg/kg
  Output enriched fines = 4.4 mg/kg
- The heavy metals were concentrated in the same manner as the PCBs.
- The coarse clean sand consisted of approximately 82 percent of the input sediment.

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# BERKELEY ENVIRONMENTAL RESTORATION CENTER
## (In Situ Steam Enhanced Extraction Process)

## TECHNOLOGY DESCRIPTION:

The in situ steam enhanced extraction (ISEE) process removes volatile organic compounds (VOC) and semivolatile organic compounds (SVOC) from contaminated water and soils above and below the water table (see figure below). Pressurized steam is introduced through injection wells to force steam through the soil to thermally enhance the vapor and liquid extraction processes.

The extraction wells have two purposes: (1) to pump groundwater for ex situ treatment; and (2) to transport steam and vaporized contaminants under vacuum to the surface. Recovered contaminants are condensed and recycled, processed with the contaminated groundwater, or treated in the gas phase. The ISEE process uses readily available components such as injection, extraction, and monitoring wells; manifold piping; vapor and liquid separators; vacuum pumps; and gas emission control equipment.

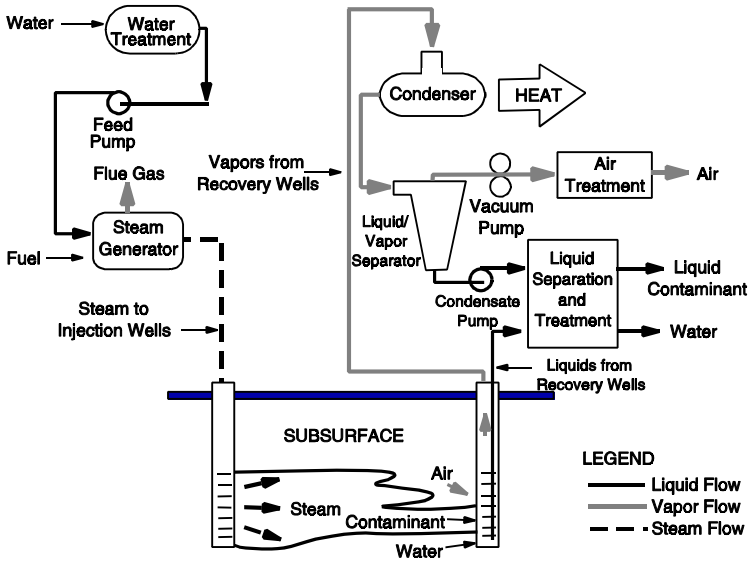
## WASTE APPLICABILITY:

The ISEE process extracts VOCs and SVOCs from contaminated soils and groundwater. The primary compounds suitable for treatment include hydrocarbons such as gasoline, diesel, and jet fuel; solvents such as trichloroethene, 1,1,1-trichloroethane, and dichlorobenzene; or a mixture of these compounds. The process may be applied to contaminants above or below the water table. After treatment is complete, subsurface conditions are amenable to biodegradation of residual contaminants, if necessary. The process can be applied to contaminated soil very near the surface with a cap. Compounds denser than water may be treated only in low concentrations, unless a barrier exists or can be created to prevent downward percolation of a separate phase.

## STATUS:

In August 1988, a successful pilot-scale demonstration of the ISEE process was completed at a site contaminated with a mixture of solvents. Contaminants amounting to 764 pounds were removed from the 10-foot-diameter, 12-foot-deep test region. After 5 days of steam injection, soil contaminant concentrations dropped by a factor of 10.

In December 1993, a full-scale demonstration was completed at a gasoline spill site at Lawrence Livermore National Laboratory (LLNL) in




In Situ Steam Enhanced Extraction Process



The SITE Program assesses but does not approve or endorse technologies.

Altamont Hills, California. Gasoline was dispersed both above and below the water table due to a 25-foot rise in the water table since the spill occurred. The lateral distribution of liquid-phase gasoline was within a region 150 feet in diameter and up to 125 feet deep. Appendix A of the Hughes Environmental Systems Innovative Technology Evaluation Report (EPA/540/R-94/510) contains detailed results from the LLNL SITE demonstration. This report is available from EPA.

A pilot-scale test of the ISEE process was conducted in 1994 at Naval Air Station (NAS) Lemoore in California. During 3 months of operation, over 98,000 gallons of JP-5 jet fuel was recovered from medium permeability, partially saturated sand to a depth of 20 feet. Preliminary soil sampling showed reductions of JP-5 jet fuel concentrations from several thousand parts per million (ppm) above the water table to values less than 25 ppm.

During Fall 1998, Berkeley is scheduled to use the ISEE process to remediate a groundwater contaminant plume at Alameda Naval Air Station in California. The contaminant plume contains halogenated organic compounds, including trichlolorethene, 1,1,1-trichlorethane, and perchloroethylene.

For more information about similar technologies, see the following profiles in the Demonstration Program section: Hughes Environmental Systems, Inc., (completed projects) and Praxis Environmental Technologies, Inc. (ongoing projects).

## DEMONSTRATION RESULTS:

During the SITE demonstration at LLNL, over 7,600 gallons of gasoline were recovered from above and below the water table in 26 weeks of operation. Recovery rates were about 50 times greater than those achieved by vacuum extraction and groundwater pumping alone. The rates were highest during cyclic steam injection, after subsurface soils reached steam temperatures. The majority of the recovered gasoline came from the condenser as a separate phase liquid or in the effluent air stream.

Without further pumping, 1,2-dichloroethene, benzene, ethylbenzene, toluene, and xylene concentrations in sampled groundwater were decreased to below maximum contaminant levels after 6 months. Post-process soil sampling indicated that a thriving hydrocarbon-degrading microbial population existed in soils experiencing prolonged steam contact.

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# BILLINGS AND ASSOCIATES, INC.
## (Subsurface Volatilization and Ventilation System [SVVS®])

## TECHNOLOGY DESCRIPTION:

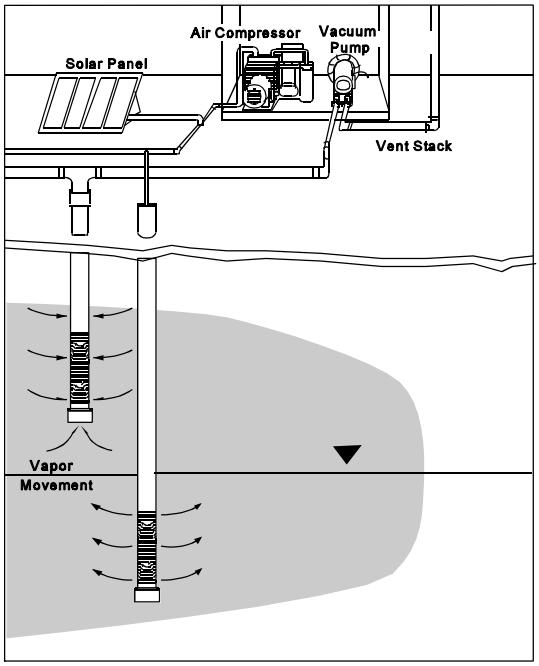
The Subsurface Volatilization and Ventilation System (SVVS®), developed by Billings and Associates, Inc. (BAI), and operated by several other firms under a licensing agreement, uses a network of injection and extraction wells (collectively called a reactor nest) to treat subsurface organic contamination through soil vacuum extraction combined with in situ biodegradation. Each system is designed to meet site-specific conditions. The SVVS® technology has three U.S. patents.

The SVVS® is shown in the figure below. A series of injection and extraction wells is installed at a site. One or more vacuum pumps create negative pressure to extract contaminant vapors, while an air compressor simultaneously creates positive pressure, sparging the subsurface treatment area. Control is maintained at a vapor control unit that houses pumps, control valves, gauges, and other process control hardware.

At most sites with subsurface organic contamination, extraction wells are placed above the water table and injection wells are placed below the groundwater. This placement allows the groundwater to be used as a diffusion device.

The number and spacing of the wells depends on the modeling results of a design parameter matrix, as well as the physical, chemical, and biological characteristics of the site. The exact depth of the injection wells and screened intervals are additional design considerations.

To enhance vaporization, solar panels are occasionally used to heat the injected air. Additional valves for limiting or increasing air flow and pressure are placed on individual reactor nest lines (radials) or, at some sites, on individual well points. Depending on groundwater depths and fluctuations, horizontal vacuum screens, "stubbed" screens, or multiple-depth completions can be applied. Positive and negative air flow can be shifted to different locations at the site to




Subsurface Volatilization and Ventilation System (SVVS®)



The SITE Program assesses but does not approve or endorse technologies.

emphasize remediation on the most contaminated areas. Negative pressure is maintained at a suitable level to prevent escape of vapors.

Because it provides oxygen to the subsurface, the SVVS® can enhance in situ bioremediation at a site, thereby decreasing remediation time. These processes are normally monitored by measuring dissolved oxygen levels in the aquifer, recording carbon dioxide levels in transmission lines and at the emission point, and periodically sampling microbial populations. When required by air quality permits, volatile organic compound emissions can be treated by a patent-pending biological filter that uses indigenous microbes from the site.

## WASTE APPLICABILITY:

The SVVS® is applicable to soils, sludges, and groundwater contaminated with gasoline, diesel fuels, and other hydrocarbons, including halogenated compounds. The technology is effective on benzene, toluene, ethylbenzene, and xylene contamination. It can also contain contaminant plumes through its unique vacuum and air injection techniques.

## STATUS:

This technology was accepted into the SITE Demonstration Program in winter 1991. A site in Buchanan, Michigan was selected for the demonstration, and initial drilling and construction began in July 1992. The demonstration began in March 1993 and was completed in May 1994. The Demonstration Bulletin (EPA/540/MR-94/529), Technology Capsule (EPA/540/R-94/529a), and Innovative Technology Evaluation Report (EPA/540/R-94/529) are available from EPA. The SVVS® has also been implemented at 95 underground storage tank sites in New Mexico, North Carolina, South Carolina, Florida, and Oklahoma.

BAI is researching ways to increase the microbiological effectiveness of the technology and is testing a mobile unit. The mobile unit will allow rapid field pilot tests to support the design process. This unit will also permit actual remediation of small sites and of small, recalcitrant areas on large sites.

## DEMONSTRATION RESULTS:

Results from the SVVS® demonstration are as follows:

- Data indicated that the overall reductions for several target analytes, as determined from individual boreholes, ranged from 71 percent to over 99 percent, over a 1-year period.
- The early phase of the remediation was characterized by higher concentrations of volatile organics in the extracted vapor stream.
- The shutdown tests indicate that the technology stimulated biodegradative processes at the site.

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# BIOGENESIS ENTERPRISES, INC.
## (BioGenesis℠ Soil and Sediment Washing Process)

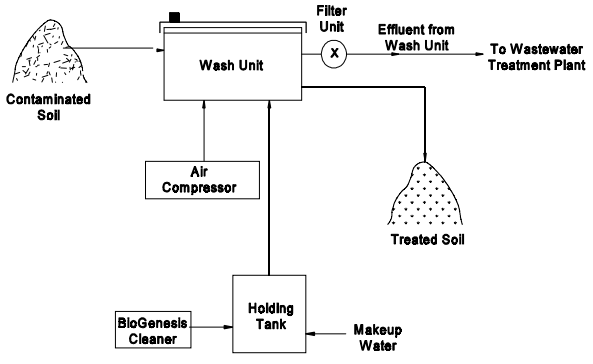
## TECHNOLOGY DESCRIPTION:

The BioGenesis℠ soil and sediment washing process uses specialized, patent-pending equipment, complex surfactants, and water to clean soil, sediment, and sludge contaminated with organic and inorganic constituents. Two types of mobile equipment wash different sizes of particles. A truck-mounted batch unit processes 20 yards per hour, and washes soil particles 10 mesh and larger. A full-scale, mobile, continuous flow unit cleans sand, silt, clay, and sludge particles smaller than 10 mesh at a rate of 20 to 40 yards per hour. Auxiliary equipment includes tanks, dewatering and water treatment equipment, and a bioreactor. Extraction efficiencies per wash cycle range from 85 to 99 percent. High contaminant levels require multiple washes.

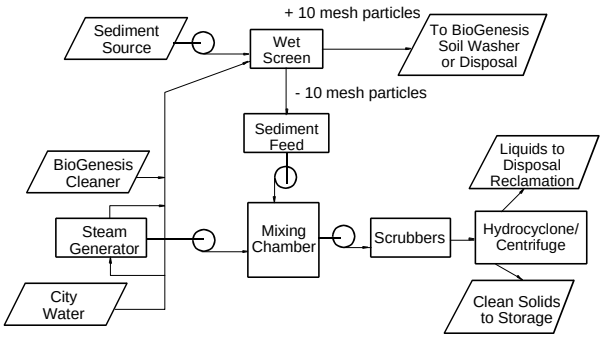
The principal components of the process consist of pretreatment equipment for particle sizing, a truck-mounted soil washer for larger particles, a sediment washing unit(s) for fine particles, and water treatment and reconditioning equipment. The BioGenesis℠ soil washing system for larger particles consists of a trailer-mounted gondola plumbed for air mixing, water and chemical addition, oil skimming, and liquid drainage (see figure below). Water, BioGenesis℠ cleaning chemicals, and soil are loaded into the gondola. Aeration nozzles feed compressed air to create a fluidized bed. The resulting slurry is agitated to release organic and inorganic contaminants from the soil particles. After mixing, a short settling period allows the soil particles to sink and the removed oil to rise to the water surface, where it is skimmed for reclamation or disposal. Following drainage of the wash water, the treated soil is evacuated by raising the gondola's dump mechanism. Processed soil contains a moisture level of 10 to 20 percent depending on the soil matrix.

A prototype BioGenesis℠ sediment washing machine was tested in Environment Canada's Contaminated Sediment Treatment Technology Program. The sediment washing machine is a continuous flow unit. Capacities of up to 80 to 100 cubic yards per hour are possible using full-scale, parallel processing equipment.

In the sediment washing machine, sediment is pretreated to form a slurry. The slurry passes to a shaker screen separator that sizes particles into two streams. Material greater than 1 millimeter (mm) in diameter is diverted to the large particlesoil washer. Material 1 mm and smaller continues to the sediment washer's feed hopper.




Soil Washing Process




Sediment Washing Process



The SITE Program assesses but does not approve or endorse technologies.

From there, the slurry is injected to the sediment cleaning chamber to loosen the bonds between the pollutant and the particle.

After the cleaning chamber, the slurry flows to the scrubber to further weaken the bonds between contaminants and particles. After the scrubber, the slurry passes through a buffer tank, where large particles separate by gravity. The slurry then flows through hydrocyclone banks to separate solids down to 3 to 5 microns in size. The free liquid routes to a centrifuge for final solid-liquid separation. All solids go to the treated soil pile; all liquid is routed to wastewater treatment to remove organic and inorganic contaminants. Decontaminated wastewater is recycled back through the process. Equipment configuration varies depending on the soil matrix.

The BioGenesis™ cleaning chemical is a light alkaline mixture of ionic and nonionic surfactants and bioremediating agents that act similarly to a biosurfactant. The proprietary cleaner contains no hazardous ingredients.

## WASTE APPLICABILITY:

This technology extracts many inorganics, volatile and nonvolatile hydrocarbons, chlorinated hydrocarbons, pesticides, polychlorinated biphenyls (PCB), polynuclear aromatic hydrocarbons, and most organics from nearly every soil and sediment type, including clay.

## STATUS:

The BioGenesis℠ soil washing technology was accepted into the SITE Demonstration Program in June 1990. The process was demonstrated in November 1992 on weathered crude oil at a refinery site in Minnesota. Results from the demonstration have been published in the Innovative Technology Evaluation Report (EPA/540/R-93/510) and the SITE Technology Capsule (EPA/540/SR-93/510). The reports are available from EPA. BioGenesis Enterprises, Inc., is planning a future demonstration of the BioGenesis℠ sediment washing process using PCB-contaminated sediment.

## DEMONSTRATION RESULTS:

Results of the SITE demonstration are presented below:

- Soil washing and biodegradation with BioGenesis℠ removed about 85 percent of the total recoverable petroleum hydrocarbon (TRPH)-related contaminants in the soil.
- Treatment system performance was reproducible at constant operating conditions.
- At the end of 90 days, TRPH concentrations decreased an additional 50 percent compared to washing alone.
- The prototype equipment operated within design parameters. New production equipment is expected to streamline overall operating efficiency.

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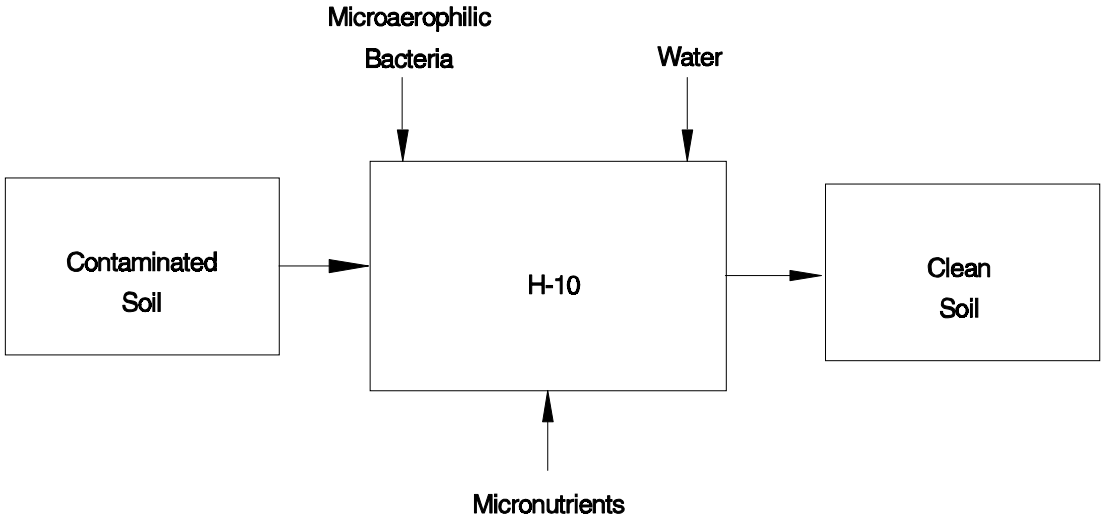
# BIO-REM, INC.
## (Augmented In Situ Subsurface Bioremediation Process)

## TECHNOLOGY DESCRIPTION:

The Bio-Rem, Inc., Augmented In Situ Subsurface Bioremediation Process uses a proprietary blend (H-10) of microaerophilic bacteria and micronutrients for subsurface bioremediation of hydrocarbon contamination in soil and water (see figure below). The insertion methodology is adaptable to site-specific situations. The bacteria are hardy and can treat contaminants in a wide temperature range. The process does not require additional oxygen or oxygen-producing compounds, such as hydrogen peroxide. Degradation products include carbon dioxide and water.

The bioremediation process consists of four steps: (1) defining and characterizing the contaminationplume; (2) selecting a site-specific application methodology; (3) initiating and propagating the bacterial culture; and (4) monitoring and reporting cleanup.

This technology treats soil and water contaminated with hydrocarbons, including halogenated hydrocarbons. Use of the augmented bioremediation process is site-specific, and therefore engineered for each individual site. The success of the process is dependent on a complete and accurate site characterization study. This data is necessary to determine the treatment magnitude and duration.




Augmented In Situ Subsurface Bioremediation Process



The SITE Program assesses but does not approve or endorse technologies.

## STATUS:

This technology was accepted into the SITE Demonstration Program in winter 1991. The technology was successfully demonstrated at Williams Air Force Base in Phoenix, Arizona from May 1992 through June 1993. The Demonstration Bulletin (EPA/540/MR-93/527) is available from EPA. Bio-Rem, Inc., has remediated sites throughout the U.S., and in Canada and Central Europe.

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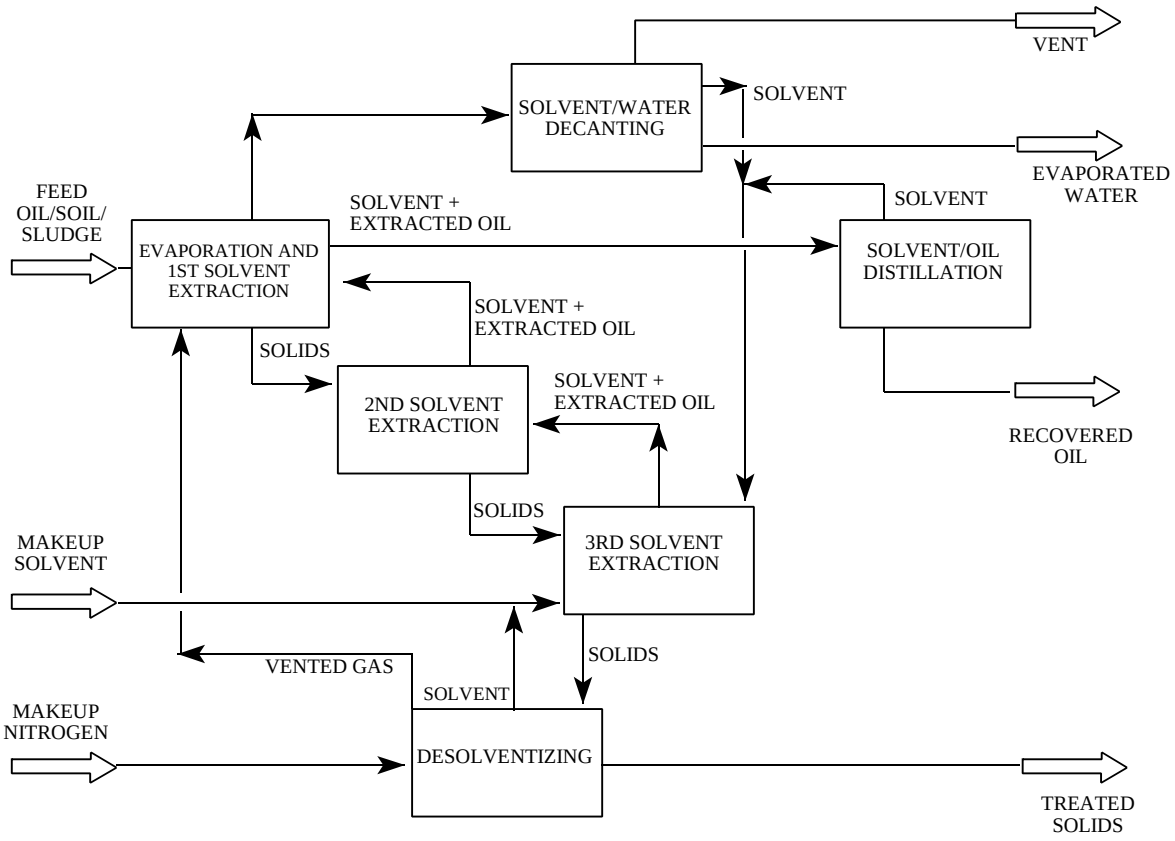
# BIOTHERM, LCC
## (formerly Dehydro-Tech Corporation)
## (Biotherm Process™)

## TECHNOLOGY DESCRIPTION:

The Biotherm Process™ combines dehydration and solvent extraction technologies to separate wet, oily wastes into their constituent solid, water, and oil phases (see figure below).

Waste is first mixed with a low-cost hydrocarbon solvent. The resultant slurry mixture is fed to an evaporator system that vaporizes water and initiates solvent extraction of the indigenous oil extraction unit, where solids contact recycled solvent until the target amount of indigenous oil is removed. Depending on the water content of the feed, single-effect or energy-saving multi-effect evaporators may be used. Next, the slurry of dried solids is treated in a multistage solvent. Finally, solids are centrifuged away from the solvent, followed by "desolventizing," an operation that evaporates residual solvent. The final solids product typically contains less than 2 percent water and less than 1 percent solvent. The spent solvent, which contains the extracted indigenous oil, is distilled to separate the solvent for reuse, and the oil for recovery or disposal.

The Biotherm Process™ yields (1) a clean, dry solid; (2) a water product virtually free of solids, indigenous oil, and solvent; and (3) the extracted indigenous oil, which contains the hazardous hydrocarbon-soluble feed components.




Biotherm Process™ Schematic Diagram



The SITE Program assesses but does not approve or endorse technologies.

The Biotherm Process™ combination of dehydration and solvent extraction has the following advantages: (1) any emulsions initially present are broken and potential emulsion formation is prevented; (2) solvent extraction is more efficient because water is not present; and (3) the dry solids product is stabilized more readily if required (for example, if metals contamination is a concern).

## WASTE APPLICABILITY:

The Biotherm Process™ can treat sludges, soils, sediments, and other water-bearing wastes containing hydrocarbon-soluble hazardous compounds, including polychlorinated biphenyls, polynuclear aromatic hydrocarbons, and dioxins. The process has been commercially applied to municipal wastewater sludge, paper mill sludge, rendering waste, pharmaceutical plant sludge, and other wastes.

## STATUS:

The Biotherm Process™ was accepted into the SITE Demonstration Program in 1990. The pilot-scale SITE demonstration of this technology was completed in August 1991 at EPA's research facility in Edison, New Jersey. Spent petroleum drilling fluids from the PAB oil site in Abbeville, Louisiana, were used as process feed. The Applications Analysis Report (EPA/540/AR-92/002), Technology Demonstration Summary (EPA/540/SR-92/002), and Technology Evaluation Report (EPA/540/R-92/002) are available from EPA.

## DEMONSTRATION RESULTS:

The SITE demonstration of the Biotherm Process™ yielded the following results:

- The process successfully separated the petroleum-contaminated sludge into its solid, indigenous oil, and water phases. No detectable levels of indigenous total petroleum hydrocarbons were present in the final solid product.
- The final solid product was a dry powder similar to bentonite. A food-grade solvent comprised the bulk of the residual hydrocarbons in the solid.
- Values for all metals and organics were well below the Resource Conservation and Recovery Act toxicity characteristic leaching procedure limits for characteristic hazardous wastes.
- The resulting water product required treatment due to the presence of small amounts of light organics and solvent. Normally, it may be disposed of at a local publicly owned treatment works.
- A full-scale Biotherm Process™ can treat drilling fluid wastes at technology-specific costs of $100 to $220 per ton of wet feed, exclusive of disposal costs for the residuals. Site-specific costs, which include the cost of residual disposal, depend on site characteristics and treatment objectives.

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# BIOTROL®
## (Methanotrophic Bioreactor System)

## TECHNOLOGY DESCRIPTION:

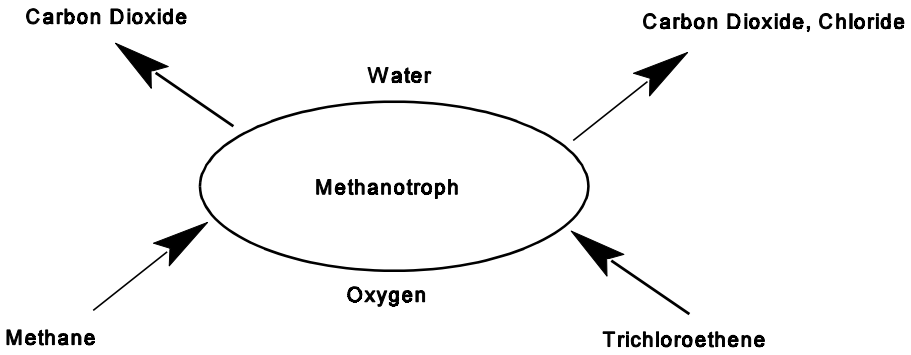
The BioTrol methanotrophic bioreactor system is an aboveground remedial technology for water contaminated with halogenated hydrocarbons. Trichloroethene (TCE) and related compounds pose a difficult challenge to biological treatment. Unlike aromatic hydrocarbons, for example, TCE cannot serve as a primary substrate for bacterial growth. Degradation depends on cometabolism (see figure below), which is attributed to the broad substrate specificity of certain bacterial enzyme systems. Although many aerobic enzyme systems reportedly cooxidize TCE and related compounds, BioTrol claims that the methane monooxygenase (MMO) produced by methanotrophic bacteria is the most promising.

Methanotrophs are bacteria that can use methane as a sole source of carbon and energy. Although certain methanotrophs can express MMO in either a soluble or particulate (membrane-bound) form, BioTrol has discovered that the soluble form used in the BioTrol process induces extremely rapid TCE degradation rates. Two patents have been obtained, and an additional patent on the process is pending. Results from experiments with *Methylosinus trichosporium* strain OB3b indicate that the maximum specific TCE degradation rate is 1.3 grams of TCE per gram of cells (dry weight) per hour. This rate is 100 to 1,000 times faster than reported TCE degradation rates for nonmethanotrophs. This species of methanotrophic bacteria reportedly removes various chlorinated aliphatic compounds by more than 99.9 percent.

BioTrol has also developed a colorimetric assay that verifies the presence of MMO in the bioreactor culture.

## WASTE APPLICABILITY:

The bioreactor system can treat water contaminated with halogenated aliphatic hydrocarbons, including TCE, dichloroethene isomers, vinyl chloride, chloroform, dichloromethane (methylene chloride), and others. In the case of groundwater treatment,




Cometabolism of TCE



The SITE Program assesses but does not approve or endorse technologies.

bioreactor effluent can either be reinjected or discharged to a sanitary sewer under a National Pollutant Discharge Elimination System permit.

## STATUS:

This technology was accepted into the SITE Emerging Technology Program in July 1990. Bench- and pilot-scale tests were conducted using a continuous-flow, dispersed-growth system. As shown in the figure below, the pilot-scale reactor displayed first-order TCE degradation kinetics. The final report on the demonstration appears in the *Journal of the Air and Waste Management Association*, Volume 45, No. 1, January 1995. The Emerging Technology Bulletin (EPA/540/F-93/506) and the Emerging Technology Summary (EPA/540/SR-93/505) are available from U. S. EPA.

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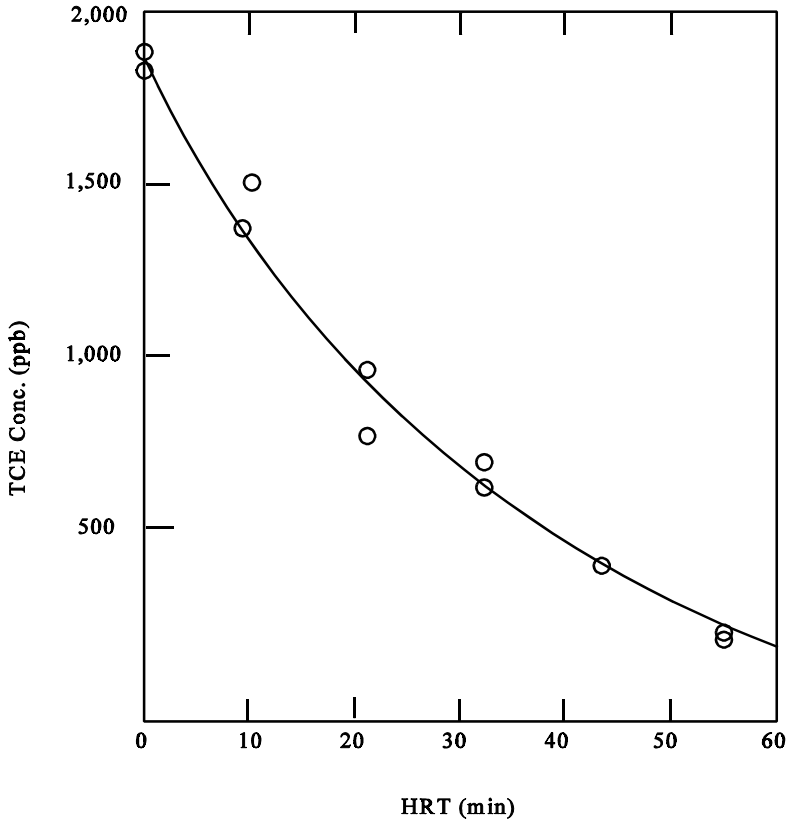



Results for Pilot-Scale, Continuous-Flow Reactor

# BIOTROL®
## (Biological Aqueous Treatment System)

## TECHNOLOGY DESCRIPTION:

The BioTrol biological aqueous treatment system (BATS) is a patented biological system that treats contaminated groundwater and process water. The system uses naturally occurring microbes; in some instances, however, a specific microorganism may be added. This technique, known as microbial amendment, is important if a highly toxic or recalcitrant target compound is present. The amended microbial system removes both the target contaminant and the background organic carbon.

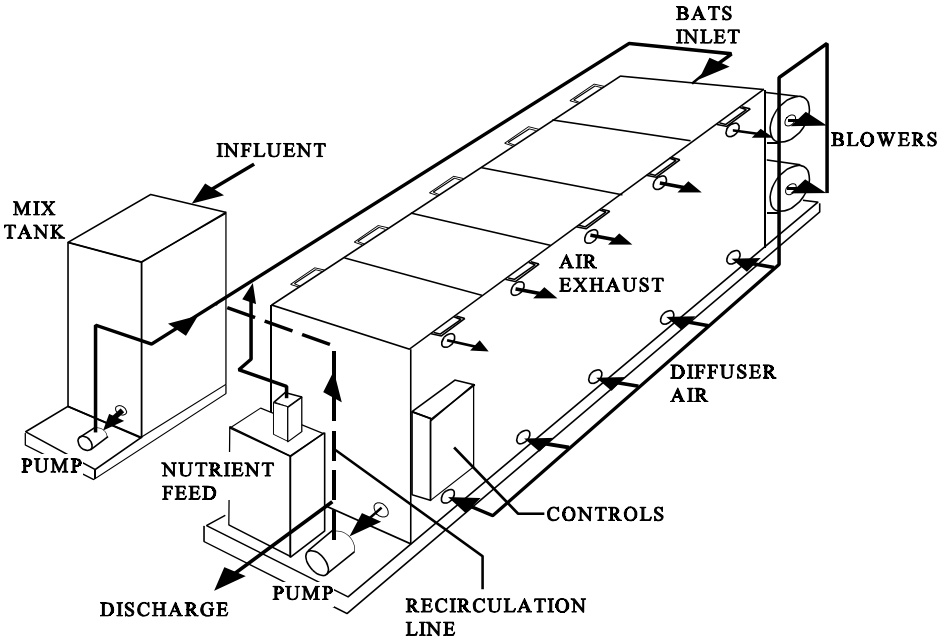
The figure below is a schematic of the BATS. Contaminated water enters a mix tank, where the pH is adjusted and inorganic nutrients are added. If necessary, the water is heated to an optimum temperature with a heater and a heat exchanger, to minimize energy costs. The water then flows to the bioreactor, where the contaminants are biodegraded.

The microorganisms that degrade the contaminants are immobilized in a multiple-cell, submerged, fixed-film bioreactor. Each cell is filled with a highly porous packing material to which the microbe s adhere. For aerobic conditions, air is supplied by fine bubble membrane diffusers mounted at the bottom of each cell. The system may also run under anaerobic conditions.

As water flows through the bioreactor, the contaminants are degraded to biological end-products, predominantly carbon dioxide and water. The resulting effluent may be discharged to a publicly owned treatment works or reused on site. In some cases, discharge with a National Pollutant Discharge Elimination System permit may be possible.

## WASTE APPLICABILITY:

The BATS may be applied to a wide variety of wastewaters, including groundwater, lagoons, and




BioTrol Biological Aqueous Treatment System (BATS)



The SITE Program assesses but does not approve or endorse technologies.

process water. Contaminants amenable to treatment include pentachlorophenol (PCP), creosote components, gasoline and fuel oil components, chlorinated hydrocarbons, phenolics, and solvents. Other potential target waste streams include coal tar residues and organic pesticides. The BATS may also be effective for treating certain inorganic compounds such as nitrates; however, this application has not yet been demonstrated. The system does not treat metals.

## STATUS:

The BATS was accepted into the SITE Demonstration Program in 1989. The system was demonstrated under the SITE Program from July to September 1989 at the MacGillis and Gibbs Superfund site in New Brighton, Minnesota. The system operated continuously for 6 weeks at three different flow rates. The Applications Analysis Report (EPA/540/A5-91/001), the Technology Evaluation Report (EPA/540/5-91/001), and the Demonstration Bulletin (EPA/540/M5-91/001) are available from EPA.

During 1986 and 1987, BioTrol performed a successful 9-month pilot-scale field test of the BATS at a wood preserving facility. Since that time, the firm has installed more than 20 full-scale systems and has performed several pilot-scale demonstrations. These systems have successfully treated waters contaminated with gasoline, mineral spirit solvents, phenol, and creosote.

## DEMONSTRATION RESULTS:

For the SITE demonstration, the BATS yielded the following results:

- Reduced PCP concentrations from about 45 parts per million (ppm) to 1 ppm or less in a single pass
- Produced minimal sludge and no PCP air emissions
- Mineralized chlorinated phenolics
- Eliminated groundwater biotoxicity
- Appeared to be unaffected by low concentrations of oil and grease (about 50 ppm) and heavy metals in groundwater
- Required minimal operator attention

The treatment cost per 1,000 gallons was $3.45 for a 5-gallon-per-minute (gpm) pilot-scale system and $2.43 for a 30-gpm system.

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# BIOTROL®
## (Soil Washing System)

## TECHNOLOGY DESCRIPTION:

The BioTrol Soil Washing System is a patented, water-based volume reduction process used to treat excavated soil. The system may be applied to contaminants concentrated in the fine-sized soil fraction (silt, clay, and soil organic matter) or in the coarse soil fraction (sand and gravel).

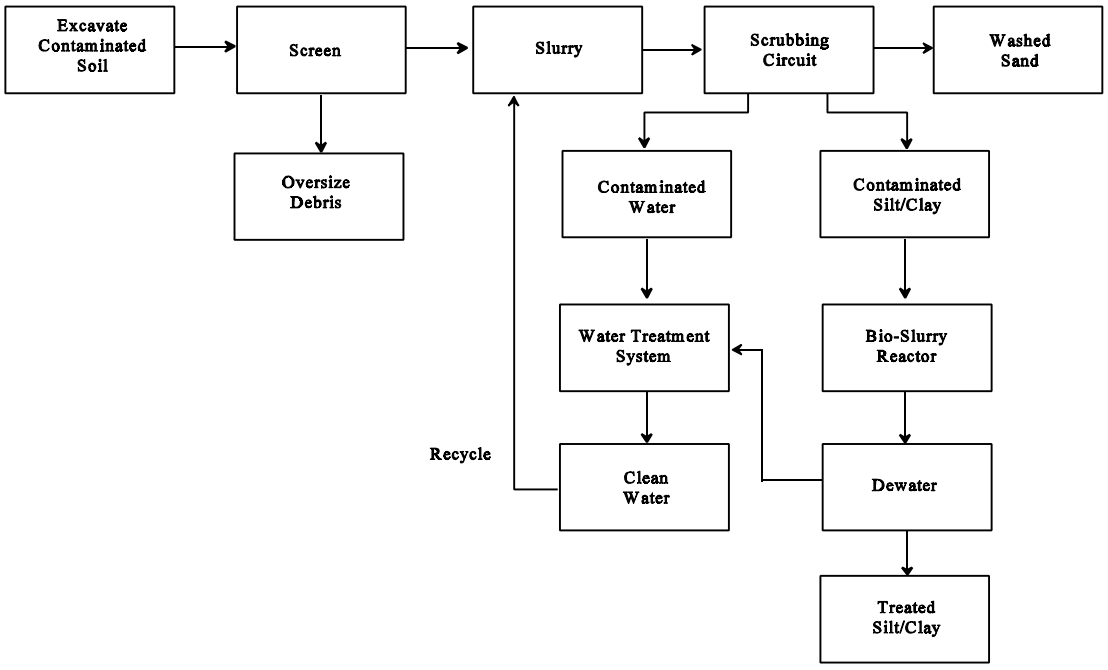
In the first part of the process, debris is removed from the soil. The soil is then mixed with water and subjected to various unit operations common to the mineral processing industry (see figure below). The equipment used in these operations can include mixing trommels, pug mills, vibrating screens, froth flotation cells, attrition scrubbing machines, hydrocyclones, screw classifiers, and various dewatering apparatus.

The core of the process is a multistage, counter-current, intensive scrubbing circuit with interstage classification. The scrubbing action disintegrates soil aggregates, freeing contaminated fine particles from the coarser material. In addition, surficial contamination is removed from the coarse fraction by the abrasive scouring action of the particles themselves. Contaminants may also be solubilized, as dictated by solubility characteristics or partition coefficients.

Contaminated residual products can be treated by other methods. Process water is normally recycled after biological or physical treatment. Contaminated fines may be disposed of off site, incinerated, stabilized, or biologically treated.

## WASTE APPLICABILITY:

This system was initially developed to clean soils contaminated with wood preserving wastes, such as polynuclear aromatic hydrocarbons (PAH) and pentachlorophenol (PCP). The system may also apply to soils contaminated with petroleum hydrocarbons, pesticides, polychlorinated biphenyls, various industrial chemicals, and metals.




BioTrol Soil Washing System Process Diagram



The SITE Program assesses but does not approve or endorse technologies.

## STATUS:

The BioTrol Soil Washing System was accepted into the SITE Demonstration Program in 1989. The system was demonstrated under the SITE Program between September and October 1989 at the MacGillis and Gibbs Superfund site in New Brighton, Minnesota. A pilot-scale unit with a treatment capacity of 500 pounds per hour operated 24 hours per day during the demonstration. Feed for the first phase of the demonstration (2 days) consisted of soil contaminated with 130 parts per million (ppm) PCP and 247 ppm total PAHs; feed for the second phase (7 days) consisted of soil containing 680 ppm PCP and 404 ppm total PAHs.

Contaminated process water was treated biologically in a fixed-film reactor and recycled. A portion of the contaminated soil fines was treated biologically in a three-stage, pilot-scale EIMCO Biolift™ reactor system supplied by the EIMCO Process Equipment Company. The Applications Analysis Report (EPA/540/A5-91/003) and the Technology Evaluation Report Volume I (EPA/540/5-91/003a) and Volume II (EPA/540/5-91/003b and EPA/540/5-91/003c) are available from EPA.

## DEMONSTRATION RESULTS:

Key findings from the BioTrol demonstration are summarized below:

- Feed soil (dry weight basis) was successfully separated into 83 percent washed soil, 10 percent woody residues, and 7 percent fines. The washed soil retained about 10 percent of the feed soil contamination; 90 percent of this contamination was contained within the woody residues, fines, and process wastes.
- The multistage scrubbing circuit removed up to 89 percent PCP and 88 percent total PAHs, based on the difference between concentration levels in the contaminated (wet) feed soil and the washed soil.
- The scrubbing circuit degraded up to 94 percent PCP in the process water during soil washing. PAH removal could not be determined because of low influent concentrations.
- The cost of a commercial-scale soil washing system, assuming use of all three technologies (soil washing, water treatment, and fines treatment), was estimated to be $168 per ton. Incineration of woody material accounts for 76 percent of the cost.

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# BRICE ENVIRONMENTAL SERVICES CORPORATION
## (Soil Washing Process)

## TECHNOLOGY DESCRIPTION:

Brice Environmental Services Corporation (Brice) developed a soil washing process that removes particulate metal contamination from soil. The process has been successfully coupled with acid leaching processes developed by Brice and others for the removal of ionic metal salts and metal coatings from soil. The Brice soil washing process is modular and uses components specifically suited to site soil conditions and cleanup standards. Component requirements and anticipated cleanup levels attainable with the process are determined during treatability testing at Brice's Fairbanks, Alaska facility laboratory. The process is designed to recirculate wash water and leachate solutions.

Particulate metal contaminants removed from soil, and metals recovered from the leaching system (if used), are recycled at a smelting facility. Instead of stabilizing the metals in place or placing the materials in a landfill, the Brice technology removes metal contaminants from the soil, thereby eliminating the health hazard associated with heavy metal contamination.

## WASTE APPLICABILITY:

The Brice soil washing process treats soils contaminated with heavy metals. Typical materials suited for treatment with the technology include soils at small arm ranges, ammunition

Brice soil Washing Plant



The SITE Program assesses but does not approve or endorse technologies.

manufacturing and testing facilities, foundry sites, and sites used for lead-acid battery recycling.

## STATUS:

The Brice soil washing process was accepted into the SITE Demonstration Program in winter 1991. Under the program, the technology was demonstrated in late summer 1992 on lead-contaminated soil at the Alaskan Battery Enterprises (ABE) Superfund site in Fairbanks, Alaska. The Demonstration Bulletin (EPA/540/MR-93/503) and the Applications Analysis Report (EPA/540/A5-93/503) are available from EPA.

A Brice soil washing plant was operated in New Brighton, Minnesota for 9 months at Twin Cities Army Ammunition Plant (TCAAP - see photograph) to process 20,000 tons of contaminated soil. The wash plant was used in conjunction with a leaching plant (operated by a separate developer) that removed ionic lead following particulate metal removal.

During Fall 1996, Brice performed a soil washing/soil leaching technology demonstration at a small arms range at Fort Polk, Louisiana. The process implemented physical separation of bullet and bullet fragments from soil particles, and included a leaching step for removing residual ionic lead. A total of 835 tons of soil were processed during this demonstration, and all demonstration goals were met with no soil requiring reprocessing.

In August 1998, Brice completed a full-scale soil washing operation at the Marine Corps Air Ground Combat Cebter in Twentynin Plams, California. This operation involved processing about 12,000 tons of soil at a small arms firing range.

Several successful demonstrations of the pilot-scale unit have been conducted. The results from the SITE demonstration have been published in a Technology Evaluation Report (EPA/540/5-91/006a), entitled "Design and Development of a Pilot-Scale Debris Decontamination System" and in a Technology Demonstration Summary (EPA/540/S5-91/006).

EPA developed a full-scale unit with ancillary equipment mounted on three 48-foot flatbed semi-trailers. EPA is expecting to formalize a nonexclusive licensing agreement for the equipment in late 1998 to increase the technology's use in treating contaminated debris.

## DEMONSTRATION RESULTS:

The demonstration at the ABE site consisted of three test runs of five hours each, with 48 tons of soil processed. Feed soils averaged 4,500 milligrams per kilogram (mg/kg) and the separated soil fines fraction averaged 13,00 mg/kg. On-line reliability was 92 percent, and all processed gravel passed TCLP testing. Battery casing removal efficiencies during the three runs were 94 percent, 100 percent and 90 percent.

The results for the demonstration at the TCAAP site indicated that the Brice technology reduced the lead load to the leaching process from 39 percent to 53 percent. Soil was continuously processed at a rate of 12 to 15 tons per hour.

Results of the Fort Polk demonstration indicate that the technology reduced lead from firing range soils by 97 percent. All soil processed was below the demonstration goals of 500 mg/kg total lead and 5 milligrams per liter (mg/L) TCLP lead. Average results for all processed soil were 156 mg/kg total lead and 2.1 mg/L TCLP lead. Processing rates ranged from 6 to 12 tons per our hour.

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# BWX TECHNOLOGIES, INC.
# (an affiliate of BABCOCK & WILCOX CO.)
## (Cyclone Furnace)

## TECHNOLOGY DESCRIPTION:

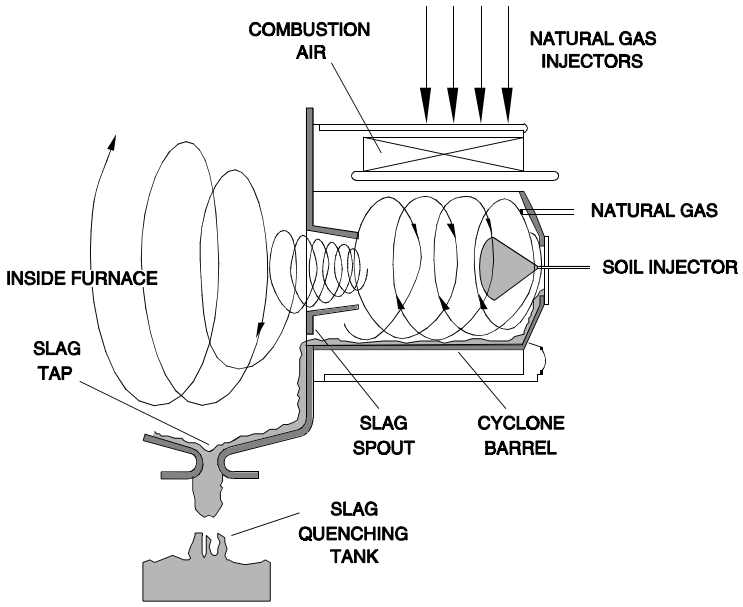
The Babcock & Wilcox Co. (Babcock & Wilcox) cyclone furnace is designed to combust coal with high inorganic content (high-ash). Through cofiring, the cyclone furnace can also accommodate highly contaminated wastes containing heavy metals and organics in soil or sludge. High heat-release rates of 45,000 British thermal units (Btu) per cubic foot of coal and high turbulence in cyclones ensures the high temperatures required for melting the high-ash fuels and combusting the organics. The inert ash exits the cyclone furnace as a vitrified slag.

The pilot-scale cyclone furnace, shown in the figure below, is a water cooled, scaled-down version of a commercial coal-fired cyclone with a restricted exit (throat). The furnace geometry is a horizontal cylinder (barrel).

Natural gas and preheated combustion air are heated to 820 °F and enter tangentially into the cyclone burner. For dry soil processing, the soil matrix and natural gas enter tangentially along the cyclone furnace barrel. For wet soil processing, an atomizer uses compressed air to spray the soil slurry directly into the furnace. The soil or sludge and inorganics are captured and melted, and organics are destroyed in the gas phase or in the molten slag layer. This slag layer is formed and retained on the furnace barrel wall by centrifugal action.

The soil melts, exits the cyclone furnace from the tap at the cyclone throat, and drops into a water-filled slag tank where it solidifies. A small quantity of soil also exits as fly ash with the flue gas from the furnace and is collected in a baghouse. In principle, this fly ash can be recycled to the furnace to increase metal capture and to minimize the volume of the potentially hazardous waste stream.

The energy requirements for vitrification are 15,000 Btu per pound of soil treated. The cyclone




Cyclone Furnace



The SITE Program assesses but does not approve or endorse technologies.

furnace can be operated with gas, oil, or coal as the supplemental fuel. If the waste is high in organic content, it may also supply a significant portion of the required fuel heat input.

Particulates are captured by a baghouse. To maximize the capture of particulate metals, a heat exchanger is used to cool the stack gases to approximately 200 °F before they enter the baghouse.

## WASTE APPLICABILITY:

The cyclone furnace can treat highly contaminated hazardous wastes, sludges, and soils that contain heavy metals and organic constituents. The wastes may be solid, a soil slurry (wet soil), or liquids. To be treated in the cyclone furnace, the ash or solid matrix must melt (with or without additives) and flow at cyclone furnace temperatures (2,400 to 3,000 °F). Because the furnace captures heavy metals in the slag and renders them nonleachable, it is particularly suited to soils that contain lower-volatility radionuclides such as strontium and transuranics.

Based on results from the Emerging Technology Program, the cyclone furnace technology was accepted into the SITE Demonstration Program in August 1991. A demonstration occurred in November 1991 at the developer's facility in Alliance, Ohio. The process was demonstrated using an EPA-supplied, wet synthetic soil matrix (SSM) spiked with heavy metals (lead, cadmium, and chromium), organics (anthracene and dimethylphthalate), and simulated radionuclides (bismuth, strontium, and zirconium). Results from the demonstrations have been published in the Applications Analysis Report (EPA/520/AR-92/017) and Technology Evaluation Report, Volumes 1 and 2 (EPA/504/R-92/017A and EPA/540/R-92/017B); these documents are available from EPA.

## DEMONSTRATION RESULTS:

Vitrified slag leachabilities for the heavy metals met EPA toxicity characteristic leaching procedure (TCLP) limits. TCLP leachabilities were 0.29 milligram per liter (mg/L) for lead, 0.12 mg/L for cadmium, and 0.30 mg/L for chromium. Almost 95 percent of the noncombustible SSM was incorporated into the slag. Greater than 75 percent of the chromium, 88 percent of the strontium, and 97 percent of the zirconium were captured in the slag. Dry weight volume was reduced 28 percent. Destruction and removal efficiencies for anthracene and dimethylphthalate were greater than 99.997 percent and 99.998 percent, respectively. Stack particulates were 0.001 grain per dry standard cubic foot (gr/dscf) at 7 percent oxygen, which was below the Resource Conservation Recovery Act limit of 0.08 gr/dscf effective until May 1993. Carbon monoxide and total hydrocarbons in the flue gas were 6.0 parts per million (ppm) and 8.3 ppm, respectively.

An independent cost analysis was performed as part of the SITE demonstration. The cost to remediate 20,000 tons of contaminated soil using a 3.3-ton-per-hour unit was estimated at $465 per ton if the unit is on line 80 percent of the time, and $529 per ton if the unit is on line 60 percent of the time.

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# CALGON CARBON ADVANCED OXIDATION TECHNOLOGIES
## (formerly VULCAN PEROXIDATION SYSTEMS, INC.)
## (perox-pure™ Chemical Oxidation Technology)

## TECHNOLOGY DESCRIPTION:

The **perox-pure™** treatment system is designed to destroy dissolved organic contaminants in groundwater or wastewater with an advanced chemical oxidation process that uses ultraviolet (UV) radiation and hydrogen peroxide.

In the process, proprietary high-powered, medium-pressure lamps emit high-energy UV radiation through a quartz sleeve into the contaminated water. Hydrogen peroxide is added to the contaminated water and is activated by the UV light to form oxidizing species called hydroxyl radicals:

$H_2O_2 + UV \rightarrow 2(\cdot OH)$

The hydroxyl radical then reacts with the dissolved contaminants, initiating a rapid cascade of oxidation reactions that ultimately fully oxidize (mineralize) the contaminants. The success of the process is based on the fact that the rate constants for the reaction of ·OH radicals with most organic pollutants are very high. The hydroxyl radical typically reacts a million to a billion times faster than chemical oxidants such as ozone and hydrogen peroxide. In addition, many organic contminants (e.g. PCE) undergo a change in their chemical structure by the direct absorption of UV light in the UV-C spectral range emitted by Calgon Carbon Corporation's proprietary medium-pressure UV lamps.

## WASTE APPLICABILITY:

The **perox-pure™** technology treats groundwater and wastewater contaminated with chlorinated solvents, pesticides, polychlorinated biphenyls, phenolics, ethers, fuel hydrocarbons, and other organic compounds. It is effective on concentrations ranging from low parts per billion to several hundred parts per million (ppm). In certain instances, when used in conjunction with photocatalysts, it can be competitive for contaminated waters at concentrations of several

**perox-pure™** Model SSB-30



The SITE Program assesses but does not approve or endorse technologies.

thousand parts per million (ppm). In some cases, the combination of the **perox-pure™** technology with activated carbon, air stripping, or biological treatment will provide a more economical approach than would be obtained by using only one technology.

## STATUS:

The **perox-pure™** technology was accepted into the SITE Demonstration Program in April 1991. A Model SSB-30 (see photograph on previous page) was demonstrated in September 1992 at the Lawrence Livermore National Laboratory Superfund site in Altamont Hills, California. The purpose of this demonstration was to measure how well the **perox-pure™** technology removed volatile organic compounds from contaminated groundwater at the site. The Demonstration Bulletin (EPA/540/MR-93/501), Technology Demonstration Summary (EPA/540/SR-93/501), Applications Analysis Report (EPA/540/AR-93/501), and Technology Evaluation Report (EPA/540/R-93/501) are available from EPA.

This technology has been successfully applied to over 250 sites throughout the United States, Canada, the Far East, and Europe. The treat-ment units at these sites have treated contaminated groundwater, industrial wastewater, contaminated drinking water, landfill leachates, and industrial reuse streams (process waters). Equipment treatment rates range from several gallons to several thousand gallons per minute.

## DEMONSTRATION RESULTS:

Operating parameters for the treatment system were varied during the demonstration. Three reproducibility tests were performed at the optimum operating conditions, which were selected from the initial test runs.

In most cases, the **perox-pure™** technology reduced trichloroethene, tetrachloroethene, chloroform, trichloroethane, and dichloroethane to below analytical detection limits. For each organic contaminant, the **perox-pure™** technology complied with California action levels and federal drinking water maximum contaminant levels at the 95 percent confidence level. The quartz sleeve wipers effectively cleaned the sleeves and eliminated the interference caused by tube scaling.

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# CF SYSTEMS CORPORATION
## (Liquified Gas Solvent Extraction [LG-SX] Technology)

## TECHNOLOGY DESCRIPTION:

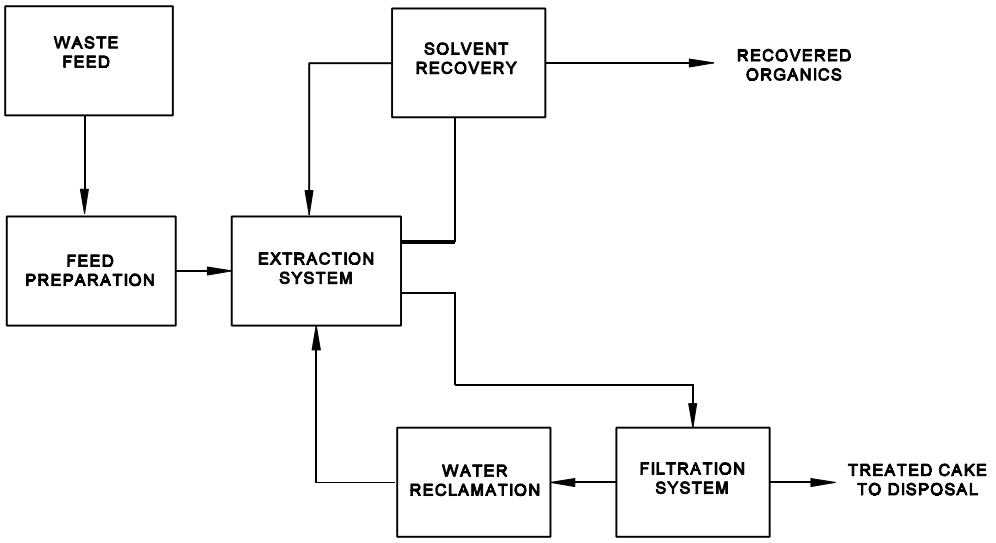
The CF Systems Corporation (CF Systems) liquified gas solvent extraction (LG-SX) technology uses liquified gas solvents to extract organics from soils, sludges, sediments, and wastewaters. Gases, when liquified under pressure, have unique physical properties that enhance their use as solvents. The low viscosities, densities, and surface tensions of these gases result in significantly higher rates of extraction compared to conventional liquid solvents. These enhanced physical properties also accelerate treated water's gravity settling rate following extraction. Due to their high volatility, gases are also easily recovered from the suspended solids matrix, minimizing solvent losses.

Liquified propane solvent is typically used to treat soils, sludges, and sediments, while liquified carbon dioxide is typically used to treat wastewater. The extraction system uses a batch extractor-decanter design for solids and sludges and a continuous trayed tower design for waste-waters and low-solids wastes.

Contaminated solids, slurries, or wastewaters are fed into the extraction system along with solvent (see figure below). After the solvent and organics are separated from the treated feed, the solvent and organic mixture passes to the solvent recovery system. Once in the solvent recovery system, the solvent is vaporized and recycled as fresh solvent. The organics are drawn off and either reused or disposed of. Treated feed is discharged from the extraction system as a slurry. The slurry is filtered and dewatered. The reclaimed water is recycled to the extraction system and the filter cake is sent for disposal or reused.

## WASTE APPLICABILITY:

The LG-SX technology can be applied to soils and sludges containing volatile and semivolatile organic compounds and other higher boiling point complex organics, such as polynuclear aromatic hydrocarbons (PAH), polychlorinated biphenyls (PCB), dioxins, and pentachlorophenol (PCP). This process can also treat refinery wastes and wastewater contaminated with organics.




Liquified Gas Solvent Extraction (LG-SX) Technology



The SITE Program assesses but does not approve or endorse technologies.

## STATUS:

This technology was accepted into the SITE Demonstration Program in 1988. Under the SITE Program, a pilot-scale mobile demonstration unit was tested in September 1988 on PCB-laden sediments from the New Bedford Harbor Superfund site in Massachusetts. PCB concentrations in the harbor sediment ranged from 300 parts per million (ppm) to 2,500 ppm. The Technology Evaluation Report (EPA/540/5-90/002) and the Applications Analysis Report (EPA/540/A5-90/002) are available from EPA.

A pilot-scale treatability study was completed on PCB-contaminated soil from a Michigan Superfund site. Analytical data showed that the treatment reduced PCB levels to below 5 parts per million (ppm), representing a 98 percent removal efficiency for this waste. A Project Summary (EPA/540/SR-95/505), which details results from this work, is available from EPA.

CF Systems completed the first commercial on-site treatment operation at Star Enterprise in Port Arthur, Texas. The propane-based solvent extraction unit processed listed refinery K- and F-wastes, producing Resource Conservation and Recovery Act treated solids that met EPA land-ban requirements. The unit operated continuously from March 1991 to March 1992 and was on-line more than 90 percent of the time. Following heavy metals fixation, the treated solids were disposed of in a Class I landfill.

Effective mid-1998, Morrison Knudsen Corporation, owner of CF Environmental Corporation, has terminated research and development of the LG-SX program, and no longer actively markets the technology.

## DEMONSTRATION RESULTS:

This technology was demonstrated concurrently with dredging studies managed by the U.S. Army Corps of Engineers. Contaminated sediments were treated by the LG-SX technology, using a liquified propane and butane mixture as the extraction solvent. The demonstration at the New Bedford site yielded the following results:

- Extraction efficiencies were 90 to 98 percent for sediments containing PCBs between 360 and 2,575 ppm. PCB concentrations were as low as 8 ppm in the treated sediment.
- Volatile and semivolatile organics in aqueous and semisolid wastes were extracted with 99.9 percent efficiency.
- Operating problems included solids retention in the system hardware and foaming in receiving tanks. The problems were corrected in the full-scale operations at Star Enterprise.
- Projected costs for PCB cleanup were estimated at $150 to $450 per ton, including material handling and pre- and posttreatment costs. These costs are highly dependent on the utilization factor and job size, which may result in lower costs for large cleanups.

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# CHEMFIX TECHNOLOGIES, INC.
## (Solidification and Stabilization)

## TECHNOLOGY DESCRIPTION:

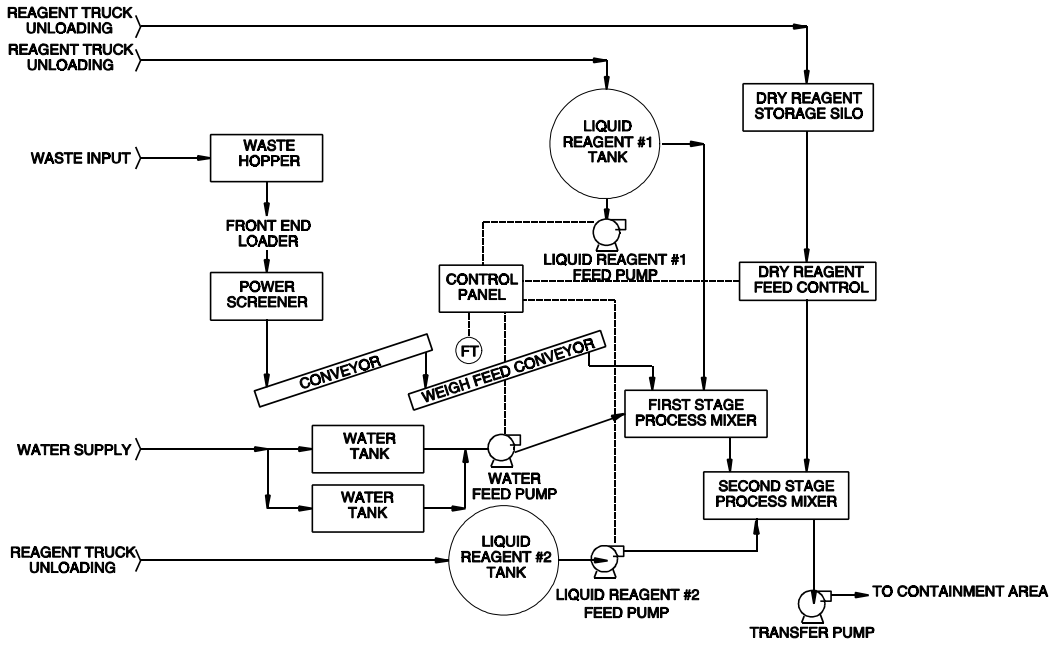
In this solidification and stabilization process, pozzolanic materials react with polyvalent metal ions and other waste components to produce a chemically and physically stable solid material. Optional binders and reagents may include soluble silicates, carbonates, phosphates, and borates. The end product may be similar to a clay-like soil, depending on the characteristics of the raw waste and the properties desired in the end product.

The figure below illustrates the Chemfix Technologies, Inc. (Chemfix), process. Typically, the waste is first blended in a reaction vessel with pozzolanic materials that contain calcium hydroxide. This blend is then dispersed throughout an aqueous phase. The reagents react with one another and with toxic metal ions, forming both anionic and cationic metal complexes. Pozzolanics that accelerate and other reagents that precipitate metals can be added before or after the dry binder is initially mixed with the waste.

When a water soluble silicate reacts with the waste and the pozzolanic binder system, colloidal silicate gel strengths are increased within the binder-waste matrix, helping to bind polyvalent metal cations. A large percentage of the heavy metals become part of the calcium silicate and aluminate colloidal structures formed by the pozzolans and calcium hydroxide. Some of the metals, such as lead, adsorb to the surface of the pozzolanic structures. The entire pozzolanic matrix, when physically cured, decreases toxic metal mobility by reducing the incursion of leaching liquids into and out of the stabilized matrices.

## WASTE APPLICABILITY:

This process is suitable for contaminated soils, sludges, ashes, and other solid wastes. The process is particularly applicable to electroplating sludges, electric arc furnace dust, heavy metal contaminated soils, oil field drilling muds and cuttings, municipal sewage sludges, and residuals from other treatment processes. This process effectively treats heavy metals, such as antimony, arsenic, lead, cadmium, hexavalent chromium,




Process Flow Diagram



The SITE Program assesses but does not approve or endorse technologies.

mercury, copper, and zinc. In addition, when combined with specialized binders and additives, this process can stabilize low-level nuclear wastes. With modifications, the system may be applied to wastes containing between 10 to 100 percent solids.

## STATUS:

The solidification and stabilization process was accepted into the SITE Demonstration Program in 1988. The process was demonstrated in March 1989 at the Portable Equipment Salvage Company site in Clackamas, Oregon. The Technology Evaluation Report (EPA/540/5-89/011a) and the Applications Analysis Report (EPA/540/A5-89/011) are available from EPA.

In addition, several full-scale remediation projects have been completed since 1977, including a 1991 high solids CHEMSET® reagent protocol designed by Chemfix to treat 30,000 cubic yards of hexavalent chromium-contaminated, high solids waste. The average chromium level after treatment was less than 0.15 milligram per liter and met toxicity characteristic leaching procedure (TCLP) criteria. The final product permeability was less than $1 \times 10^{-6}$ centimeters per second (cm/sec).

## DEMONSTRATION RESULTS:

The demonstration yielded the following results:

- The technology effectively reduced copper and lead concentrations in the wastes. The concentrations in the TCLP extracts from the treated wastes were 94 to 99 percent less than those from the untreated wastes. Total lead concentrations in the untreated waste approached 14 percent.
- The volume of excavated waste material increased between 20 and 50 percent after treatment.
- During the durability tests, the treated wastes showed little or no weight loss after 12 cycles of wetting and drying or freezing and thawing.
- The unconfined compressive strength of the wastes varied between 27 and 307 pounds per square inch after 28 days. Hydraulic conductivity of the treated material ranged between $1 \times 10^{-6}$ cm/sec and $6.4 \times 10^{-7}$ cm/sec.
- Air monitoring data suggest there was no significant volatilization of polychlorinated biphenyls during the treatment process.
- Treatment costs were approximately $73 per ton, including mobilization, labor, reagents, and demobilization, but not disposal.

## FOR FURTHER INFORMATION:

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# CENTER FOR HAZARDOUS MATERIALS RESEARCH
## (Acid Extraction Treatment System)

## TECHNOLOGY DESCRIPTION:

The acid extraction treatment system (AETS) uses hydrochloric acid to extract heavy metal contaminants from soils. Following treatment, the clean soil may be returned to the site or used as fill.

A simplified block flow diagram of the AETS is shown below. First, soils are screened to remove coarse solids. These solids, typically greater than 4 millimeters in size, are relatively clean and require at most a simple rinse with water or detergent to remove smaller attached particles.

After coarse particle removal, the remaining soil is scrubbed in an attrition scrubber to break up agglomerates and cleanse surfaces. Hydrochloric acid is then introduced into the soil in the extraction unit. The residence time in the unit varies depending on the soil type, contaminants, and contaminant concentrations, but generally ranges between 10 and 40 minutes. The soil-extractant mixture is continuously pumped out of the mixing tank, and the soil and extractant are separated using hydrocyclones.

When extraction is complete, the solids are transferred to the rinse system. The soils are rinsed with water to remove entrained acid and metals. The extraction solution and rinse waters are regenerated using a proprietary technology that removes the metals and reforms the acid. The heavy metals are concentrated in a form potentially suitable for recovery. During the final step, the soils are mixed with lime and fertilizer to neutralize any residual acid. No wastewater streams are generated by the process.

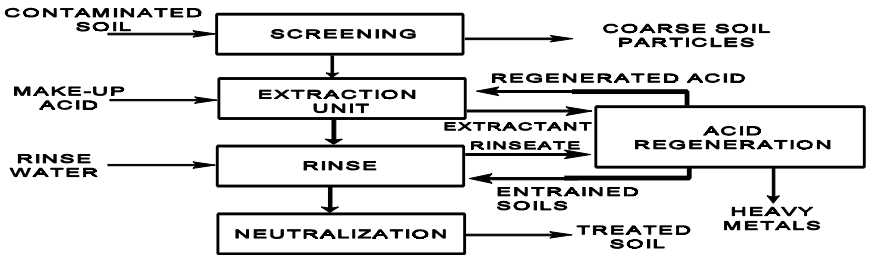
## WASTE APPLICABILITY:

The main application of AETS is extraction of heavy metals from soils. The system has been tested using a variety of soils containing one or more of the following: arsenic, cadmium, chromium, copper, lead, nickel, and zinc. The treatment capacity is expected to range up to 30 tons per hour. AETS can treat all soil fractions, including fines.

The major residuals from AETS treatment include the cleaned soil, which is suitable for fill or for return to the site, and the heavy metal concentrate. Depending on the concentration of heavy metals, the mixtures of heavy metals found at the site, and the presence of other compounds (calcium, sodium) with the metals, heavy metals may be reclaimed from the concentrate.

## STATUS:

Under the Emerging Technology Program, laboratory-scale and bench-scale tests were conducted to develop the AETS technology. The bench-scale pilot system was constructed to process between 20 and 100 kilograms of soil per hour. Five soils were tested, including an EPA synthetic soil matrix (SSM) and soils from four Superfund sites, including NL Industries in Pedricktown, New Jersey; King of Prussia site in Winslow Township, New Jersey; a smelter site in Butte, Montana; and Palmerton Zinc site in



Acid Extraction Treatment System (AETS) Process


The SITE Program assesses but does not approve or endorse technologies.

Palmerton, Pennsylvania. These soils contained elevated concentrations of some or all of the following: arsenic, cadmium, chromium, copper, lead, nickel, and zinc. The table below summarizes soil treatability results based on the EPA Resource Conservation and Recovery Act (RCRA) hazardous waste requirements for toxicity characteristic leaching procedure (TCLP) and the California standards for total metal concentrations. The Emerging Technology Report (EPA/540/R-94/513) and Emerging Technology Summary (EPA/540/SR-94/513) are available from EPA.

The results of the study are summarized below:

- AETS can treat a wide range of soils containing a wide range of heavy metals to reduce the TCLP below the RCRA limit. AETS can also reduce the total metals concentrations below the California-mandated total metals limitations.
- In most cases, AETS can treat the entire soil, without separate stabilization and disposal for fines or clay particles, to the required TCLP and total metal limits. The only exception was the SSM, which may require separate stabilization and disposal of 20 percent of the soil to reduce the total TCLP lead concentrations appropriately. However, AETS successfully treated arsenic, cadmium, chromium, copper, nickel, and zinc in the soil.
- Treatment costs under expected process conditions range from $100 to $180 per cubic yard of soil, depending on the site size, soil types, and contaminant concentrations. Operating costs ranged from $50 to $80 per cubic yard.

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Fax: 412-826-5552

| | Soil | | | | |
|---|---|---|---|---|---|
| Metal | SSM | Butte | King of Prussia | Pedricktown | Palmerton |
| As | *,T,L | *,T,L | | | |
| Cd | *,T | | | | *,T,L |
| Cr | *,T,L | | ***,T,L** | *,T,L | |
| Cu | ***,T,L** | *,T,L | *,T,L | | *,T,L |
| Nl | *,T,L | | *,T,L | | |
| Pb | * | *,T,L | | ***,T,L** | *,T,L |
| Zn | ***,T,L** | *,T,L | | *,T,L | *,T,L |

Key: * -- Metal is present in that soil
T -- Successful treatment for total metals
L -- Reduction in leachability to below standards

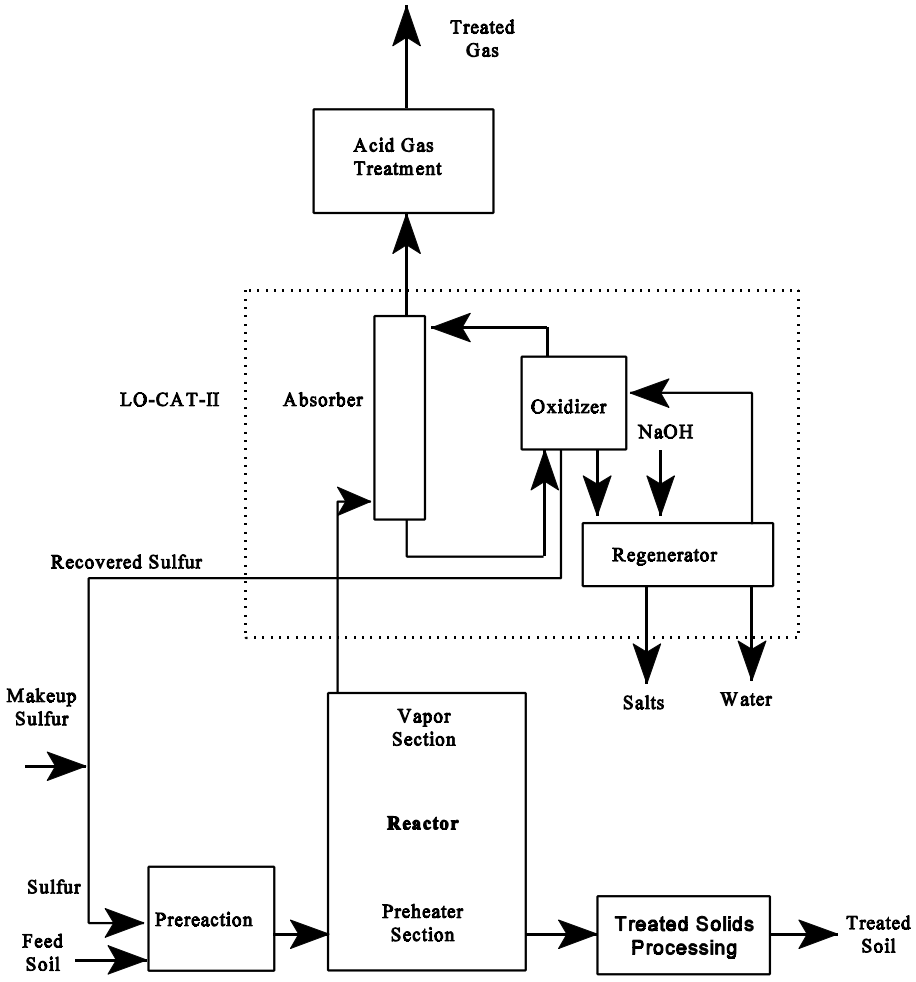
Boldface and larger font indicates high initial metals concentration (at least double the regulatory standards)

# CENTER FOR HAZARDOUS MATERIALS RESEARCH
## (Organics Destruction and Metals Stabilization)

## TECHNOLOGY DESCRIPTION:

This technology is designed to destroy hazardous organics in soils while simultaneously stabilizing metals and metal ions (see figure below). The technology causes contaminated liquids, soils, and sludges to react with elemental sulfur at elevated temperatures. All organic compounds react with sulfur. Hydrocarbons are converted to an inert carbon-sulfur powdered residue and hydrogen sulfide gas; treated chlorinated hydrocarbons also produce hydrochloric acid gas. These acid gases are recovered from the off-gases. The hydrogen sulfide is oxidized in a conventional acid gas treating unit (such as ARI Technologies LO-CAT™), recovering the sulfur for reuse.

In addition to destroying organic compounds, the technology converts heavy metals to sulfides, which are rendered less leachable. If required, the sulfides can be further stabilized before




Organics Destruction and Metals Stabilization



The SITE Program assesses but does not approve or endorse technologies.

disposal. Thus, heavy metals can be stabilized in the same process step as the organics destruction. The technology's main process components consist of the following:

- A prereaction mixer where the solid and reagent are mixed
- An indirectly heated, enclosed reactor that includes a preheater section to drive off water, and two integrated reactor sections to react liquid sulfur with the solids and further react desorbed organic compounds with vapor-phase sulfur
- An acid gas treatment system that removes the acid gases and recovers sulfur by oxidizing the hydrogen sulfide
- A treated solids processing unit that recovers excess reagent and prepares the treated product to comply with on-site disposal requirements

Initial pilot-scale testing of the technology has demonstrated that organic contaminants can be destroyed in the vapor phase with elemental sulfur. Tetrachloroethene, trichloroethene, and polychlorinated biphenyls were among the organic compounds destroyed.

Batch treatability tests of contaminated soil mixtures have demonstrated organics destruction and immobilization of various heavy metals. Immobilization of heavy metals is determined by the concentration of the metals in leachate compared to EPA toxicity characteristic leaching procedure (TCLP) regulatory limits. Following treatment, cadmium, copper, lead, nickel, and zinc were significantly reduced compared to TCLP values. In treatability tests with approximately 700 parts per million of Aroclor 1260, destruction levels of 99.0 to 99.95 percent were achieved. Destruction of a pesticide, malathion, was also demonstrated. The process was also demonstrated to be effective on soil from manufactured gas plants, containing a wide range of polynuclear aromatics.

The current tests are providing a more detailed definition of the process limits, metal concentrations, and soil types required for stabilization of various heavy metals to meet the limits specified by TCLP. In addition, several process enhancements are being evaluated to expand the range of applicability.

## WASTE APPLICABILITY:

The technology is applicable to soils and sediments contaminated with both organics and heavy metals.

## STATUS:

This technology was accepted into the SITE Emerging Technology Program in January 1993. Bench-scale testing in batch reactors was completed in 1993. The pilot-scale program was directed at integrating the process concepts and obtaining process data in a continuous unit. The program was completed in 1995 and the Emerging Technology Report will be available in 1997.

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# COGNIS, INC.
## (Biological/Chemical Treatment)

## TECHNOLOGY DESCRIPTION:

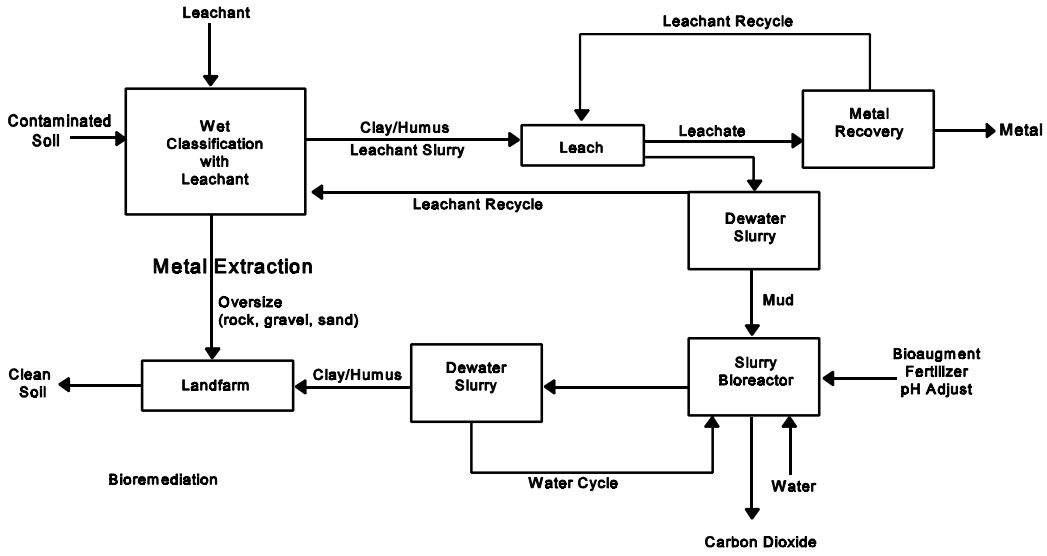
The COGNIS, Inc. biological/chemical treatment is a two-stage process that treats soils, sediments, and other media contaminated with metals and organics. Metals are first removed from the contaminated matrix by a chemical leaching process. Organics are then removed by bioremediation.

Although metals removal usually occurs in the first stage, bioremediation may be performed first if organic contamination levels are found to inhibit the metals extraction process. Bioremediation is more effective if the metal concentrations in the soil are sufficiently low so as not to inhibit microbial activity. However, even in the presence of inhibitory metal concentrations, a microbe population may be enriched to perform the necessary bioremediation.

Soil handling requirements for both stages are similar, so unit operations are fully reversible.

The final treatment products are a recovered metal or metal salt, biodegraded organic compounds, and clean soil. Contaminated soil is first exposed to a leachant solution and classified by particle size (see figure below). Size classification allows oversized rock, gravel, and sand to be quickly cleaned and separated from the sediment fines (such as silt, clay, and humus), which require longer leaching times. Typically, organic pollutants are also attached to the fines.

After dissolution of the metal compounds, metal ions such as zinc, lead, and cadmium are removed from the aqueous leachate by liquid ion exchange, resin ion exchange, or reduction. At this point, the aqueous leaching solution is freed of metals and can be reused to leach additional metal from the contaminated soil. If an extraction agent is used, it is later stripped of the bound metal and the agent is fully regenerated and recycled. Heavy metals are recovered in a saleable, concentrated form as solid metal or a metal salt. The method of metals recovery




Metal Leaching and Bioremediation Process



The SITE Program assesses but does not approve or endorse technologies.

depends on the metals present and their concentrations.

After metals extraction is complete, the "mud" slurry settles and is neutralized. Liquids are returned to the classifier, and the partially treated soil is transferred to a slurry bioreactor, a slurry-phase treatment lagoon, or a closed land treatment cell for bioremediation. The soil and the residual leachate solution are treated to maximize contaminant biodegradation. Nutrients are added to support microbial growth, and the most readily biodegradable organic compounds are aerobically degraded.

Bench-scale tests indicate that this process can remediate a variety of heavy metals and organic pollutants. The combined process is less expensive than separate metals removal and organic remediation.

## WASTE APPLICABILITY:

This remediation process is intended to treat combined-waste soils contaminated by heavy metals and organic compounds. The process can treat contaminants including lead, cadmium, zinc, and copper, as well as petroleum hydrocarbons and polynuclear aromatic hydrocarbons that are subject to aerobic microbial degradation. The combined process can also be modified to extract mercury and other metals, and to degrade more recalcitrant halogenated hydrocarbons.

## STATUS:

This remediation process was accepted into the SITE Emerging Technology Program in August 1992. Bench- and pilot-scale testing of the bioremediation process is complete. A full-scale field test of the metals extraction process was completed under the Demonstration Program. For further information on the full-scale process, refer to the profile in the Demonstration Program section.

This remediation process is no longer available through COGNIS, Inc. For further information about the process, contact the EPA Project Manager.

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# COGNIS, INC.
## (TERRAMET® Soil Remediation System)

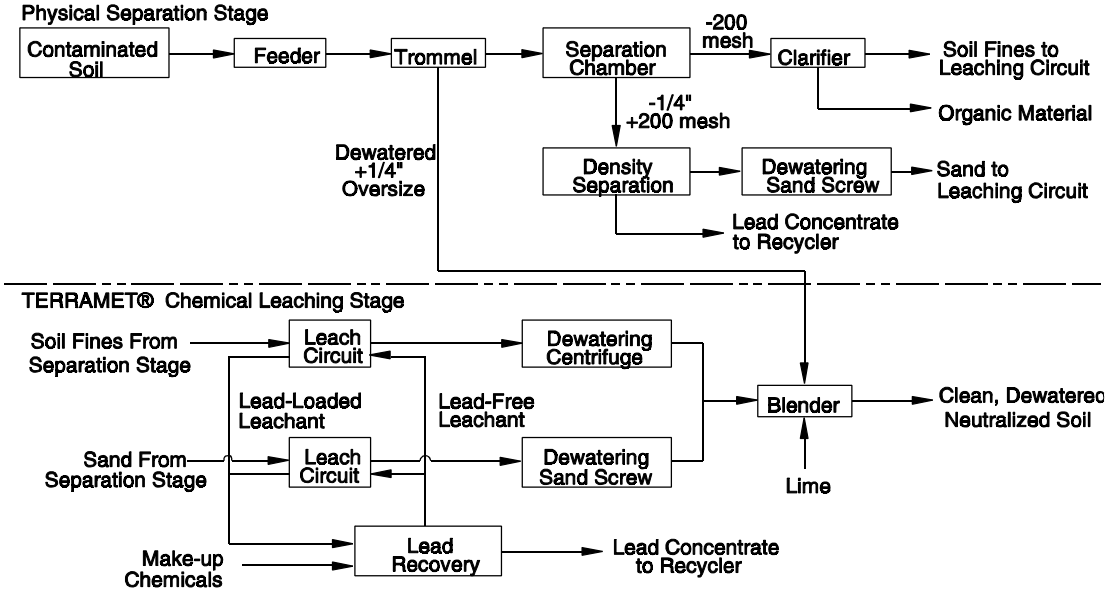
## TECHNOLOGY DESCRIPTION:

The COGNIS, Inc. (COGNIS), TERRAMET® soil remediation system leaches and recovers lead and other metals from contaminated soil, dust, sludge, or sediment. The system uses a patented aqueous leachant that is optimized through treatability tests for the soil and the target contaminant. The TERRAMET® system can treat most types of lead contamination, including metallic lead and lead salts and oxides. The lead compounds are often tightly bound by fine soil constituents such as clay, manganese and iron oxides, and humus.

The figure below illustrates the process. A pretreatment, physical separation stage may involve dry screening to remove gross oversized material. The soil can be separated into oversized (gravel), sand, and fine (silt, clay, and humus) fractions. Soil, including the oversized fraction, is first washed. Most lead contamination is typically associated with fines fraction, and this fraction is subjected to countercurrent leaching to dissolve the adsorbed lead and other heavy metal species. The sand fraction may also contain significant lead, especially if the contamination is due to particulate lead, such as that found in battery recycling, ammunition burning, and scrap yard activities. In this case, the sand fraction is pretreated to remove dense metallic or magnetic materials before subjecting the sand fraction to countercurrent leaching. Sand and fines can be treated in separate parallel streams.

After dissolution of the lead and other heavy metal contaminants, the metal ions are recovered from the aqueous leachate by a metal recovery process such as reduction, liquid ion exchange, resin ion exchange, or precipitation. The metal recovery technique depends on the metals to be recovered and the leachant employed. In most cases, a patented reduction process is used so that the metals are recovered in a compact form suitable for recycling. After the metals are recovered, the leachant can be reused within the TERRAMET® system for continued leaching.

Important characteristics of the TERRAMET® leaching/recovery combination are as follows: (1) the leachant is tailored to the substrate and the contaminant; (2) the leachant is fully recycled within the treatment plant; (3) treated soil can be returned on site; (4) all soil fractions can be treated; (5) end products include treated soil and recycled




TERRAMET® Soil Remediation System



The SITE Program assesses but does not approve or endorse technologies.

metal; and (6) no waste is generated during processing.

## WASTE APPLICABILITY:

The COGNIS TERRAMET® soil remediation system can treat soil, sediment, and sludge contaminated by lead and other heavy metals or metal mixtures. Appropriate sites include contaminated ammunition testing areas, firing ranges, battery recycling centers, scrap yards, metal plating shops, and chemical manufacturers. Certain lead compounds, such as lead sulfide, are not amenable to treatment because of their exceedingly low solubilities. The system can be modified to leach and recover other metals, such as cadmium, zinc, copper, and mercury, from soils.

## STATUS:

This technology was accepted into the SITE Emerging Technology Program in August 1992. Based on results from the Emerging Technology Program, the technology was accepted into the SITE Demonstration Program in 1994. The demonstration took place at the Twin Cities Army Ammunition Plant (TCAAP) Site F during August 1994. The TERRAMET® system was evaluated during a full-scale remediation conducted by COGNIS at TCAAP. The full-scale system was linked with a soil washing process developed by Brice Environmental Services Corporation (BESCORP). The system treated soil at a rate of 12 to 15 tons per hour. An Innovative Technology Evaluation Report describing the demonstration and its results will be available in 1998.

The TERRAMET® system is now available through Doe Run, Inc. (see contact information below). For further information about the development of the system, contact the Dr. William Fristad (see contact information below). For further information on the BESCORP soil washing process, refer to the profile in the Demonstration Program section (completed projects).

## DEMONSTRATION RESULTS:

Lead levels in the feed soil ranged from 380 to 1,800 milligrams per kilogram (mg/kg). Lead levels in untreated and treated fines ranged from 210 to 780 mg/kg and from 50 to 190 mg/kg, respectively. Average removal efficiencies for lead were about 75 percent. The TERRAMET® and BESCORP processes operated smoothly at a feed rate of 12 to 15 tons per hour. Size separation using the BESCORP process proved to be effective and reduced the lead load to the TERRAMET® leaching process by 39 to 63 percent. Leaching solution was recycled, and lead concentrates were delivered to a lead smelting facility. The cost of treating contaminated soil at the TCAAP site using the COGNIS and BESCORP processes is about $200 per ton of treated soil, based on treatment of 10,000 tons of soil. This cost includes the cost of removing ordnance from the soil.

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# COLORADO DEPARTMENT OF PUBLIC HEALTH AND ENVIRONMENT
## (developed by COLORADO SCHOOL OF MINES)
## (Constructed Wetlands-Based Treatment)

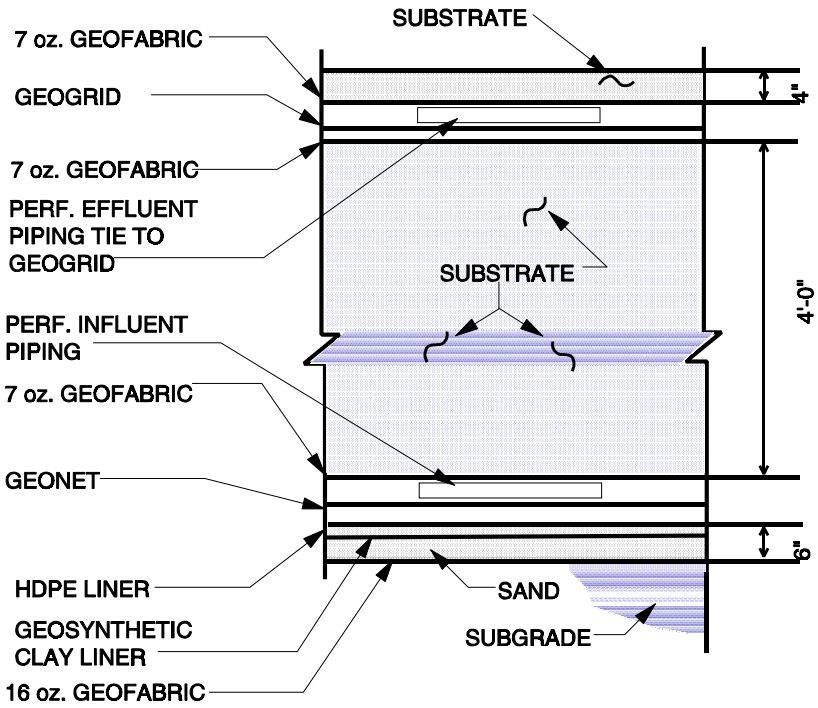
## TECHNOLOGY DESCRIPTION:

The constructed wetlands-based treatment technology uses natural geochemical and microbiological processes inherent in an artificial wetland ecosystem to accumulate and remove metals from influent waters. The treatment system incorporates principal ecosystem components found in wetlands, such as organic materials (substrate), microbial fauna, and algae.

Influent waters with high metal concentrations flow through the aerobic and anaerobic zones of the wetland ecosystem. Metals are removed by ion exchange, adsorption, absorption, and precipitation through geochemical and microbial oxidation and reduction. Ion exchange occurs as metals in the water contact humic or other organic substances in the soil medium. Oxidation and reduction reactions that occur in the aerobic and anaerobic zones, respectively, precipitate metals as hydroxides and sulfides. Precipitated and adsorbed metals settle in quiescent ponds or are filtered out as the water percolates through the soil or substrate.

## WASTE APPLICABILITY:

The constructed wetlands-based treatment process is suitable for acid mine drainage from metal or coal mining activities. These wastes typically contain high concentrations of metals and low pH. Wetlands treatment has been applied with some success to wastewater in the eastern United States. The process may have to be adjusted to account for differences in geology, terrain, trace metal composition, and climate in the metal mining regions of the western United States.




Schematic Cross Section of Pilot-Scale Upflow Cell



The SITE Program assesses but does not approve or endorse technologies.

## STATUS:

Based on the results of tests conducted during the SITE Emerging Technology Program (ETP), the constructed wetlands-based treatment process was selected for the SITE Demonstration Program in 1991. Results from the ETP tests indicated an average removal rate of 50 percent for metals. For further information on the ETP evaluation, refer to the Emerging Technology Summary (EPA/540/SR-93/523), the Emerging Technology Report (EPA/540/R-93/523), or the Emerging Technology Bulletin (EPA/540/F-92/001), which are available from EPA.

## DEMONSTRATION RESULTS:

Studies under the Demonstration Program evaluated process effectiveness, toxicity reduction, and biogeochemical processes at the Burleigh Tunnel, near Silver Plume, Colorado. Treatment of mine discharge from the Burleigh Tunnel is part of the remedy for the Clear Creek/Central City Superfund site. Construction of a pilot-scale treatment system began in summer 1993 and was completed in November 1993. The pilot-scale treatment system covered about 4,200 square feet and consisted of an upflow cell (see figure on previous page) and a downflow cell. Each cell treats about 7 gallons per minute of flow. Preliminary results indicated high removal efficiency (between 80 to 90 percent) for zinc, the primary contaminant in the discharge during summer operation. Zinc removal during the first winter of operation ranged from 60 to 80 percent.

Removal efficiency of dissolved zinc for the upflow cell between March and September remained above 90 percent; however, the removal efficiency between September and December 1994 declined to 84 percent due to the reduction in microbial activity in the winter months. The removal efficiency in the downflow cell dropped to 68 percent in the winter months and was between 70 and 80 percent during the summer months. The 1995 removal efficiency of dissolved zinc for the upflow cell declined from 84 percent to below 50 percent due to substrate hydrologic problems originating from attempts to insulate this unit during the summer months. A dramatic upset event in the spring of 1995 sent about four times the design flow through the upflow cell, along with a heavy zinc load. The heavy zinc load was toxic to the upflow cell and it never recovered to previous performance levels. Since the upset event, removal efficiency remained at or near 50 percent.

The 1995 removal efficiency of the downflow cell declined from 80 percent during the summer months to 63 percent during winter, again a result of reduced microbial activity. The 1996 removal efficiency of dissolved zinc calculated for the downflow cell increased from a January low of 63 percent to over 95 percent from May through August. The increase in the downflow removal efficiency is related to reduced flow rates through the downflow substrate, translating to increased residence time.

The SITE demonstration was completed in mid-1998, and the cells were decommissioned in August 1998. An Innovative Technology Evaluation Report for the demonstration will be available in 1999. Information on the technology can be obtained through below-listed sources.

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# COMMODORE APPLIED TECHNOLOGIES, INC.
## (Solvated Electron Technology, SET™ Remediation System)

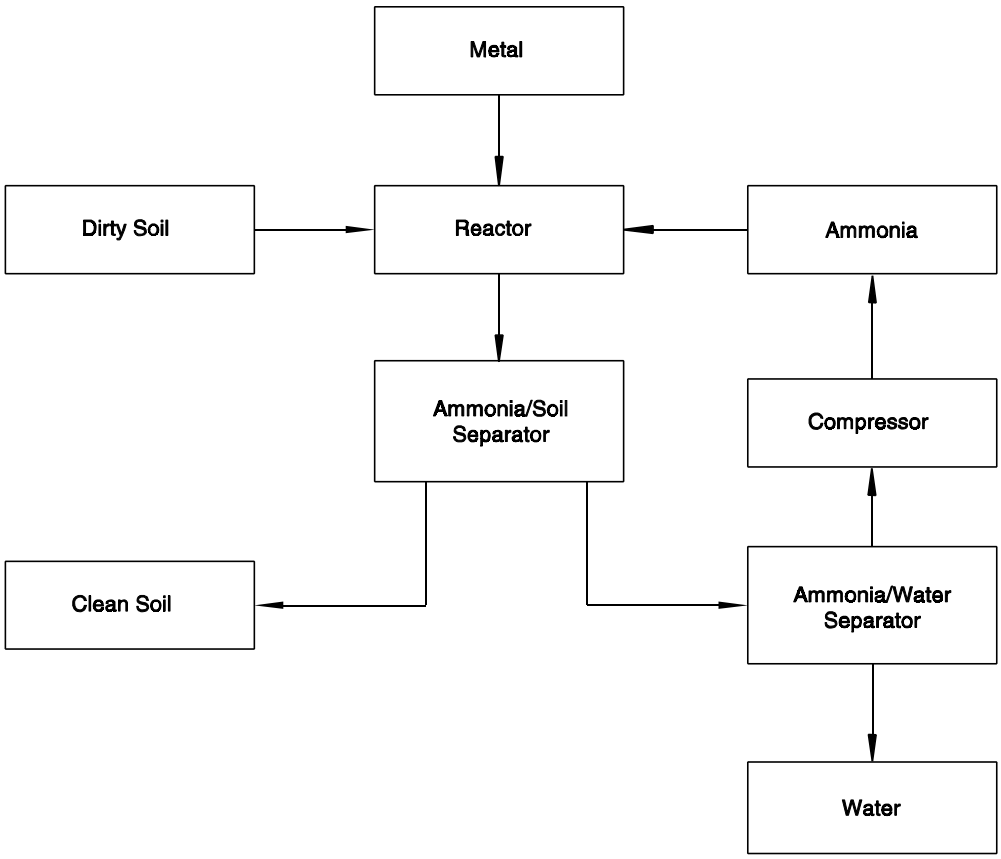
## TECHNOLOGY DESCRIPTION:

Commmodore Applied Technologies, Inc.'s (Commodore), solvated electron technology (SET™) remediation system chemically reduces toxic contaminants such as polychlorinated biphenyls (PCB), pesticides, and other halogenated compounds into benign substances. The solvating system uses a solution of ammonia and an "active" metal to create a powerful reducing agent that can clean up contaminated soils, sediments, and liquids.

A solvated electron solution is a liquid homogeneous mixture that produces a large supply of free electrons. It can be created by combining liquid ammonia with a metal such as sodium, calcium, lithium, or potassium. When a solvated electron solution is mixed with a contaminated material, the free electrons in the solution chemically convert the contaminant to relatively harmless substances and salts.

The SET™ process consists of components to move and recover the ammonia (such as piping, pumps, and tanks), along with reactor vessels which hold the contaminated medium and the solvating solution. The system can be transported to different field sites, but the process is performed ex situ, meaning that the contaminated medium must be introduced into the reactor vessels.

The treatment process begins by placing the contaminated medium into the reactor vessels, where the medium is then mixed with ammonia.




Schematic Diagram of the Solvated Electron Remediation System



The SITE Program assesses but does not approve or endorse technologies.

One of the reactive metals (usually sodium) is then added to the contaminated medium-ammonia mixture, and a chemical reaction ensues. After the chemical reaction is complete (about 1 minute), the ammonia is removed to a discharge tank for reuse. The treated medium is then removed from the reactor vessels, tested for contamination, and returned to the site.

## WASTE APPLICABILITY:

Commodore claims that its solvating electron remediation system can effectively decontaminate soils, sludges, sediments, oils, hand tools, and personal protective clothing. The technology chemically transforms PCBs, pesticides, and other halogenated compounds into relatively benign salts. Commodore also believes that the technology is effective in treating chemical warfare agents and radionuclides.

## STATUS:

Commodore was accepted into the SITE Demonstration Program in 1995 and is also participating in the Rapid Commercialization Initiative (RCI). RCI was created by the Department of Commerce, Department of Defense, Department of Energy, and EPA to assist in the integration of innovative technologies into the marketplace.

Commodore demonstrated the solvating system at the Construction Battalion Supply Center in Port Hueneme, California in September 1996. The demonstration was designed to evaluate the system's performance capability, costs, and design parameters. Results from the demonstration will be presented in an Innovative Technology Evaluation Report, which is available from EPA.

In October 1997, Commodore was awarded a contract to remediate mixed waste material at the U.S. Department of Energy site at Weldon Spring, Missouri using the SET™ technology.

A nationwide permit for the destruction of PCBs and metals in soils was issued for the SET™ process by the EPA in March, 1997. This permit was amended in May 1998 to include the destruction of PCBs in oil.

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# CONCURRENT TECHNOLOGIES
## (Formerly Center for Hazardous Materials Research)
## (Smelting Lead-Containing Waste)

## TECHNOLOGY DESCRIPTION:

Secondary lead smelting is a proven technology that reclaims lead from lead-acid battery waste sites. The Concurrent Technologies and Exide Corporation (Exide) have demonstrated the use of secondary lead smelting to reclaim usable lead from various types of waste materials from Superfund and other lead-containing sites. Reclamation of lead is based on existing lead smelting procedures and basic pyrometallurgy.

The figure below is a generalized process flow diagram. Waste material is first excavated from Superfund sites or collected from other sources. The waste is then preprocessed to reduce particle size and to remove rocks, soil, and other debris. Next, the waste is transported to the smelter.

At the smelter, waste is fed to reverberatory or blast furnaces, depending on particle size or lead content. The two reverberatory furnaces normally treat lead from waste lead-acid batteries, as well as other lead-containing material. The furnaces are periodically tapped to remove slag, which contains 60 to 70 percent lead, and a soft pure lead product.

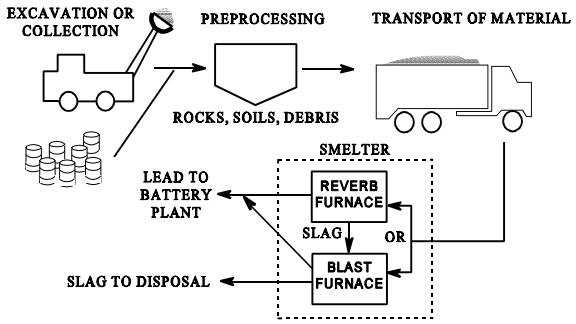
The two blast furnaces treat slag generated from the reverberatory furnaces, as well as larger-sized lead-containing waste. These furnaces aretapped continuously for lead and tapped intermittently to remove slag, which is transported offsite for disposal. The reverberatory and blast furnace combination at Exide can reclaim lead from batteries and waste with greater than 99 percent efficiency.

## WASTE APPLICABILITY:

The process has been demonstrated to reclaim lead from a variety of solid materials, including rubber battery case material, lead dross, iron shot abrasive blasting material, and wood from demolition of houses coated with lead paint. The technology is applicable to solid wastes containing more than 2 percent lead, provided that they do not contain excessive amounts of calcium, silica, aluminum, or other similar constituents. Explosive and flammable liquids cannot be processed in the furnace. As tested, this technology is not applicable to soil remediation.

## STATUS:

This technology was accepted into the SITE Emerging Technology Program in July 1991. Field work for the project was completed in February 1993.




Smelting Lead-Containing Waste Process



The SITE Program assesses but does not approve or endorse technologies.

The process was tested at three Superfund sites. Materials obtained from two additional sites were also used for these tests. Results from the Emerging Technology Program, presented in the table below, show that the process is applicable to waste materials at each site and economically feasible for all but demolition material. The Emerging Technology Bulletin (EPA/540/F-94/510), the Emerging Technology Summary (EPA/540/SR-95/504), and the Emerging Technology Report (EPA/540/R-95/504) are available from EPA. An article about the technology was also published by the *Journal of Hazardous Materials* in February 1995.

Specific technical problems encountered included (1) loss of furnace production due to material buildup within the furnaces, (2) breakdowns in the feed system due to mechanical overloads, and (3) increased oxygen demands inside the furnaces. All of these problems were solved by adjusting material feed rates or furnace parameters. Based on these tests, Concurrent Technologies has concluded that secondary lead smelting is an economical method of reclaiming lead from lead-containing waste material collected at Superfund sites and other sources.

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| Source of Material/ Type of Material Tested | % Lead | Economical* | Test Results |
|---|---|---|---|
| Tonolli Superfund site (PA)/ Battery cases | 3 to 7 | Yes | Lead can be reclaimed in secondary lead smelter; incorporated into regular blast furnace feed stock. |
| Hebalka Superfund site (PA)/ Battery cases | 10 | Yes | Lead can be reclaimed in secondary lead smelter; reduced in size and incorporated into regular reverberatory furnace feed stock. |
| Pedricktown Superfund site (NJ)/ Battery cases; lead dross, residue, and debris | 45 | Yes | Lead can be reclaimed in secondary lead smelter; screened and incorporated into regular reverberatory and blast furnace feed stocks. |
| Laurel House Women's Shelter (PA)/ Demolition material contaminated with lead-based paint. | 1 | No | Lead can be reclaimed in secondary lead smelter; however, the cost of processing the material was estimated to be very high. |
| PennDOT/ Abrasive bridge blasting material | 3 to 5 | Yes | Lead can be reclaimed in secondary lead smelter; incorporated into regular blast furnace feed stock. |

* Compared to stabilization or landfilling

Results from Field Tests of the Smelting Lead-Containing Waste Technology

# WESTERN RESEARCH INSTITUTE
## (Contained Recovery of Oily Wastes)

**TECHNOLOGY DESCRIPTION:**

The contained recovery of oily wastes (CROW®) process recovers oily wastes from the ground by adapting a technology used for secondary petroleum recovery and primary production of heavy oil and tar sand bitumen. Steam or hot water displacement moves accumulated oily wastes and water to production wells for aboveground treatment.

Injection and production wells are first installed in soil contaminated with oily wastes (see figure below). If contamination has penetrated into or below the aquifer, low-quality steam can be injected below the organic liquids to dislodge and sweep them upward into the more permeable aquifer soil regions. Hot water is injected above the impermeable regions to heat and mobilize the oily waste accumulation. The mobilized wastes are then recovered by hot water displacement.

When the organic wastes are displaced, organic liquid saturation in the subsurface pore space increases, forming a free-fluid bank. The hot water injection displaces the free-fluid bank to the production well. Behind the free-fluid bank, the contaminant saturation is reduced to an immobile residual saturation in the subsurface pore space. The extracted contaminant and water are treated for reuse or discharge.

During treatment, all mobilized organic liquids and water-soluble contaminants are contained within the original boundaries of waste accumulation. Hazardous materials are contained laterally by groundwater isolation and vertically by organic liquid floatation. Excess water is treated in compliance with discharge regulations.

The CROW® process removes large portions of contaminant accumulations; stops the downward and lateral migration of organic contaminants; immobilizes any remaining organic wastes as a residual saturation; and reduces the volume, mobility, and toxicity of the contaminants. The process can be used for shallow and deep areas, and can recover light and dense nonaqueous phase liquids. The system uses readily available mobile equipment. Contaminant removal can be increased by adding small quantities of selected biodegradable chemicals in the hot water injection.

In situ biological treatment may follow the displacement, which continues until groundwater contaminants are no longer detected in water samples from the site.

**WASTE APPLICABILITY:**

The CROW® process can be applied to manufactured gas plant sites, wood-treating sites, petroleum-refining facilities, and other areas with soils and aquifers containing light to dense organic liquids such as coal tars, pentachlorophenol (PCP) solutions, chlorinated solvents, creosote, and petroleum by-products. Depth to the contamination is not a limiting factor.

**STATUS:**

The CROW® process was tested in the laboratory and at the pilot-scale level under the SITE Emerging Technology Program (ETP). The process demonstrated the effectiveness of hot water displacement and the benefits of including chemicals with the hot water. Based on results from the ETP, the CROW® process was invited to participate in the SITE Demonstration Program. The process was demonstrated at the Pennsylvania Power and Light (PP&L) Brodhead Creek Superfund site at Stroudsburg, Pennsylvania.

The site contained an area with high concentrations of by-products from past operations. The demonstration began in July 1995; field work was completed in June 1996. Follow-up sampling was completed in 1998. The Innovative Technology Evaluation Report is available from EPA.

Sponsors for this program, in addition to EPA and PP&L, are the Gas Research Institute, the Electric Power Research Institute, and the U.S. Department of Energy. Remediation Technologies, Inc., assisted Western Research Institute with the demonstration.

Also, a pilot-scale demonstration was completed at a wood treatment site in Minnesota. Over 80 percent of nonaqueous phase liquids were removed in the pilot test, as predicted by treatability studies, and PCP concentrations decreased by 500 percent. The full-scale remediation for this site is underway. Early results show an organic removal rate an order-of-magnitude greater than conventional pump-and-treat processes. Several other sites are being evaluated.

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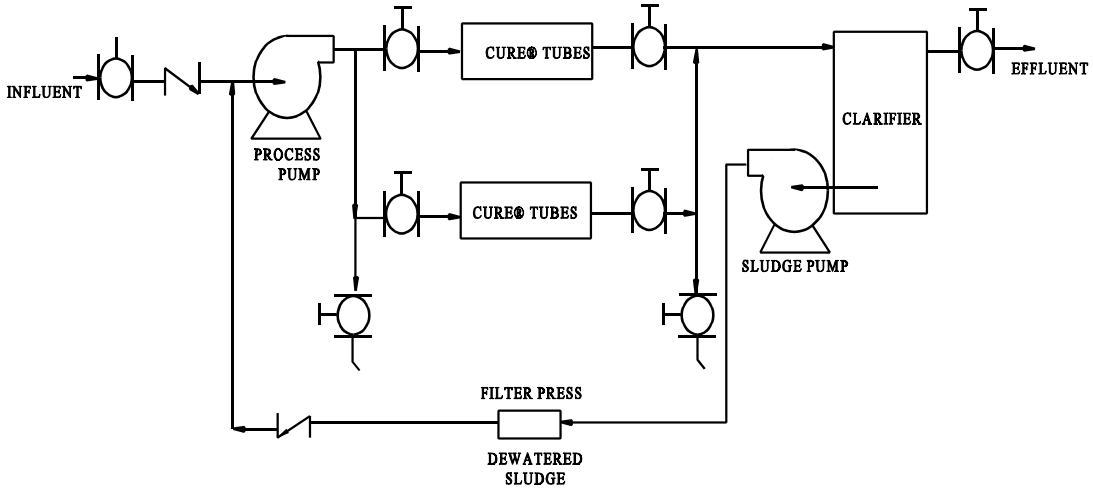
# CURE INTERNATIONAL, INC.
## (CURE®-Electrocoagulation Wastewater Treatment System)

## TECHNOLOGY DESCRIPTION:

The CURE® - Electrocoagulation (CURE®) system is designed to remove ionic metal species and other charged particles from water (see figure below). Because many toxic metal ions such as nickel, lead, and chromates are held in solution by electrical charges, they will precipitate out of solution if they are neutralized with oppositely charged ions. The CURE® system is effective at breaking oily emulsions and removing suspended solids. The system improves on previous electrocoagulation methods through a unique geometrical configuration.

The CURE® system's patented geometry maximizes liquid surface contact between the anode and concentric cathode electrocoagulation tubes, thus minimizing the power requirements for efficient operation. The CURE® system allows the contaminated water to flow continuously through the cathode tube, enabling a direct current to pass uniformly through a water system. The contaminated water then passes through the annular space between the cathode and anode tubes and is exposed to sequential positive and negative electrical fields. Typical retention time is less than 20 seconds. Water characteristics such as pH, oxidation-reduction potential, and conductivity can be adjusted to achieve maximum removal efficiencies for specific contaminants.

After the treated water exits the electrocoagulation tubes, the destabilized colloids are allowed to flocculate and are then separated with an integrated clarifier system. Polymers can be added to enhance flocculation, but in most cases they are not required. The sludge produced by this process is usually very stable and acid-resistant. Tests have shown that sludges produced by the CURE®




CURE®-Electrocoagulation System

system pass the toxicity characteristic leaching procedure (TCLP) and are often disposed of as nonhazardous waste.

## WASTE APPLICABILITY:

The CURE® system can treat a broad range of dissolved metals, including aluminum, arsenic, barium, cadmium, chromium, cyanide, iron, lead, nickel, uranium, and zinc. The system can also treat contaminants such as emulsified oils, suspended solids, paints, and dyes. Radionuclides were removed by the system at the Rocky Flats Environmental Technology Site (RFETS).

Because this system treats a wide range of contaminants, it is suited for industries and utilities such as plating, mining, electronics, industrial wastewater, as well as remediation projects.

## STATUS:

This technology was accepted into the SITE Demonstration Program in 1993. A bench-scale test of the technology was conducted in April 1995 to determine the ability of the system to remove radionuclides from solar evaporation water at RFETS. The system removed over 90 percent of uranium and plutonium from the test water. The technology was demonstrated during August and September 1995 at RFETS under a joint agreement between the Department of Energy, the State of Colorado, and EPA.

The technology has proven to be very effective in a diverse number of industrial applications including metal refinishing, oil treatment plants, acid mine drainage and cooling towers in the U.S. and internationally. Full or pilot scale units are available from CURE® International, Inc.

## DEMONSTRATION RESULTS:

During the SITE demonstration, four 3-hour test runs were conducted at RFETS over a 2-week period. Prior to the demonstration, operating parameters were adjusted during several optimization runs.

The demonstration showed that the system removed 30 to 50 percent of uranium and 60 to 99 percent of plutonium from the solar pond water at RFETS. The radionuclide and metal content of the dewatered sludge indicated that these contaminants were highly concentrated in the sludge. Uranium and plutonium were only slightly leachable by TCLP and no metals were leachable by TCLP. These results suggest that the sludge is very stable and resistant to breakdown.

The Demonstration Bulletin (EPA/540/MR-96/502), Technology Capsule (EPA/540/R-92/502a), and Innovative Technology Evaluation Report (EPA/540/R-96/502) are available from EPA.

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# DYNAPHORE, INC.
## (FORAGER® Sponge)

## TECHNOLOGY DESCRIPTION:

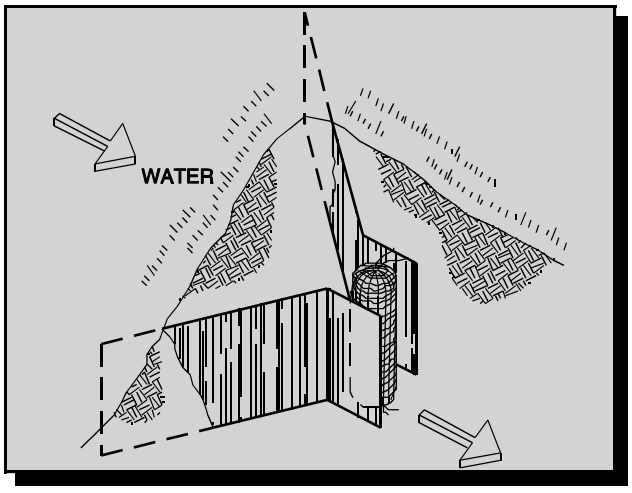
The FORAGER® Sponge (Sponge) is an open-celled cellulose sponge containing a polymer with selective affinity for dissolved heavy metals in both cationic and anionic states. The polymer contains iminodiacetic acid groups which enter into chelation bonding with transition-group heavy metal cations. The polymer's affinity for particular cations is influenced by solution parameters such as pH, temperature, and total ionic content. In general, the following affinity sequence for several representative ions prevails:

$Cd^{++} > Cu^{++} > Hg^{++} > Pb^{++} > Au^{+++} > Zn^{++} > Fe^{+++} > Ni^{++} > Co^{++} >> Al^{+++} > Ca^{++} > Mg^{++} >> Na^{+}$

During absorption, a cation is displaced from the polymer. The displaced cation may be $H^{+}$ or a cation below the absorbed cation in the affinity sequence.

The polymer also contains tertiary amine salt groups which exhibit selective bonding for anion species such as the following:

$CrO_4^{-2}$, $AsO_4^{-3}$, $Au(CN)_2^{-}$, $SeO_4^{-2}$, $HgCl_3^{-}$, $Ag(S_2O_3)^{-3}$, $SiO_3^{-2}$, $UO_4^{-2}$



Fishnet Bags Placed Vertically in a Well

The absorption of certain anion species can be enhanced by preabsorption of a cation that ordinarily reacts with a sought anion to produce a highly insoluble compound. For example, a Sponge presaturated with $Fe^{+3}$ strongly absorbs arsenate anion because ferric arsenate is highly insoluble.

The removal efficiency for transition-group heavy metals is about 90 percent at a flow rate of 0.1 bed volume per minute. The Sponge's highly porous nature speeds diffusional effects, promoting high rates of ion absorption. The Sponge can be used in columns, fishnet-type enclosures, or rotating drums. When used in a column, flow rates of three bed volumes per minute can be obtained at hydrostatic pressures only 2 feet above the bed and without additional pressurization. Therefore, Sponge-packed columns are suitable for unattended field use.

Absorbed ions can be eluted from the Sponge using techniques typically employed to regenerate ion-exchange resins and activated carbon. Following elution, the Sponge can be used in the next absorption cycle. The number of useful cycles depends on the nature of the absorbed ions and the elution technique used. Alternatively, the metal-saturated Sponge can be incinerated. In some instances, the Sponge may be dried and reduced in volume to facilitate disposal.

A trailer-mounted pump-and-treat apparatus can handle up to 10 gallons per minute with low pumping pressures of 4 to 10 pounds per square inch. The apparatus employs four or six Plexiglas columns, connected in series, with valving to expedite regeneration and staging. Each column accommodates a fishnet container of Sponge in the form of half-inch cubes. Groundwater can be remediated in situ using elongated fishnet bags that confine the Sponge. The bags are placed vertically in wells, as shown in the figure to the left, or placed horizontally in trenches, as shown in the figure on the next page. Alternatively, the groundwater can be treated aboveground in a packed column configuration.


The SITE Program assesses but does not approve or endorse technologies.

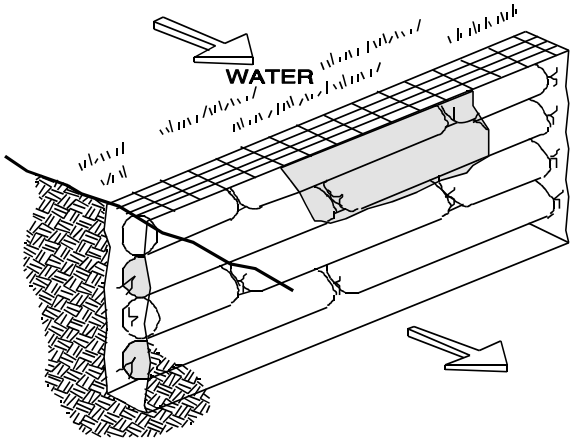
## WASTE APPLICABILITY:

The Sponge can scavenge metals in concentration levels of parts per million and parts per billion from industrial discharges, municipal sewage, process streams, and acid mine drainage. The Sponge is particularly useful when treating water with low contaminant levels, especially in polishing or end-of-pipe treatments. Because of the low capital investment required, the Sponge is well-suited for use in short-term remediation projects and for sporadic flow conditions.

## STATUS:

This technology was accepted into the SITE Demonstration Program in June 1991. The Sponge was demonstrated in April 1994 at the National Lead Industry site in Pedricktown, New Jersey. The Demonstration Bulletin (EPA/540/MR-94/522), Technology Capsule (EPA/540/R-94/522a), and Innovative Technology Evaluation Report (EPA/540/R-94/522) are available from EPA.

According to the developer, the Sponge has also effectively removed trace heavy metals from acid mine drainage at three locations in Colorado. In bench-scale tests, the Sponge reduced mercury, lead, nickel, cadmium, and chromium in groundwater from various Superfund sites to below detectable levels. The Sponge was also demonstrated in a field-scale installation at a photoprocessing operation. The process reduced chromate and silver by 75 percent at a cost of $1,100 per month. In bench-scale tests, the Sponge has removed lead, mercury, and copper from pourable sludges such as simulated municipal sewage, and from soils slurried with water.




Fishnet Bags Placed Horizontally in a Trench

## DEMONSTRATION RESULTS:

Treatment performance from the SITE demonstration was as follows:

| Analyte | Average Influence Concentration ($\mu$g/L) | Percent Removal |
|---|---|---|
| Cadmium | 537 | 90 |
| Copper | 917 | 97 |
| Lead | 578 | 97 |
| Chromium$^{III}$ | 426 | 32 |

In 1996, the Sponge, configured in a column, was employed in a pump-and-treat remediation of 360,000 gallons of water that had accumulated as a result of a fuel handling operation. The water, containing 0.2 parts per million (ppm) arsenic, was treated at 12 gallons per minute (0.1 bed volume per minute) to produce an effluent having a nondetect level of arsenic.

According to the developer, a newly developed modification of the Sponge (designated Grade 0) has proven effective in removing methyl tert-butyl ether (MTBE) from groundwater and in removing dense non-aqueous phase liquids (DNAPL) from stormwater. The sponge is currently being used in passive, end-of-pipe installations to remove nickel from electroplating effluents.

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The SITE Program assesses but does not approve or endorse technologies.

# ECOVA CORPORATION
## (Bioslurry Reactor)

## TECHNOLOGY DESCRIPTION:

The ECOVA Corporation (ECOVA) slurry-phase bioremediation (bioslurry) technology aerobically biodegrades creosote-contaminated materials. The technology uses batch and continuous flow bioreactors to process polynuclear aromatic hydrocarbon (PAH)-contaminated soils, sediments, and sludges. The bioreactors are supplemented with oxygen, nutrients, and a specific inoculum of enriched indigenous microorganisms to enhance the degradation process.

Because site-specific environments influence biological treatment, all chemical, physical, and microbial factors are designed into the treatment process. The ultimate goal is to convert organic wastes into relatively harmless by-products of microbial metabolism, such as carbon dioxide, water, and inorganic salts. Biological reaction rates are accelerated in a slurry system because of the increased contact efficiency between contaminants and microorganisms. The photograph below shows the bioslurry reactor.

## WASTE APPLICABILITY:

The bioslurry reactor is designed to treat highly contaminated creosote wastes. It can also treat other concentrated contaminants that can be aerobically biodegraded, such as petroleum wastes. The bioslurry reactor system must be engineered to maintain parameters such as pH, temperature, and dissolved oxygen within ranges conducive to the desired microbial activity.

## STATUS:

This technology was accepted into the SITE Demonstration Program in spring 1991. From May through September 1991, EPA conducted a

Bioslurry Reactor



The SITE Program assesses but does not approve or endorse technologies.

SITE demonstration using six bioslurry reactors at EPA's Test and Evaluation Facility in Cincinnati, Ohio.

ECOVA conducted bench- and pilot-scale studies to evaluate bioremediation of PAHs in creosote-contaminated soil from the Burlington Northern Superfund site in Brainerd, Minnesota. Bench-scale studies were conducted before pilot-scale evaluations to determine optimal treatment protocols. EIMCO Biolift™ slurry reactors were used for the pilot-scale processing. Data from the optimized pilot-scale program were used to establish treatment standards for K001 wastes as part of EPA's Best Demonstrated Available Technology program.

This technology is no longer available through ECOVA. However, the technology is being implemented by Walsh Environmental Scientists & Engineers. For further information on the technology, contact the EPA Project Manager.

## DEMONSTRATION RESULTS:

Results from the SITE demonstration indicated that slurry-phase biological treatment significantly improved biodegradation rates of carcinogenic 4- to 6-ring PAHs. The pilot-scale bioslurry reactor reduced 82 ±15 percent of the total soil-bound PAHs in the first week. After 14 days, total PAHs had been biodegraded by 96 ±2 percent. An overall reduction of 97 ±2 percent was observed over a 12-week treatment period, indicating that almost all biodegradation occurred within the first 2 weeks of treatment. Carcinogenic PAHs were biodegraded by 90 ±3.2 percent to 501 ±103 milligrams per kilogram (mg/kg) from levels of 5,081 ±1,530 mg/kg.

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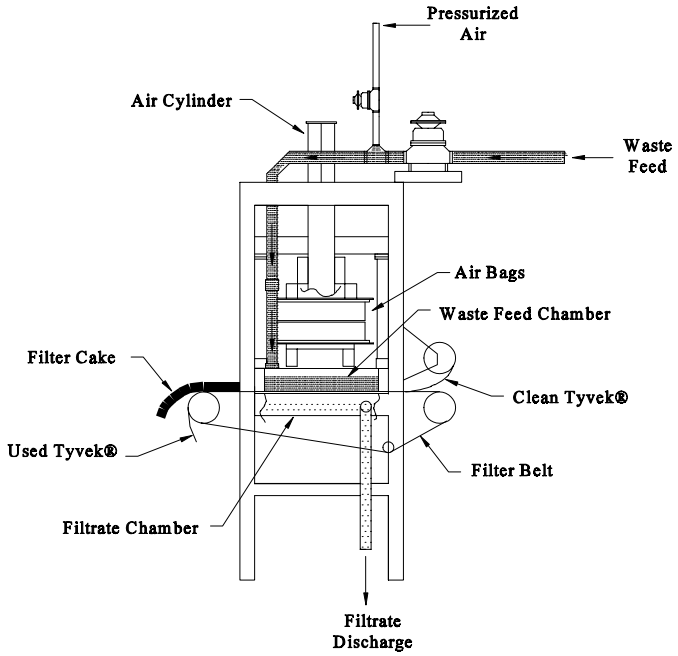
# E.I. DUPONT DE NEMOURS AND COMPANY, and OBERLIN FILTER COMPANY
## (Membrane Microfiltration)

## TECHNOLOGY DESCRIPTION:

This membrane microfiltration system is designed to remove solid particles from liquid wastes, forming filter cakes typically ranging from 40 to 60 percent solids. The system can be manufactured as an enclosed unit, requires little or no attention during operation, is mobile, and can be trailer-mounted.

The membrane microfiltration system uses an automatic pressure filter (developed by Oberlin Filter Company), combined with a special Tyvek® filter material (Tyvek® T-980) made of spun-bonded olefin (invented by E.I. DuPont de Nemours and Company) (see figure below). The filter material is a thin, durable plastic fabric with tiny openings about 1 ten-millionth of a meter in diameter. These openings allow water or other liquids and solid particles smaller than the openings to flow through. Solids in the liquid stream that are too large to pass through the openings accumulate on the filter and can be easily collected for disposal.

The automatic pressure filter has two chambers: an upper chamber for feeding waste through the filter, and a lower chamber for collecting the filtered liquid (filtrate). At the start of a filter cycle, the upper chamber is lowered to form a liquid-tight seal against the filter. The waste feed is then pumped into the upper chamber and through the filter. Filtered solids accumulate on the Tyvek® surface, forming a filter cake, while filtrate collects in the lower chamber. Following filtration, air is fed into the upper chamber at a pressure of about 45 pounds per square inch. Air removes any liquid remaining in the upper chamber and further dries the filter cake. When the filter cake is dry, the upper chamber is lifted, and the filter cake is automatically discharged. Clean filter material is then drawn from a roll into the system for the next cycle. Both the filter cake and the filtrate can be collected and treated further before disposal, if necessary.




Membrane Microfiltration System



The SITE Program assesses but does not approve or endorse technologies.

## WASTE APPLICABILITY:

This membrane microfiltration system may be applied to (1) hazardous waste suspensions, particularly liquid heavy metal- and cyanide bearing wastes (such as electroplating rinsewaters), (2) groundwater contaminated with heavy metals, (3) constituents in landfill leachate, and (4) process wastewaters containing uranium. The technology is best suited for treating wastes with solids concentrations of less than 5,000 parts per million; otherwise, the cake capacity and handling become limiting factors. The system can treat any type of solids, including inorganics, organics, and oily wastes, with a wide variety of particle sizes. Moreover, because the system is enclosed, it can treat liquid wastes that contain volatile organics.

## STATUS:

The membrane microfiltration system, accepted into the SITE Demonstration Program in 1988, was demonstrated at the Palmerton Zinc Superfund site in Palmerton, Pennsylvania. The demonstration was conducted over a 4-week period in April and May 1990. Groundwater from the shallow aquifer at the site was contaminated with dissolved heavy metals, including cadmium, lead, and zinc. This contaminated groundwater served as the feed waste for the demonstration. The system treated waste at a rate of about 1 to 2 gallons per minute.

The Applications Analysis Report (EPA/540/A5-90/007), the Technology Evaluation Report (EPA/540/5-90/007), and a videotape of the demonstration are available from EPA.

Since 1991, about 12 commercial installations of the technology have been operational.

## DEMONSTRATION RESULTS:

During the demonstration at the Palmerton Zinc Superfund site, the membrane microfiltration system achieved the following results:

- Removal efficiencies for zinc and total suspended solids ranged from 99.75 to 99.99 percent (averaging 99.95 percent).
- Solids in the filter cake ranged from 30.5 to 47.1 percent.
- Dry filter cake in all test runs passed the Resource Conservation and Recovery Act paint filter liquids test.
- Filtrate met the applicable National Pollutant Discharge Elimination System standards for cadmium, lead, zinc, and total suspended solids.
- A composite filter cake sample passed the extraction procedure toxicity and toxicity characteristic leaching procedure tests for metals.

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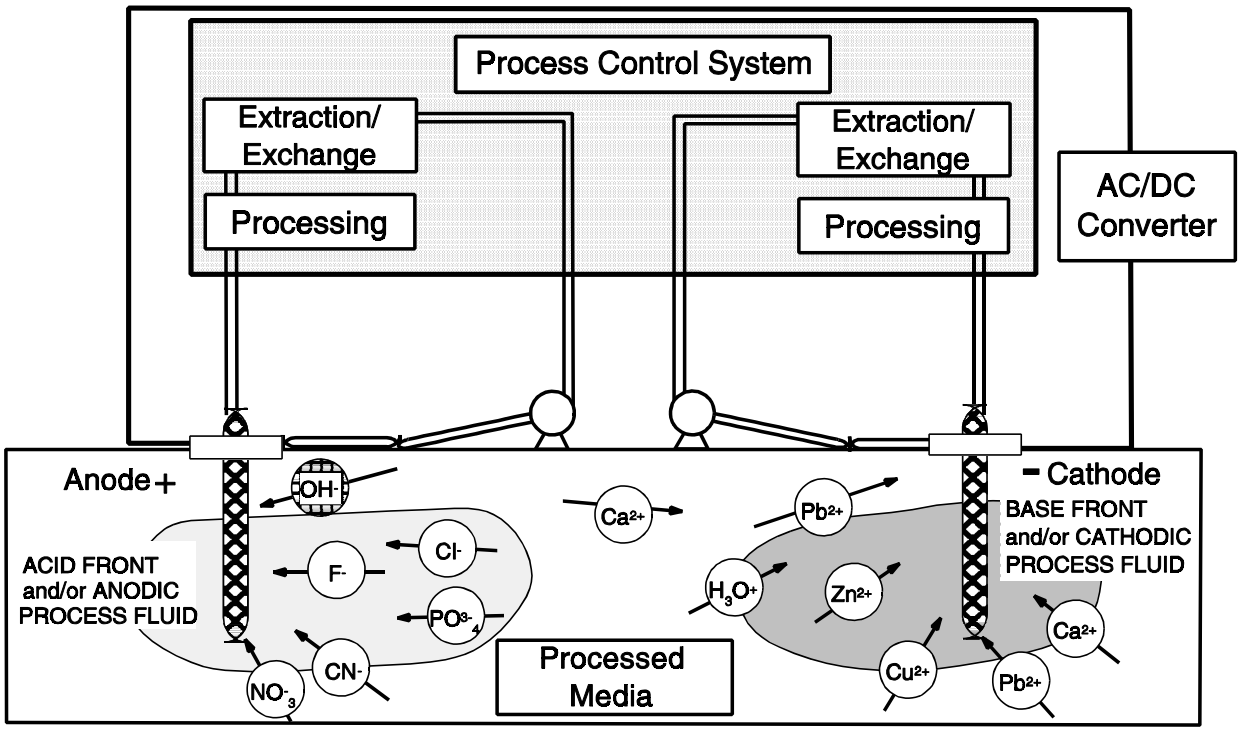
# ELECTROKINETICS, INC.
## (Electrokinetic Soil Processing)

## TECHNOLOGY DESCRIPTION:

Electrokinetic, Inc.'s, soil processes extract or remediate heavy metals and organic contaminants in soils. The process can be applied in situ or ex situ with suitable chemical agents to optimize the remediation. For example, conditioning fluids such as suitable acids may be used for electrode (cathode) depolarization to enhance the electrodeposition of certain heavy metals.

The figure below illustrates the field-processing scheme and the flow of ions to respective boreholes (or trenches). The mechanism of electrokinetic soil remediation for the removal of toxic metals involves the application of an electrical field across the soil mass. An in-situ generated acid causes the solubilization of metal salts into the pore fluid. The free ions are then transported through the soil by electrical migration towards the electrode of opposing charge. Metal species with a positive charge are collected at the cathode, while species with a negative charge are collected at the anode.

An acid front migrates towards the negative electrode (cathode), and contaminants are extracted through electroosmosis (EO) and electromigration (EM). The concurrent mobility of the ions and pore fluid decontaminates the soil mass. Electrokinetic remediation is extremely effective in fine-grained soils where other techniques such as pump and treat are not feasible. This is due to the fact that the contaminants are transported under charged electrical fields and not hydraulic gradients.




Electrokinetic Remediation Process



The SITE Program assesses but does not approve or endorse technologies.

Bench-scale results show that the process works in both unsaturated and saturated soils. Pore fluid flow moves from the positive electrodes (anodes) to the cathodes under the effect of the EO and EM forces. Electrode selection is important, since many metal or carbon anodes rapidly dissolve after contact with strong oxidants. When the removal of a contaminant is not feasible, the metal can be stabilized in-situ by injecting stabilizing agents or creating an electrokinetic "fence" (reactive treatment wall) that reacts with and immobilizes the contaminants.

## WASTE APPLICABILITY:

Electrokinetic soil processing extracts heavy metals, radionuclides, and other inorganic contaminants below their solubility limits. During bench-scale testing, the technology has removed arsenic, benzene, cadmium, chromium, copper, ethylbenzene, lead, mercury, nickel, phenol, trichloroethylene, toluene, xylene, and zinc from soils. Bench-scale studies under the SITE Emerging Technology Program demonstrated the feasibility of removing uranium and thorium from kaolinite.

Limited pilot-scale field tests resulted in lead and copper removal from clays and saturated and unsaturated sandy clay deposits. Treatment efficiency depended on the specific chemicals, their concentrations, and the buffering capacity of the soil. The technique proved 85 to 95 percent efficient when removing phenol at concentrations of 500 parts per million (ppm). In addition, removal efficiencies for lead, chromium, cadmium, and uranium at levels up to 2,000 micrograms per gram ranged between 75 and 98 percent.

## STATUS:

Based on results from the Emerging Technology Program, the electrokinetic technology was invited in 1994 to participate in the SITE Demonstration Program. For further information on the pilot-scale system, refer to the Emerging Technology Bulletin (EPA/540/F-95/504), which is available from EPA.The SITE demonstration began in July 1995 at an inactive firing range at the Fort Polk Army Ammunition Reservation in Louisiana. The soil at the site is contaminated with lead, copper, and zinc, which have accumulated over several decades. Concentrations of lead in the sandy clay soil range from 1,000 to 5,000 ppm and are less than 100 ppm at a 3-foot depth. A 20-foot by 60-foot area was remediated to a depth of 3 feet. This demonstration represents the first comprehensive study in the United States of an in situ electrokinetic separation technology applied to heavy metals in soils. Electrokinetics Inc. received the 1996 SBIR Phase II Quality Award from the Department of Defense for its technical achievement on this project.

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# ELI ECO LOGIC INC.
## (Gas-Phase Chemical Reduction Process)

## TECHNOLOGY DESCRIPTION:

The patented ELI Eco Logic Inc. (ECO LOGIC), Gas-Phase Chemical Reduction (GPCR) Process (see photograph below) uses a gas-phase reduction reaction of hydrogen with organic and chlorinated organic compounds at elevated temperatures to produce a hydrocarbon-rich gas product.

The GPCR is a non-incineration technology based upon the ability of hydrogen, at elevated temperatures, to chemically reduce organic and chlorinated organic molecules to primarily methane and hydrochloric acid. The destruction process takes place within a closed-loop system at normal atmospheric pressures with no uncontrolled emissions. As a result, the process involves no free oxygen and therefore eliminates the potential for formation of chlorinated dioxins and furans, which are more toxic than most materials being treated. Any dioxins and furans in the waste are also destroyed in the process.

Waste pretreatment technologies are incorporated into the process to vaporize the organic contaminants that are then carried in the vapor phase to the GPCR reactor for complete reduction. A Thermal Reduction Batch Processor (TRBP) is used to treat bulk solid materials such as drums and electrical equipment.

Watery wastes are preheated with boiler steam in a preheater vessel before injection into the reactor. Hot contaminated material exits the bottom of the vaporizer at a controlled flow rate and enters the reactor through atomizing nozzles. A liquid waste pumping system is used to inject high-strength oily waste directly into the reactor through the atomizing nozzles.

In the reactor, the vaporized organic compounds from the injection of liquid wastes or from the TRBP are chemically reduced in a hydrogen-rich environment to primarily methane and acidic gases. The gas leaving the GPCR reactor is scrubbed in caustic scrubber towers to remove acid gases, water, heat, and fine particulates. The scrubbed product gas is compressed and routed to the product gas storage tank and recycled as fuel to heat various system components.

ECO LOGIC's computerized process control system ensures protection of the workers and the public with its state-of-the-art instrumentation. This instrumentation continuously monitors critical system operating parameters and provides a continuous indication of destruction efficiency. A chemical ionization mass spectrometer and a micro gas chromatograph are used on-line as diagnostic tools for trace monitoring of organic compounds in the product gas stream.

Gas-Phase Chemical Remediation Process



The SITE Program assesses but does not approve or endorse technologies.

Process outputs are analytically tested onsite to ensure compliance with regulatory criteria prior to reuse in the system or off-site disposal. Treated solids are separated into metals and nonmetals, which are then recycled or sent to a landfill.

## WASTE APPLICABILITY:

The GPCR process converts organic hazardous waste into clean, reusable or safely disposable products. The process can eliminate most types of organic contaminant in liquids or bulk solid materials in an environmentally acceptable manner. ECO LOGIC has successfully performed numerous laboratory- and pilot-scale demonstrations on liquids, solids, and soils containing polychlorinated biphenyls, pesticides, chemical warfare agents or other complex hazardous organic contaminants.

## STATUS:

In October and November 1992, the ECO LOGIC process was demonstrated at the Middleground Landfill in Bay City, Michigan, under a Toxic Substances Control Act research and development permit. The Demonstration Bulletin (EPA/540/MR-93/522) and the Applications Analysis Report (EPA/540/AR-93/522) are available from EPA.

In 1995, the Western Australian government approved the setup of the first commercial-scale ECO LOGIC waste processing system in Kwinana, Western Australia. This unit treats DDT- and PCB-contaminated wastes.

In 1997, ECO LOGIC completed the treatment of over 1,000 tons of PCB-contaminated material at the General Motors of Canada Ltd facility in St. Catharines, Ontario. The materials treated included soil, sediment, and other granular solid material. As part of this project, the Province of Ontario's Ministry of Environment and Energy (MOEE) conducted regulatory testing to evaluate system performance during the treatment of high-strength PCB oil. The ECO LOGIC Process was capable of achieving a DRE of at least seven nines (99.99999 percent) for PCBs and at least six nines for chlorobenzenes in all tests. The MOEE also conducted an air monitoring survey in St. Catharines to determine PCB levels downwind of the treatment system. The MOEE survey concluded that PCBs were not impacting ambient air in the vicinity of the treatment site during treatment of high-strength PCB oil.

## DEMONSTRATION RESULTS:

During the Bay City demonstration, two separate waste feed conditions were used: (1) wastewater containing an average PCB concentration of 4,600 parts per million, and (2) waste oil containing an average PCB concentration of 24.5 percent. Both feeds were tested in triplicate. The demonstration of the ECO LOGIC process yielded the following results:

- At least 99.99 percent destruction and removal efficiency for PCBs during all runs
- A 99.99 percent destruction efficiency for perchloroethene, a tracer compound, during all runs
- Net destruction of trace feedstock dioxin and furan compounds during all runs

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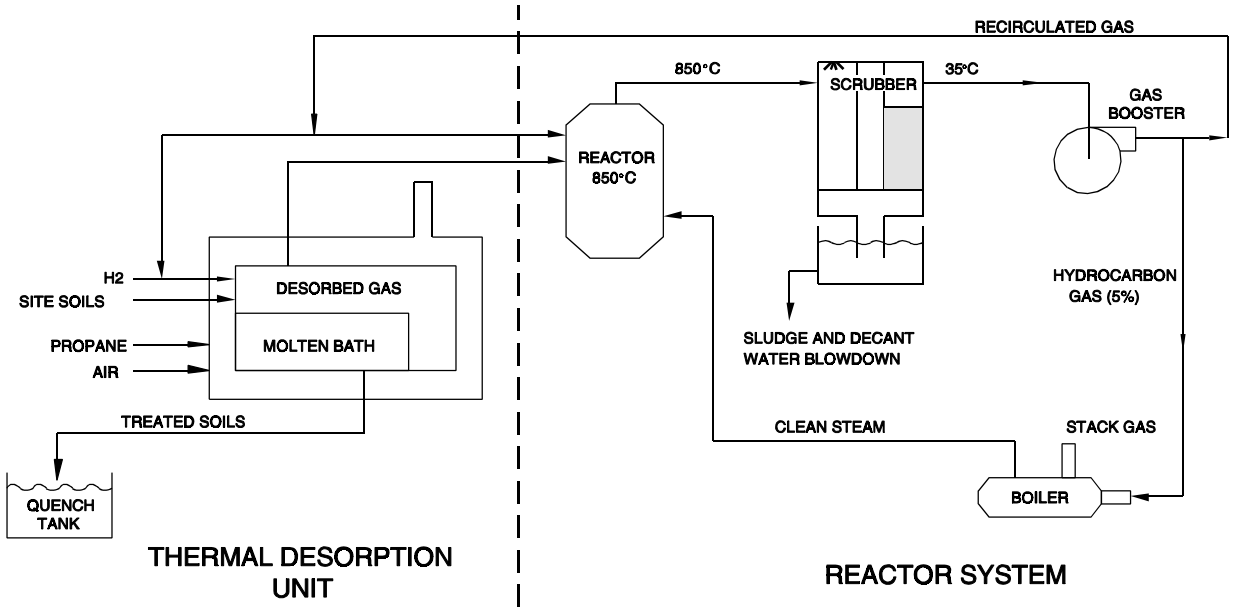
# ELI ECO LOGIC INTERNATIONAL INC.
## (Thermal Desorption Unit)

## TECHNOLOGY DESCRIPTION:

The ELI Eco Logic International Inc. (Eco Logic), thermal desorption unit (TDU) is specially designed for use with Eco Logic's gas-phase chemical reduction process. The TDU, shown in the figure below, consists of an externally heated bath of molten tin metal (heated with propane) in a hydrogen gas atmosphere. Tin is used for several reasons: tin and hydrogen are nonreactive; tin's density allows soils to float on the molten bath; molten tin is a good fluid for heat transfer; tin is nontoxic in soil; and tin is used as a bath medium in the manufacture of plate glass.

Contaminated soil is conveyed into the TDU feed hopper, where an auger feeds the soil into the TDU. A screw feeder provides a gas seal between the outside air and the hydrogen atmosphere inside the TDU. The auger's variable speed drive provides feed rate control. Soil inside the TDU floats on top of the molten tin and is heated to 600 °C, vaporizing the water and organic material. Decontaminated soil is removed from the tin bath into a water-filled quench tank. The water in the quench tank provides a gas seal between the TDU's hydrogen atmosphere and the outside air. A scraper mechanism removes decontaminated soil from the quench tank into drums.

After desorption from the soil, the organic contaminants are carried from the TDU to Eco Logic's proprietary gas-phase reduction reactor. In the reactor, the organic contaminants undergo gas-phase chemical reduction reactions with hydrogen at elevated temperatures and ambient pressure. This reaction converts organic and chlorinated organic contaminants into a hydrocarbon-rich gas product. After passing through a scrubber, the gas product's primary components are hydrogen, nitrogen, methane, carbon monoxide, water vapor, and other lighter hydrocarbons. Most of this gas product recirculates into the process, while excess gas can be compressed for later analysis and reuse as supplemental fuel. For further information on the Eco Logic gas-phase chemical reduction process, see the profile in the Demonstration Program section (completed projects).




Thermal Desorption Unit



The SITE Program assesses but does not approve or endorse technologies.

## WASTE APPLICABILITY:

The Eco Logic TDU, when used with the gas-phase chemical reduction reactor, is designed to desorb soils and sludges contaminated with hazardous organic contaminants such as polychlorinated biphenyls (PCB), polynuclear aromatic hydrocarbons, chlorinated dioxins and dibenzofurans, chlorinated solvents, chlorobenzenes, and chlorophenols. The combined technologies are suited for wastes with high water content since water is a good source of hydrogen.

## STATUS:

In October and November 1992, the Eco Logic process, including the TDU, was demonstrated at the Middleground Landfill in Bay City, Michigan, under a Toxic Substances Control Act research and development permit. The Demonstration Bulletin (EPA/540/MR-94/504) and the Applications Analysis Report (EPA/540/AR-94/504) are available from EPA.

Further research and development since the demonstration has focused on optimizing the process for commercial operations and improving the design of the soil and sediment processing unit. According to Eco Logic, the TDU design currently in commercial operation has achieved excellent results, with contaminants in soils and sediments desorbed from high parts per million (ppm) levels to low parts per billion levels.

Two commercial-scale SE25 treatment units are currently in operation: one in Perth, Western Australia, and the other at a General Motors of Canada Ltd (GMCL) facility in Ontario. Both are currently treating a variety of waste matrices including DDT residues and PCBs in soils, oils, electrical equipment, concrete, and other solids. Following the GMCL project, the unit will be relocated to Toronto, Ontario where General Electric (GE) and Eco Logic have a contract to destroy PCB-impacted materials stored aboveground at GE's Lansdowne and Davenport facilities.

Eco Logic also has teamed with Westinghouse Electric to treat chemical warfare agents using the process. Eco Logic has been awarded a contract through the Department of Energy's Morgantown Energy Technology Center for treatment of hazardous wastes, radioactive mixed low-level wastes, and energetics-explosives.

## DEMONSTRATION RESULTS:

During the demonstration in Bay City, Michigan, the Eco Logic TDU achieved the following:

- Desorption efficiencies for PCBs from the soil of 93.5 percent in run one and 98.8 percent in run two
- Desorption efficiency for hexachlorobenzene (a tracer compound) from the soil of 72.13 percent in run one and 99.99 percent in run two
- PCB destruction and removal efficiencies of 99.99 percent for the combined TDU and reduction reactor

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# ENERGIA, INC.
## (Reductive Photo-Dechlorination Treatment)

## TECHNOLOGY DESCRIPTION:

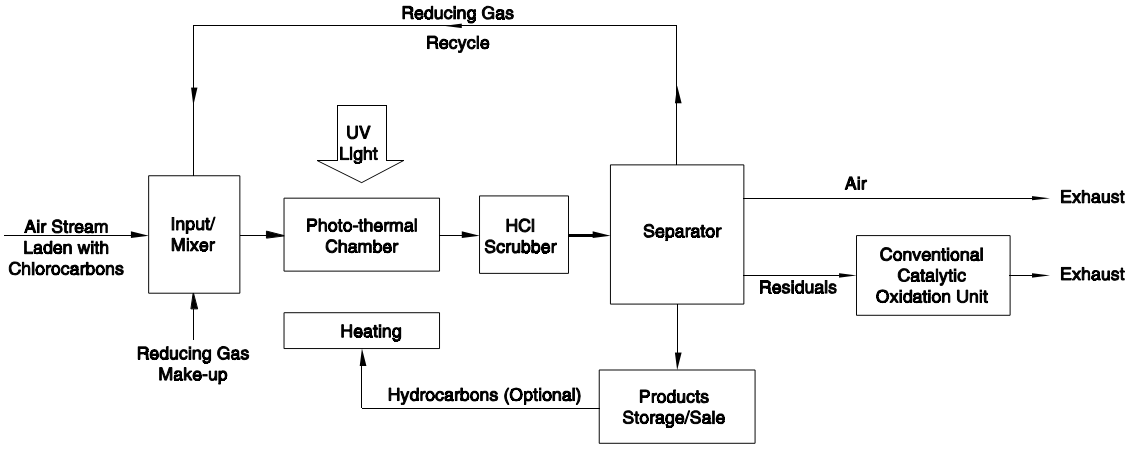
The Reductive Photo-Dechlorination (RPD) treatment uses ultraviolet (UV) light in a reducing atmosphere and at moderate temperatures to treat waste streams containing chlorinated hydrocarbons (CIHC). Because CIHCs are destroyed in a reducing environment, the only products are hydrocarbons and hydrogen chloride (HCl).

The RPD process is depicted in the figure below. The process consists of five main units: (1) input/mixer (2) photo-thermal chamber (3) HCl scrubber (4) separator and (5) products storage and recycling. Chlorinated wastes may be introduced into the process in one of three ways: vapor, liquid, or bound to an adsorbent, such as activated carbon.

Air laden with chlorocarbon vapors is first passed through a condenser, which removes chlorinated materials as liquids. Chlorocarbon liquids are fed into a vaporizer, mixed with a reducing gas, and passed into the photo-thermal chamber.

Chlorinated contaminants adsorbed onto activated carbon are purged with reducing gas and mildly heated to induce vaporization. The ensuing vapors are then fed into the photo-thermal chamber.

The photo-thermal chamber is the heart of the RPD process because all reactions central to the process occur in this chamber. Saturated, olefinic, or aromatic chlorocarbons with one or more carbon-chlorine bonds are exposed to UV light, heat, and a reducing atmosphere, such as hydrogen gas or methane. According to ENERGIA, Inc., carbon-chlorine bonds are broken, resulting in chain-propagating hydrocarbon reactions. Chlorine atoms are eventually stabilized as HCl, which is easily removed in a scrubber. Hydrocarbons may hold their original structures, rearrange, cleave, couple, or go through additional hydrogenation. Hydrocarbons produced from the dechlorination of wastes include ethane, acetylene, ethene, and methane. Valuable hydrocarbon products can be stored, sold, or recycled as auxiliary fuel to heat the photo-thermal chamber.




Reductive Photo-Dechlorination (RPD) Treatment



The SITE Program assesses but does not approve or endorse technologies.

## WASTE APPLICABILITY:

The RPD process is designed specifically to treat volatile chlorinated wastes in the liquid, gaseous, or adsorbed states. The RPD process was tested on methyl chloride, dichloromethane (DCM), chloroform, carbon tetrachloride, trichloroethane (TCA), dichloroethene (PCE), and trichloroethene (TCE).

Field applications include treatment of organic wastes discharged from soil vapor extraction operations, vented from industrial hoods and stacks, and adsorbed on activated carbon. The process can be used to (1) treat gas streams containing chlorinated hydrocarbons, and (2) pretreat gas streams entering catalytic oxidation systems by reducing chlorine content and protecting the catalyst against poisoning.

In comparison to other photo-thermal processes (such as reductive photo-thermal oxidation [RPTO] and photo-thermal oxidation [PTO]), the RPD process is mostly applicable to streams without air and very high concentrations of contaminants (bulk down to greater than 1 percent). At very low concentrations (parts per million) and in the presence of air, the other photo-thermal processes may more cos- effective.

## STATUS:

Bench-scale experiments were conducted on several contaminants (such as DCM, DCE, TCA, and TCE). Measurements of concentrations of parent compounds and products as a function of residence time were obtained at several test conditions. From these measurements, conversion and dechlorination efficiencies were determined at optimal operating conditions.

Experimental results on a representative chlorocarbon contaminant (TCA) are available in the Emerging Technology Bulletin (EPA/540/F-94/508). Greater than 99 percent conversion and dechlorination were demonstrated with high selectivity towards two saleable hydrocarbon products, ethane and methane. Similar favorable results were obtained for other saturated and unsaturated chlorocarbons treated by the RPD process.

Results of a cost analysis based on experimental data indicate that the RPD process is extremely cost competitive. For example, the cost of treating TCE concentrations of 1,000 ppm and 10,000 ppm is $1.10 and $0.25 per pound treated, respectively. The cost per 1,000 cubic feet of contaminated stream with 1,000 ppm is $0.38 and $0.88, respectively.

All technical data have been gathered and optimization has been completed. Design and assembly of a pilot-scale prototype are underway. The field demonstration may take place during 1999. The developer is seeking appropriate sites for field demonstration. After successful demonstration, the RPD process will be ready for full-scale commercialization.

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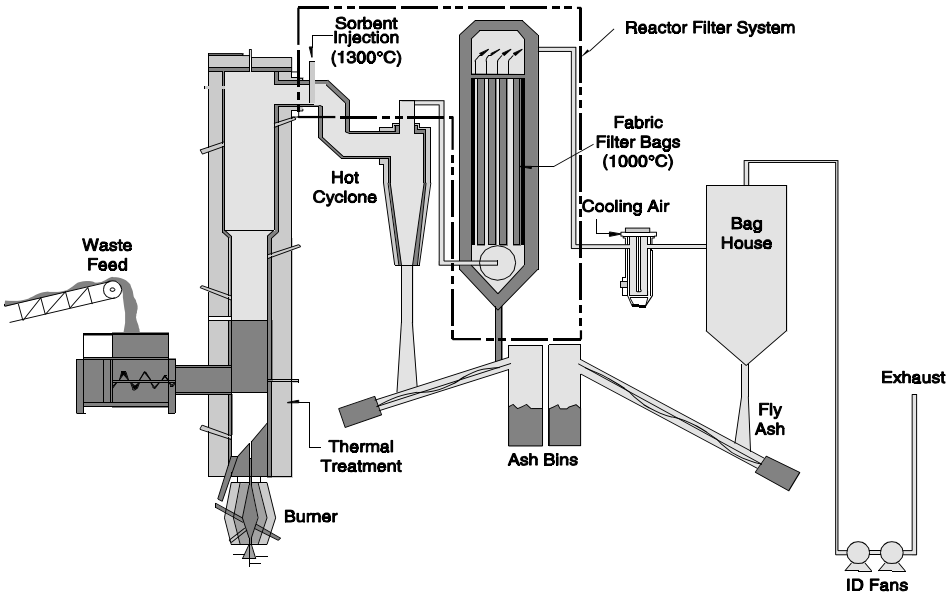
# ENERGY AND ENVIRONMENTAL RESEARCH CORPORATION
## (Reactor Filter System)

## TECHNOLOGY DESCRIPTION:

The Energy and Environmental Research Corporation (EER) Reactor Filter System (RFS) technology is designed to control gaseous and entrained particulate matter emissions from the primary thermal treatment of sludges, soils, and sediments. Most Superfund sites are contaminated with toxic organic chemicals and metals. Currently available thermal treatment systems for detoxifying these materials release products of incomplete combustion (PIC) and volatile toxic metals. In addition, the large air pollution control devices (APCD) often required to control PICs and metals are generally not suitable for transport to remote Superfund sites. EER designed the RFS to avoid some of these logistical problems. The RFS uses a fabric filter installed immediately downstream of the thermal treatment process; the filter controls toxic metals, particulates, and unburned organic species. The RFS involves the following three steps:

- First, solids are treated with a primary thermal process, such as a rotary kiln, fluidized bed, or other system designed for thermal treatment.
- Next, a low-cost, aluminosilicate sorbent, such as kaolinite, is injected into the flue gases at temperatures near 1,300 °C (2,370 °F). The sorbent reacts with volatile metal species such as lead, cadmium, and arsenic in the gas stream; the metals chemically adsorb onto the surfaces of the sorbent particles. This adsorbtion forms insoluble, nonleachable alumino-silicate complexes similar to cementitious species.
- Finally, fabric filtration, operating at temperatures up to 1,000 °C (1,830 °F) provides additional residence time for the sorbent/metalreaction, producing nonleachable by-products. This step also provides additional time for the destruction of organic compounds associated with particulate matter, reducing ash toxicity.




Example Application of RFS Equipment



The SITE Program assesses but does not approve or endorse technologies.

Because of the established link between PIC formation and gas-particle chemistry, this process can virtually eliminate potential polychlorinated dioxin formation.

The RFS may improve the performance of existing thermal treatment systems for Superfund wastes containing metals and organics. During incineration, hazardous organics are often attached to the particulate matter that escapes burning in the primary zone. The RFS provides sufficient residence time at sufficiently high temperatures to destroy such organics. Also, by increasing gas-solid contact parameters, the system can decrease metal emissions by preventing the release of metals in vapors or retained on entrained particles.

The figure on the previous page shows the RFS installed immediately downstream of the primary thermal treatment zone at EER's Spouted Bed Combustion Facility. Because the spouted bed generates a highly particulate-laden gas stream, a high-temperature cyclone is used to remove coarse particulate matter upstream of the RFS. Sorbent is injected into the flue gas upstream of the high temperature fabric filter. A conventional baghouse was available for comparison with RFS performance during the demonstration. However, the baghouse is not needed in typical RFS applications because the high-temperature filtration medium has shown similar performance to conventional fabric filtration media.

## WASTE APPLICABILITY:

The RFS is designed to remove entrained particulates, volatile toxic metals, and condensed-phase organics present in high-temperature (800 to 1,000 °C) gas streams generated from the thermal treatment of contaminated soils, sludges, and sediments. Many conventional treatments can be combined with the RFS technology. Process residuals will consist of nonleachable particulates that are essentially free of organic compounds, thus reducing toxicity, handling risks, and landfill disposal.

## STATUS:

The RFS was accepted into the Emerging Technology Program in 1993. EER developed the pilot-scale process through a series of bench-scale screening studies, which were completed in September 1994. The screening studies guided the sorbent selection and operating conditions for the pilot-scale demonstration. The tests were completed in 1996; the final report will be available from the National Technical Information Service.

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# ENERGY AND ENVIRONMENTAL RESEARCH CORPORATION
## (Hybrid Fluidized Bed System)

## TECHNOLOGY DESCRIPTION:

The Hybrid Fluidized Bed (HFB) system treats contaminated solids and sludges by incinerating organic compounds and extracting and detoxifying volatile metals. The system consists of three stages: a spouted bed, a fluidized afterburner, and a high-temperature particulate soil extraction system.

First, the spouted bed rapidly heats solids and sludges to allow extraction of volatile organic and inorganic compounds. The spouted bed retains larger soil clumps until they are reduced in size but allows fine material to pass through quickly. This segregation process is beneficial because organic contaminants in fine particles vaporize rapidly. The decontamination time for large particles is longer due to heat and mass transfer limitations.

The central spouting region is operated with an inlet gas velocity of greater than 150 feet per second. This velocity creates an abrasion and grinding action, rapidly reducing the size of the feed materials through attrition. The spouted bed operates between 1,500 and 1,700 °F under oxidizing conditions.

Organic vapors, volatile metals, and fine soil particles are carried from the spouted bed through an open-hole type distributor, which forms the bottom of the second stage, the fluidized bed afterburner. The afterburner provides sufficient retention time and mixing to incinerate the organic compounds that escape the spouted bed, resulting in a destruction and removal efficiency of greater than 99.99 percent. The afterburner also contains bed materials that absorb metal vapors, capture fine particles, and promote formation of insoluble metal silicates. The bed materials are typically made of silica-supported bauxite, kaolinite, or lime.

In the third stage, the high-temperature particulate soil extraction system removes clean processed soil from the effluent gas stream with one or two hot cyclones. Clean soil is extracted hot to prevent unreacted volatile metal species from condensing in the soil. Off-gases are then quenched and passed through a conventional baghouse to capture the condensed metal vapors.

Generally, material handling problems create major operational difficulties for soil cleanup devices. The HFB system uses a specially designed auger feed system. Solids and sludges are dropped through a lock hopper system into an auger shredder, which is a rugged, low-revolutions-per-minute, feeding-grinding device. Standard augers are simple and reliable, but often they are susceptible to clogging from feed compression in the auger. In the HFB system, the auger shredder is close-coupled to the spouted bed to reduce compression and clump formation during feeding. The close-couple


The SITE Program assesses but does not approve or endorse technologies.

arrangement locates the tip of the auger screw several inches from the internal surface of the spouted bed, preventing the formation of soil plugs.

## WASTE APPLICABILITY:

This technology is applicable to soils and sludges contaminated with organic and volatile inorganic contaminants. Nonvolatile inorganics are not affected.

## STATUS:

This technology was accepted into the SITE Emerging Technology Program in January 1990. Design and construction of the commercial prototype HFB system and a limited shakedown are complete. The Emerging Technology Bulletin (EPA/540/F-93/508) is available from EPA.

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# ENVIROMETAL TECHNOLOGIES INC.
## (In Situ and Ex Situ Metal-Enhanced Abiotic Degradation of Dissolved Halogenated Organic Compounds in Groundwater)

## TECHNOLOGY DESCRIPTION:

This remedial technology, developed by the University of Waterloo and EnviroMetal Technologies Inc., degrades dissolved halogenated organic compounds in groundwater with an in situ permeable wall containing reactive metal (usually iron) (see photograph below). The technology may also be used in an aboveground reactor for ex situ treatment.

The technology employs an abiotic electrochemical process. Contaminated groundwater passes through the specially prepared granular reactive iron, which oxidizes, inducing reductive dehalogenation of contaminants. Halogenated organics are degraded to nonhazardous substances, preventing contaminants from migrating further downstream. Observed degradation rates are several times higher than those reported for natural abiotic degradation processes.

In most in situ applications of this technology, groundwater moves naturally through the permeable subsurface wall or is directed by flanking impermeable sections such as sheet piles or slurry walls. This passive remediation method is a cost-effective alternative to conventional pump-and-treat methods. Aboveground reactor vessels employing this technology may replace or add to treatment units in conventional pump-and-treat systems.

Process residuals may include dissolved ethane, ethene, methane, hydrogen gas, chloride, and ferrous iron. Because contaminants are degraded to nonhazardous substances and not transferred to another medium, this process eliminates the need for waste treatment or disposal.

## WASTE APPLICABILITY:

The process was developed to treat dissolved halogenated organic compounds in groundwater.

**Figure 37**

Installation of Pilot-Scale In Situ Treatment System
at an Industrial Facility in Northeast United States



The SITE Program assesses but does not approve or endorse technologies.

The technology has degraded a wide variety of chlorinated alkanes and alkenes, including trichloroethene (TCE), tetrachloroethene (PCE), vinyl chloride, 1,1,1-trichloroethane, and 1,2-dichloroethene (DCE). The technology also degrades other organic contaminants, including Freon-113, ethylene dibromide, certain nitroaromatics, and N-nitrosodimethylamine.

This technology was accepted into the SITE Demonstration Program in spring 1993. A pilot-scale demonstration of the aboveground reactor (ex situ) technology took place from November 1994 to February 1995 at an industrial facility in New Jersey. Groundwater at the facility contained dissolved TCE and PCE.

A second SITE demonstration was performed in New York from May through December 1995. A pilot-scale in situ permeable wall was installed in a shallow sand and gravel aquifer containing TCE, DCE, vinyl chloride, and 1,1,1-trichloroethane. This project may eventually be expanded to full-scale.

A successful permeable in situ wall was installed at the Canadian Forces Base Borden test site in June 1991. The technology removed about 90 percent of the TCE and PCE from groundwater passing through the reactive iron wall. The wall has performed consistently for 5 years. More than 400 sites have been identified where the technology could be applied. Over 75 successful bench-scale feasibility tests have been completed using groundwater from industrial and government facilities in the United States and Canada.

The first full-scale commercial in situ installation of this technology was completed at an industrial facility in California in December 1994. Since that time, twelve additional full-scale in situ systems and ten pilot-scale systems have been installed in locations including Colorado, Kansas, North Carolina and Belfast, Northern Ireland. Aboveground treatment systems have been proposed at sites in the U.S. and Germany.

## DEMONSTRATION RESULTS:

During the New Jersey (ex situ) demonstration, about 60,833 gallons of groundwater was treated during 13 weeks of sampling. Conversion efficiency of PCE during the demonstration period exceeded 99.9 percent. Vinyl chloride and cis-1,2-dichloroethene occasionally exceeded the New Jersey Department of Environmental Protection limits. This exceedance may have been caused by a reduction in the iron's reactive capacity due to precipitate formation. Complete demonstration results are published in the Technology Capsule and Innovative Technology Evaluation Report (ITER), which is available from EPA.

For the New York (in situ) demonstration, preliminary data indicate a significant reduction in all critical contaminants present, and no apparent decrease in removal efficiency over the seven month demonstration period. Results of the in situ demonstration of the process are published in an ITER that is available from EPA.

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# ENVIRONMENTAL BIOTECHNOLOGIES, INC.
## (Fungal Degradation Process)

## TECHNOLOGY DESCRIPTION:

Polycyclic aromatic hydrocarbons (PAH) are typical pollutants at creosote wood treatment sites and at manufacturing gas plants (MGP). Media contaminated with these compounds are considered hazardous due to the potential carcinogenic effects of specific PAHs.

Environmental BioTechnologies, Inc. (EBT), investigated the bioremediation of contaminants associated with former MGP sites in a program cosponsored by the Electric Power Research Institute and the U. S. EPA. Initially, EBT screened over 500 fungal cultures (mostly brown and white rot fungi) for their ability to degrade PAHs and other organic pollutants. A group of 30 cultures were more intensely examined and several cultures were optimized for use in a soil composting process.

EBT conducted bench-scale treatability studies to assess the feasibility of PAH degradation in soil using a fungal-augmented system designed to enhance natural biological metabolic processes. Results of one study are shown in the figure below. Concentrations of 10 PAHs were determined over a 59-day treatment period.

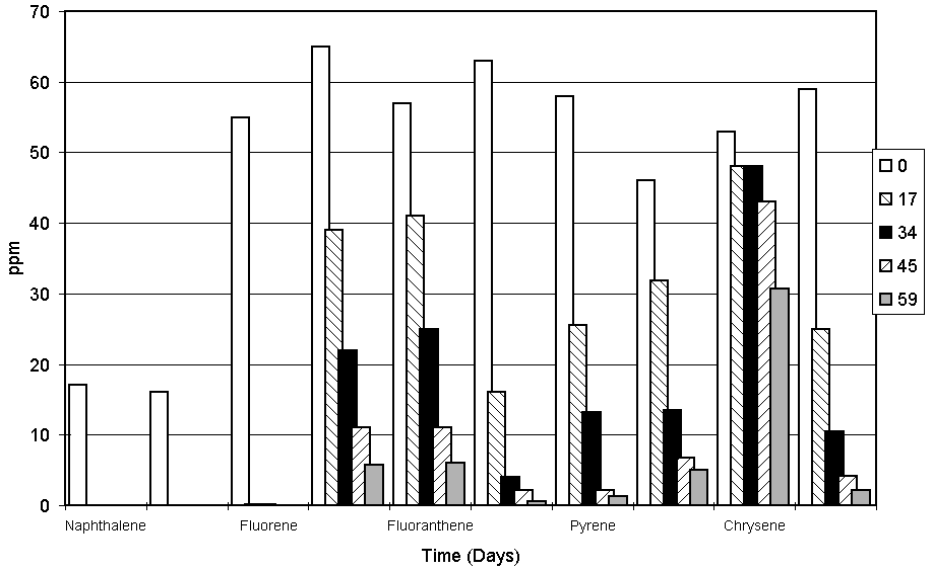
Some states have a soil treatment standard of 100 parts per million for total PAHs. EBT's fungal treatment process was able to reach this cleanup standard within a 5- to 6-week treatment period for one PAH-contaminated soil, as shown in the figure on the next page.

## WASTE APPLICABILITY:

One intended environmental application for this technology is the treatment of soil and sediment contaminated with coal tar wastes from former MGP sites. Soils at these sites are contaminated with PAHs and are difficult to cost-effectively remediate. EBT's fungal soil treatment process is projected to cost $66 to $80 per ton, which is more cost-effective than other technical approaches such as coburning in utility burners, thermal desorption, and incineration.

## STATUS:

EBT was accepted into the SITE Emerging Technology Program in 1993 and began laboratory studies in 1994. The project was completed in 1996. The overall project objectives were to (1) identify fungal and bacterial cultures that efficiently degrade coal tar




Fungal Degradation of Five PAHs in Soil Over A 59-Day Period



The SITE Program assesses but does not approve or endorse technologies.

wastes, and (2) develop and demonstrate a pilot-scale process that can be commercialized for utility industry applications.

EBT initially worked with PAH-spiked water and soils. EBT then tested, under optimized conditions, selected soil cultures from several MGP sites identified by New England Electric Services, a utility company sponsor. Testing identified several possibly superior fungal cultures capable of degrading PAHs. These cultures exhibited degradative preferences for either lower molecular weight or higher molecular weight PAHs, suggesting a consortia as a possible best approach. These cultures were then examined in nutrient-supplemented systems to determine optimal PAH degradation rates.

A bench-scale composter system was used to determine optimal moisture content, soil amendment requirements, and inoculation procedures for accelerating PAH degradation. During the second year, small (less than 1 cubic yard) plots of MGP-site soil were used to test the optimized process in laboratory studies before a field demonstration is conducted. Results from the evaluation was published by U. S. EPA in 1997. Based on its performance during the Emerging Technology Program evaluation, the microbial composting process has been invited to participate in the SITE Demonstration Program.

EBT has also conducted a bench-scale treatability study for a company in France to determine the feasibility of fungal PAH degradation in MGP soil. Results demonstrated an increased rate of biodegradation in the fungal-augmented system for all of the measured individual PAH compounds in the 80-day treatment period, compared with the natural, unamended system.

EBT is also currently conducting a 10-ton soil PAH field project to demonstrate that the fungal degradation process can be scaled up and used in commercial applications.

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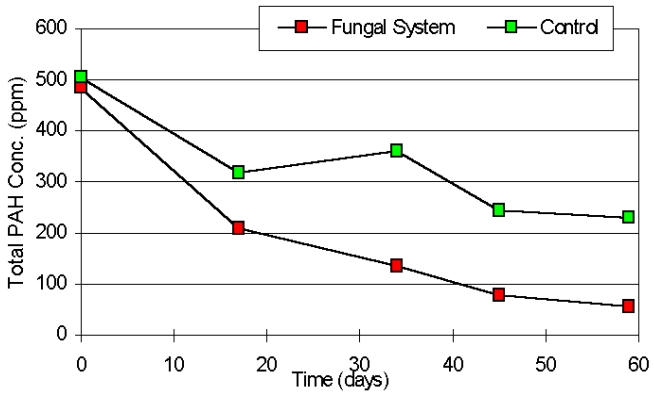


Degradation of Total PAHs In Soil

# EPOC WATER, INC.
## (Precipitation, Microfiltration, and Sludge Dewatering)

## TECHNOLOGY DESCRIPTION:

The precipitation, microfiltration, and sludge dewatering treatment uses a combination of processes to treat a variety of wastes. In the first step of the process, heavy metals are chemically precipitated. Precipitates and all particles larger than 0.2 micron are filtered through a unique tubular textile crossflow microfilter (EXXFLOW). The concentrate stream is then dewatered in a filter press of the same material.

EXXFLOW microfilter modules are fabricated from a proprietary tubular woven polyester. Wastes pumped into the polyester tubes form a dynamic membrane, which produces a high quality filtrate and removes all particle sizes larger than 0.2 micron. The flow velocity continually maintains the membrane, maximizing treatment efficiency.

Metals are removed through precipitation by adjusting the pH in the EXXFLOW feed tank. Metal hydroxides or oxides form a dynamic membrane with any other suspended solids. The EXXFLOW concentrate stream, which contains up to 5 percent solids, is then dewatered. A semidry cake, up to 0.25 inch thick, is formed inside the tubular filter. When the discharge valve is opened, rollers on the outside of the tubes move to form a venturi within the tubes. The venturi creates an area of high velocity within the tubes, which aggressively cleans the cloth and discharges the cake in chip form onto a wedge wire screen. Discharge water is recycled to the feed tank. Filter cakes are typically 40 to 60 percent solids by weight.

Constituents other than metals can be removed using seeded slurry methods in EXXFLOW. Hardness can be removed by using lime. Oil and grease can be removed by adding adsorbents. Nonvolatile organics and solvents can be removed using adsorbents, activated carbon, or powdered ion-exchange resins. The EXXFLOW demonstration unit (see photograph below) is

EXXFLOW Demonstration Unit



The SITE Program assesses but does not approve or endorse technologies.

transportable and is mounted on skids. The unit is designed to process approximately 30 pounds of solids per hour and 10 gallons of wastewater per minute.

## WASTE APPLICABILITY:

When flocculation and precipitation techniques are used at close to stoichiometric dosing rates, the EXXFLOW technology removes mixed metals, oil and grease, and suspended solids sized at 0.10 micron.

When the EXXFLOW technology operates with finely divided adsorbent powders, it removes contaminants such as isophthalic acid, acetic acid, methyl ethyl ketone, fluorides, and phos-phates from effluents generated by semiconductor manufacture. Treated effluents can then be reclaimed for reuse.

## STATUS:

This technology was accepted into the SITE Demonstration Program in 1989. Bench-scale tests were conducted in 1990. The SITE demonstration was conducted during May and June 1992 on highly acidic mine drainage from the Old Number 8 mine seep at the Iron Mountain Superfund site in Redding, California. The Demonstration Bulletin (EPA/540/MR-93/513) and the Applications Analysis Report (EPA/540/AR-93/513) are available from EPA.

This technology was commercialized in 1988. Treatment systems have since been installed at over 45 sites worldwide. System capacities range from 1 gallon per minute to over 2 million gallons per day.

## DEMONSTRATION RESULTS:

During the SITE demonstration, developer claims for metal removal efficiencies on acid mine drainage, when neutralizing with sodium hydroxide (NaOH) and calcium hydroxide [$Ca(OH)_2$], were generally met or exceeded except for aluminum. This was most likely due to excessive alkalinity (high pH) produced by the added NaOH and $Ca(OH)_2$, which redissolved the aluminum. The claims for all metals, including aluminum, were exceeded when magnesium oxide (MgO) was used as the neutralizing agent. In most cases, no detectable concentrations of heavy metals were present in the permeate samples.

Filter cake produced from the demonstration test contained approximately 12 percent, 31 percent, and 30 percent solids when NaOH, $Ca(OH)_2$, and MgO, respectively, were used as the treatment chemicals. Toxicity characteristic leaching procedure (TCLP) tests performed on the filter cake showed that leachable levels of TCLP metals were below regulatory limits for each treatment chemical tested.

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# FERRO CORPORATION
## (Waste Vitrification Through Electric Melting)

## TECHNOLOGY DESCRIPTION:

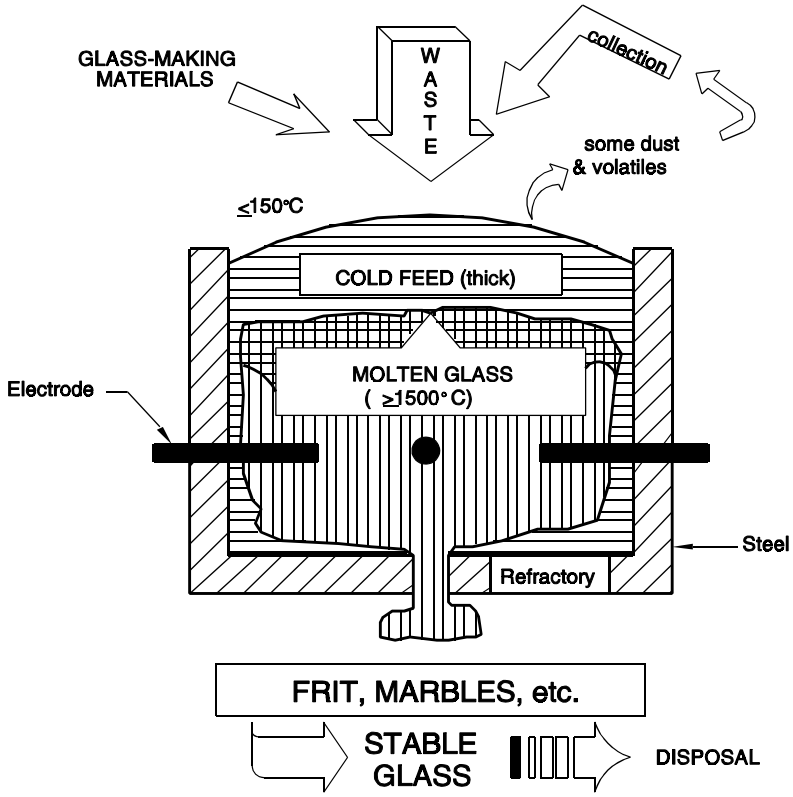
Vitrification technology converts contaminated soils, sediments, and sludges into oxide glasses, chemically rendering them nontoxic and suitable for landfilling as nonhazardous materials. Successful vitrification of soils, sediments, and sludges requires (1) development of glass compositions tailored to a specific waste, and (2) glass melting technology that can convert the waste and additives into a stable glass without producing toxic emissions.

In an electric melter, glass — an ionic conductor of relatively high electrical resistivity — stays molten with heating. Such melters process waste under a relatively thick blanket of feed material, which forms a counterflow scrubber that limits volatile emissions (see figure below).

Commercial electric melters have significantly reduced the loss of inorganic volatile constituents such as boric anhydride ($B_2O_3$) or lead oxide (PbO). Because of its low emission rate and small volume of exhaust gases, electric melting is a promising technology for incorporating waste into a stable glass matrix.

## WASTE APPLICABILITY:

Vitrification stabilizes inorganic components found in hazardous waste. In addition, the high temperature involved in glass production (about 1,500 °C) decomposes organic compounds in the waste such as anthracene, bis(2-ethylhexyl phthalate), and pentachlorophenol. The decomposition products can easily be removed from the low volume of melter off-gas.




Electric Furnace Vitrification



The SITE Program assesses but does not approve or endorse technologies.

## STATUS:

Under the Emerging Technology Program, synthetic soil matrix IV (SSM-IV) has been developed and subjected to toxicity characteristic leaching procedure (TCLP) testing.

Ten independent replicates of the preferred composition produced the following results:

| | TCLP analyte concentration, parts per million | |
|---|---|---|
| Metal | Remediation Limit | Mean of Glass Replicates |
| As | 5 | <0.100 |
| Cd | 1 | <0.010 |
| Cr | 5 | 0.019 |
| Cu | 5 | 0.355 |
| Pb | 5 | 0.130 |
| Ni | 5 | <0.010 |
| Zn | 5 | 0.293 |

SSM-IV and additives (including sand, soda ash, and other minerals) required to convert SSM-IV to the preferred glass composition have been processed in a laboratory-scale electric melter. Three separate campaigns have produced glass at 17 pounds per hour at a fill of 67 percent SSM-IV and 33 percent glass-making additives. The TCLP mean analyte concentrations were less than 10 percent of the remediation limit at a statistical confidence of 95 percent. Ferro Corporation's experience indicates that this melting rate would produce an equivalent rate of 1 ton per hour in an electric melter used to treat wastes at a Superfund site. The Emerging Technology Bulletin (EPA/540/F-95/503) is available from EPA.

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# FILTER FLOW TECHNOLOGY, INC.
## (Colloid Polishing Filter Method®)

## TECHNOLOGY DESCRIPTION:

The Colloid Polishing Filter Method® (CPFM®) uses inorganic, oxide-based sorption particles (FF-1000®) and optimized fluidics control to remove ionic, colloidal heavy metals and nontritium radionuclides from water. Beta- and alpha-emitting radionuclides can be treated selectively by modifying the bed formulation. The methodology efficiently removes inorganics from groundwater, pond water, or wastewater based on sorption, chemical and physical properties of the pollutant species, and filtration. The CPFM® is also an efficient heavy metals and radionuclide polishing filter for groundwater and wastewater. Excess solids and total dissolved solids must be removed first, since they overload the beds, resulting in frequent bed backwashing and regeneration cycles and shorter bed lifetimes. Three different types of CPFM® equipment have been designed and successfully tested: (1) vertical plate design beds with FF-1000®sorption bed particles packaged in polymesh bags or filter packs for field applications; (2) small, filter-housing units for processing less than 1,000 gallons of contaminated water; and (3) deep-bed, epoxy-coated, stainless steel and carbon steel tanks equipped with special fluidics controls and bed sluicing ports for continuous processing. The photograph below shows a mobile CPFM® unit.

## WASTE APPLICABILITY:

The CPFM® has proved to be effective in removing heavy metals and nontritium radionuclides from water to parts per million or parts per billion levels. The ion exchange/sorption method can be used separately to treat water with low total suspended solids; in a treatment train downstream from other technologies (such as soil washing, organics oxidation; or conventional wastewater treatment).

Mobile CPFM® Unit, Including Mixing Tanks, Pumps, Filter Apparatus, and Other Equipment



The SITE Program assesses but does not approve or endorse technologies.

The CPFM®'s major advantages are its high performance; alpha and beta emitter efficiency; and its application to monovalent, divalent, multivalent, and high valence forms existing as colloids, and ionic, chelated, and complexed forms. The same equipment can treat water at different sites, but the preconditioning chemistry and pH must be optimized for each site through bench-scale and field testing.

## STATUS:

This technology was accepted into the SITE Demonstration Program in July 1991. EPA and the U.S. Department of Energy (DOE) cosponsored the technology evaluation. The SITE demonstration occurred in September 1993 at DOE's Rocky Flats Plant (RFP) in Denver, Colorado. The Demonstration Bulletin (EPA/540/MR-94/501), Technology Capsule (EPA/540/R-94/501a), and Innovative Technology Evaluation Report (EPA/540/R-94/501) are available from EPA.

The CPFM has been demonstrated independent of the SITE Program at two locations at DOE's Hanford facility, where it removed Strontium-90, Cesium-137, Plutonium-239, and Americium-241 from water at K-Basin and Strontium-90 from groundwater at Site 100N Area (N-Spring). It also has proven to be effective at several other individual sites. A report detailing the results is available from DOE (DOE/RL-95-110).

## DEMONSTRATION RESULTS:

During the SITE demonstration, the CPFM® treated about 10,000 gallons of water that contained about 100 micrograms per liter of uranium and 100 picoCuries per liter of gross alpha contamination. The demonstration consisted of three tests. The first test consisted of three 4-hour runs, at a flow rate of about 5 gallons per minute (gpm). For the second test, also run for 4 hours at 5 gpm, the influent water was pretreated with sodium sulfide. The third test was a 15-hour run designed to determine the amount of contamination each filter pack could treat.

The CPFM® system removed up to 95 percent uranium and 94 percent gross alpha contamination. However, due to the significant variation in removal efficiencies between runs, average removal efficiencies were significantly less: 80 percent for uranium and 72 percent for gross alpha. Though removal is largely attributable to the colloid filter pack, uranium was significantly removed in runs one and four before colloid filter treatment. Significant gross alpha was also removed before colloid filter treatment in runs one and three. At less than the maximum removal efficiency, effluent from the CPFM® system did not meet the Colorado Water Quality Control Commission standards for discharge of waters from RFP.

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# FUNDERBURK & ASSOCIATES
## (formerly HAZCON, INC.)
## (Dechlorination and Immobilization)

## TECHNOLOGY DESCRIPTION:

This technology mixes hazardous wastes with cement (or fly ash), water, and one of 18 patented reagents, commonly known as Chloranan, to immobilize heavy metals. The developers also claim that certain chlorinated organics are dechlorinated by the treatment reagents.

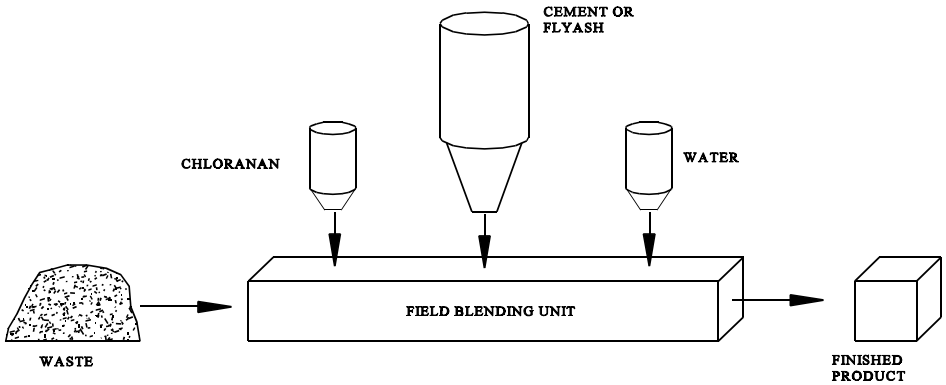
Soils, sludges, and sediments can be treated in situ or excavated and treated ex situ. Sediments can be treated under water. In the finished product, immobilized metals have a very low solubility. Ex situ treatment occurs in batches, with volumetric throughput rated at 120 tons per hour. The treatment process begins by adding Chloranan and water to the blending unit (see figure below). Waste is then added and mixed for 2 minutes. Cement or fly ash is added and mixed for a similar time. After 12 hours, the treated material hardens into a concrete-like mass that exhibits unconfined compressive strengths (UCS) ranging from 1,000 to 3,000 pounds per square inch (psi), with permeabilities of $10^{-9}$ centimeters per second (cm/sec). The hardened concrete-like mass can withstand several hundred freeze and thaw cycles.

## WASTE APPLICABILITY:

The technology is applicable to solid wastes containing heavy metals and organics. The developer claims that, since the 1987 SITE demonstration, the technology has been refined to dechlorinate certain chlorinated organics and to immobilize other wastes, including those with high levels of metals. Wastes with organic and inorganic contaminants can be treated together. The process can treat contaminated material with high concentrations (up to 25 percent) of oil.

## STATUS:

This technology was accepted into the SITE Demonstration Program in 1987. The process was demonstrated in October 1987 at a former oil processing plant in Douglassville, Pennsylvania.




Dechlorination and Immobilization Treatment Process



The SITE Program assesses but does not approve or endorse technologies.

The site soil contained high levels of oil and grease (250,000 parts per million [ppm]) and heavy metals (22,000 ppm lead), and low levels of volatile organic compounds (VOC) (100 ppm) and polychlorinated biphenyls (PCB) (75 ppm). The Applications Analysis Report (EPA/540/A5-89/001) and Technology Evaluation Report (EPA/540/5-89/001a) are available from EPA. A report on long-term monitoring may be also obtained from EPA. The technology has also been used to remediate a California Superfund site with zinc contamination as high as 220,000 ppm.

Since the demonstration in 1987, 17 additional reagent formulations have been developed. These reagents supposedly dechlorinate many chlorinated organics, including PCBs, ethylene dichloride, trichloroethene, and pentachlorophenol.

## DEMONSTRATION RESULTS:

For the SITE demonstration, samples were taken after treatment at intervals of 7 days, 28 days, 9 months, and 22 months. Analytical results from these samples were generally favorable. The physical test results indicated a UCS between 220 and 1,570 psi. Low permeabilities ($10^{-9}$ cm/sec) were recorded, and the porosity of the treated wastes was moderate. Durability test results showed no change in physical strength after the wet and dry and freeze and thaw cycles. The waste volume increased by about 120 percent. However, technology refinements now restrict volumetric increases to 15 to 25 percent. Using a smaller volume of additives reduces physical strength, but toxicity reduction is not affected.

The results of the leaching tests were mixed. Toxicity characteristic leaching procedure (TCLP) results for the stabilized wastes showed that concentrations of metals, VOCs, and semivolatile organic compounds (SVOC) were below 1 ppm. Lead concentrations in leachate decreased by a factor of 200 to below 100 parts per billion. VOC and SVOC concentrations in the TCLP leachate were not affected by treatment. Oil and grease concentrations were greater in the treated waste TCLP leachate (4 ppm) than in the untreated waste TCLP leachate (less than 2 ppm).

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# GENERAL ATOMICS
## (Circulating Bed Combustor)

## TECHNOLOGY DESCRIPTION:

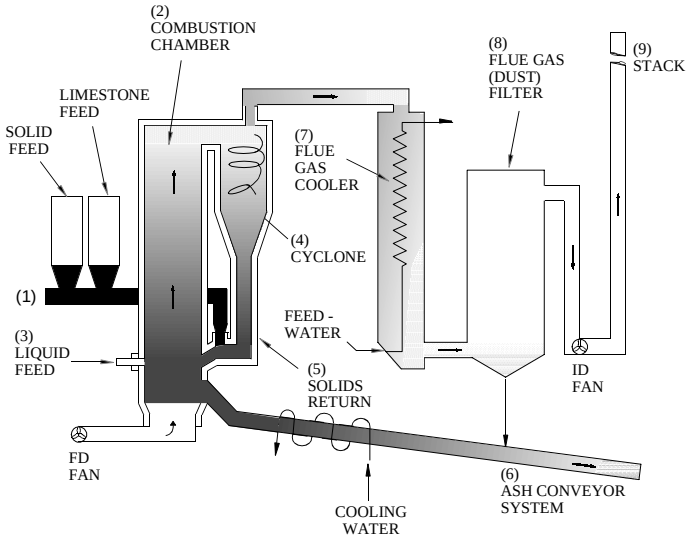
General Atomics' circulating bed combustor (CBC) uses high velocity air to entrain circulating solids and create a highly turbulent combustion zone that destroys toxic hydrocarbons. The commercial-scale, 3-foot combustion chamber can treat up to 150 tons of contaminated soil daily, depending on the heating value of the feed material.

The CBC operates at lower temperatures than conventional incinerators (1,450 to 1,600 °F). The CBC's high turbulence produces a uniform temperature around the combustion chamber and hot cyclone. The CBC also completely mixes the waste material during combustion. Effective mixing and low combustion temperature reduce operating costs and potential emissions of such gases as nitrogen oxide ($NO_x$) and carbon monoxide (CO). Natural gas, fuel oil, or diesel can be used as auxiliary fuel. No auxiliary fuel is needed for waste streams with a net heating value greater than 2,900 British thermal units per pound.

As shown in the figure below, waste material and limestone are fed into the combustion chamber along with the recirculating bed material. The limestone neutralizes acid gases. A conveyor transports the treated ash out of the system for proper disposal. Hot combustion gases pass through a convective gas cooler and baghouse before they are released to the atmosphere.

## WASTE APPLICABILITY:

The CBC process can treat liquids, slurries, solids, and sludges contaminated with corrosives, cyanides, dioxins and furans, inorganics, metals, organics, oxidizers, pesticides, polychlorinated biphenyls (PCB), phenols, and volatile organic compounds. The CBC is permitted under the Toxic Substances Control Act to burn PCBs in all 10 EPA regions, having demonstrated a 99.99 percent destruction removal efficiency (DRE). Applications of the CBC include a variety of industrial wastes and contaminated site materials. Waste feed for the CBC must be sized to less than 1 inch. Metals in the waste do not inhibit performance and become less leachable after




Circulating Bed Combustor (CBC)



The SITE Program assesses but does not approve or endorse technologies.

incineration. Treated residual ash can be replaced on site or stabilized for landfill disposal if metals exceed regulatory limits.

## STATUS:

The CBC (formerly owned by Ogden Environmental Services) was accepted into the SITE Demonstration Program in 1986. A treatability study on wastes from the McColl Superfund site in California was conducted under the guidance of the SITE Program, EPA Region 9, and the California Department of Health Services in March 1989. A pilot-scale demonstration was conducted at the General Atomics research facility in San Diego, California using a 16-inch-diameter CBC. The demonstration was conducted on soil from the McColl Superfund Site in Fullerton, California.

Several 3-foot-diameter CBCs have been built and successfully operated. At the Swanson River project in Alaska, over 100,000 tons of PCB-contaminated soil was successfully treated to limits of detection that were far below allowable limits. The process took just over 3 years, from mobilization of the transportable unit to demobilization. The unit operated at over 85 percent availability all year, including winter, when temperatures were below -50 °F. The soil was delisted and returned to the original site. The unit has subsequently been moved to a Canadian site.Another unit of similar size treated soils contaminated with #6 fuel oil. Over 14,000 tons of soil was successfully treated and delisted.
Upon completion, the site was upgraded to permit operation as a merchant facility treating a wide range of materials from leaking underground fuel tanks at other sites. Two other units of the same size have been constructed in Germany for treatment of munitions wastes consisting of slurried explosives and propellant. These units have been operational since early 1995 and have been permitted under stringent German regulations.

## DEMONSTRATION RESULTS:

During the SITE demonstration, the CBC performed as follows:

- Achieved DRE values of 99.99 percent or greater for principal organic hazardous constituents
- Minimized formation of products of incomplete combustion
- Met research facility permit conditions and California South Coast Basin emission standards
- Controlled sulfur oxide emissions by adding limestone and residual materials (fly ash and bed ash); these emissions were nonhazardous. No significant levels of hazardous organic compounds were found in the system, the stack gas, or the bed and fly ash.
- Minimized emissions of sulfur oxide, $NO_x$, and particulates. Other regulated pollutants were controlled to well below permit levels.

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# GEO-CON, INC.
## (In Situ Solidification and Stabilization Process)

## TECHNOLOGY DESCRIPTION:

The in situ solidification and stabilization process immobilizes organic and inorganic compounds in wet or dry soils, using reagents (additives) to produce a cement-like mass. The basic components of this technology are (1) Geo-Con, Inc.'s (Geo-Con), deep soil mixing (DSM) system, to deliver and mix the chemicals with the soil in situ; and (2) a batch mixing plant to supply proprietary additives (see figure below).

The proprietary additives generate a complex, crystalline, connective network of inorganic polymers in a two-phase reaction. In the first phase, contaminants are complexed in a fast-acting reaction. In the second phase, macromolecules build over a long period of time in a slow-acting reaction.

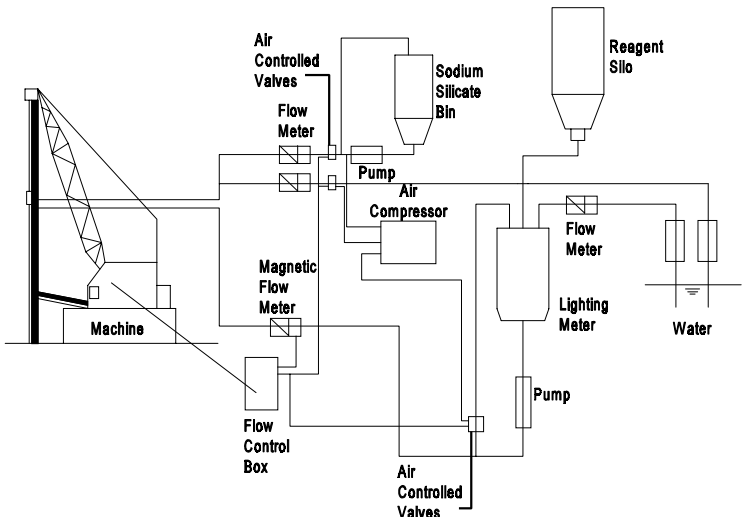
The DSM system involves mechanical mixing and injection. The system consists of one set of cutting blades and two sets of mixing blades attached to a vertical drive auger, which rotates at approximately 15 revolutions per minute. Two conduits in the auger inject the additive slurry and supplemental water. Additives are injected on the downstroke; the slurry is further mixed upon auger withdrawal. The treated soil columns are 36 inches in diameter and are positioned in an overlapping pattern of alternating primary and secondary soil columns.

## WASTE APPLICABILITY:

The process treats soils, sediments, and sludge-pond bottoms contaminated with organic compounds and metals. The process has been laboratory-tested on soils containing polychlorinated biphenyls (PCB), pentachlorophenol, refinery wastes, and chlorinated and nitrated hydrocarbons.

## STATUS:

A SITE demonstration was conducted as a joint effort between International Waste Technologies (IWT) and Geo-Con. The demonstration was conducted at the General Electric Service Shop site in Hialeah, Florida in April 1988. IWT provided the treatment reagent, specifically the proprietary additive (HWT-20), and Geo-Con provided both engineering and hardware for the in situ soil treatment. Two 10-by-20-foot areas were treated — one to a depth of 18 feet, and the other to a depth of 14 feet. Ten months after the demonstration, long-term monitoring tests were performed on the treated sectors. A four-auger




In Situ Solidification and Stabilization Process Flow Diagram



The SITE Program assesses but does not approve or endorse technologies.

process was later used to remediate the PCB-contaminated Hialeah site during the winter and spring of 1990. Cooperative efforts between Geo-Con and IWT ended with the remediation of the Hialeah site.

Presently, Geo-Con offers the entire in situ stabilization package, including the treatment chemicals. Geo-Con has used the process to complete over 40 in situ stabilization projects throughout the United States. Significant projects completed to date include the following:

- Construction of a 110,000-square-foot, 60-foot-deep, soil-bentonite DSM wall to contain contaminated groundwater from a former waste pond. All DSM permeabilities were less than $10^{-7}$ centimeters per second (cm/s).
- Shallow soil mixing and stabilization of 82,000 cubic yards of contaminated soils at a former manufactured gas plant site. The site was declared clean and ultimately converted to a city park.

The DSM system augers have been scaled up to diameters as large as 12 feet. To date, Geo-Con has used this process to treat over 1 million cubic yards of contaminated soils and sludges.

## DEMONSTRATION RESULTS:

The SITE demonstration yielded the following results:

- PCB immobilization appeared likely, but could not be confirmed because of low PCB concentrations in the untreated soil. Leachate tests on treated and untreated soil samples showed mostly undetectable PCB levels. Leachate tests performed 1 year later on treated soil samples showed no increase in PCB concentrations, indicating immobilization.
- Data were insufficient to evaluate the system's performance on other organic compounds and metals.
- Each test sample showed high unconfined compressive strength (UCS), low permeability, and low porosity. These physical properties improved in samples retested 1 year later, indicating the potential for long-term durability.
- Bulk density of the soil increased 21 percent after treatment. This treatment increased the treated soil volume by 8.5 percent and caused a small ground rise of 1 inch per foot of treated soil.
- The UCS of treated soil was satisfactory, with values up to 1,500 pounds per square inch.
- The permeability of the treated soil was satisfactory, decreasing to $10^{-6}$ and $10^{-7}$ cm/s compared to $10^{-2}$ cm/s for untreated soil.
- Data were insufficient to confirm immobilization of volatile and semivolatile organics. This may be due to organophilic clays present in the reagent.
- Process costs were $194 per ton for the 1-auger machine used in the demonstration, and $111 per ton for a commercial four-auger operation. More recent experience with larger scale equipment reduced process costs to about $15 per ton plus the cost of reagents. The Technology Evaluation Report (EPA/540/5-89/004a) and the Applications Analysis Report (EPA/540/A5-89/004) are available from EPA.

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# GEOSAFE CORPORATION
## (GeoMelt Vitrification, previously In Situ Vitrification)

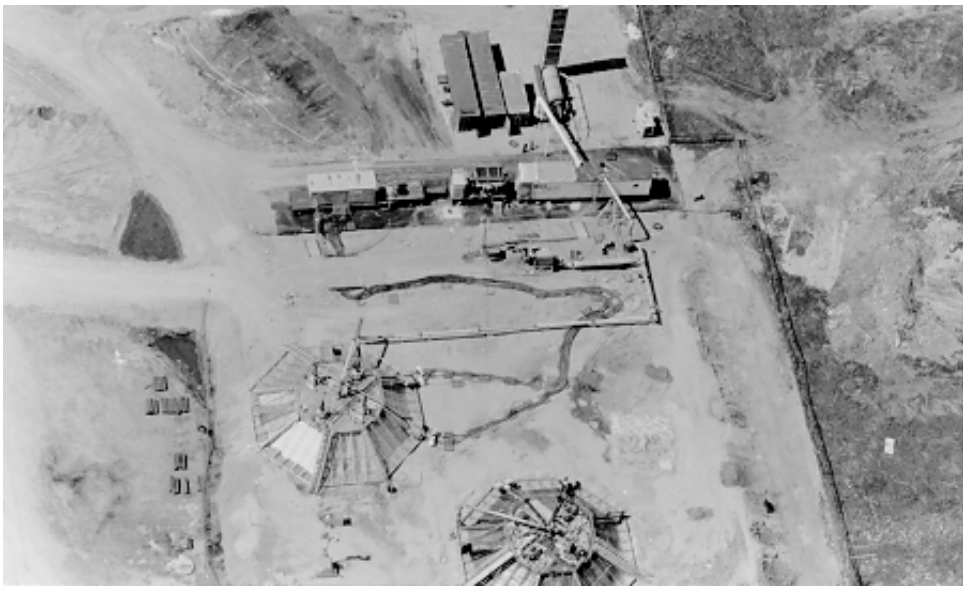
## TECHNOLOGY DESCRIPTION:

Geosafe Corporation's (Geosafe) GeoMelt vitrification process uses electricity to melt soil or other earthen materials at temperatures of 1600 to 2000 °C, destroying organic pollutants by pyrolysis. Inorganic pollutants are immobilized within the vitrified glass and monolith. Water vapor and organic pyrolysis products are captured in a hood, which draws the off-gases into a treatment system that removes particulates, acid gases and other pollutants.

The process can be applied to materials in situ, or where staged below grade or ex situ. By the addition of feeding and melt withdrawal fewtures, the process can be operated semi-continuosly. To begin the vitrification process, an array of large electrode pairs is inserted into contaminated zones containing enough soil for melting to occur (see photograph below). A graphite starter path is used to melt the adjacent soil, which then becomes the primary current-carrying medium for further processing. As power is applied, the melting continues downward and outward at an average rate of 4 to 6 tons per hour, or 1 to 2 inches per hour. The electrode array is lowered progressively, as the melt grows to the desired treatment depth. After cooling, a vitrified monolith with a glass and microcrystalline structure remains. This monolith possesses high strength and excellent weathering and leaching properties.

The melting process is performed under a hood through which air flow is controlled to maintain a negative pressure. Excess oxygen is supplied for combustion of any organic pyrolysis products. Off-gases are treated by quenching, pH-controlled scrubbing, dewatering (mist elimination), heating (for dew point control), particulate filtration, and either activated carbon adsorption or thermal oxidation as a final off-gas polishing step. Individual melt settings may encompass a total melt mass of up to 1,400 tons, a maximum width of 40 feet, and depths as great as 22 feet. Special settings to reach deeper contamination are also possible. Void volume and volatile material removal results in a 30 to 50 percent volume reduction for typical soils.

The mobile GeoMelt system is mounted on three semi-trailers. Electric power may be provided by local utility or on-site diesel generator. Typical



In Situ Vitrification Process Equipment



The SITE Program assesses but does not approve or endorse technologies.

power consumption ranges from 600 to 800 kilowatt-hours per ton of soil. The electrical supply system has an isolated ground circuit to provide safety.

## WASTE APPLICABILITY:

The GeoMelt vitrification process can destroy or remove organics and immobilize most inorganics in contaminated soils, sediments, sludges, or other earthen materials. The process has been tested on a broad range of volatile and semivolatile organic compounds, other organics including dioxins and polychlorinated biphenyls (PCB), and on most priority pollutant metals and heavy metal radio-nuclides. The process can also treat large amounts of debris and waste materials present in soil. In addition to soils applications, the process has been used to treat mixed- transuranic (TRU) buried waste and underground tanks containing waste. Underground tank treatment employs a new method of vertically planar melting which enable sidewards melting rather than top-down melting. Tanks to 4,500 gallons have been treated to date.

## STATUS:

The SITE demonstration of the process occurred during March and April 1994 at the former Parsons Chemical (Parsons) site in Grand Ledge, Michigan. The soil at Parsons was contaminated with pesticides, metals, and low levels of dioxins. The Innovative Technology Evaluation Report (EPA/540/R-94/520) and the Demonstration Bulletin (EPA/540/MR-94/520) are available from EPA.

In October 1995, Geosafe was issued a National Toxic Substances Control Act permit for the treatment of soils contaminated with up to 17,860 parts per million PCBs.

In December 1995, Geosafe completed the remediation of the Wasatch Chemical Superfund Site in Salt Lake City, Utah. This site contained about 6,000 tons of dioxin, pentachlorophenol, herbicide, pesticide, and other organic contaminants in soil containing up to 30 percent debris by weight. In 1996, Geosafe completed remediation of the Apparatus Service Shop Site in Spokane, Washington. A total of 6,500 tons of PCB-contaminated soil was treated at the site. GeoMelt vitirification is currently being employed for the in situ treatment of mixed-TRU buried waste at the Maralinga Test Range in South Australia. Twenty-one pits containing Plutonium, Uranium, Lead, Barium, and Beryllium are being treated there. That project will be completed in 1999.

## DEMONSTRATION RESULTS:

During the SITE demonstration, about 330 cubic yards of a saturated clayey soil was vitrified in 10 days. This is the equivalent to a production rate of 53 tons per day. The technology met cleanup levels specified by EPA Region 5 for chlordane, 4,4-dichlorodiphe-nyltrichloroethane, dieldrin, and mercury. Pesticide concentrations were nondetectible in the vitrified soil. Results also indicated that leachable mercury was below the regulatory guidelines (40 CFR Part 261.64), and no target pesticides were detected in the leachate. No target pesticides were detected in the stack gas samples, and metal emissions were below regulatory requirements. Continuous emission monitoring showed that total hydrocarbon and carbon monoxide emissions were within EPA Region 5 limits.

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# GEOTECH DEVELOPMENT CORPORATION
## (Cold Top Ex-Situ Vitrification of Chromium-Contaminated Soils)

## TECHNOLOGY DESCRIPTION:

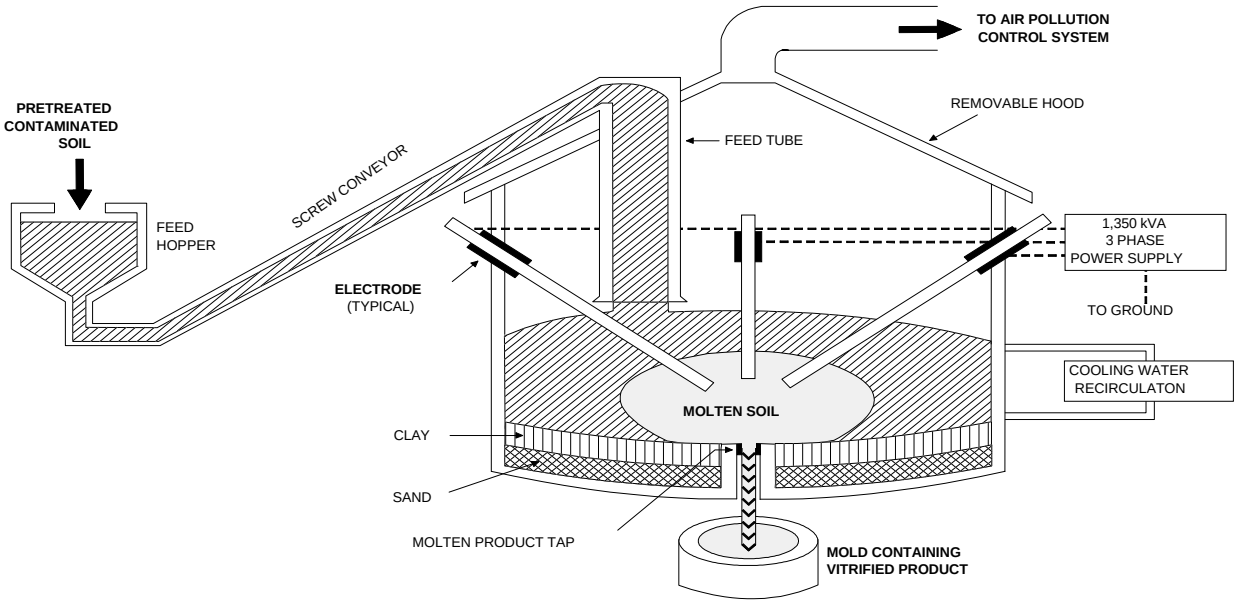
The Geotech Cold Top technology is an ex-situ vitrification process designed to transform metal-contaminated soils into a nonleachable product. The primary component of the technology is a water-cooled, double-walled, steel vessel or furnace with submerged-electrode resistance heating. The furnace and associated equipment are capable of attaining a melting temperature of up to 5,200 °F.

The furnace is initially charged with a mixture of sand and alumina/silica clay. Through electrical resistance heating, a molten pool forms; the voltage to the furnace is properly adjusted; and, finally, contaminated soil is fed into the furnace by a screw conveyor. When the desired soil melt temperature is achieved, the furnace plug from below the molten product tap is removed. As the soil melts, the outflow is poured into refractory-lined and insulated molds for slow cooling, and additional soil is added to the furnace to maintain a "cold top." Excess material can be discharged to a water sluice for immediate cooling and collection before off-site disposal.

Geotech Development Corporation (Geotech) claims that the Cold Top Vitrification process converts quantities of contaminated soil from a large number of particles into an essentially monolithic, vitrified mass. According to Geotech, vitrification transforms the physical state of contaminated soil from assorted crystalline matrices to a glassy, amorphous solid state comprised of interlaced polymeric chains. These chains typically consist of alternating oxygen and silicon atoms. It is expected that chromium can readily substitute for silicon in the chains. According to Geotech, such chromium should be immobile to leaching by aqueous solvents and, therefore, biologically unavailable and nontoxic.

## WASTE APPLICABILITY:

According to Geotech, the Cold Top Vitrification process has been used to treat soils contaminated with hazardous heavy metals such as lead, cadmium, and chromium; asbestos and asbestos-containing materials; and municipal solid waste combustor ash residue. Geotech claims that radioactive wastes can also be treated by this




Cold Top Ex-Situ Vitrification Technology



The SITE Program assesses but does not approve or endorse technologies.

technology. All waste material must be reduced in size to less than 0.25 inches in diameter. The Cold Top Vitrification process is most efficient when feed materials have been dewatered to less than 5 percent water and organic chemical concentrations have been minimized. Some wastes may require the addition of carbon and sand to ensure that the vitrification process produces a glass-like product. Geotech claims that the vitrified product can have many uses, including shore erosion blocks, decorative tiles, road-bed fill, and cement or blacktop aggregate.

## STATUS:

This technology was accepted into the SITE Demonstration Program in December 1994. In February and March, 1997, this process was demonstrated at Geotech's pilot plant in Niagara Falls, New York. Approximately 10,000 pounds of chromium-contaminated soil from two New Jersey-Superfund sites in the Jersey City area were collected crushed, sieved, dried, mixed with carbon and sand, and shipped to the Geotech plant. The SITE demonstration consisted of one vitrification test run on soil from each site.

## DEMONSTRATION RESULTS:

The demonstration results indicate that the Cold Top Vitrification process reduced the concentration of leachable chromium to meet the Resource Conservation and Recovery Act (RCRA) toxicity characteristic leaching procedure (TCLP) total chromium standard. For example, concentrations of 29 and 58 mg/L of TCLP chromium in feed soils were reduced to 1.0 and 0.31 mg/L, respectively, in vitrified products. Field observations and measurements made during the demonstration indicate that several operational issues must be addressed during technology scale-up. First, a consistent and controlled feed system needs to be developed that spreads the waste uniformly over the surface of the molten soil. This feed system must also minimize dust generation. Second, an emission control system needs to be configured to control particulate and gaseous emissions from the furnace and feed system.

The SITE Demonstration Bulletin (EPA/540/HR-97/506) and Technology Capsule (EPA/540/R-97/506a) are available from EPA. Geotech owns a 50-ton-per-day Cold Top Vitrification pilot plant in Niagara Falls, New York. This facility has been used for over 38 research and customer demonstrations, including the SITE demonstration. Geotech has built or assisted with the construction or upgrading of more than five operating vitrification plants. Geotech has tentative plans to build a commercial Colt Top Vitrification facility within 50 miles of the New Jersey sites. The planned capacity of this facility is 300 tons per day. The facility will be designed to receive, dry, vitrify, and dispose of vitrified product from the chromium sites and municipal solid waste incinerators, as well as other producers of hazardous and nonhazardous waste.

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# GIS\SOLUTIONS, INC.
## (GIS\Key™ Environmental Data Management System)

## TECHNOLOGY DESCRIPTION:

GIS\Key™ v.3.0 is a comprehensive environmental database management system that integrates site data and graphics, enabling the user to create geologic cross-sections, boring logs, potentiometric maps, isopleth maps, structure maps, summary tables, hydrographs, chemical time series graphs, and numerous other maps and line graphs (see table below). The software is networkable, multi-user, 32 bit and year 2000 compliant. It is menu-driven, making it relatively simple to use. All system outputs meet Resource Conservation and Recovery Act (RCRA) and Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) reporting requirements and are consistent with current industry practices.

In addition to complete integration between data and graphics, GIS\Key™ v.3.0 integrates different data types, allowing swift production of complex graphics such as geo-chemical cross sections and flux graphics.

GIS\Key™ v.3.0 stores and independently manages metadata (such as maps, graphs, reports, boring logs and sections) from multiple sites. Metadata is geocoded, stored separately from a facility's source data and retrieved by performance of a spatial query. Metadata from a facility may be retrieved, viewed and studied independently or combined with metadata from other facilities for multi-site management.

The GIS\Key™ software can directly export data into the leading three-dimensional visualization systems. These systems produce three-dimensional contaminant plume models and groundwater flow models as well as fence diagrams. GIS\Key™ includes audit or transaction logging capabilities for source data as well as metadata.

The GIS\Key™ v3.0 also employs two new project management and data navigation tools called Scout™ and Smart Query™. Scout™ helps users find and access existing projects, start new projects, browse data and initiate queries that result in reports, maps, and other graphics.

| CHEMISTRY | GEOLOGY | HYDROLOGY |
|---|---|---|
| • Isopleth maps of soil or water quality (plan or section view)<br>• Graphs<br>- Time series graphs<br>- Chemical versus chemical and inter-well and intra-well<br>- Concentration versus position<br>- Summary of statistics<br>• Trilinear Piper & Stiff diagrams<br>• User alerts<br>- When QA/QC results fall outside data quality objectives<br>- When sample results fall outside historical ranges<br>- When sample results exceed applicable regulatory standards<br>• Sample Tracking; Electronic Lab Interface<br>• Presentation-quality data tables | • Completely customizable boring logs<br>• Geologic cross-section maps<br>• Isopach maps<br>• Structure maps<br>• Presentation-quality data tables<br><br>**ALL MODULES:**<br>• GIS\Key Scout™ Interface<br>• Independent management of metadata<br>• Multi-site management capability<br>• Integration between data types<br>• Smart Query™ Data Retrieval<br>• 3D Modeling, Statistics, GIS Integration | • Density-corrected water level, floating product, hydraulic conductivity, and contour maps<br>• Water elevation and floating product thickness versus time graphs<br>• Flow versus time and chemical flux graphs<br>• Presentation-quality data tables<br><br>**SYSTEM REQUIREMENTS:**<br>• Hardware: Pentium Class PC 32 MB RAM<br>• Operating System: Windows 95/98 or Windows NT |

GIS\Key™ Environmental Data Management System Outputs



The SITE Program assesses but does not approve or endorse technologies.

Scout™ also manages data security and multi-user network installations of GIS\Key™ v.3.0. Smart Query™
users set conditions on project data, displays data meeting those conditions, then creates desired output. GIS\Key™ v3.0 also has new modules for radiological chemistry and RCRA Statistics. Site data related to ecological assessment and air emissions is not managed by this system.

The GIS\Key™ software can be used at any Superfund site to facilitate the collection, reporting, and analysis of site data. The software is designed with numerous checks to assure the quality of the data, including comprehensive quality assurance/quality control protocols. System outputs, listed in the table below, are presentation-quality and meet RCRA and CERCLA reporting requirements. GIS\Key™ software provides a three level data validation system which includes 1) sample tracking by custody, sample ID and/or date and time, 2) an electronic laboratory import program that immediately finds, and helps the user fix, quality control (QC) problems with the laboratory data delivery and 3) a series of "User Alert" reports which find data thst falls outside of project QC objectives, historical data ranges, or above federal, state, and local or project specific action levels.

## STATUS:

This technology was accepted into the SITE Demonstration Program in summer 1992. The demonstration was held in August 1993 in San Francisco, California, and December 1993 in Washington, DC. The Demonstration Bulletin (EPA/540/MR-94/505), Technology Capsule (EPA/540/SR-94/505), Innovative Technology Evaluation Report (EPA/540/R-94/505), and project videotape are available from EPA.

## DEMONSTRATION RESULTS:

The GIS\Key™ software is in use at several Superfund sites including the Crazyhorse site near Salinas, Califonia, and the Moffett Field site near San Jose, California. The U.S. AirForce's Environmental Data Management and Decision Support working group has successfully tested the effectiveness of the GIS\Key™ technology at Norton Air Force Base in California. The technology is also being used by consultants at over 30 other U.S. Air Force and Department of Energy facilities.

Results from the SITE demonstration indicated that the GIS\Key™ software generated the four types of contour maps necessary to assist in groundwater mapping: hydrogeologic maps, chemical concentration isopleths, geologic structure maps, and geologic structure thickness isopach maps. Several advanced chemistry reports and construction and borehole summary tables were also automatically prepared using customized GIS\Key™ menu commands. The system automated well and borehole logs based on the information contained in the database. GIS\Key™ provided several editable reference lists, including a list of regulatory thresholds, test methods, and a list of chemical names, aliases, and registry numbers. The GIS\Key™ database menu provided commands for electronic database import and export. Any of the database files used by GIS\Key™ can be used with the general import and export commands available in the database menu.

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# GRACE BIOREMEDIATION TECHNOLOGIES
## (DARAMEND™ Bioremediation Technology)

## TECHNOLOGY DESCRIPTION:

The GRACE Bioremediation Technologies organic amendment-enhanced bioremediation technology (DARAMEND™) is designed to degrade many organic contaminants in industrial soils and sediments, including pentachlorophenol (PCP), polynuclear aromatic hydrocarbons (PAH), and petroleum hydrocarbons. The technology has been applied both in situ and ex situ. In either case, soil may be treated in lifts up to 2 feet deep using available mixing equipment. The technology may also be applied ex situ, as a biopile.

The technology treats batches of soil using DARAMEND™ soil amendments. These amendments are introduced using conventional agricultural equipment (see photograph below), followed by regular tilling and irrigation. DARAMEND™ soil amendments are solid-phase products prepared from natural organic materials to have soil-specific particle size distribution, nutrient content, and nutrient releases kinetics. Soil amendments sharply increase the ability of the soil matrix to supply water and nutrients to the microorganisms that degrade the hazardous compounds. The amendments can also transiently bind contaminants, reducing the acute toxicity of the soil aqueous phase. This reduction allows microorganisms to survive in soils containing very high concentrations of toxic compounds.

DARAMEND™ treatment involves three fundamental steps. First, the treatment area is prepared. For the ex situ application, a lined treatment cell is constructed. In situ application requires the treatment area to be cleared and ripped to reduce soil compaction. Second, the soil is pretreated; this includes removing debris larger than 4 inches, such as metal or rocks, that may damage the tilling equipment. Sediments undergoing treatment must be dewatered. And third, the DARAMEND™ soil amendment is incorporated, usually at 1 percent to 5 percent by weight, followed by regular tilling and irrigating.

Soil is tilled with a rotary tiller to reduce variation in soil properties and contaminant concentrations. Tilling also incorporates the required soil amendments and helps deliver oxygen to contaminant-degrading microorganisms.

An irrigation system is used to maintain soil moisture in the desired range. If the treatment area is not covered, leachate or surface runoff

DARAMEND™ Bioremediation Technology



The SITE Program assesses but does not approve or endorse technologies.

caused by heavy precipitation is collected and reapplied to the soil as needed.

Equipment needed to implement this technology includes a rotary tiller, irrigation equipment, and excavation and screening equipment. Depending on site-specific factors such as contaminant type and initial concentration, and project schedule and climate, a waterproof cover may be constructed over the treatment area.

## WASTE APPLICABILITY:

The DARAMEND™ technology can treat soil, sediment, and other solid wastes such as lagoon sludge. These matrices may be contaminated by a wide range of organic compounds including, but not limited to, PAHs, PCP, petroleum hydrocarbons, and phthalates. Matrices of lead, manganese, and zinc have been effectively treated with the DARAMEND™ technology.

This technology was accepted into the SITE Demonstration Program in spring 1993. The ex situ application of the technology was demonstrated from fall 1993 to summer 1994 at the Domtar Wood Preserving facility in Trenton, Ontario, Canada. The demonstration was one component of a 5,000-ton remediation project underway at the site.

Currently, the DARAMEND™ technology has received regulatory approval, and has been applied at field-scale at five sites in the United States. These sites include the full-scale treatment of PCP impacted soil in Montana, Washington, and Wisconsin, the full-scale treatment of phthalate impacted soil in New Jersey and a pilot-scale demonstration of toxaphene impacted soil in South Carolina. In addition, the technology has been applied at a number of Canadian sites including a 2,500 tonne biopile in New Brunswick, and two pilot-scale projects targeting pesticides and herbicides in Ontario. The first full-scale application to soil containing organic explosives is scheduled for late 1998.

## DEMONSTRATION RESULTS:

In the ex situ demonstration area, the DARAMEND™ technology achieved the following overall reductions: PAHs, 94 percent (1,710 milligram/kilogram [mg/kg] to 98 mg/kg); chlorophenols, 96 percent (352 mg/kg to 13.6 mg/kg); and total petroleum hydrocarbons (TPH), 87 percent. These reductions were achieved in 254 days of treatment, including winter days when no activity occurred because of low soil temperatures. The control area showed a reduction of 41 percent in PAH concentrations; no reduction was seen in the concentration of either chlorinated phenols or TPH during the treatment time. Results from the toxicity analysis (earthworm mortality and seed germination) showed that the toxicity was eliminated or greatly reduced in the treated soil.

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# GRUPPO ITALIMPRESSE
# (developed by SHIRCO INFRARED SYSTEMS, INC.)
## (Infrared Thermal Destruction)

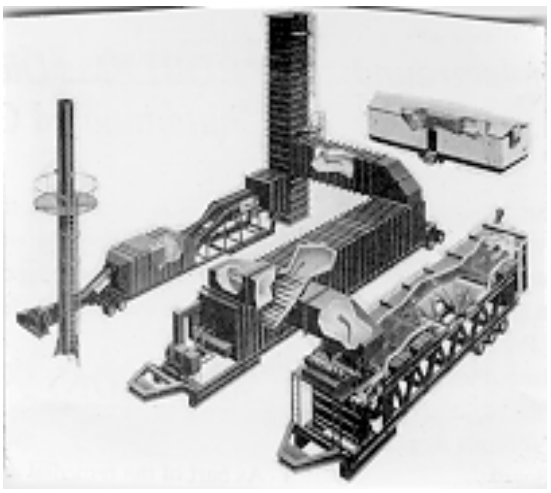
## TECHNOLOGY DESCRIPTION:

The infrared thermal destruction technology is a mobile thermal processing system that uses electrically powered silicon carbide rods to heat organic wastes to combustion temperatures. Any remaining combustibles are incinerated in an afterburner. One configuration for this mobile system (see figure below) consists of four components: (1) an electric-powered infrared primary chamber; (2) a gas-fired secondary combustion chamber; (3) an emissions control system; and (4) a control center.

Waste is fed into the primary chamber and exposed to infrared radiant heat (up to 1,850 °F) provided by silicon carbide rods above the conveyor belt. A blower delivers air to selected locations along the belt to control the oxidation rate of the waste feed.

The ash material in the primary chamber is quenched with scrubber water effluent. The ash is then conveyed to an ash hopper, where it is removed to a holding area and analyzed for organic contaminants such as polychlorinated biphenyls (PCB).

Volatile gases from the primary chamber flow into the secondary chamber, which uses higher temperatures, greater residence time, turbulence, and supplemental energy (if required) to destroy these gases. Gases from the secondary chamber are ducted through the emissions control system. In the emissions control system, the particulates are removed in a venturi scrubber. Acid vapor is neutralized in a packed tower scrubber. An induced draft blower draws the cleaned gases from the scrubber into the free-standing exhaust stack. The scrubber liquid effluent flows into a clarifier, where scrubber sludge settles and is removed for disposal. The liquid then flows through an activated carbon filter for reuse or to a publicly owned treatment works for disposal.



Mobile Thermal Processing System

## WASTE APPLICABILITY:

This technology is suitable for soils or sediments with organic contaminants. Liquid organic wastes can be treated after mixing with sand or soil. Optimal waste characteristics are as follows:

- Particle size, 5 microns to 2 inches
- Moisture content, up to 50 percent by weight
- Density, 30 to 130 pounds per cubic foot
- Heating value, up to 10,000 British thermal units per pound
- Chlorine content, up to 5 percent by weight
- Sulfur content, up to 5 percent by weight
- Phosphorus, 0 to 300 parts per million (ppm)
- pH, 5 to 9
- Alkali metals, up to 1 percent by weight

## STATUS:

EPA conducted two evaluations of the infrared thermal destruction technology. A full-scale unit was evaluated during August 1987 at the Peak Oil Superfund site in Brandon, Florida. The system treated nearly 7,000 cubic yards of waste oil sludge containing PCBs and lead. A pilot-scale demonstration took place at the Rose Township-Demode Road Superfund site in



The SITE Program assesses but does not approve or endorse technologies.

Michigan during November 1987. Organics, PCBs, and metals in soil were the target waste compounds. Two Applications Analysis Reports (EPA/540/A5-89/010 and EPA/540/A5-89/007) and two Technology Evaluation Reports (EPA/540/5-88/002a and EPA/540/5-89/007a) are available from EPA. In addition, the technology has been used to remediate PCB contamination at the Florida Steel Corporation and the LaSalle Electric Superfund sites.

This technology is no longer available through vendors in the United States. For further information about the technology, contact the EPA Project Manager.

## DEMONSTRATION RESULTS:

The results from the two SITE demonstrations are summarized below.

- PCBs were reduced to less than 1 ppm in the ash, with a destruction removal efficiency (DRE) for air emissions greater than 99.99 percent (based on detection limits).
- In the pilot-scale demonstration, the Resource Conservation and Recovery Act standard for particulate emissions (0.08 gram per dry standard cubic foot) was achieved. In the full-scale demonstration, however, this standard was not met in all runs because of scrubber inefficiencies.
- Lead was not immobilized; however, it remained in the ash. Significant amounts were not transferred to the scrubber water or emitted to the atmosphere.
- The pilot-scale unit demonstrated satisfactory performance with high feed rate and reduced power consumption when fuel oil was added to the waste feed and the primary chamber temperature was reduced.
- Economic analysis suggests an overall waste remediation cost of less than $800 per ton.

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# HARDING LAWSON ASSOCIATES
# (Formerly ABB Environmental Services, Inc.)
### (Two-Zone, Plume Interception, In Situ Treatment Strategy)

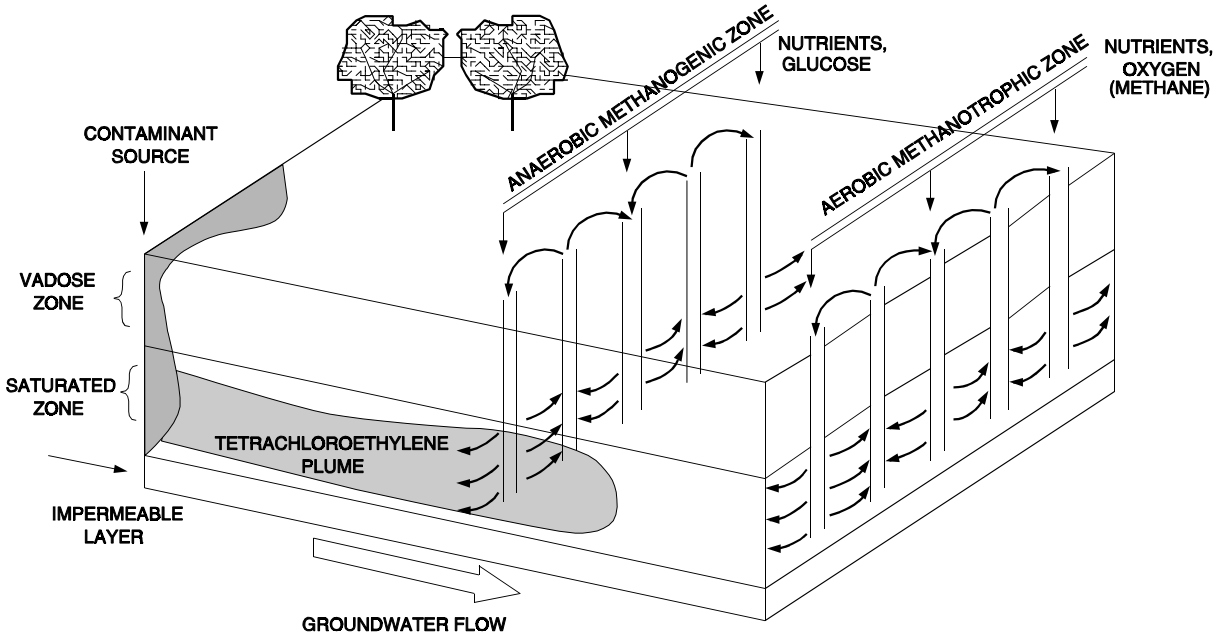
## TECHNOLOGY DESCRIPTION:

The two-zone, plume interception, in situ treatment strategy is designed to treat chlorinated and nonchlorinated organic compounds in saturated soils and groundwater using a sequence of anaerobic and aerobic conditions (see figure below). The in situ anaerobic and aerobic system constitutes a treatment train that biodegrades a wide assortment of chlorinated and nonchlorinated compounds.

When applying this technology, anaerobic and aerobic conditions are produced in two distinct, hydraulically controlled, saturated soil zones. Groundwater passes through each zone as it is recirculated through the treatment area. The first zone, the anaerobic zone, is designed to partially dechlorinate highly chlorinated solvents such as tetrachloroethene (PCE), trichloroethene (TCE), and 1,1,1-trichloroethane with natural biological processes. The second zone, the aerobic zone, is designed to biologically oxidize the partially dechlorinated products from the first zone, as well as other compounds that were not susceptible to the anaerobic treatment phase.

Anaerobic conditions are produced or enhanced in the first treatment zone by introducing a primary carbon source, such as lactic acid, and mineral nutrients, such as nitrogen and phosphorus. When proper anaerobic conditions are attained, the target contaminants are reduced. For example, PCE is dechlorinated to TCE, and TCE is dechlorinated to dichloroethene (DCE) and vinyl chloride. Under favorable conditions, this process can completely dechlorinate the organics to ethene and ethane.

Aerobic conditions are produced or enhanced in the second treatment zone by introducing oxygen, mineral nutrients such as nitrogen and phosphorus, and possibly an additional carbon source, such as methane (if an insufficient supply




Two-Zone, Plume Interception, In Situ Treatment Strategy



The SITE Program assesses but does not approve or endorse technologies.

of methane results from the upstream, anaerobic zone). When proper aerobic conditions are attained in this zone, partially dechlorinated products and other target compounds from the first zone are oxidized. For example, less-chlorinated ethenes such as DCE and vinyl chloride are cometabolized during the aerobic microbiological degradation of methane.

The treatment strategy is designed to biologically remediate subsoils by enhancing indigenous microorganism activity. If indigenous bacterial populations do not provide the adequate anaerobic or aerobic results, specially adapted cultures can be introduced to the aquifer. These cultures are introduced using media-filled trenches that can support added microbial growth.

## WASTE APPLICABILITY:

The two-zone, plume interception, in situ treatment strategy is designed to treat groundwater and saturated soils containing chlorinated and nonchlorinated organic compounds.

## STATUS:

The two-zone, plume interception, in situ treatment strategy was accepted into the SITE Emerging Technology Program in July 1989. Optimal treatment parameters for field testing were investigated in bench-scale soil aquifer simulators. The objectives of bench-scale testing were to (1) determine factors affecting the development of each zone, (2) evaluate indigenous bacterial communities, (3) demonstrate treatment of chlorinated and nonchlorinated solvent mixtures, and (4) develop a model for the field remediation design. The Emerging Technology Bulletin (EPA/540/F-95/510), which details the bench-scale testing results, is available from EPA.

A pilot-scale field demonstration system was installed at an industrial facility in Massachusetts. Pilot-scale testing began in September 1996. Results from this testing indicate the following:

- The reductive dechlorination of PCE and TCE to DCE, VC, and ethene has been accomplished primarily by sulfate-reducing bacteria.
- A time lag of about 4 months was required before significant reductive dechlorination occurred. This corresponded to the time and lactic acid dosing required to reduce the redox to about -100 throughout the treatment cell.
- Sequential anaerobic-aerobic (Two-Zone) biodegradation of PCE and its degradation products appear to be a viable and cost-effective treatment technology for the enhancement of natural reductive dechlorination processes.

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# HAZARDOUS SUBSTANCE MANAGEMENT RESEARCH CENTER AT NEW JERSEY INSTITUTE OF TECHNOLOGY and RUTGERS, THE STATE UNIVERSITY OF NEW JERSEY

**(Pneumatic Fracturing and Bioremediation Process)**

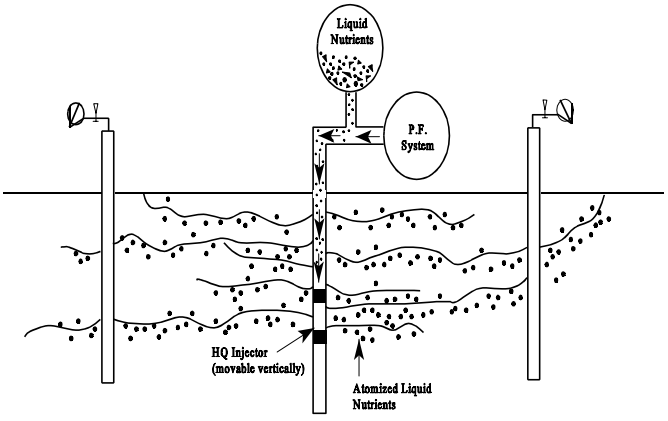
## TECHNOLOGY DESCRIPTION:

The Hazardous Substance Management Research Center (HSMRC) has developed a technology for the in situ remediation of organic contaminants. The process enhances in situ bioremediation through pneumatic fracturing to establish an extended biodegradation zone supporting aerobic, denitrifying, and methanogenic populations. The technique is designed to provide faster transport of nutrients and electron acceptors (for example, oxygen and nitrate) to the microorganisms, particularly in geologic formations with moderate to low permeability.

An overview of the process is shown in the figure below. First, the formation is pneumatically fractured by applying high pressure air in 2-foot-long, discrete intervals through a proprietary device known as an HQ Injector. After the formation has been fractured with air, nutrients or other chemicals are introduced into the fracture network to stimulate biological activity. The carrier gas and the particular amendments (atomized liquid or dry media) injected into the formation can be adjusted according to the target contaminant and the desired degradation environment (aerobic, denitrifying, and anaerobic). The high air-to-liquid ratio atomizes the liquid supplements during injection, increasing their ability to penetrate the fractured formation. In the final step of the process, the site is operated as an in situ bioremediation cell to degrade the contaminants. A continuous, low-level air flow is maintained through the fracture network by a vacuum pump that provide oxygen to the microbial populations. Periodically, additional injections are made to replenish nutrients and electron acceptors.

## WASTE APPLICABILITY:

The integrated process can be applied to a wide variety of geologic formations. In geologic formations with low to moderate permeabilities, such as those containing clay, silt, or tight bedrock, the process creates artificial fractures that increase formation permeability. In




Overview of the Integrated Pneumatic Fracturing and Bioremediation Process



The SITE Program assesses but does not approve or endorse technologies.

formations with higher permeabilities, the process is still useful for rapid aeration and delivery of amendments to the microorganisms.

## STATUS:

This technology was accepted into the SITE Emerging Technology Program in July 1991 and was evaluated at a gasoline refinery located in the Delaware Valley. Soil at the site was contaminated with benzene, toluene, and xylene (BTX) at concentrations up to 1,500 milligrams per kilogram, along with other hydrocarbons. The evaluation was completed in May 1994. Contact the EPA Project Manager for a copy of the results from the evaluation. A journal article has been submitted to the *Journal of Air and Waste Management*.Throughout the 50-week pilot-scale evaluation, off-gases were monitored for BTX, carbon dioxide, and methane, which served as indicators of biological activity. Process effectiveness was evaluated by comparing analytical results of soil samples collected at the beginning and the end of the evaluation.

Vapor extraction tests revealed postfracture air flows to be 24 to 105 times higher than prefracture air flows. Measurements of ground surface heave and observations of fractures venting to the ground surface indicated that the fractures had effective radii of up to 20 feet from the injection point.

Soil gas data collected at the monitoring wells show that the indigenous microbial populations responded favorably to the injection of the soil amendments. Soil gas data consistently showed elevated levels of carbon dioxide immediately following each injection, indicating increased rates of BTX mineralization. Correspondingly, BTX concentrations in the wells gradually declined over time after depletion of oxygen and nitrate, at which time methanogenic processes began to dominate until the next subsurface amendment injection.

Comparative analysis of soil samples extracted from the site before and after the evaluation period showed that a substantial amount of BTX was degraded as a result of the integrated process. Total soil-phase BTX was reduced from 28 to 6 kilograms over the 50-week pilot test, corresponding to a 79 percent reduction in total BTX mass. An assessment of pathways of BTX loss from the formation showed a large proportion of the mass reduction (85 percent) was attributable to bioremediation.

Process development for this evaluation was supported in part by the U.S. Department of Defense, Advanced Research Projects Agency, and the Office of Naval Research.

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# HIGH VOLTAGE ENVIRONMENTAL APPLICATIONS, INC.
## (formerly ELECTRON BEAM RESEARCH FACILITY, FLORIDA INTERNATIONAL UNIVERSITY, and UNIVERSITY OF MIAMI)
## (High-Energy Electron Irradiation)

## TECHNOLOGY DESCRIPTION:

High-voltage electron irradiation of water produces a large number of reactive chemical species, including the aqueous electron ($e^-_{aq}$), the hydrogen radical (H·), and the hydroxyl radical (OH·). These short-lived intermediates break down organic contaminants in aqueous wastes.

In the principal reaction, the aqueous electron transfers to halogen-containing compounds, breaking the halogen-carbon bond and liberating halogen anions such as chloride ($Cl^-$) or bromide ($Br^-$). The hydroxyl radical can undergo addition or hydrogen abstraction reactions, producing organic free radicals that decompose in the presence of other hydroxyl radicals and water. In most cases, organics are converted to carbon dioxide, water, and salts. Lower molecular weight aldehydes, haloacetic acids, and carboxylic acids form at low concentrations in some cases.

During the high-voltage electron irradiation process, electricity generates high energy electrons. The electrons are accelerated by the voltage to approximately 95 percent of the speed of light. They are then directed into a thin stream of water or sludge. All reactions are complete in less than 0.1 second. The electron beam and waste flow are adjusted to deliver the necessary dose of electrons. Although this is a form of ionizing radiation, there is no residual radioactivity.

High Voltage Environmental Applications, Inc. (High Voltage), has developed a mobile facility to demonstrate the treatment process (see photograph below).

## WASTE APPLICABILITY:

This treatment process can effectively treat more than 100 common organic compounds. These compounds include the following:

The Mobile Electron Beam Hazardous Waste Treatment System

- Trihalomethanes (such as chloroform), which are found in chlorinated drinking water
- Chlorinated solvents, including carbon tetrachloride, trichloroethane, tetrachloroethene (PCE), trichloroethene (TCE), ethylene dibromide, dibromo-chloropropane, hexachlorobutadiene, and hexachloroethane
- Aromatics found in gasoline, including benzene, toluene, ethylbenzene, and xylene (BTEX)
- Chlorobenzene and dichlorobenzenes
- Phenol
- Dieldrin, a persistent pesticide
- Polychlorinated biphenyls
- A variety of other organic compounds

The treatment process is appropriate for removing various hazardous organic compounds from aqueous waste streams and sludges.

The high-energy electron irradiation process was accepted into the SITE Emerging Technology Program (ETP) in June 1990. For further information on the pilot-scale facility evaluated under the ETP, refer to the Emerging Technology Bulletins (EPA/540/F-93/502, EPA/540/F-92/009, and EPA/540/F-93/509), which are available from EPA. Based on results from ETP, the process was invited to participate in the Demonstration Program.

The ability of the technology to treat contaminated soils, sediments, or sludges is also being evaluated under the ETP. For further information on this evaluation, refer to the the High Voltage profile in the ETP section (ongoing projects).

The treatment process was demonstrated at the U.S. Department of Energy's Savannah River site in Aiken, South Carolina during two different periods totaling 3 weeks in September and November 1994. A trailer-mounted treatment system was demonstrated on a portion of the Savannah River site known as M-Area.

## DEMONSTRATION RESULTS:

During the demonstration, the system treated about 70,000 gallons of M-Area groundwater contaminated with volatile organic compounds (VOC). The principal groundwater contaminants were TCE and PCE, which were present at concentrations of about 27,000 and 11,000 micrograms per liter ($\mu$g/L), respectively. The groundwater also contained low levels of cis-1,2-dichloroethene (40 $\mu$g/L). The following compounds were also spiked into the influent stream at approximately 500 $\mu$g/L: 1,2-dichloroethane, carbon tetrachloride, 1,1,1-trichloroethane, chloroform, and BTEX.

The highest VOC removal efficiencies were observed for TCE (99.5 percent), PCE (99.0 percent), and dichloroethene (greater than 99 percent). Removal efficiencies for chlorinated spiking compounds ranged from 68 to 98 percent, and removal efficiencies for BTEX ranged from 88 to 99.5 percent.

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# HIGH VOLTAGE ENVIRONMENTAL APPLICATIONS, INC.

**(High-Energy Electron Beam Irradiation)**

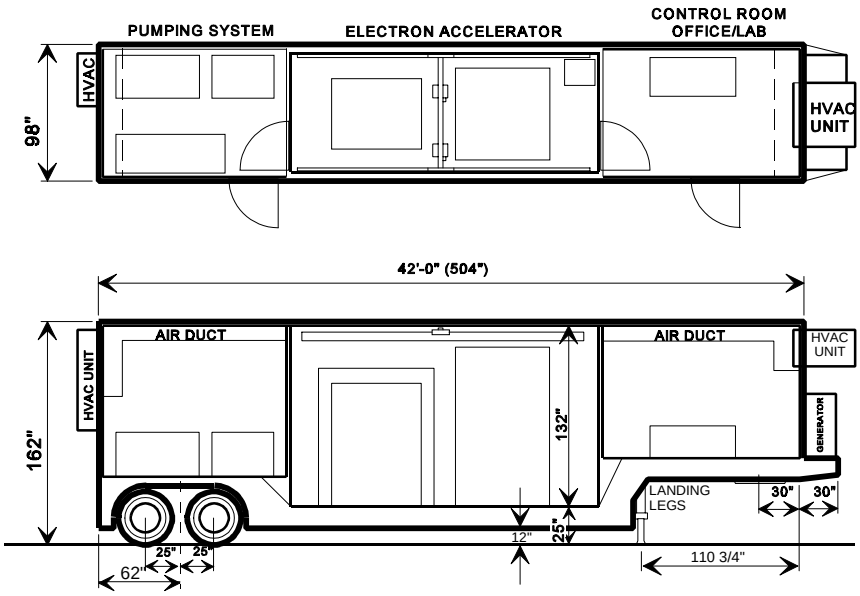
## TECHNOLOGY DESCRIPTION:

The high-energy electron beam irradiation technology is a low-temperature method for destroying complex mixtures of hazardous organic chemicals in hazardous wastes. These wastes include slurried soils, river or harbor sediments, and sludges. The technology can also treat contaminated soils and groundwater.

The figure below illustrates the mobile electron beam treatment system. The system consists of a computer-automated, portable electron beam accelerator and a delivery system. The 500-kilovolt electron accelerator produces a continuously variable beam current from 0 to 40 milliamperes. At full power, the system is rated at 20 kilowatts. The waste feed rate and beam current can be varied to obtain doses of up to 2,000 kilorads in a one-pass, flow-through mode.

The system is trailer-mounted and is completely self-contained, including a 100-kilowatt generator for remote locations or line connectors where power is available. The system requires only a mixing tank to slurry the treatable solids. The system also includes all necessary safety checks.

The computerized control system continuously monitors the waste feed rate, absorbed dose, accelerator potential, beam current, and all safety shutdown features. The feed rate is monitored with a calibrated flow valve. The absorbed dose is estimated based on the difference in the temperature of the waste stream before and after irradiation. The system is equipped with monitoring devices that measure the waste stream temperature before and after irradiation. Both the accelerating potential and the beam current are obtained directly from the transformer.




Mobile Electron Beam Treatment System



The SITE Program assesses but does not approve or endorse technologies.

Except for slurrying, this technology does not require any pretreatment of wastes.

## WASTE APPLICABILITY:

This technology treats a variety of organic compounds, including wood-treating chemicals, pesticides, insecticides, petroleum residues, and polychlorinated biphenyls (PCB) in slurried soils, sediments, and sludges.

## STATUS:

High Voltage Environmental Applications, Inc. (HVEA), was accepted into the SITE Emerging Technology Program in 1993. Under this program, HVEA will demonstrate its mobile pilot plant on soils, sediments, or sludges at various hazardous waste sites. Candidate sites are being identified. On-site studies will last up to 2 months.

Initial studies by HVEA have shown that electron beam irradiation effectively removes 2,4,6-trinitrotoluene from soil slurries.

As part of the Emerging Technology Program, HVEA has identified 350 tons of soil contaminated with an average Aroclor 1260 concentration of about 1,000 milligrams per kilogram. A small 1-ton feasibility study was conducted in August 1995. After results are available from the 1-ton study, HVEA plans to make its mobile unit available for full-scale remediations.

In a recent bench-scale study, a multisource hazardous waste leachate containing 1 percent dense nonaqueous phase liquid was successfully treated. In another bench-scale study, a leachate containing a light nonaqueous phase liquid contaminated with PCBs was treated to F039 standards.

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# HORSEHEAD RESOURCE DEVELOPMENT CO., INC.
## (Flame Reactor)

## TECHNOLOGY DESCRIPTION:

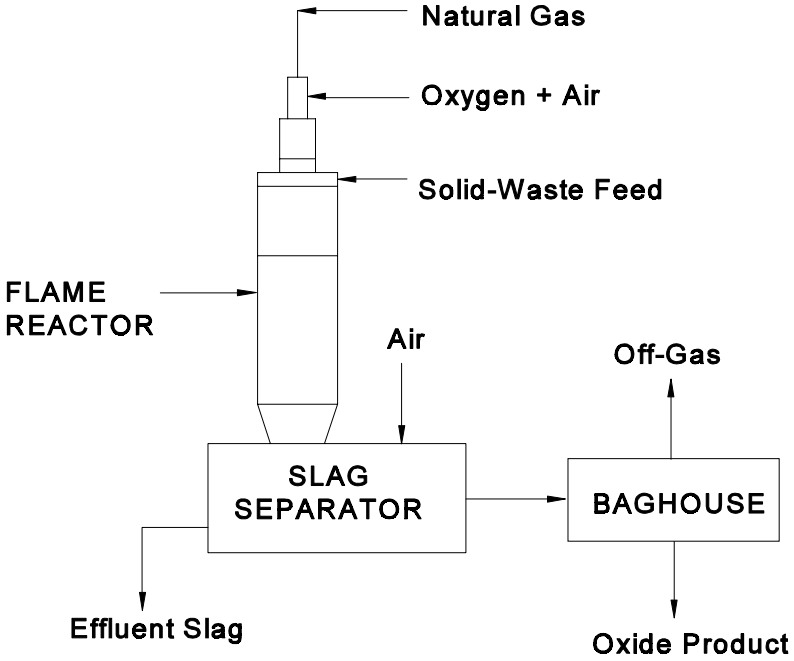
The Horsehead Resource Development Co., Inc. (HRD), flame reactor system is a patented, hydrocarbon-fueled, flash-smelting system that treats residues and wastes contaminated with metals (see figure below). The reactor processes wastes with hot (greater than 2,000 °C) reducing gases produced by combusting solid or gaseous hydrocarbon fuels in oxygen-enriched air.

In a compact, low-capital cost, water-cooled reactor, the feed materials react rapidly, allowing a high waste throughput. The end products are glass-like slag; a potentially recyclable, heavy metal-enriched oxide; and in some cases, a metal alloy. The glass-like slag is not toxicity characteristic leaching procedure (TCLP) leachable. The volatile metals are fumed and captured in a baghouse; nonvolatile metals partition to the slag or may be separated as a molten alloy. Organic compounds should be destroyed at the elevated temperature of the flame reactor technology. Volume reduction (of waste to slag plus oxide) depends on the chemical and physical properties of the waste.

In general, the system requires that wastes be dry enough (less than 5 percent total moisture) to be pneumatically fed and fine enough (less than 200 mesh) to react rapidly. HRD claims larger particles (up to 20 mesh) can be processed; however, the efficiency of metals recovery is decreased. The prototype system has a capacity of 1 to 3 tons per hour. According to HRD, individual units can be scaled to a capacity of 7 tons per hour.

## WASTE APPLICABILITY:

The flame reactor system can be applied to granular solids, soil, flue dusts, slags, and sludges that contain heavy metals. HRD claims that the flame reactor technology has successfully treated the following wastes: (1) electric arc furnace dust, (2) lead blast furnace slag, (3) soil, (4) iron residues, (5) primary copper flue dust, (6) lead smelter nickel matte, (7) zinc plant leach




HRD Flame Reactor Process Flow



The SITE Program assesses but does not approve or endorse technologies.

residues and purification residues, (8) brass mill dusts and fumes, and (9) electroplating sludges.

The system has treated wastes with the following metal species and concentrations: zinc (up to 40 percent); lead (up to 10 percent); chromium (up to 4 percent); cadmium (up to 3 percent); arsenic (up to 1 percent); copper (up to 8 percent); cobalt; and nickel. According to HRD, the system can also treat soils that are contaminated with a variety of toxic organics.

## STATUS:

This technology was accepted into the SITE Demonstration Program in 1990. Currently, the prototype flame reactor system operates as a stationary unit at HRD's facility in Monaca, Pennsylvania. EPA and HRD believe that a mobile system could be designed and constructed for on-site treatment of hazardous waste.

The SITE demonstration was conducted in March 1991 using secondary lead smelter soda slag from the National Smelting and Refining Company (NSR) Superfund site in Atlanta, Georgia. The demonstration was conducted at the Monaca, Pennsylvania facility under a Resource Conservation and Recovery Act research, development, and demonstration permit. This permit allows treatment of wastes containing high concentrations of metals, but only negligible concentrations of organics.

The major objectives of the SITE technology demonstration were to investigate the reuse potential of the recovered metal oxides, evaluate the levels of contaminants in the residual slag and their leaching potential, and determine the efficiency and economics of processing.

A 30,000-standard-tons-per-year commercial flame reactor system processes steel mill baghouse dust (K061) at the North Star Steel Mini Mill near Beaumont, Texas. The plant was activated June 1, 1993, and is reported to be performing as designed.

## DEMONSTRATION RESULTS:

Approximately 72 tons of NSR waste material were processed during the demonstration. Partial test results are shown in the table below.

Metal Concentration Ranges in Influent and Effluent

| | Waste Feed (mg/kg)* | Effluent Slag (mg/kg) | Oxide Product (mg/kg) |
|---|---|---|---|
| Arsenic | 428-1,040 | 92.1-1,340 | 1,010-1,170 |
| Cadmium | 356-512 | <2.3-13.5 | 1,080-1,380 |
| Copper | 1,460-2,590 | 2,730-3,890 | 1,380-1,780 |
| Iron | 95,600-130,000 | 167,000-228,000 | 29,100-35,600 |
| Lead | 48,200-61,700 | 1,560-11,400 | 159,000-184,000 |
| Zinc | 3,210-6,810 | 709-1,680 | 10,000-16,200 |

* milligrams per kilogram

All effluent slag passed toxicity characteristic leaching procedure criteria. The oxide was recycled to recover lead. The Technology Evaluation Report (EPA/540/5-91/005) and the Applications Analysis Report (EPA/540/A5-91/005) are available from EPA.

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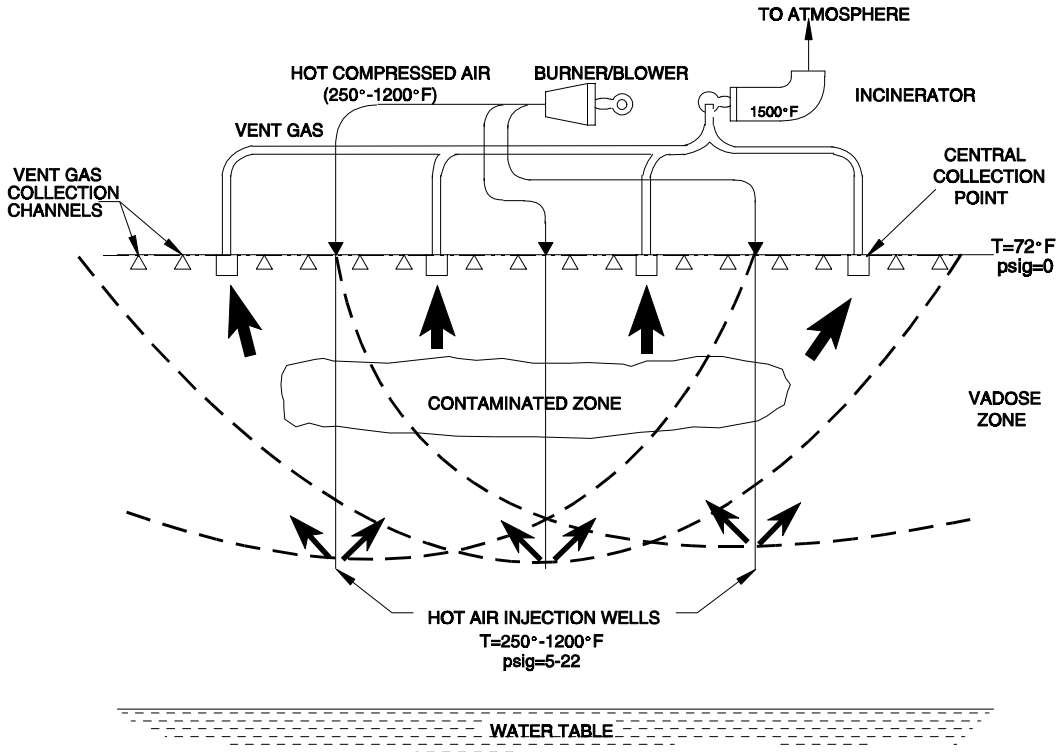
# HRUBETZ ENVIRONMENTAL SERVICES, INC.
## (HRUBOUT® Process)

## TECHNOLOGY DESCRIPTION:

The HRUBOUT® process is a thermal, in situ and ex situ treatment process designed to remove volatile organic compounds (VOC) and semivolatile organic compounds (SVOC) from contaminated soils. The in situ process is shown in the figure below. Heated air is injected into the soil below the contamination zone, evaporating soil moisture and removing volatile and semivolatile hydrocarbons. As the water evaporates, soil porosity and permeability increase, further facilitating the air flow at higher temperatures. As the soil temperature increases, the less volatile constituents volatilize or are thermally oxidized.

Injection wells are drilled in a predetermined distribution pattern to depths below the contamination zone. The wells are equipped with steel casings, perforated at the bottom, and cemented into the hole above the perforations. Heated, compressed air is introduced at temperatures of up to 1,200 $^{o}$F, and the pressure is slowly increased. As the air progresses upward through the soil, the moisture is evaporated, removing the VOCs and SVOCs. A surface collection system captures the exhaust gases under negative pressure. These gases are transferred to a thermal oxidizer, where the hydrocarbons are thermally destroyed in an incinerator at a temperature of 1,500 $^{o}$F.

The air is heated in an adiabatic burner at 2.9 million British thermal units per hour (MMBtu/hr). The incinerator has a rating of 3.1 MMBtu/hr. The air blower can deliver up to 8,500 pounds per hour. The units employ a fully modulating fuel train that is fueled by natural gas or propane. All equipment is mounted on custom-designed mobile units and can operate 24 hours per day.




HRUBOUT® Process



The SITE Program assesses but does not approve or endorse technologies.

## WASTE APPLICABILITY:

The HRUBOUT® process can remediate soils contaminated with halogenated or nonhalogenated organic volatiles and semivolatiles, such as gasoline, diesel oil, jet fuel, heating oil, chemical solvents, or other hydrocarbon compounds.

## STATUS:

The HRUBOUT® process was accepted into the SITE Demonstration Program in July 1992. The technology was demonstrated at Kelly Air Force Base in San Antonio, Texas from January through February 1993. A 30-foot by 40-foot area of an 80,000-gallon JP-4 jet fuel spill site was chosen as the treatment area. Six heated air injection wells, spaced on a 3-by-2 grid 10 feet apart, were drilled to a depth of approximately 20 feet. The Demonstration Bulletin (EPA/540/MR-93/524) is available from EPA.

In September 1993, an in situ project was completed at the Canadian Forces military base in Ottawa, Ontario, Canada. Levels up to 1,900 parts per million (ppm) of total petroleum hydrocarbons (TPH) were encountered over a 17-foot by 17-foot area on the base. Five injection wells were drilled to a depth of 30 feet. After 12 days of treatment, borehole samples ranged from nondetect to 215 ppm TPH, meeting closure requirements of 450 ppm TPH.

The containerized version of the HRUBOUT® process was tested in July 1993 at a west Texas site contaminated with Varsol, or naphtha. The soil was excavated for treatment in Hrubetz's insulated container. Analysis of untreated soil revealed TPH at 1,550 ppm. Three loads were treated for about 60 to 65 hours each. Post-treatment samples ranged from nondetect to 7 ppm TPH, meeting the Texas Natural Resource Conservation Commission's background target level of 37 ppm. Large-scale mobile container units, holding up to 40 cubic yards and capable of ex situ treatment of a load in 8 hours, are under development.

The ex situ version of the technology was selected to remediate a site in Toronto, Ontario, Canada, which consisted of about 1,500 cubic yards ($yd^3$) of soil contaminated with gasoline and diesel. Soil contamination was measured at 200 ppm TPH. Following treatment, seven soil samples were collected. Two samples had detectable concentrations of TPH (25 and 37 ppm) and the remaining five samples had nondetectable levels of TPH, achieving the 100 ppm TPH cleanup goal.

About 100 $yd^3$ of toluene-contaminated soil was remediated in Orlando, Florida using the soil pile process with a smaller 5-ton unit. A composite analysis of the excavated soil found toluene at concentrations of up to 1,470 parts per billion; nondetect levels were required for closure. A composite soil sample collected after 96 hours of operation met the closure criteria.

Four patents have been granted, and additional patents are pending. The process was approved by the Texas Natural Resources Conservation Commission in 1991.

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# HUGHES ENVIRONMENTAL SYSTEMS, INC.
## (Steam Enhanced Recovery Process)

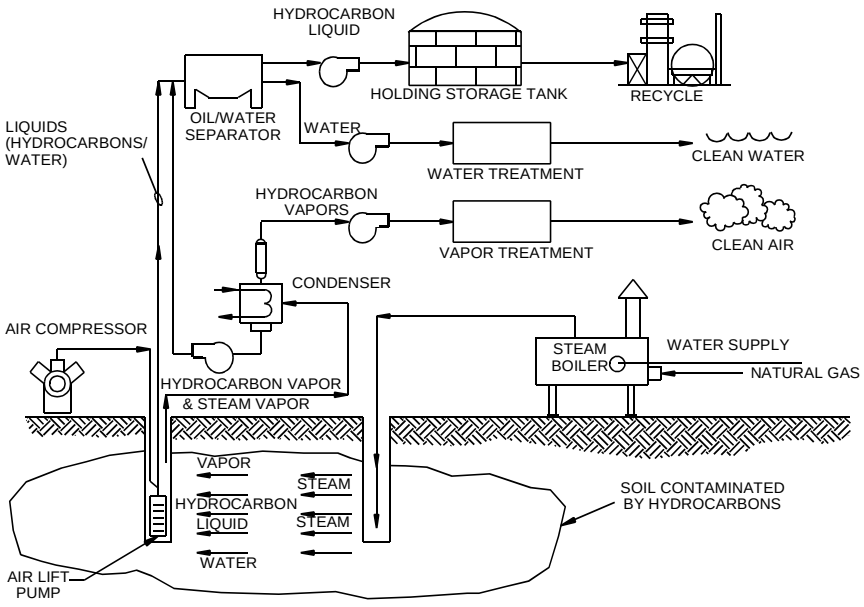
## TECHNOLOGY DESCRIPTION:

The Steam Enhanced Recovery Process (SERP) removes most volatile organic compounds (VOC) and semivolatile organic compounds (SVOC) from perched groundwater and contaminated soils both above and below the water table (see figure below). The technology is applicable to the in situ remediation of contaminated soils below ground surface and below or around permanent structures. The process accelerates contaminant removal rates and can be effective in all soil types.

Steam is forced through the soil by injection wells to thermally enhance the recovery of VOCs and SVOCs. Extraction wells are used for two purposes: to pump and treat groundwater, and to transport steam and vaporized contaminants to the surface. Recovered nonaqueous liquids are separated by gravity separation. Hydrocarbons are collected for recycling, and water is treated before being discharged to a storm drain or sewer. Vapors can be condensed and treated by any of several vapor treatment techniques (for example, thermal oxidation and catalytic oxidation). The technology uses readily available components such as extraction and monitoring wells, manifold piping, vapor and liquid separators, vacuum pumps, and gas emission control equipment.

## WASTE APPLICABILITY:

The SERP can extract VOCs and SVOCs from contaminated soils and perched groundwater. Compounds suitable for treatment are petroleum hydrocarbons such as gasoline and diesel and jet fuel; solvents such as trichloroethene, trichloroethane, and dichlorobenzene; or a mixture of these compounds. After application of the process, subsurface conditions are excellent for biodegradation of residual contaminants. The process cannot be applied to contaminated soil very near the ground surface unless a cap exists.




Steam Enhanced Recovery Process



The SITE Program assesses but does not approve or endorse technologies.

## STATUS:

This technology was accepted into the SITE Demonstration Program in 1991. The demonstration of the technology began in August 1991 and was completed in September 1993. The demonstration took place in Huntington Beach, California, at a site contaminated by a large diesel fuel spill. The Demonstration Bulletin (EPA/540/MR-94/510), Technology Capsule (EPA/540/R-94/510a), and Innovative Technology Evaluation Report (EPA/540/R-94/510) are available from EPA.

For more information regarding this technology, see the profiles for Berkeley Environmental Restoration Center (completed projects) or Praxis Environmental Technologies, Inc., in the Demonstration Program section (ongoing profiles).

This technology is no longer available through a vendor. For further information on the technology, contact the EPA Project Manager.

## DEMONSTRATION RESULTS:

Evaluation of the posttreatment data suggests the following conclusions:

- The geostatistical weighted average for total petroleum hydrocarbon (TPH) concentrations in the treated soils was 2,290 milligrams per kilogram (mg/kg). The 90 percent confidence interval for this average concentration is 996 mg/kg to 3,570 mg/kg, indicating a high probability that the technology did not meet the cleanup criterion. Seven percent of soil samples had TPH concentrations in excess of 10,000 mg/kg.
- The geostatistical weighted average for total recoverable petroleum hydrocarbon (TRPH) concentrations was 1,680 mg/kg, with a 90 percent confidence interval of 676 mg/kg to 2,680 mg/kg. Levels of benzene, toluene, ethylbenzene, and xylenes (BTEX) were below the detection limit (6 micrograms per kilogram) in treated soil samples; BTEX was detected at low mg/kg levels in a few pretreatment soil samples.
- Analysis of triplicate treated soil samples showed marked variability in soil contaminant concentrations over short distances. Analogous results for TPH and TRPH triplicate samples suggest that the contaminant concentration variability exists within the site soil matrix and is not the result of analytical techniques. This variability is the reason that confidence intervals for the average concentrations are so large.
- The data suggest that lateral or downward migration of contaminants did not occur during treatment.

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# IIT RESEARCH INSTITUTE/ BROWN AND ROOT ENVIRONMENTAL
## (Radio Frequency Heating)

## TECHNOLOGY DESCRIPTION:

Radio frequency heating (RFH) is an in situ process that uses electromagnetic energy to heat soil and enhance soil vapor extraction (SVE). Developed by IIT Research Institute, the patented RFH technique heats a discrete volume of soil using rows of vertical electrodes embedded in soil (or other media). Heated soil volumes are bounded by two rows of ground electrodes with energy applied to a third row midway between the ground rows. The three rows act as a buried triplate capacitor. When energy is applied to the electrode array, heating begins at the top center and proceeds vertically downward and laterally outward through the soil volume. The technique can heat soils to over 300 °C.

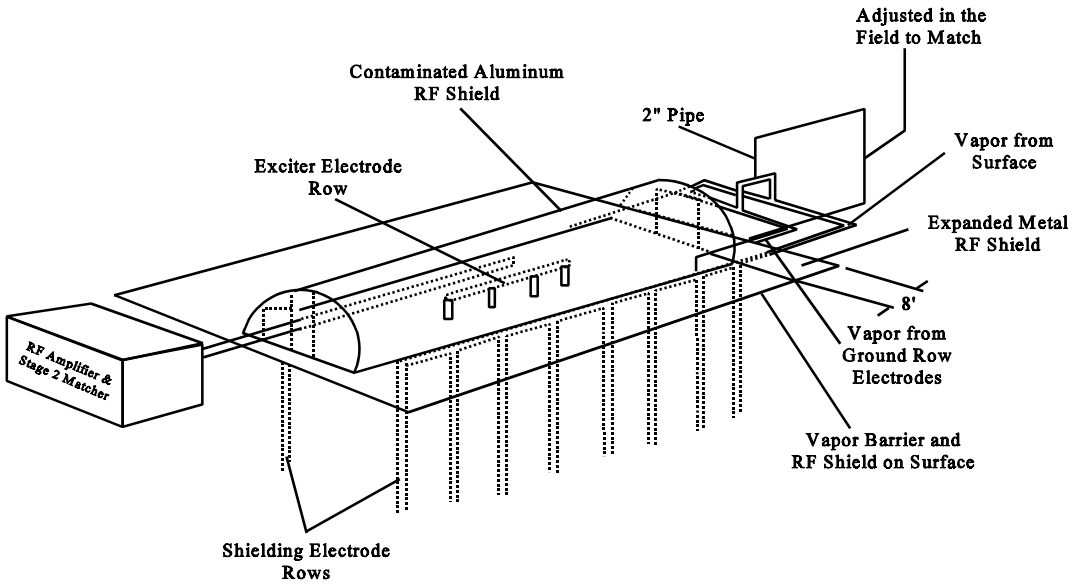
RFH enhances SVE in two ways: (1) contaminant vapor pressures are increased by heating, and (2) the soil permeability is increased by drying. Extracted vapor can then be treated by a variety of existing technologies, such as granular activated carbon or incineration.

## WASTE APPLICABILITY:

RFH can treat petroleum hydrocarbons, volatile organic compounds, semivolatile organic compounds, and pesticides in soils. The technology is most efficient in subsurface areas with low groundwater recharge. In theory, the technology should be applicable to any polar compound in any nonmetallic media.

## STATUS:

The RFH technique was accepted into the SITE Demonstration Program in summer 1992. The technique was demonstrated in August 1993 at Kelly Air Force Base (AFB), Texas, as part of a joint project with the U.S. Air Force. Brown




In Situ Radio Frequency Heating System



The SITE Program assesses but does not approve or endorse technologies.

and Root Environmental was the prime contractor evaluating and implementing RFH forthe U.S. Air Force. A field demonstration of the KAI Technologies, Inc. (KAI), RFH technology was completed in June 1994 at the same site for comparison. The Demonstration Bulletin (EPA/540/MR-94/527), Technology Capsule (EPA/540/R-94/527a), and the Innovative Technology Evaluation Report (EPA/540/R-94-527) are available from EPA. For further information on the KAI technology, see the profile in the Demonstration Program section (completed projects).

In 1995, the RFH technique was tested at the former chemical waste landfill at Sandia National Laboratories in Albuquerque, New Mexico. Approximately 800 cubic yards of silty soil was heated. Preliminary results indicate that the contaminant concentration in the extracted vapors increased by a factor of 10 compared to in situ venting.

Two previous field tests were completed using in situ RFH. The first test was completed at a fire training pit, located at the Volk Air National Guard Base in Camp Douglas, Wisconsin. The sandy soil in the pit was contaminated with jet fuel. The second test was completed at Rocky Mountain Arsenal in Colorado, where clayey soil was contaminated by organochlorine pesticides.

## DEMONSTRATION RESULTS:

Under the SITE demonstration, statistical analyses for the design treatment zone indicate that total recoverable petroleum hydrocarbons, pyrene, and bis(2-ethylhexyl)phthalate exhibited statistically significant decreases (at the 95 and 97.5 percent confidence levels). Chlorobenzene concentrations appeared to increase during treatment, possibly due to volatilization of chlorobenzene present in the groundwater.

Significant concentrations of 2-hexanone, 4-methyl-2-pentanone, acetone, and methyl ethyl ketone were found in the treated soils, although virtually no ketones were found before treatment. Soil temperatures as high as 1,000 $^{o}$C during the demonstration may have caused partial oxidation of petroleum hydrocarbons. Alternatively, the ketones may have been volatilized from groundwater. At this time, insufficient data are available to determine the source of ketones found in treated soils.

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# INSTITUTE OF GAS TECHNOLOGY
## (Chemical and Biological Treatment)

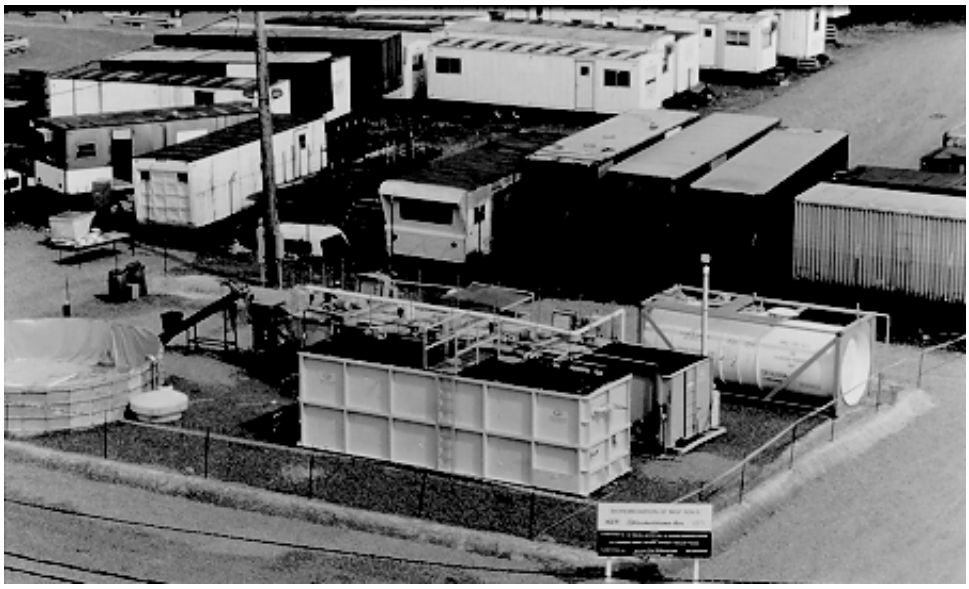
## TECHNOLOGY DESCRIPTION:

The Institute of Gas Technology (IGT) chemical and biological treatment (CBT) process remediates sludges, soils, groundwater, and surface water contaminated with organic pollutants, such as polynuclear aromatic hydrocarbons (PAH) and polychlorinated biphenyls. The treatment system (see photograph below) combines two remedial techniques: (1) chemical oxidation as pretreatment, and (2) biological treatment using aerobic and anaerobic biosystems in sequence or alone, depending on the waste. The CBT process uses mild chemical treatment to produce intermediates that are biologically degraded, reducing the cost and risk associated with a more severe treatment process such as incineration.

During the pretreatment stage, the contaminated material is treated with a chemical reagent that degrades the organics to carbon dioxide, water, and partially oxidized intermediates. In the second stage of the CBT process, biological systems degrade the hazardous residual materials and the partially oxidized intermediates from the first stage. Chemically treated wastes are subjected to cycles of aerobic and anaerobic degradation, if aerobic or anaerobic treatment alone is not sufficient. Several cycles of chemical and biological treatment are also used for extremely recalcitrant contaminants.

## WASTE APPLICABILITY:

The CBT process can be applied to soils, sludges, groundwater, and surface water containing (1) high waste concentrations that would typically inhibit bioremediation, or (2) low waste concentrations for which bioremediation alone is too slow. The process is not adversely affected by radionuclides or heavy metals. Depending on the types of heavy metals present, these metals will bioaccumulate in the biomass,



Chemical and Biological Treatment Process



The SITE Program assesses but does not approve or endorse technologies.

complex with organic or inorganic material in the soil slurries, or become soluble in the recycled water.

The CBT process can be applied to a wide range of organic pollutants, including alkenes, chlorinated alkenes, aromatics, substituted aromatics, and complex aromatics.

## STATUS:

IGT evaluated the CBT process for 2 years under the SITE Emerging Technology Program. The Emerging Technology Bulletin (EPA/540/F-94/540), which details results from the evaluation, is available from EPA. Based on results from the Emerging Technology Program, this technology was invited to participate in the SITE Demonstration Program.

Under the SITE Demonstration Program, IGT plans to conduct a full-scale demonstration of the CBT process on sediments containing PAHs. Different operating scenarios will be used to demonstrate how effectively the CBT process treats sediments in a bioslurry reactor. Several sites are being considered for the demonstration.

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# INSTITUTE OF GAS TECHNOLOGY
## (Fluid Extraction-Biological Degradation Process)

## TECHNOLOGY DESCRIPTION:

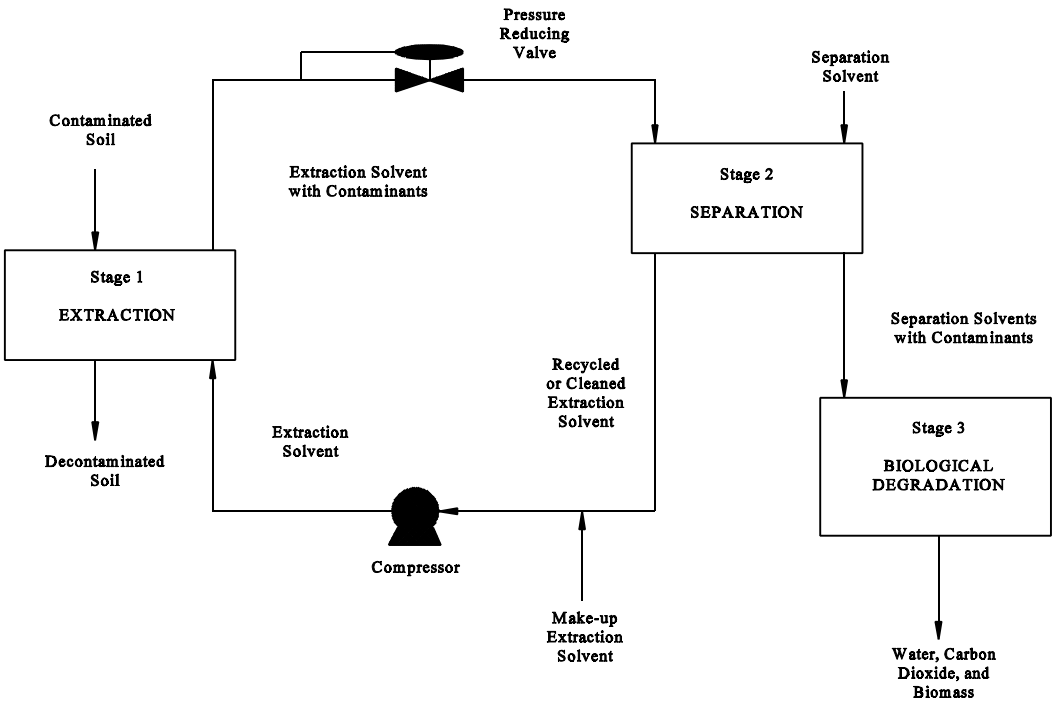
The three-step, fluid extraction-biological degradation (FEBD) process removes organic contaminants from soil (see figure below). The process combines three distinct technologies: (1) fluid extraction, which removes the organics from contaminated solids; (2) separation, which transfers the pollutants from the extract to a biologically compatible solvent or activated carbon carrier; and (3) biological degradation, which destroys the pollutants and leaves innocuous end-products.

In the fluid extraction step, excavated soils are placed in a pressure vessel and extracted with a recirculated stream of supercritical or near-supercritical carbon dioxide. An extraction cosolvent may be added to enhance the removal of additional contaminants.

During separation, organic contaminants are transferred to a biologically compatible separation solvent, such as water or a water-methanol mixture. The separation solvent is then sent to the final stage of the process, where bacteria degrade the waste to carbon dioxide and water. Clean extraction solvent is then recycled for use in the extraction stage.

Organic contaminants are biodegraded in aboveground aerobic bioreactors, using mixtures of bacterial cultures. Specific cultures are selected based on site contaminant characteristics. For example, if a site is primarily contaminated with polynuclear aromatic hydrocarbons (PAH), cultures able to metabolize or cometabolize these hydrocarbons are used. In this way the bioreactors can be configured to enhance the rate and extent of biodegradation.

Research continues on using bound, activated carbon in a carrier system during the separation step. Bound activated carbon should allow high-pressure conditions to be maintained in the fluid extraction step, resulting in enhanced extraction




Fluid Extraction-Biological Degradation Process



The SITE Program assesses but does not approve or endorse technologies.

efficiency and decreased extraction time. Bound, activated carbon should also limit the loss of carbon dioxide, thereby decreasing costs. Activated carbon containing the bound PAHs could then be treated in the biodegradation step by converting the carrier system to a biofilm reactor. The activated carbon carrier systems could then be recycled into the high-pressure system of the extraction and separation steps.

## WASTE APPLICABILITY:

This technology removes organic compounds from contaminated solids. It is more effective on some classes of organics, such as hydrocarbons (for example, gasoline and fuel oils), than on others, such as halogenated solvents and polychlorinated biphenyls. The process has also been effective in treating nonhalogenated aliphatic hydrocarbons and PAHs.

## STATUS:

This technology was accepted into the SITE Emerging Technology Program in June 1990. The Institute of Gas Technology has evaluated all three stages of the technology with soils from a Superfund site and from three other manfactured gas sites. These soils exhibited a variety of physical and chemical characteristics. About 85 to 99 percent of detectable PAHs, including two- to six-ring compounds, were removed from the soils.

The measurable PAHs were biologically converted in both batch-fed and continuously fed, constantly stirred, tank reactors. The conversion rate and removal efficiency were high in all systems. The PAHs were biologically removed or transformed at short hydraulic retention times. All PAHs, including four- to six-ring compounds, were susceptible to biological removal.

Results from this project were published in the Emerging Technology Bulletin (EPA/540/F-94/501), which is available from EPA. An article on the project was also submitted to the *Journal of Air and Waste Management*.

Potential users of the technology have expressed interest in continuing research, and the technology has been invited to participate in the SITE Demonstration Program. The technology would be able to remediate other manufactured gas sites, wood treatment sites, and contaminated soils and sediments.

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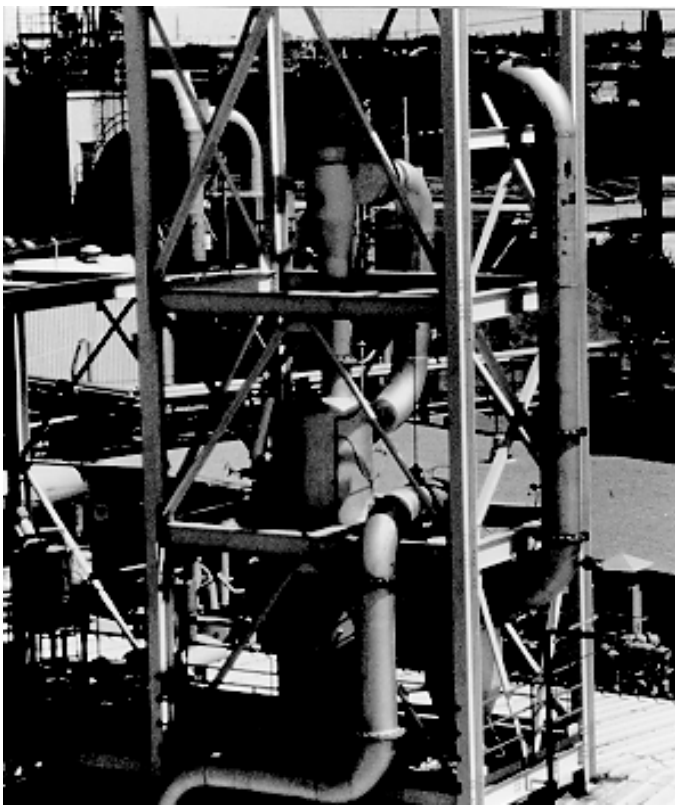
# INSTITUTE OF GAS TECHNOLOGY
## (Fluidized-Bed/Cyclonic Agglomerating Combustor)

## TECHNOLOGY DESCRIPTION:

The Institute of Gas Technology (IGT) has developed a two-stage, fluidized-bed/cyclonic agglomerating combustor (AGGCOM) based on a combination of IGT technologies. In the combined system, solid, liquid, and gaseous organic wastes are destroyed efficiently. Solid, nonvolatile, inorganic contaminants are combined within a glassy matrix consisting of discrete pebble-sized agglomerates that are suitable for disposal in a landfill.

The first stage of the combustor is an agglomerating fluidized-bed reactor, which can operate under substoichiometric conditions or with excess air. The system can operate from low temperature (desorption) to high temperature (agglomeration). The system can also gasify materials with high calorific values (for example, municipal solid wastes). With a unique fuel and air distribution, most of the fluidized bed is maintained at 1,500 F° to 2,000 F°, while the central hot zone temperature can be varied between 2,000 F° and 3,000 F°.

When contaminated soils and sludges are fed into the fluidized bed, the combustible fraction of the waste is rapidly gasified and combusted. The solid fraction, containing inorganic and metallic contaminants, undergoes a chemical transformation in the hot zone and is agglomerated into glassy pellets. The pellets are essentially nonleachable under the conditions



AGGCOM Pilot Plant



The SITE Program assesses but does not approve or endorse technologies.

of the Toxicity Characteristic Leaching Procedure (TCLP). The product gas from the fluidized bed may contain unburned hydrocarbons, furans, dioxins, and carbon monoxide, as well as carbon dioxide and water, which are the products of complete combustion.

Product gas from the fluidized bed is fed into the second stage of the combustor, where it is further combusted at a temperature of 1,800 F° to 2,400 F°. The second stage is a high-intensity cyclonic combustor and separator that provides sufficient residence time (0.25 second) to oxidize carbon monoxide and organic compounds to carbon dioxide and water vapor. This stage has a combined destruction and removal efficiency of greater than 99.99 percent. Volatilized metals are collected downstream in the flue gas scrubber condensate.

The two-stage AGGCOM process is based on IGT's experience with other fluidized-bed and cyclonic combustion systems. The patented sloping-grid design and ash discharge port in this process were initially developed for IGT's U-GAS coal gasification process. The cyclonic combustor and separator is a modification of IGT's low-emissions combustor.

## WASTE APPLICABILITY:

The two-stage AGGCOM process can destroy organic contaminants in gaseous, liquid, and solid wastes, including soils and sludges. Gaseous wastes can be fired directly into the cyclonic combustor. Liquid, sludge, and solid wastes can be co-fired directly into the fluidized bed. Solid particles must be less than about 6 millimeters in diameter to support fluidized bed operation; therefore, certain wastes may require grinding or pulverizing prior to remediation.

Because the solid components in the waste are heated above fusion temperature during the agglomeration process, metals and other inorganic materials are encapsulated and immobilized within the glassy matrix.

## STATUS:

This technology was accepted into the SITE Emerging Technology Program in July 1990. Tests conducted in the batch, 6-inch-diameter, fluidized bed have demonstrated that agglomerates can be formed from the soil. The agglomerates, produced at several different operating conditions from soil spiked with lead and chromium compounds, passed the TCLP test for leachability.

A pilot-scale combustor with a capacity of 6 tons per day has been constructed (see photograph on previous page), and testing has produced samples of agglomerated soil. Future testing will focus on sustained and continuous operation of the pilot-scale plant using different types of soil, as well as other feedstocks. Tests with organic and inorganic hazardous waste surrogates admixed with the feed soil will also be conducted. A final report on the project has been submitted to EPA.

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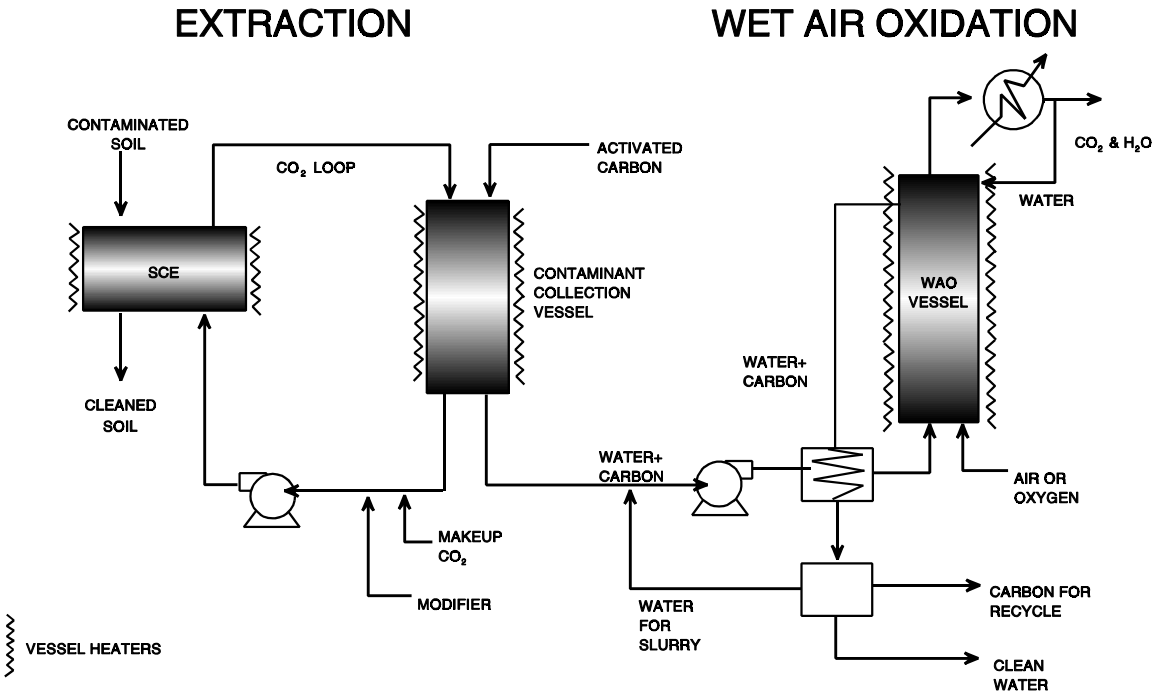
# INSTITUTE OF GAS TECHNOLOGY
## (Supercritical Extraction/Liquid Phase Oxidation)

## TECHNOLOGY DESCRIPTION:

The Institute of Gas Technology's (IGT) Supercritical Extraction/Liquid Phase Oxidation (SELPhOx) process (see figure below) removes organic contaminants from soils and sludges and destroys them. SELPhOx combines two processing steps: (1) supercritical extraction (SCE) of organic contaminants, and (2) wet air oxidation (WAO) of the extracted contaminants. The two-step process, linked by a contaminant collection stage, offers great flexibility for removing and destroying both high and low concentrations of organic contaminants.

Combining SCE and WAO in a single two-step process allows development of a highly efficient and economical process for remediating contaminated soils. Supercritical extraction with carbon dioxide ($CO_2$) removes organic contaminants from the soil while leaving much of the original soil organic matrix in place. The contaminants are collected on activated carbon in a contaminant collection vessel. The activated carbon with sorbed contaminants is then transported in an aqueous stream to a WAO reactor for destruction. Concentrating the organic contaminants on activated carbon in water provides a suitable matrix for the WAO feed stream and improves process economics by decreasing WAO reactor size. The activated carbon is regenerated in the WAO reactor with minimal carbon loss and can be recycled to the contaminant collection vessel.

The SELPhOx process requires only water, air, makeup activated carbon, and the extractant ($CO_2$). Primary treatment products include cleaned soil, water, nitrogen (from the air fed to the WAO step), and $CO_2$. Organic sulfur, nitrogen, and chloride compounds that may be present in the original soil or sludge matrix are




Supercritical Extraction/Liquid Phase Oxidation (SELPhOx) Process



The SITE Program assesses but does not approve or endorse technologies.

transformed to relatively innocuous compounds in the product water. These compounds include sulfuric acid and hydrogen chloride, or their salts. The treated soil can be returned to the original site, and the water can be safely discharged after thermal energy recovery and minor secondary treatment. The gas can be depressurized by a turbo expander for energy recovery and then vented through a filter.

## WASTE APPLICABILITY:

The SELPhOx process removes organic contaminants from soils and sludges, including chlorinated and nonchlorinated polynuclear aromatic hydrocarbons (PAH), polychlorinated biphenyls, and other organic contaminants. The process is targeted toward sites that are contaminated with high levels of these organics (hot spots).

The SELPhOx process was accepted into the SITE Emerging Technology Program in July 1994. The primary objectives of the project are to (1) evaluate SCE's contaminant removal efficiency, (2) determine the potential for $CO_2$ recovery and reuse, and (3) determine destruction efficiencies of extracted contaminants in the WAO process. Analytical results from the project will provide the necessary information for the full-scale process design.

Laboratory-scale SCE tests have been completed using soils contaminated with PAHs. Operating conditions for the SCE stage and the activated carbon adsorption stage have been selected. A transportable field test unit was constructed and tested with PAH-contaminated soil. The final report has yet to be submitted by the developer.

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# IONICS RCC
## (B.E.S.T. Solvent Extraction Technology)

## TECHNOLOGY DESCRIPTION:

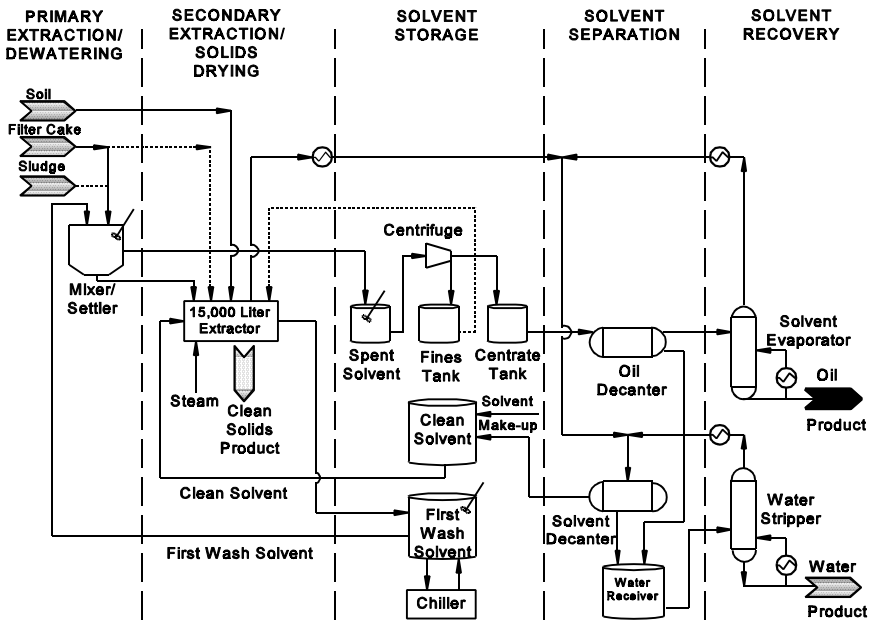
Solvent extraction treats sludges, sediments, and soils contaminated with a wide range of hazardous contaminants including polychlorinated biphenyls (PCB), polynuclear aromatic hydrocarbons (PAH), pesticides, and herbicides. The waste matrix is separated into three fractions: oil, water, and solids. Organic contaminants, such as PCBs, are concentrated in the oil fraction, while metals are separated into the solids fraction. The volume and toxicity of the original waste is thereby reduced, and the concentrated waste streams can be efficiently treated for disposal.

The B.E.S.T. technology is a mobile solvent extraction system that uses secondary or tertiary amine solvents to separate organics from soils, sediments, and sludges. The B.E.S.T. solvents are hydrophobic above 20 °C and hydrophilic below 20 °C. This property allows the process to extract both aqueous and nonaqueous compounds by changing the solvent temperature.

Pretreatment includes screening the waste to remove particles larger than 1 inch in diameter, which are treated separately.

The B.E.S.T. process begins by mixing and agitating the solvent and waste in a mixer/settler. Solids from the mixer/settler are then transferred to the extractor/dryer vessel. (In most cases, waste materials may be added directly to the extractor/dryer and the mixer/settler is not required.) Hydrocarbons and water in the waste simultaneously solubilize with the solvent, creating a homogeneous mixture. As the solvent breaks the oil-water-solid emulsions in the waste, the solids are released and settle by gravity. The solvent mixture is decanted from the solids and centrifuged to remove fine particles.

The solvent-oil-water mixture is then heated. As the mixture's temperature increases, the water separates from the organics and solvent. The organics-solvent fraction is decanted and sent to a solvent evaporator, where the solvent is recycled. The organics are discharged for




B.E.S.T. Solvent Extraction Technology



The SITE Program assesses but does not approve or endorse technologies.

recycling, disposal, or treatment. The water passes to a steam stripping column where residual solvent is recovered for recycling. The water is typically discharged to a local wastewater treatment plant.

The B.E.S.T. technology is modular, allowing for on-site treatment. The process significantly reduces the organic contamination concentration in the solids. B.E.S.T. also concentrates the contaminants into a smaller volume, allowing for efficient final treatment and disposal.

## WASTE APPLICABILITY:

The B.E.S.T. technology can remove hydrocarbon contaminants such as PCBs, PAHs, pesticides, and herbicides from sediments, sludges, or soils. System performance can be influenced by the presence of detergents and emulsifiers.

## STATUS:

The B.E.S.T. technology was accepted into the SITE Demonstration Program in 1987. The SITE demonstration was completed in July 1992 at the Grand Calumet River site in Gary, Indiana. The following reports are available from EPA:

- Applications Analysis Report (EPA/540/AR-92/079)
- Technology Evaluation Report - Volume I (EPA/540/R-92/079a)
- Technology Evaluation Report - Volume II, Part 1 (EPA/540/R-92/079b)
- Technology Evaluation Report - Volume II, Part 2 (EPA/540/R-92/079c)
- Technology Evaluation Report - Volume II, Part 3 (EPA/540/R-92/079d)
- Technology Demonstration Summary (EPA/540/SR-92/079)

The first full-scale B.E.S.T. unit was used at the General Refining Superfund site in Garden City, Georgia. A 75-ton-per-day B.E.S.T. unit is being installed at Idaho National Engineering Laboratory to extract organic contaminants from mixed wastes.

## DEMONSTRATION RESULTS:

The SITE demonstration showed that the B.E.S.T. process removed greater than 99 percent of the PCBs found in river sediments without using mechanical dewatering equipment. Treated solids contained less than 2 milligrams per kilogram PCBs. Comparable removal efficiencies were noted for PAHs.

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# IT CORPORATION
## (Batch Steam Distillation and Metal Extraction)

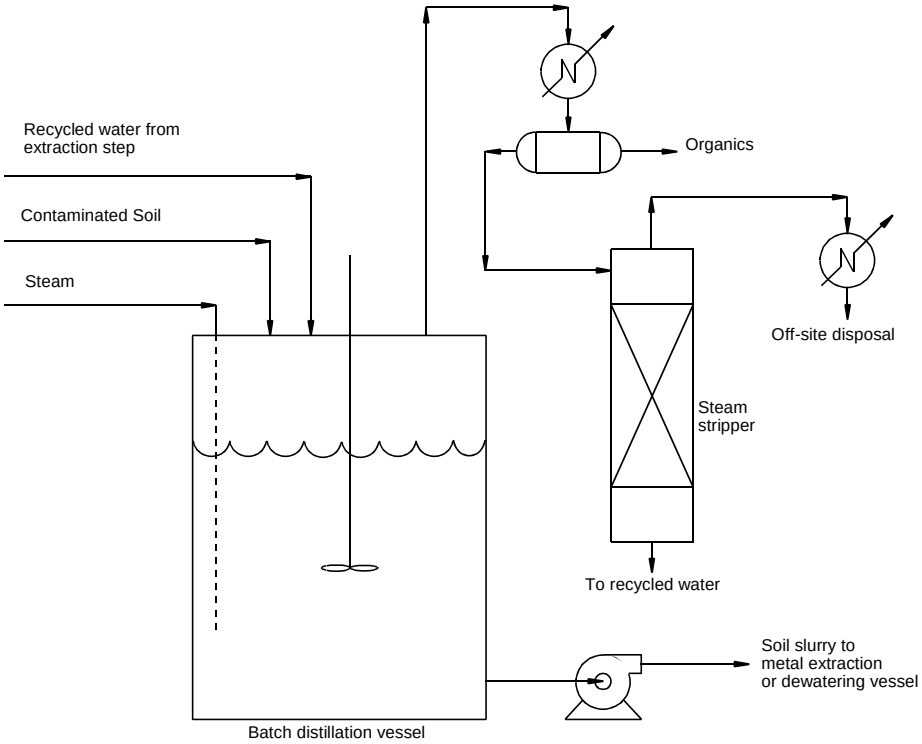
## TECHNOLOGY DESCRIPTION:

The batch steam distillation and metal extraction treatment process is a two-stage system that treats soils contaminated with organics and inorganics. The system uses conventional, readily available process equipment and does not generate hazardous combustion products. Hazardous materials are separated from soils as concentrates, which can then be disposed of or recycled. Treated soil can be returned to the site.

During treatment, waste soil is slurried in water and heated to 100° C. The heat vaporizes volatile organic compounds (VOC) and produces an amount of steam equal to 5 to 10 percent of the slurry volume. Resulting vapors are condensed and decanted to separate organic contaminants from the aqueous phase. Condensed water from this step can be recycled through the system after soluble organics are removed. The soil is then transferred as a slurry to the metal extraction step.

In the metal extraction step, the soil slurry is washed with hydrochloric acid. Subsequent countercurrent batch washing with water removes residual acid from the soil. The solids are then separated from the final wash solution by gravimetric sedimentation. Most heavy metals are converted to chloride salts in this step. The acid extract stream is then routed to a batch steam distillation system, where excess hydrochloric acid is recovered (see figure below). Bottoms from the still, which contain heavy metals, are precipitated as hydroxide salts and are drawn off as a sludge for off-site disposal or recovery.

As a batch process, this treatment technology is targeted at sites with less than 5,000 tons of soil




Batch Steam Distillation Step



The SITE Program assesses but does not approve or endorse technologies.

requiring treatment. Processing time depends on equipment size and batch cycle times; about one batch of soil can be treated every 4 hours.

## WASTE APPLICABILITY:

This process may be applied to soils and sludges contaminated with organics, inorganics, and heavy metals.

The batch steam distillation and metal extraction process was accepted into the SITE Emerging Technology Program in January 1988. The evaluation was completed in 1992. The Emerging Technology Bulletin (EPA/540/F-95/509), which details results from the test, is available from EPA.

Under the program, three pilot-scale tests have been completed on three soils, for a total of nine tests. The removal rates for benzene, toluene, ethylbenzene, and xylene were greater than 99 percent. The removal rates for chlorinated solvents ranged from 97 to 99 percent. One acid extraction and two water washes resulted in a 95 percent removal rate for heavy metals. Toxicity characteristic leaching procedure tests on the treated soils showed that soils from eight of the nine tests met leachate criteria. Data were also collected on the recovery rate for excess acid and the precipitation rate of heavy metals into a concentrate.

Estimated treatment costs per ton, including capital recovery, for the two treatment steps are shown in the box below.

| | |
|---|---|
| Batch Steam Distillation | |
| 500-ton site | $299-393/ton |
| 2,500-ton site | $266-350/ton |
| Metals Extraction (including acid recovery) | |
| 500-ton site | $447-619/ton |
| 2,500-ton site | $396-545/ton |

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# IT CORPORATION
## (Chelation/Electrodeposition of Toxic Metals from Soils)

## TECHNOLOGY DESCRIPTION:

IT Corporation has conducted laboratory-scale research on an innovative process that removes heavy metals from contaminated soils and sludges by forming a soluble chelate. The metals and the chelating agent are then separated from the soils and recovered.

The treatment employs two key steps (see figure below): (1) a water-soluble chelating agent, such as ethylenediamine tetraacetic acid, bonds with heavy metals and forms a chelate; and (2) an electromembrane reactor (EMR) recovers the heavy metals from the chelate and regenerates the chelating agent.

Soils are screened before the chelation step to remove large particles such as wood, metal scrap, and large rocks.

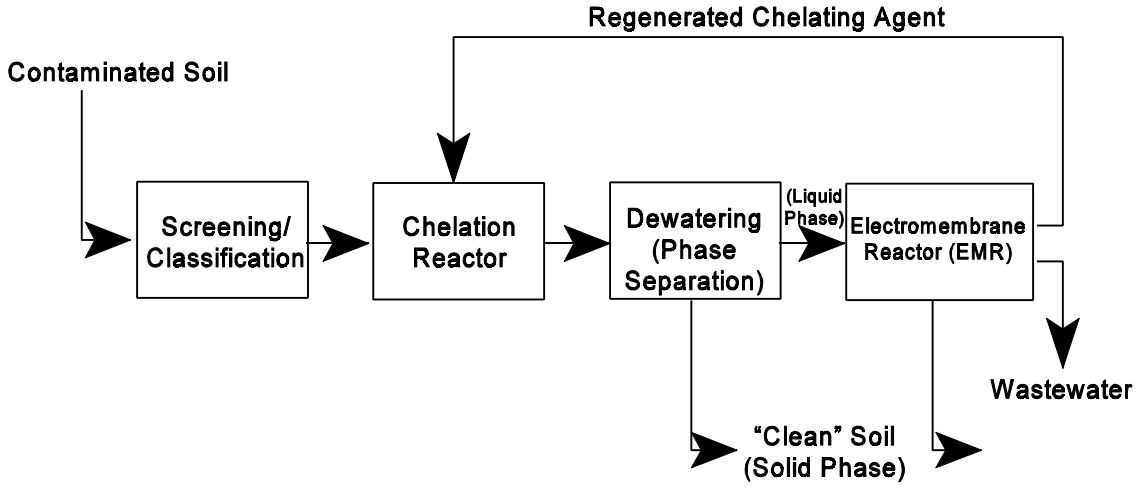
The chelated soil is dewatered to separate the water-soluble chelating agent from the solid phase. The separated chelating agent, which contains heavy metals, is then treated in the EMR. The EMR consists of an electrolytic cell with a cation transfer membrane separating the cathode and anode chambers.

## WASTE APPLICABILITY:

The technology is applicable to a wide variety of metal-contaminated hazardous wastes, including soils and sludges. To date, IT Corporation has demonstrated the technology's effectivenessin removing lead and cadmium from soils and sludges.

## STATUS:

This technology was accepted into the SITE Emerging Technology Program in July 1994. The Jack's Creek site, located near Maitland, Pennsylvania, was selected as a site for technology evaluation. The site operated as a precious and nonprecious metal smelting and nonferrous metal recycling operation from 1958 to 1977. A portion of the property is currently operated as a scrap yard. Lead concentrations in the contaminated soil used for the evaluation was




Simplified Process Flow Diagram of Treatment Process



The SITE Program assesses but does not approve or endorse technologies.

approximately 2 percent. Toxicity characteristic leaching procedure (TCLP) analysis on the contaminated soil showed lead levels of 7.7 milligrams per liter (mg/L), which exceeds the regulatory limit of 5 mg/L. During the project, IT Corporation established appropriate conditions for lead removal and recovery from the soil and reduced TCLP concentrations of lead in the soil to below regulatory levels.

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# IT CORPORATION
## (Mixed Waste Treatment Process)

## TECHNOLOGY DESCRIPTION:

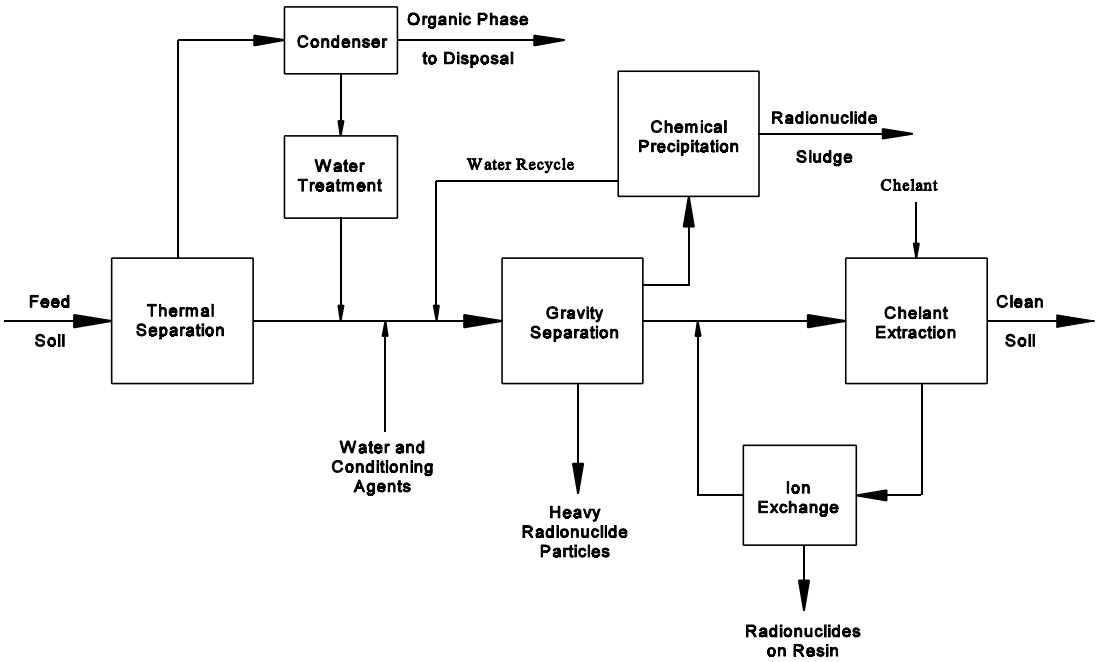
IT Corporation's mixed waste treatment process integrates thermal desorption, gravity separation, water treatment, and chelant extraction technologies to treat soils contaminated with hazardous and radioactive constituents. The process separates contaminants into distinct organic and inorganic phases that can then be further minimized, recycled, or destroyed at commercial disposal facilities. Decontaminated soil can then be returned to the site. Each technology has been individually demonstrated on selected contaminated materials. The process flow diagram below shows how the technologies have been integrated to treat mixed waste streams.

During the initial treatment step, feed soil is prepared using standard techniques, such as screening, crushing, and grinding to remove oversized material and provide a consistent feed material.

Thermal treatment removes volatile and semi-volatile organics from the soil. Soil is indirectly heated in a rotating chamber, volatilizing the organic contaminants and any moisture in the soil. The soil passes through the chamber and is collected as a dry solid. The volatilized organics and water are condensed into separate liquid phases. The organic phase is decanted and removed for disposal. The contaminated aqueous phase passes through activated carbon, which removes soluble organics, before the aqueous phase is combined with the thermally treated soil.

Inorganic contaminants are removed by three physical and chemical separation techniques: (1) gravity separation of high density particles (2) chemical precipitation of soluble metals and (3) chelant extraction of chemically bound metals.

Gravity separation is used to separate higher density particles from common soil. Radionuclide contaminants are typically found in




Mixed Waste Treatment Process



The SITE Program assesses but does not approve or endorse technologies.

this fraction. The gravity separation device (such as a shaker table, jig, cone, or spiral) depends on the contaminant distribution and the physical properties of the thermally treated soil.

Many radionuclides and other heavy metals are dissolved or suspended in the aqueous media. These contaminants are separated from the soils and are precipitated. A potassium ferrate formulation precipitates radionuclides. The resulting microcrystalline precipitant is removed, allowing the aqueous stream to be recycled.

Some insoluble radionuclides remain with the soil following the gravity separation process. These radionuclides are removed by chelant extraction. The chelant solution then passes through an ion-exchange resin to remove the radionuclides, and the solution is recycled to the chelant extraction step.

The contaminants are collected as concentrates from all waste process streams for recovery or off-site disposal at commercial hazardous waste or radiological waste facilities. Decontaminated soil can be returned to the site as clean fill.

## WASTE APPLICABILITY:

This process treats soils contaminated with organic, inorganic, and radioactive material.

## STATUS:

The mixed waste treatment process was selected for the SITE Emerging Technology Program in October 1991. Bench- and pilot-scale testing was completed in late 1995; a report detailing evaluation results was made available from EPA in 1997. Individual components of the treatment process have been demonstrated on various wastes from the U.S. Department of Energy, (DOE), the U.S. Department of Defense, and commercial sites. Thermal separation has removed and recovered polychlorinated biphenyls from soils contaminated with uranium and technetium. These soils were obtained from two separate DOE gaseous diffusion plants.

Gravity separation of radionuclides has been demonstrated at pilot scale on Johnston Atoll in the Pacific Ocean. Gravity separation successfully removed plutonium from native soils.

Water treatment using potassium ferrate formulations has been demonstrated at several DOE facilities in laboratory- and full-scale tests. This treatment approach reduced cadmium, copper, lead, nickel, plutonium, silver, uranium, and zinc to dischargeable levels.

Chelant extraction has successfully treated surface contamination in the nuclear industry for more than 20 years. Similar results are expected for subsurface contamination.

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# IT CORPORATION
## (Photolytic and Biological Soil Detoxification)

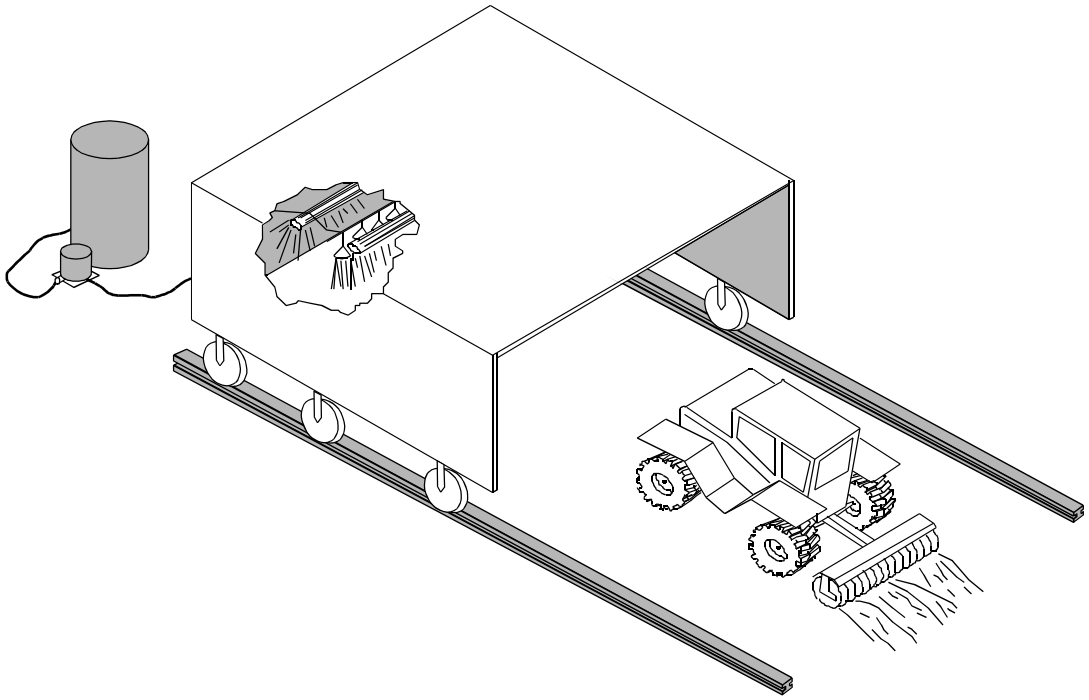
## TECHNOLOGY DESCRIPTION:

This technology is a two-stage, in situ photolytic and biological detoxification process designed for shallow soil contamination. The first step in the process degrades the organic contaminants with ultraviolet (UV) radiation. The photolytic degradation rate is several times faster with artificial UV light than with natural sunlight. The degradation process is enhanced by adding detergent-like chemicals (surfactants) to mobilize the contaminants. Photolysis of the contaminants converts them to more easily degraded compounds. Periodic sampling and analysis determines when photolysis is complete. Biodegradation, the second step, further destroys organic contaminants and detoxifies the soil.

When sunlight is used to treat shallow soil contamination, the soil is first tilled with a power tiller and sprayed with surfactant. The soil is tilled frequently to expose new surfaces and sprayed often to promote the degradation process. Water may also be added to maintain soil moisture.

When UV lights are used, parabolic reflectors suspended over the soil increase the amount of UV irradiation (see figure below). After photolysis is complete, biodegradation is enhanced by adding microorganisms and nutrients and further tilling the soil.

When these techniques are applied to soils with deep contamination, the soil must be excavated and treated in a specially constructed shallow treatment basin that meets Resource Conservation and Recovery Act requirements. When soil contamination is shallow, photolysis and housing prevent contaminants from migrating to groundwater.



Photolytic Degradation Process Using UV Lights



The SITE Program assesses but does not approve or endorse technologies.

The only treatment residuals of the process are soil contaminated with surfactants and the end metabolites of the biodegradation processes.

The end metabolites depend on the original contaminants. The surfactants are common materials used in agricultural formulations, the soils can be left on site.

## WASTE APPLICABILITY:

This photolytic and biological soil detoxification process destroys organics, particularly dioxins such as tetrachlorodibenzo-p-dioxin (TCDD), polychlorinated biphenyls (PCB), other polychlorinated aromatics, and polynuclear aromatic hydrocarbons.

## STATUS:

This technology was accepted into the SITE Emerging Technology Program in 1989; the evaluation was completed in 1992. The Emerging Technology Report (PB95-159992) is available for purchase from the National Technical Information Services. The Emerging Technology Bulletin (EPA/540/F-94/502) and Emerging Technology Summary (EPA/540/SR-94/531) are available from EPA.

Bench-scale tests conducted on dioxin-contaminated soil showed that the effectiveness of surface irradiation to degrade TCDDs or PCBs is strongly influenced by soil type. Early tests on sandy soils showed greater than 90 percent removals for both TCDDs and PCBs. Using a 450-watt mercury lamp, the irradiation time was more than 20 hours for greater than 90 percent destruction of TCDD and more than 4 hours for greater than 90 percent destruction of PCBs. However, a high humic content decreased the effectiveness of the UV photolysis. Soil contaminated with PCBs in the bench-scale tests had a high clay content. The highest removal rate for these soils was 30 percent, measured over a 16-hour irradiation time. Bench-scale tests used a medium-pressure, mercury UV lamp; sunlight was ineffective. No significant improvement in PCB destruction was achieved using a pulsed UV lamp.

The process was also tested with Fenton's reagent chemistry as an alternate method of degrading PCBs to more easily biodegraded compounds. PCB destruction ranged from nondetectable to 35 percent. Data indicates that no significant change in PCB chlorine levels occurred during treatment.

Other studies examined PCB biodegradation in (1) soil treated with a surfactant and UV radiation, (2) untreated soil, and (3) soil known to have PCB-degrading microorganisms. Study results were as follows:

- PCB removal in the UV-treated soil, untreated soil, and soil with known biological activity was higher when augmented with an isolated PCB degrading microorganism.
- In the untreated soil, biphenyl was more efficient at inducing PCB degradation than 4-bromobiphenyl.
- For the treated soil, surfactant treatment may have inhibited microbial activity due to high total organic carbon and low pH.

Isolation and enrichment techniques have made it possible to isolate microorganisms capable of biodegrading PCBs in contaminated soil.

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# IT CORPORATION
## (Tekno Associates Bioslurry Reactor)

## TECHNOLOGY DESCRIPTION:

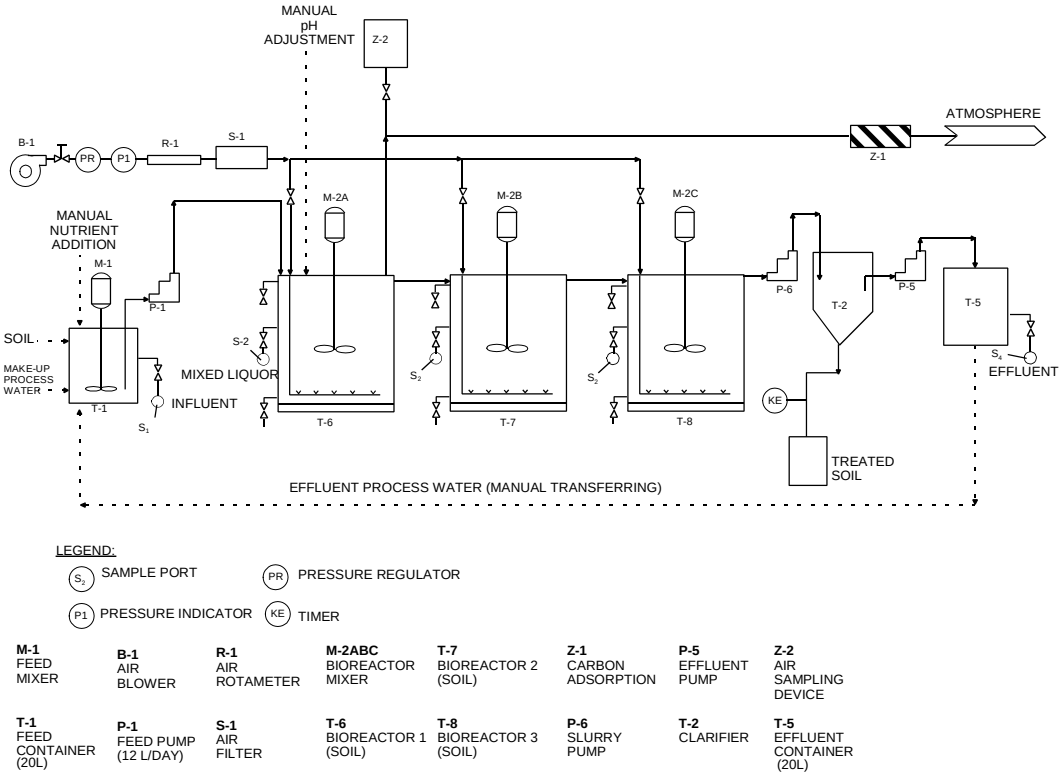
IT Corporation (IT) has used the Bioslurry Reactor (developed by Tekno Associates of Salt Lake City, Utah) to treat polynuclear aromatic hydrocarbons (PAH) in soil. Traditional biological treatments, such as landfarming and in situ bioremediation, may not reduce PAHs in soil to target levels in a timely manner. Slurry reactors are more efficient for bioremediation and are more economical than thermal desorption and incineration.

During the project, IT operated one 10-liter and two 60-liter bioslurry reactors (see figure below) in semicontinuous, plug-flow mode. The first 60-liter reactor received fresh feed daily and supplements of salicylate and succinate.

Succinate is a by-product of naphthalene metabolism and serves as a general carbon source. Salicylate induces naphthalene degradation of PAH plasmids in the microorganisms. The system has been shown to degrade phenanthrene and anthracene. The naphthalene pathway may also play a role in carcinogenic PAH (CPAH) metabolism.

The first 60-liter reactor removed easily degradable carbon and increased biological activity against more recalcitrant PAHs (three-ring compounds and higher).

Effluent from the first reactor overflowed to the second 60-liter reactor in series, where Fenton's reagent (hydrogen peroxide and iron salts) was added to accelerate oxidation for four- to six-ring




Tekno Associates Bioslurry Reactor System



The SITE Program assesses but does not approve or endorse technologies.

PAHs. Fenton's reagent produces a free radical that can oxidize multiring aromatic hydrocarbons.

The T-8 reactor (third in a series) was used as a polishing reactor to remove any partially oxidized contaminants remaining after treatment with Fenton's reagent. Slurry was removed from this reactor and clarified using gravity settling techniques.

The reactors increased the rate and extent of PAH biodegradation, making bioslurry treatment of soils and sludges a more effective and economical remediation option.

## WASTE APPLICABILITY:

This technology is applicable to PAH-contaminated soils and sludges that can be readily excavated for slurry reactor treatment. Soils from coal gasification sites, wood-treating facilities, petrochemical facilities, and coke plants are typically contaminated with PAHs.

## STATUS:

This technology was accepted into the SITE Emerging Technology Program in 1993. Under this program, IT Corporation conducted a pilot-scale investigation of the three slurry reactors operating in series. A suitable soil for the pilot-scale test was obtained from a wood-treating facility in the southeastern United States. About 4,000 pounds of PAH-contaminated soil was screened and treated during 1994. CPAH and PAH removals were demonstrated at 84 and 95 percent, respectively. A final report was available from EPA in 1997.

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# J.R. SIMPLOT COMPANY
## (The SABRE™ Process)

## TECHNOLOGY DESCRIPTION:

The patented Simplot Anaerobic Biological Remediation (SABRE™) process reduces contamination through on-site bioremediation of soils contaminated with the herbicide dinoseb (2-*sec*-butyl-4,6-dinitrophenol) or nitroaromatic explosives. The biodegradation process begins when contaminated soil is placed in a bioreactor and flooded with buffered water. A source of carbon and a nitroaromatic-degrading consortium of anaerobic bacteria are then added to the bioreactor. Anaerobic conditions are quickly established, allowing the bacteria to degrade the target compounds while preventing polymerization of intermediate breakdown products. A photograph of the technology in operation is shown below.

Soil can be treated in above- or in-ground containment ponds. Temperature, pH, and redox potential in the bioreactor are monitored during treatment. A hydromixing system has been engineered to efficiently solubilize the target compound from the soil while maintaining anaerobic conditions. Frequency of mixing depends upon the contaminants present, concentration, soil heterogeneity, and soil type.

## WASTE APPLICABILITY:

This technology is designed to treat soils contaminated with nitroaromatic pesticides and explosives. This contamination most often occurs at rural crop dusting aircraft sites and at ordnance handling and manufacturing facilities.

## STATUS:

This technology was accepted into the SITE Emerging Technology Program in January 1990. Based on bench- and pilot-scale results from the Emerging Technology Program, this technology was accepted in the SITE Demonstration Program

Bioreactors and Soil Mixing System at a TNT-Contaminated Site in Washington



The SITE Program assesses but does not approve or endorse technologies.

in winter 1992. Demonstrations for dinoseb and the explosive TNT (2,4,6-trinitrotoluene) were performed at Bowers Field in Ellensberg, Washington and at Weldon Spring Ordnance Works in Weldon Spring, Missouri, respectively. A Technology Capsule describing the dinoseb project (EPA/540/R-94/508a) and an Innovative Technology Evaluation Report describing the TNT project (EPA/540/R-95/529) are available from EPA.

Since then, the process has been evaluated at several other sites. During the winters of 1994 and 1995, two 10-cubic-yard ($yd^3$) batches of soils from Bangor Naval Submarine Base, Washington were treated using the SABRE™ Process. One batch contained TNT, while the other was contaminated with TNT and RDX. Cost savings were realized by using in-ground ponds for bioreactors and efficient mixing. Heaters were also installed to maintain optimum biological activity during the sub-freezing temperatures. Treatment goals were met or surpassed in the 90 days allowed for the project.

A full-scale remediation of 321 $yd^3$ of dinoseb-contaminated soils was completed in October 1995. The site was a former herbicide distributor located near Reedley, California. The treatment was performed in an aboveground containment already existing on site. Concentrations ranging from 40 to 100 milligrams per kilogram were reduced to nondetect after 28 days of treatment. The soil was mixed three times during treatment using a full-scale, expandable hydromixing system.

A larger evaluation was conducted in fall 1996 at Naval Weapons Station - Yorktown. About 500 $yd^3$ of soil were contained in an in-ground pond measuring 86 feet by 150 feet deep. A full-scale hydromixing system was used to periodically slurry the soil and water mixture.

Process optimization work is ongoing. Collaborative projects with the U.S. Army Corps of Engineers Waterways Experiment Station and the U.S. Army Environmental Center are underway.

## DEMONSTRATION RESULTS:

During the Weldon Spring demonstration, TNT was reduced from average concentrations of 1,500 parts per million (ppm) to an average of 8.7 ppm, for an average removal rate of 99.4 percent. Toxicity testing, which included early seedling growth, root elongation, and earthworm reproduction tests, showed that soil toxicity was significantly reduced. The Weldon Spring demonstration showed the effectiveness of this process even in unfavorable conditions. The treatment time was lengthened by unseasonably cool ambient temperatures. Temperatures in the bioreactor were as low as 4 °C; ideal temperatures for the SABRE™ process are 35 to 37 °C.

During the Ellensburg demonstration, dinoseb was reduced from 27.3 ppm to below the detection limit, a greater than 99.8 percent removal. Other pesticides were also degraded in this process, highlighting the effectiveness of the process even in the presence of co-contaminants. The process was completed in just 23 days, despite 18 °C temperatures.

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The SITE Program assesses but does not approve or endorse technologies.

# KAI TECHNOLOGIES, INC./ BROWN AND ROOT ENVIRONMENTAL
## (Radio Frequency Heating)

## TECHNOLOGY DESCRIPTION:

Radio frequency heating (RFH) is an in situ process that uses electromagnetic energy to heat soil and enhance bioventing and soil vapor extraction (SVE). The patented RFH technique, developed by KAI Technologies, Inc. (KAI), uses an antenna-like applicator inserted in a single borehole to heat a volume of soil. Large volumes of soil can be treated by RFH employing a control system and an array of applicators. When energy is applied by the applicator to the soil, heating begins near the borehole and proceeds radially outward. This technique can achieve soil temperatures from just above ambient to over 250 ºC.

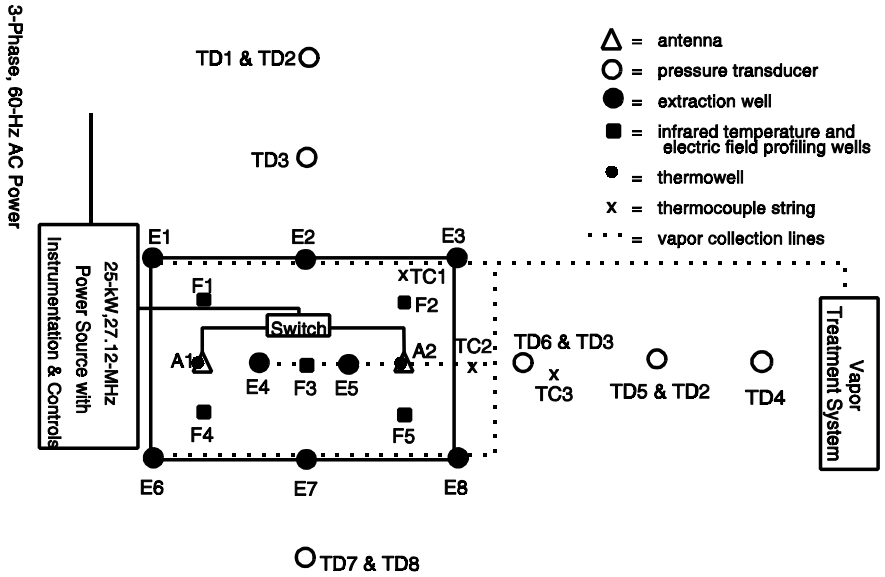
RFH enhances SVE in two ways: (1) contaminant vapor pressures are increased by heating, and (2) soil permeability is increased by drying. Extracted vapor can then be treated by a variety of existing technologies.

## WASTE APPLICABILITY:

The RFH technique has been tested using pilot-scale vertical and horizontal antenna orientations to remove petroleum hydrocarbons and volatile and semivolatile organics from soils. The technology is most efficient in subsurface areas with low groundwater recharge. In theory, the technology should be applicable to any polar compound in any nonmetallic medium. The flexible design permits easy access for in situ treatment of organics and pesticides under buildings or fuel storage tanks.

## STATUS:

The KAI RFH technique was accepted into the SITE Demonstration Program in summer 1992. The technique was demonstrated between January and July 1994 at Kelly Air Force Base, Texas as part of a joint project with the U.S. Air Force Armstrong Laboratory. Brown and Root Environmental was the prime contractor evaluating and implementing RFH for the U.S. Air Force. A field demonstration of the IIT Research Institute RFH technology was completed in summer 1993 at the same site for comparison. The Demonstration Bulletin (EPA/540/MR-94/528), Technology Capsule (EPA/540/R-94/528a), and Innovative Technology Evaluation Report (EPA/540/R-94/528) are available from EPA. For further information on the IIT Research Institute technology, see the profile in the Demonstration Program section




KAI Antenna System



The SITE Program assesses but does not approve or endorse technologies.

(completed projects). KAI is now leasing commercial units to engineering companies throughout the U.S.

## DEMONSTRATION RESULTS:

For this demonstration, the original treatment zone was 10 feet wide, 15 feet long, and 20 feet deep. This treatment zone was based on RFH operation at 13.56 megahertz (MHz); however, RFH was applied at 27.12 MHz to the top 10 feet of the original treatment zone to reduce the time on site by half. Demonstration results were as follows:

- Uniform heating within the revised heating zone: significant regions had soil temperatures in excess of 100 $^{o}$C with soil temperatures within a 3-foot radius of the antenna exceeding 120 $^{o}$C.
- Significant amounts of liquid were heated to around 240 $^{o}$C as strongly suggested by a measurement of 233.9 $^{o}$C on the outside wall of the heating well liner.
- Soil permeability increased by a factor of 20 within the revised treatment zone.
- In the original treatment zone, the mean removal for total recoverable petroleum hydrocarbons (TRPH) was 30 percent at the 90 percent confidence level. Concentrations in the pretreatment samples varied from less than 169 to 105,000 parts per million (ppm); posttreatment concentrations varied from less than 33 to 69,200 ppm.
- In the revised treatment zone, the mean removal for TRPH was 49 percent at the 95 percent confidence level. Concentrations in the pretreatment samples varied from less than 169 ppm to 6,910 ppm; posttreatment concentrations varied from less than 33 ppm to 4,510 ppm.
- Benzo(o)fluoranthene, benzo(a)pyrene, and bis(2-ethylhexyl)phthalate exhibited statistically significant removals within the original treatment zone. Benzo(o)-fluoranthene, benzo(a)pyrene, chrysene, pyrene, and fluoranthene exhibited statistically significant removals within the revised treatment zone.
- Contaminants may have migrated into and out of the revised treatment zone due to the design and operation of the SVE system. The design of the heated vapor recovery system is an essential component of the efficiency of the overall system.
- Cleanup costs are estimated to range from less than $80 per ton for large scale treatments to between $100 to $250 per ton for small-scale (hot spot) treatments.

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# KSE, INC.
## (Adsorption-Integrated-Reaction Process)

## TECHNOLOGY DESCRIPTION:

The Adsorption-Integrated-Reaction (AIR 2000) process combines two unit operations, adsorption and chemical reaction, to treat air streams containing dilute concentrations of volatile organic compounds (VOC) (see photograph below).

The contaminated air stream containing dilute concentrations of VOCs flows into a photocatalytic reactor, where chlorinated and nonchlorinated VOCs are destroyed. The VOCs are trapped on the surface of a proprietary catalytic adsorbent. This catalytic adsorbent is continuously illuminated with ultraviolet light, destroying the trapped, concentrated VOCs through enhanced photocatalytic oxidation. This system design simultaneously destroys VOCs and continuously regenerates the catalytic adsorbent. Only oxygen in the air is needed as a reactant. The treated effluent air contains carbon dioxide and water, which are carried out in the air stream exiting the reactor. For chlorinated VOCs, the chlorine atoms are converted to hydrogen chloride with some chlorine gas. If needed, these gases can be removed from the air stream with conventional scrubbers and adsorbents.

The AIR 2000 process offers advantages over other photocatalytic technologies because of the high activity, stability, and selectivity of the photocatalyst. The photocatalyst, which is not primarily titanium dioxide, contains a number of different semiconductors, which allows for rapid and economical treatment of VOCs in air. Previous results indicate that the photocatalyst is highly resistant to deactivation, even after thousands of hours of operation in the field.

The particulate-based photocatalyst allows for more freedom in reactor design and more economical scale-up than reactors with a catalyst film coated on a support medium. Packed beds, radial flow reactors, and monolithic reactors are all feasible reactor designs. Because the catalytic adsorbent is continuously regenerated, it does not require disposal or removal for regeneration, as traditional carbon adsorption typically does. The AIR 2000 process produces no residual wastes or by-products needing further treatment or disposal as hazardous waste. The treatment system is self-contained and mobile, requires a small amount of space, and requires less energy than thermal incineration or catalytic oxidation. In addition, it has lower total system costs than

AIR2000



The SITE Program assesses but does not approve or endorse technologies.

these traditional technologies, and can be constructed of fiberglass reinforced plastic (FRP) due to the low operating temperatures.

## WASTE APPLICABILITY:

The AIR 2000 process is designed to treat a wide range of VOCs in air, ranging in concentration from less than 1 to as many as thousands of parts per million. The process can destroy the following VOCs: chlorinated hydrocarbons, aromatic and aliphatic hydrocarbons, alcohols, ethers, ketones, and aldehydes.

The AIR 2000 process can be integrated with existing technologies, such as thermal desorption, air stripping, or soil vapor extraction, to treat additional media, including soils, sludges, and groundwater.

## STATUS:

The AIR 2000 process was accepted into the SITE Emerging Technology Program in 1995. Studies under the Emerging Technology Program are focusing on (1) developing photocatalysts for a broad range of chlorinated and nonchlorinated VOCs, and (2) designing advanced and cost-effective photocatalytic reactors for remediation and industrial service.

The AIR 2000 Process was initially evaluated at full-scale operation for treatment of soil vapor extraction off-gas at Loring Air Force Base (AFB). Destruction efficiency of tetrachloroethene exceeded 99.8 percent. The performance results were presented at the 1996 World Environmental Congress.

The AIR-I process, an earlier version of the technology, was demonstrated as part of a groundwater remediation demonstration project at Dover AFB in Dover, Delaware, treating effluent air from a groundwater stripper. Test results showed more than 99 percent removal of dichloroethane (DCA) from air initially containing about 1 ppm DCA and saturated with water vapor.

A 700 SCFM commercial unit is now operating at a Superfund Site in Rhode Island, destroying TCE, DCE and vinyl chloride in the combined off-gas from a SVE system and a groundwater stripper. Preliminary results show that the system is operating at 99.99% destruction efficiency. The AIR 2000 unit is operating unattended, with the number of UV lamps being illuminated changing automatically in response to changing flow conditions for maximum performance at minimum cost.

The AIR 2000 Process was accepted into the SITE Demonstration program in 1998, with the objective of demonstrating the performance of the system at the Superfund site in Rhode Island.

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# LEWIS ENVIRONMENTAL SERVICES, INC./ HICKSON CORPORATION

## (Chromated Copper Arsenate Soil Leaching Process)

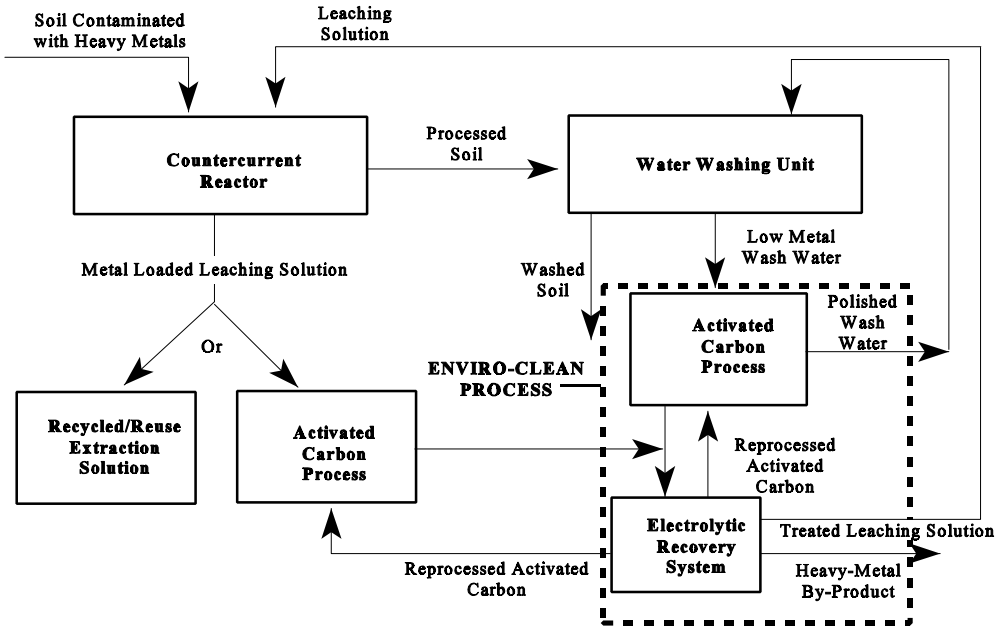
## TECHNOLOGY DESCRIPTION:

Lewis Environmental Services, Inc. (Lewis), has developed a soil leaching process to remediate soils contaminated with inorganics and heavy metals, including chromium, copper, cadmium, mercury, arsenic, and lead.

The soil leaching process consists of leaching contaminated soil in a countercurrent stirred reactor system (see figure below). A screw feeder delivers soil into the reactor, where it is leached with sulfuric acid for 30 to 60 minutes. The sulfuric acid solubilizes the inorganics and heavy metals into the leaching solution. Any organic contaminants are separated and decanted from the leaching solution, using strong acid leachate, space separation, and skimming. The processed soil is then washed with water and air-dried.

The wash water is then treated with the Lewis' ENVIRO-CLEAN, which consists of a granulated activated carbon system followed by an electrolytic recovery system. The ENVIRO-CLEAN recovers heavy metals from the leaching solution and wash water and produces an effluent that meets EPA discharge limits for heavy metals. The treated wash water can then be reused in the soil washing step. The leaching solution can be returned directly to the stirred reactor system, depending on its metals concentration.

Contaminated soil must be properly sized and screened to facilitate leaching in the stirred reactor system. Large pieces of debris such as rocks, wood, and bricks must be removed before treatment. Standard screening and classification equipment, such as that used in municipal waste treatment plants, is suitable for this purpose.




Chromated Copper Arsenate Soil Leaching Process



The SITE Program assesses but does not approve or endorse technologies.

The soil leaching process does not generate appreciable quantities of treatment by-products or waste streams containing heavy metals. The treated soil meets toxicity characteristic leaching procedure (TCLP) criteria and can be either returned to the site or disposed of at a nonhazardous landfill. The granular activated carbon requires disposal after about 20 to 30 treatment cycles and should also meet TCLP criteria. Heavy metals recovered by the ENVIRO-CLEAN process can be reused by industry.

## WASTE APPLICABILITY:

The soil leaching process can treat wastes generated by the wood preserving and metal plating industries, battery waste sites, and urban lead sites.

## STATUS:

The soil leaching process was accepted into the Emerging Technology Program in 1993. Laboratory-scale tests have shown that the process successfully treats soil contaminated with chromated copper arsenate (CCA). The evaluation of the technology under the SITE Program was completed in September 1996. Results from the evaluation was made available in 1997.

In 1992, Lewis treated a 5-gallon sample of CCA-contaminated soil from a Hickson Corporation (Hickson), a major CCA chemical manufacturer. The treated soil met TCLP criteria, with chromium and arsenic, the two main leaching solution constituents, averaging 0.8 and 0.9 milligram per kilogram (mg/kg) respectively. Analysis also revealed 3,330 milligrams per liter (mg/L) of chromium; 13,300 mg/L of copper; and 22,990 mg/L of iron in the leaching solution. In addition, analysis indicated 41.4 mg/L of chromium, 94.8 mg/L of copper, and 3.0 mg/L of arsenic in the wash water. After treatment, the wash water contained metals levels below 0.01 mg/L for copper and chromium and 0.3 mg/L for arsenic.

Lewis plans further laboratory-scale testing at its faculty in Pittsburgh, Pennsylvania, followed by bench- or pilot-scale testing at Hickson's facility in Conley, Georgia.

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# MAGNUM WATER TECHNOLOGY
## (CAV-OX® Process)

## TECHNOLOGY DESCRIPTION:

The CAV-OX® process uses a combination of hydrodynamic cavitation and ultraviolet (UV) radiation to oxidize contaminants in water. The process (see figure below) is designed to remove organic contaminants from wastewater and groundwater without releasing volatile organic compounds into the atmosphere.

The process generates free radicals to degrade organic contaminants. The cavitation process alone has been demonstrated to achieve trichloroethene (TCE) reductions of up to 65 percent. UV excitation and, where necessary, addition of hydrogen peroxide and metal catalysts, provide synergism to achieve overall reductions of over 99 percent. Neither the cavitation chamber nor the UV lamp or hydrogen peroxide reaction generates toxic by-products or air emissions.

Magnum Water Technology (Magnum) estimates the cost of using the CAV-OX® process to be about half the cost of other advanced UV oxidation systems and substantially less than carbon adsorption. Because the process equipment has one moving part, maintenance costs are minimal. According to Magnum, the CAV-OX® process does not exhibit the quartz tube scaling common with other UV equipment.

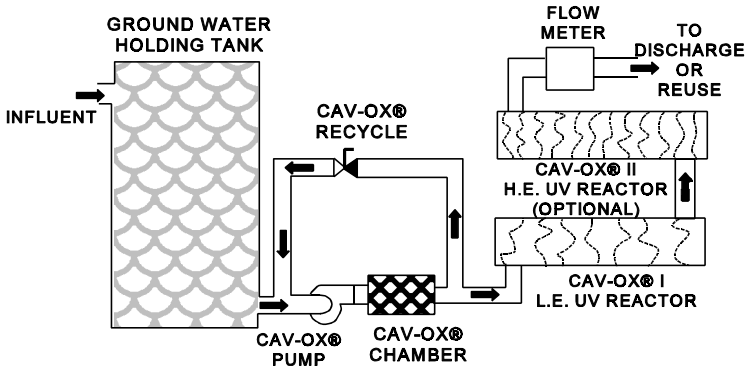
## WASTE APPLICABILITY:

The process is designed to treat groundwater or wastewater contaminated with organiccompounds. Contaminants such as halogenated solvents; phenol; pentachlorophenol (PCP); pesticides; polychlorinated biphenyls; explosives; benzene, toluene, ethylbenzene, and xylenes; methyl tertiary butyl ether; other organic compounds; and cyanide are suitable for this treatment process. Bacteria and virus strains are also eliminated.

## STATUS:

This technology was accepted into the SITE Demonstration Program in summer 1992 and was demonstrated for 4 weeks in March 1993 at Edwards Air Force Base (AFB) Site 16 in California. The Applications Analysis Report (EPA/540/AR-93/520), Technology Evaluation Report (EPA/540/R-93/520), and a videotape are available from EPA.

Magnum reports that improvements in UV lamp and reactor technologies have improved the efficiency of the CAV-OX® process three- to five-fold, compared with the pilot-scale unit tested at Edwards AFB under the SITE Program. CAV-OX® recently (1996) has proven very effective in potentiating ozone concentrations in




The CAV-OX® Process



The SITE Program assesses but does not approve or endorse technologies.

water reclamation applications. Ozone gas ($O_3$) is relatively insoluble in water. However, hydrodynamic cavitation used in the CAV-OX® process continuously develops micro bubbles which enhances the dispersion of ozone in water. Three $O_3$ techniques are available to Magnum: corona discharge with air feed, electrochemical 'water splitting' method, and electrochemical anodic oxidation.

The CAV-OX® process has been tested at several public and private sites, including the San Bernadino and Orange County Water Department in California. At a Superfund site, the process treated leachate containing 15 different contaminants. PCP, one of the major contaminants, was reduced by 96 percent in one test series. The process has also been used to remediate former gasoline station sites and successfully reduced contaminants in process streams at chemical and pharmaceutical plants.

The CAV-OX® unit was part of an ongoing evaluation at the U.S. Army Aberdeen Proving Ground (Aberdeen). Special features of the unit tested include remote monitoring and control systems for pH, flow rates, $H_2O_2$ flow rate, storage level and pump rate, UV lamp, main power, pump function, and remote system shutdown control. The 15-gallon-per-minute CAV-OX®I Low Energy unit was operated by Army contractors for 9 months. Upon completion of testing at Aberdeen, further CAV-OX® II High Energy Tests were conducted at El Segundo. The CAV-OX® process achieved contaminant concentrations of greater than 95 percent. During 1997 tests of CAV-OX® equipment and/or Pilot Tests were made in Taiwan, Thailand, and Australia. Also, a continuing series of tests for major U.S. corporations are on-going. The CAV-OX® process achieved removal efficiencies of greater than 99.9 percent for TCE, benzene, toluene, ethylbenzene, and xylenes. SITE demonstration results for the CAV-OX® process are shown in the table below. Results are presented for both the CAV-OX® I (cavitation chamber by itself) and CAV-OX® II (cavitation chamber combined with UV) demonstrations.

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| $H_2O_2$[1] Concentrations (mg/L)[2] | CAV-OX® I Flow (gpm)[3] | CAV-OX® I Removal Efficiencies (%) TCE | Benzene | Toluene | Xylene | CAV-OX® II Flow (gpm) | CAV-OX® II Removal Efficiencies (%) TCE 5-kW[4] | TCE 10-kW | Benzene 5-kW | Benzene 10-kW | Toluene 5-kW | Toluene 10-kW | Xylene 5-kW | Xylene 10-kW |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 33.1 | 0.5 | 99.9 | >99.9 | 99.4 | 92.9 | 1.5 | 99.6 | 99.2 | 99.4 | 98.8 | >99.9 | 98.6 | >99.9 | >99.9 |
| 23.4 | 0.6 | 99.9 | >99.9 | >99.9 | >99.9 | 2.0 | 99.7 | 99.7 | 99.5 | 99.6 | >99.9 | >99.9 | >99.9 | >99.9 |
| 4.9 | 1.5 | 71.4 | 88.6 | 87.4 | 65.6 | 4.0 | 87.7 | 98.1 | 89.7 | 98.7 | 88.8 | 97.1 | 78.7 | 87.2 |
| 48.3 | 0.6 | 99.7 | >99.9 | >99.9 | >99.9 | 1.4 | 99.8 | 99.7 | 99.8 | 99.8 | >99.9 | >99.9 | 98.7 | >99.9 |
| 6.0 | 0.7 | 87.8 | 96.9 | 94.5 | 92.1 | 1.9 | 98.4 | 99.3 | 98.8 | 99.3 | 96.9 | 98.6 | 93.6 | 97.0 |
| 4.9 | 1.5 | 61.7 | 81.6 | 83.8 | 80.2 | 3.9 | 85.1 | 97.1 | 89.5 | 97.8 | 91.8 | 97.9 | 90.4 | 96.0 |
| 5.9 | 0.5 | 96.4 | 99.4 | 99.8 | 98.9 | 1.4 | 99.6 | 99.4 | 99.6 | 99.6 | 99.8 | 99.8 | 99.5 | 99.5 |
| 5.9 | 0.7 | 87.1 | 96.5 | 97.6 | 98.1 | 1.9 | 97.8 | 99.2 | 99.4 | 99.5 | 99.5 | 99.7 | 99.2 | 99.7 |
| 6.1 | 1.5 | 60.6 | 86.1 | 87.3 | >99.9 | 4.0 | 86.3 | 98.9 | 93.5 | 99.5 | 94.5 | 99.6 | 95.4 | >99.9 |
| 0 | - | - | - | - | - | 1.6 | 94.1 | 99.2 | 49.1 | 68.1 | 20.7 | 54.7 | 43.3 | 46.7 |
| 0 | - | - | - | - | - | 1.8 | 80.6 | 97.6 | 38.5 | 60.5 | 48.6 | 75.2 | 56.9 | 83.8 |

[1] hydrogen peroxide [2] milligrams per liter [3] gallons per minute [4] kilowatts

CAV-OX® Process Demonstration Results

The SITE Program assesses but does not approve or endorse technologies.

# MATRIX PHOTOCATALYTIC INC.
## (Photocatalytic Water Treatment)

## TECHNOLOGY DESCRIPTION:

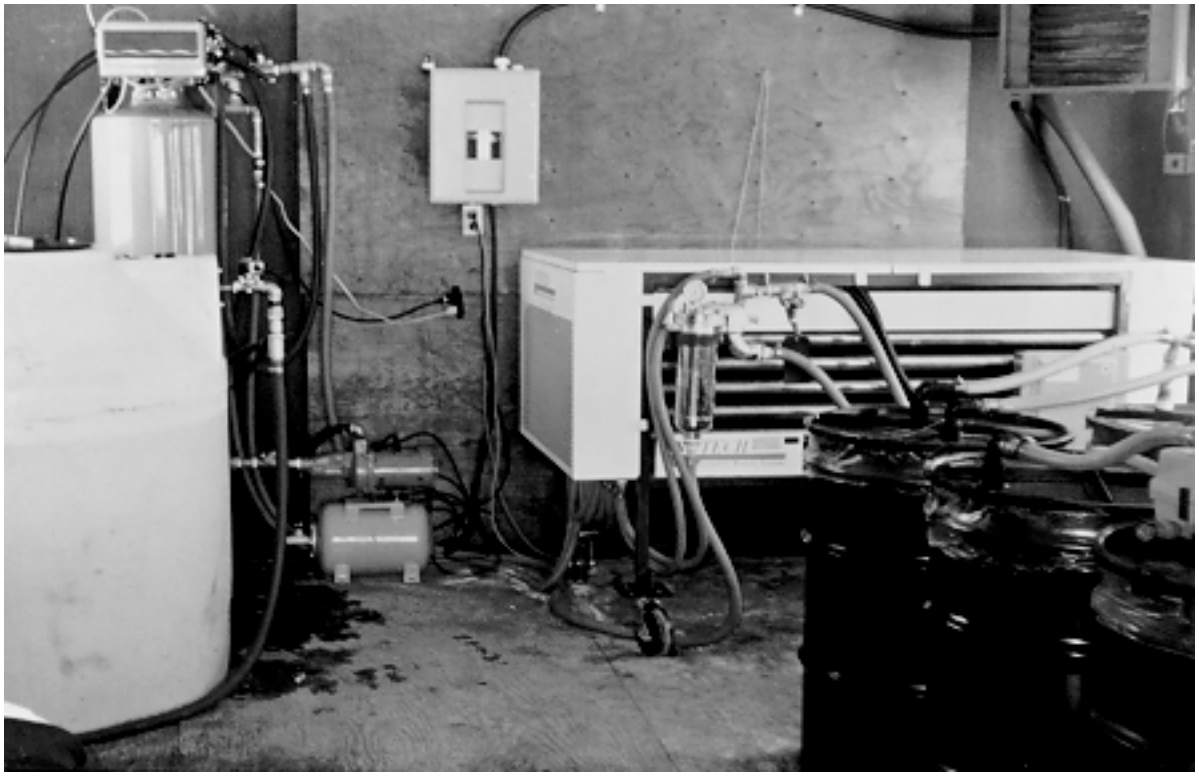
The Matrix Photocatalytic Inc. (Matrix) photocatalytic oxidation system, shown in the photograph below, removes dissolved organic contaminants from water and destroys them in a continuous flow process at ambient temperatures. When excited by light, the titanium dioxide ($TiO_2$) semiconductor catalyst generates hydroxyl radicals that oxidatively break the carbon bonds of hazardous organic compounds.

The Matrix system converts organics such as polychlorinated biphenyls (PCB); phenols; benzene, toluene, ethylbenzene, and xylene (BTEX); and others to carbon dioxide, halides, and water. Efficient destruction typically occurs between 30 seconds and 2 minutes actual exposure time. Total organic carbon removal takes longer, depending on the other organic molecules and their molecular weights.

The Matrix system was initially designed to destroy organic pollutants or to remove total organic carbon from drinking water, groundwater, and plant process water. The Matrix system also destroys organic pollutants such as PCBs, polychlorinated dibenzodioxins, polychlorinated dibenzofurans, chlorinated alkenes, chlorinated phenols, chlorinated benzenes, alcohols, ketones, aldehydes, and amines. Inorganic pollutants such as cyanide, sulphite, and nitrite ions can be oxidized to cyanate ion, sulphate ion, and nitrate ion, respectively.

## WASTE APPLICABILITY:

The Matrix system can treat a wide range of concentrations of organic pollutants in industrial wastewater and can be applied to the ultrapure water industry and the drinking water industry. The Matrix system can also remediate groundwater.



10-Gallon-Per-Minute $TiO_2$ Photocatalytic System Treating BTEX in Water



The SITE Program assesses but does not approve or endorse technologies.

## STATUS:

The system was accepted into the SITE Emerging Technology Program (ETP) in May 1991. Results from the ETP evaluation were published in a journal article (EPA/540/F-94/503) available from EPA. Based on results from the ETP, Matrix was invited to participate in the Demonstration Program.

During August and September 1995, the Matrix system was demonstrated at the K-25 site at the Department of Energy's Oak Ridge Reservation in Oak Ridge, Tennessee. Reports detailing the results from the demonstration are available from EPA.

## DEMONSTRATION RESULTS:

Results from the demonstration are detailed below:

- In general, high percent removals (up to 99.9 percent) were observed for both aromatic volatile organic compounds (VOCs) and unsaturated VOCs. However, the percent removals for saturated VOCs were low (between 21 and 40 percent).
- The percent removals for all VOCs increased with increasing number of path lengths and oxidant doses. At equivalent contact times, changing the flow rate did not appear to impact the treatment system performance for all aromatic VOCs and most unsaturated VOCs (except 1,1-dichloroethene [DCE]). Changing the flow rate appeared to impact the system performance for saturated VOCs.
- The effluent met the Safe Drinking Water Act maximum contaminant levels (MCL) for benzene; cis-1,2-DCE; and 1,1-DCE at a significant level of 0.05. However, the effluent did not meet the MCLs for tetrachloroethene (PCE); trichloroethene (TCE); 1,1-dichloroethane (DCA); and 1,1,1-trichloroethane (TCA) at a significant level of 0.05. The influent concentrations for toluene and total xylenes were below the MCLs.
- In tests performed to evaluate the effluent's acute toxicity to water fleas and fathead minnows, more than 50 percent of the organisms died. Treatment by the Matrix system did not reduce the groundwater toxicity for the test organisms at a significant level of 0.05.
- In general, the percent removals were reproducible for aromatic and unsaturated VOCs when the Matrix system was operated under identical conditions. However, the percent removals were not reproducible for saturated VOCs. The Matrix system's performance was generally reproducible in (1) meeting the target effluent levels for benzene; cis-1,2-DCE; and 1,1-DCE; and (2) not meeting the target effluent levels for PCE; TCE; 1,1-DCA; and 1,1,1-TCA.
- Purgable organic compounds and total organic halides results indicated that some VOCs were mineralized in the Matrix system. However, formulation of aldehydes, haloacetic acids, and several tentatively identified compounds indicated that not all VOCs were completely mineralized.

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# MAXYMILLIAN TECHNOLOGIES, INC.
## (formerly CLEAN BERKSHIRES, INC.)
## (Thermal Desorption System)

## TECHNOLOGY DESCRIPTION:

The Maxymillian Technologies, Inc., mobile Thermal Desorption System (TDS) uses rotary kiln technology to remove contaminants from soils. The TDS can remediate soils contaminated with volatile organic compounds (VOC), semivolatile organic compounds (SVOC), and polynuclear aromatic hydrocarbons (PAH). The TDS is fully transportable, requires a footprint of 100-by-140 feet, and can be set up on site in 4 to 6 weeks. The system combines high throughput with the ability to remediate mixed consistency soil, including sands, silts, clays, and tars.

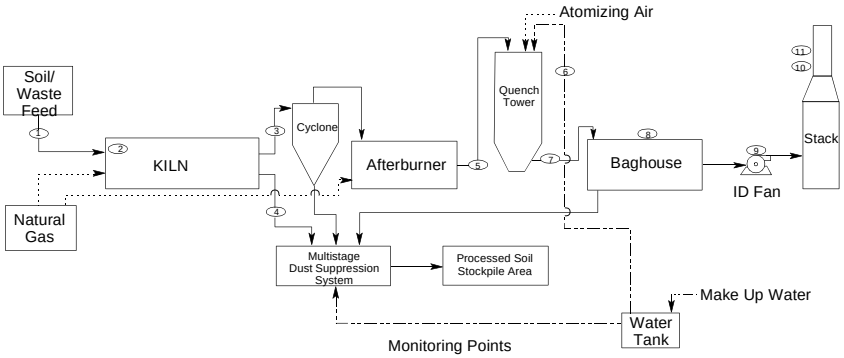
The TDS consists of the following components (see figure below):

- Waste feed system
- Rotary kiln drum desorber
- Cyclone
- Afterburner
- Quench tower
- Baghouse
- Fan and exhaust stack
- Multistage dust suppression system
- Process control room

Soil is first shredded, crushed, and screened to achieve a uniform particle size of less than 0.75 inch. Feed soils are also mixed to achieve uniform moisture content and heating value.

The thermal treatment process involves two steps: contaminant volatilization followed by gas treatment. During the volatilization step, contaminated materials are exposed to temperatures ranging from 600 to 1,000 °F in a co-current flow rotary kiln drum desorber where contaminants volatilize to the gas phase. Clean soils are then discharged through a multistage dust suppression system for remoisturization and are stockpiled for testing.

The gas and particulate stream passes from the kiln to the cyclone, where coarse particles are removed. The stream then enters the afterburner, which destroys airborne contaminants at temperatures ranging from 1,600 to 2,000 °F. The gas stream is cooled by quenching before passing through a high-efficiency baghouse, where fine particles are removed. The clean gas is then released to the atmosphere through a 60-foot stack. Processed soil, after discharge from the dust suppression




Mobile Thermal Desorption System



The SITE Program assesses but does not approve or endorse technologies.

system, is stockpiled and allowed to cool prior to sampling.

## WASTE APPLICABILITY:

The TDS is designed to remove a wide variety of contaminants from soil, including VOCs, SVOCs, PAHs, coal tars, and cyanide.

## STATUS:

The TDS was accepted into the SITE Demonstration Program in 1993. The demonstration was conducted in November and December 1993 at the Niagara Mohawk Power Corporation Harbor Point site, a former gas plant in Utica, New York. During the demonstration, the TDS processed three replicate runs of four separate waste streams. Stack emissions and processed soil were measured to determine achievement of cleanup levels. The Demonstration Bulletin (EPA/540/MR-94/507) and Technology Capsule (EPA/540/R-94/507a) are available from EPA.

Following the SITE demonstration, the TDS was chosen to remediate approximately 17,000 tons of VOC-contaminated soil at the Fulton Terminals Superfund site in Fulton, New York. This project was completed in 1995. The system has since been moved to a location in North Adams, Massachusetts.

## DEMONSTRATION RESULTS:

Results from the SITE Demonstration are summarized below:

- The TDS achieved destruction removal efficiencies (DRE) of 99.99 percent or better in all 12 runs using total xylenes as a volatile principal organic hazardous constituent (POHC).
- DREs of 99.99 percent or better were achieved in 11 of 12 runs using naphthalene as a semivolatile POHC.
- Average concentrations for critical pollutants in treated soils were 0.066 milligram per kilogram (mg/kg) benzene, toluene, ethylbenzene, and xylene (BTEX); 12.4 mg/kg PAHs; and 5.4 mg/kg total cyanide.
- C
  concentration of pollutants in the feed and treated soil showed the following average removal efficiencies: 99.9 percent for BTEX; 98.6 percent for PAHs; and 97.4 percent for total cyanide.
- The TDS showed good operating stability during the demonstration with only a minor amount of downtime.

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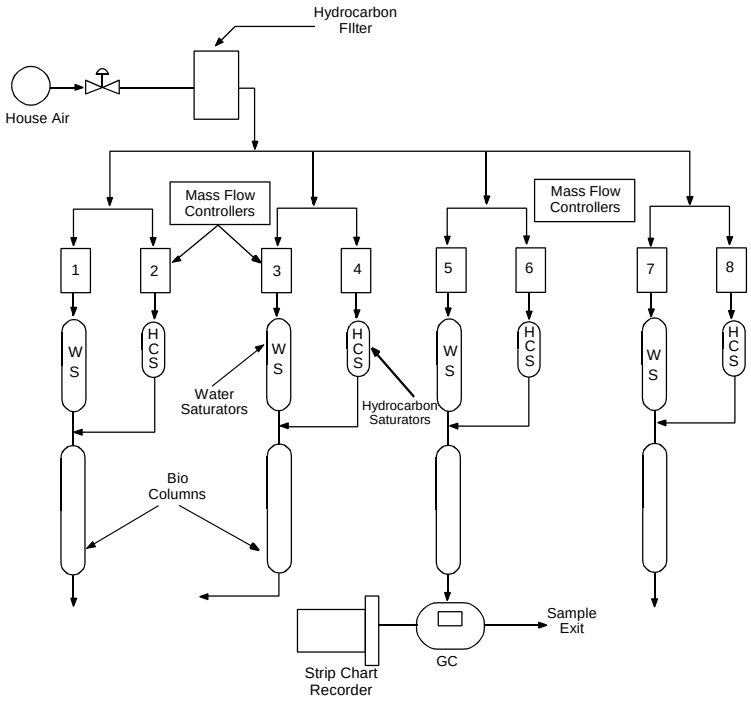
# MEDIA & PROCESS TECHNOLOGY
## (formerly ALUMINUM COMPANY OF AMERICA andALCOA SEPARATION TECHNOLOGY, INC.)
## (Bioscrubber)

## TECHNOLOGY DESCRIPTION:

This bioscrubber technology digests hazardous organic emissions generated by soil, water, and air decontamination processes. The bioscrubber consists of a filter with an activated carbon medium that supports microbial growth. This unique medium, with increased microbial population and enhanced bioactivity, converts diluted organics into carbon dioxide, water, and other nonhazardous compounds. The filter removes biomass, supplies nutrients, and adds moisture. A pilot-scale unit with a 4-cubic-foot-per-minute capacity is being field-tested (see figure below).

In addition to efficient degradation, the bioscrubber provides an effective sink to mitigate feed fluctuations. During an 11-month bench-scale test, the bioscrubber consistently removed contaminants such as petroleum hydrocarbons, alcohols, ketones, and amines from the waste feed at levels ranging from less than 5 to 40 parts per million (ppm).

The bioscrubber provides several advantages over conventional activated carbon adsorbers. First, bioregeneration keeps the maximum adsorption capacity constantly available; thus, the mass transfer zone remains stationary and relatively short. The carbon does not require refrigeration, and the required bed length is greatly reduced, thereby reducing capital and operating expenses. Finally, the chromatographic effect (premature desorption) common in an adsorber is eliminated because the maximum capacity is available constantly. The bioscrubber's advantages are fully exploited




Bioscrubber Pilot-Scale Unit



The SITE Program assesses but does not approve or endorse technologies.

when the off-gas contains weakly adsorbedcontaminants, such as methylene chloride, or adsorbates competing with moisture in the stream. The bioscrubber may replace activated carbon in some applications.

## WASTE APPLICABILITY:

The bioscrubber technology removes organic contaminants in air streams from soil, water, or air decontamination processes. The technology is especially suited to treat streams containing aromatic solvents, such as benzene, toluene, and xylene, as well as alcohols, ketones, hydrocarbons, and others. The technology has several applications to Superfund sites, including (1) organic emission control for groundwater decontamination using air strippers, (2) emission control for biological treatment of ground and surface water, and (3) emission control for soil decontamination. These primary treatment processes have not been designed to prevent volatile organic compound discharges into the atmosphere. The bioscrubber is an ideal posttreatment component for these processes because it handles trace organic volatiles economically and effectively.

## STATUS:

This technology was accepted into the SITE Emerging Technology Program in July 1990. Bench-scale bioscrubbers operated continuously for more than 11 months to treat an air stream with trace concentrations of toluene at about 10 to 20 ppm. The bioscrubbers accomplished a removal efficiency of greater than 95 percent. The filter had a biodegradation efficiency 40 to 80 times greater than existing filters. The project was completed in June 1993. Based on results from the Emerging Technology Program, the bioscrubber technology was invited to participate in the SITE Demonstration Program.

Evaluation results have been published in the report "Bioscrubber for Removing Hazardous Organic Emissions from Soil, Water and Air Decontamination Processes" (EPA/540/R-93/521). This report is available from the National Technical Information Service. The Emerging Technology Bulletin (EPA/540/F-93/507) and the Emerging Technology Summary (EPA/540/SR-93/521) are available from EPA. An article on the technology was also published in the *Journal of Air and Waste Management*, Volume 44, March 1994, pp. 299-303.

The pilot-scale unit has also been tested on discharge from an air stripping tower at a flow rate of 2 standard cubic feet per minute. The discharge contained from less than 10 to 200 ppm toluene. The unit demonstrated the effectiveness, efficiency, and reliability of its design. Additional tests are underway to confirm results at higher flow rates and with other contaminants.

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# MEMBRANE TECHNOLOGY AND RESEARCH, INC.
## (VaporSep® Membrane Process)

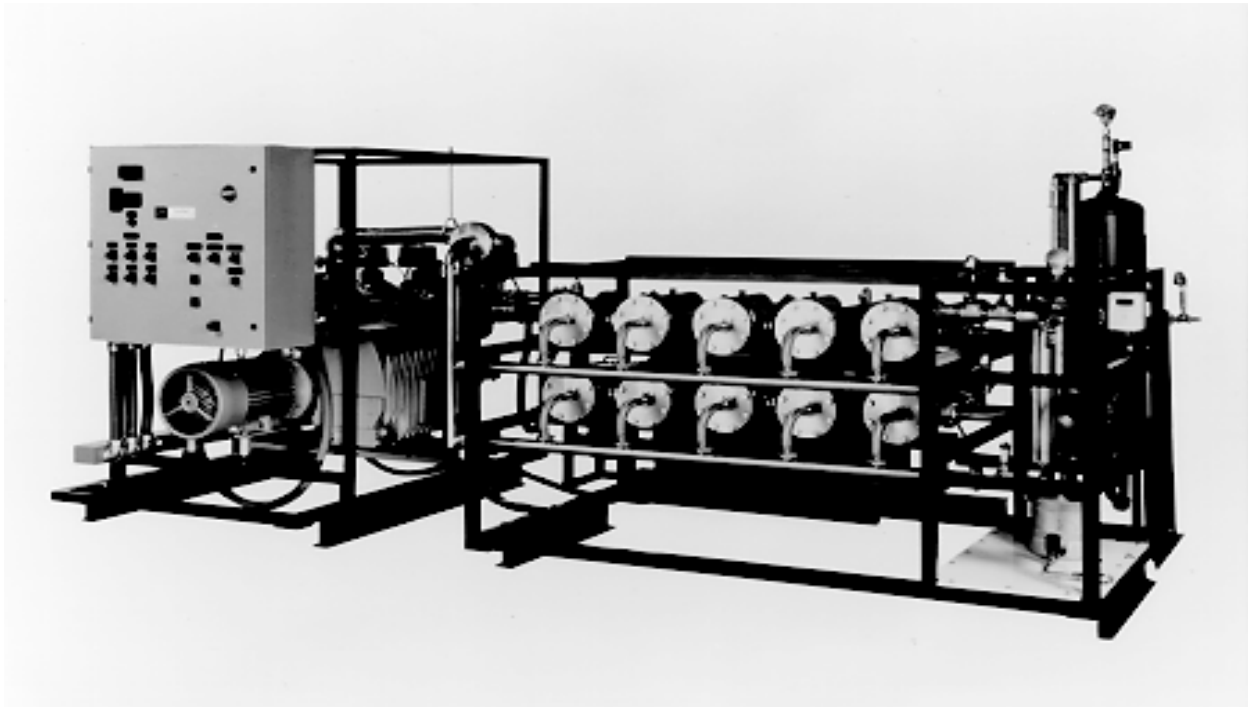
## TECHNOLOGY DESCRIPTION:

The Membrane Technology and Research, Inc., VaporSep® system, shown in the figure below, uses synthetic polymer membranes to remove organic vapors from contaminated air streams. The process generates a clean air stream and a liquid organic stream.

Air laden with organic compounds contacts one side of a membrane that is 10 to 100 times more permeable to the organic compound than to air. The membrane separates the air into two streams: a permeate stream containing most of the organic vapor and a clean residual air stream. The organic vapor is condensed and removed as a liquid; the purified air stream may be vented or recycled.

The VaporSep® system maintains a lower vapor pressure on the permeate side of the membrane to drive the permeation process. This pressure difference can be created by either compressing the feed stream or using a vacuum pump on the permeate stream.

The VaporSep® systems built to date range in capacity from 1 to 700 standard cubic feet per minute. The systems are significantly smaller than carbon adsorption systems of similar capacity and can be configured for a wide range of feed flow rates and compositions. The process has been tested on air streams contaminated with a wide range of organic compounds at concentrations of 100 to more than 100,000 parts per million.



VaporSep® Membrane Organic Vapor Recovery System



The SITE Program assesses but does not approve or endorse technologies.

The VaporSep® system removes between 90 and 99 percent of the organic vapor, depending on the class of organic compound and the system design. The system produces a purified air stream and a small volume of organic condensate. The concentration of organics in the purified air stream is generally low enough for discharge to the atmosphere.

## WASTE APPLICABILITY:

VaporSep® systems can treat most air streams containing flammable or nonflammable halogenated and nonhalogenated organic compounds, including chlorinated hydrocarbons, chlorofluorocarbons (CFC), and fuel hydrocarbons. Typical applications include the following:

- Reduction of process vent emissions, such as those regulated by EPA source performance standards for the synthetic organic chemical manufacturing industry
- Treatment of air stripper exhaust before discharge to the atmosphere
- Recovery of CFCs and hydro-chlorofluorocarbons
- Recovery of valuable organic feedstocks for recycling to the process
- Recovery of gasoline vapors

## STATUS:

This technology was accepted into the SITE Emerging Technology Program in 1989; the project was completed in 1991. The process, demonstrated at both the bench and pilot scales, achieved removal efficiencies of over 99.5 percent for selected organic compounds. The Emerging Technology Bulletin (EPA/540/F-94/503) is available from EPA.

Almost 40 VaporSep® systems have been supplied to customers in the United States and overseas for applications such as the following:

- CFC and halocarbon recovery from process vents and transfer operations
- CFC recovery from refrigeration systems
- Vinyl chloride monomer recovery from polyvinyl chloride manufacturing operations
- CFC-12/ethylene oxide recovery from sterilizer emissions
- Recovery of monomers, other hydrocarbons, and nitrogen in polyolefin degassing processes

A VaporSep® system successfully treated an air stream from a soil vacuum extraction operation at a U.S. Department of Energy site.

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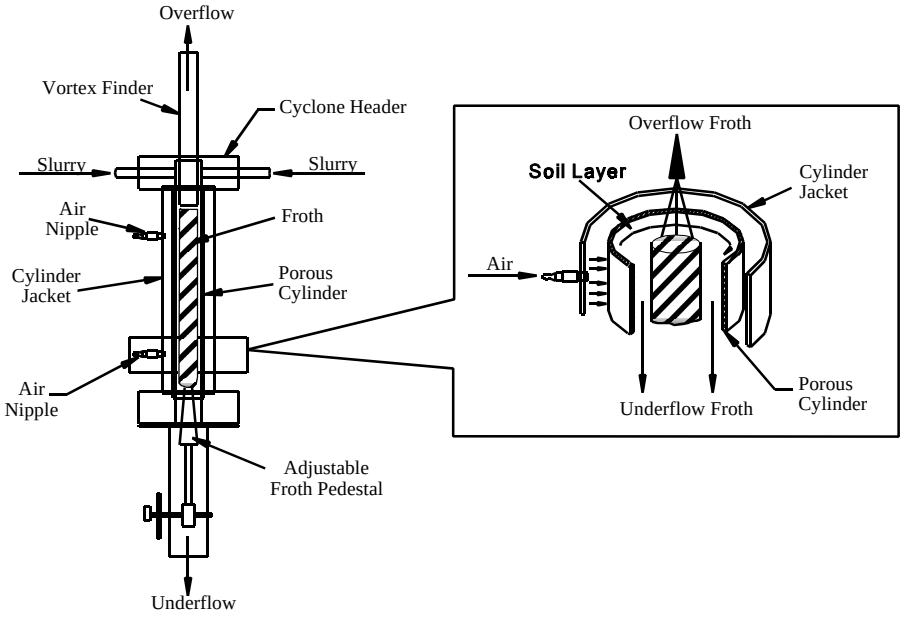
# MONTANA COLLEGE OF MINERAL SCIENCE AND TECHNOLOGY
## (Air-Sparged Hydrocyclone)

## TECHNOLOGY DESCRIPTION:

The air-sparged hydrocyclone (ASH) was developed at the University of Utah during the early 1980s to achieve fast flotation of fine particles in a centrifugal field. The ASH consists of two concentric right-vertical tubes with a conventional cyclone header at the top and a froth pedestal at the bottom (see figure below). The inner tube is a porous tube through which air is sparged. The outer tube serves as an air jacket to evenly distribute air through the porous inner tube.

Slurry is fed tangentially through the conventional cyclone header to develop a swirl flow of a certain thickness in the radial direction (the swirl-layer thickness). The swirl is discharged through an annular opening between the porous tube wall and the froth pedestal. Air is sparged through the porous inner tube wall and is sheared into small bubbles. These bubbles are then radially transported, together with attached hydrophobic particles, into a froth phase that forms on the cyclone axis. The froth phase is stabilized and constrained by the froth pedestal at the underflow, moved toward the vortex finder of the cyclone header, and discharged as an overflow product. Water-wetted hydrophilic particles generally remain in the slurry phase and are discharged as an underflow product through the annulus created by the froth pedestal.

During the past decade, large mechanical flotation cells, such as aeration-stirred tank reactors, have been designed, installed, and operated for mineral processing. In addition, considerable effort has been made to develop column flotation technology in the United States and elsewhere; a number of such systems have been installed in industries. Nevertheless, for both mechanical and column cells, the specific flotation capacity is generally limited to 1 to 2 tons per day (tpd) per cubic foot of cell volume.




Air-Sparged Hydrocyclone



The SITE Program assesses but does not approve or endorse technologies.

In contrast, the ASH has a specific flotation capacity of at least 100 tpd per cubic foot of cell volume.

## WASTE APPLICABILITY:

Standard flotation techniques used in industrial mineral processing are effective ways of concentrating materials. However, metal value recovery is never complete and the valuable material escaping the milling process is frequently concentrated in the very fine particle fraction.

The ASH can remove fine mineral particles that are amenable to the froth flotation process. These particles are generally sulfide minerals, such as galena (lead sulfide), sphalerite (zinc sulfide) and chalcopyrite (copper-iron-sulfide). Finely divided mining wastes containing these minerals oxidize and release the metallic elements as dissolved sulfates into the groundwater. Particularly applicable are tailings from older operations conducted before the development of froth flotation. Earlier operations recovered minerals by gravity concentration, which did not effectively capture fine particles and left tailings with relatively large concentrations of the environmentally hazardous fine sulfide minerals.

## STATUS:

This technology was accepted into the SITE Emerging Technology Program in June 1990. The most recent pilot plant trials on tailings generated by gravity concentration have confirmed both the technology's ability to recover sulfide minerals and the high throughput capacity claimed by proponents of the ASH. However, results on the economics of ash processing were inconclusive. Studies under the SITE Program were completed in August 1994. The pilot plant was dismantled after 4 years of operation.

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# MONTANA COLLEGE OF MINERAL SCIENCE AND TECHNOLOGY
## (Campbell Centrifugal Jig)

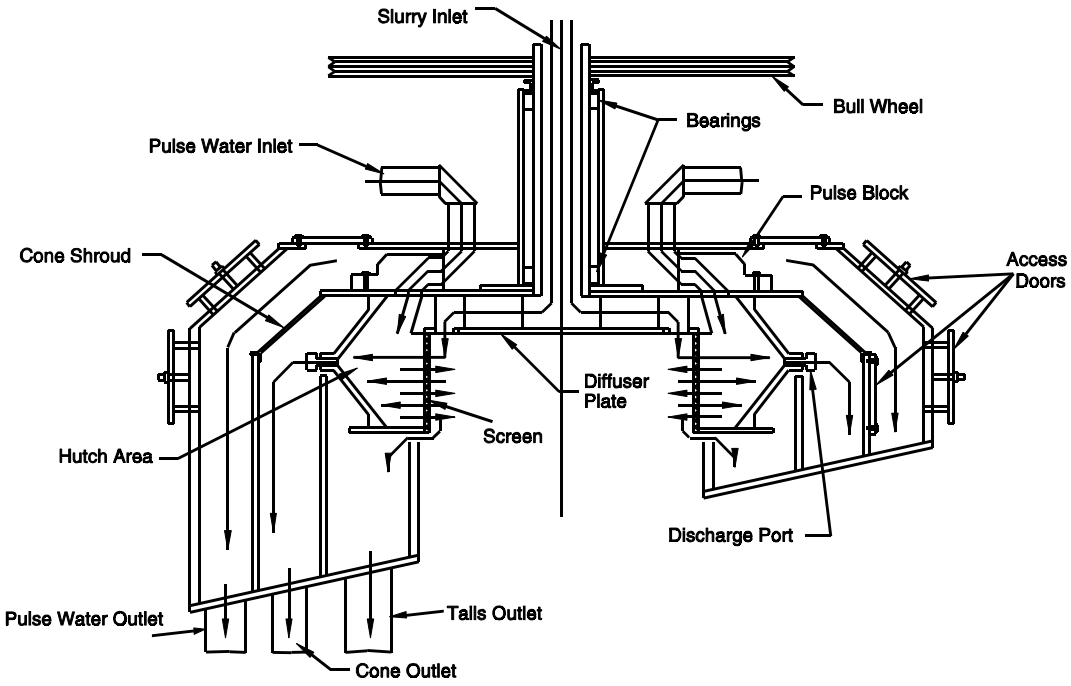
## TECHNOLOGY DESCRIPTION:

The Campbell Centrifugal Jig (CCJ) is a mechanical device that uses centrifugal force to separate fine heavy mineral and metal particles from waste materials. The CCJ combines jigging and centrifuging to separate these particles from a fluid slurry. TransMar, Inc., owns the patents and rights to the CCJ technology.

Standard jigs separate solids of different specific gravities by differential settling in a pulsating bed and gravitational field. Jigs operating in this mode can recover solids larger than about 150 mesh (105 microns). Centrifuges are effective in separating solids from liquids but are not effective in separating solids from solids.

The CCJ, shown in the figure below, combines the continuous flow and pulsating bed of the standard jig with the high acceleration forces of a centrifuge to segregate and concentrate heavy particles from the waste. The CCJ can recover particles ranging in size from 1 to about 500 microns, depending on whether the particles are sufficiently disaggregated from the host material. The disaggregated particle should have a specific gravity at least 50 percent greater than the waste material. The CCJ does not need chemicals to separate the solids.

Appropriately sized, slurried material is fed into the CCJ through a hollow shaft inlet at the top of the machine. The slurried material discharges from the shaft onto a diffuser plate, which has




Campbell Centrifugal Jig (CCJ)



The SITE Program assesses but does not approve or endorse technologies.

vanes that distribute the material radially to the jig bed. The jig bed's surface is composed of stainless-steel shot ragging that is slightly coarser than the screen aperture. The jig bed is pulsated by pressurized water admitted through a screen by four rotating pulse blocks. The pulsing water intermittently fluidizes the bed, causing heavier particles to move through the ragging and screen to the concentrate port, while lighter particles continue across the face of the jig bed to the tailings port.

The effectiveness of separation depends on how well the original solids are disaggregated from the waste material and the specific gravity of each solid. The slurried feed material may require grinding to ensure disaggregation of the heavy metals. Operating parameters include pulse pressure, rotation speed or g-load, screen aperture, ragging type and size, weir height, and feed percent solids.

The CCJ produces heavy mineral or metal concentrates which, depending on the waste material, may be further processed for extraction or sale. A clean tailings stream may be returned to the environment.

## WASTE APPLICABILITY:

The CCJ can separate and concentrate a wide variety of materials, ranging from base metals to fine coal ash and fine (1-micron) gold particles. Applications include (1) remediation of heavy metal-contaminated soils, tailings, or harbor areas containing spilled concentrates; (2) removal of pyritic sulfur and ash from fine coal; and (3) treatment of some sandblasting grit.

## STATUS:

The CCJ was accepted into the SITE Emerging Technology Program in May 1992. The CCJ was evaluated at the Montana College of Mineral Science and Technology Research Center (Montana Tech). Montana Tech equipped a pilot plant to evaluate the Series 12 CCJ, which has a capacity of 1 to 3 tons per hour. Tests were completed in August 1994 on base-metal mine tailings from various locations in western Montana.

In addition, under the U.S. Department of Energy (DOE) Integrated Demonstration Program, the CCJ was tested on clean Nevada test site soil spiked with bismuth as a surrogate for plutonium oxide. These tests occurred at the University of Nevada, Reno, during August and September 1994.

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# MORRISON KNUDSEN CORPORATION/ SPETSTAMPONAZHGEOLOGIA ENTERPRISES
## (Clay-Based Grouting Technology)

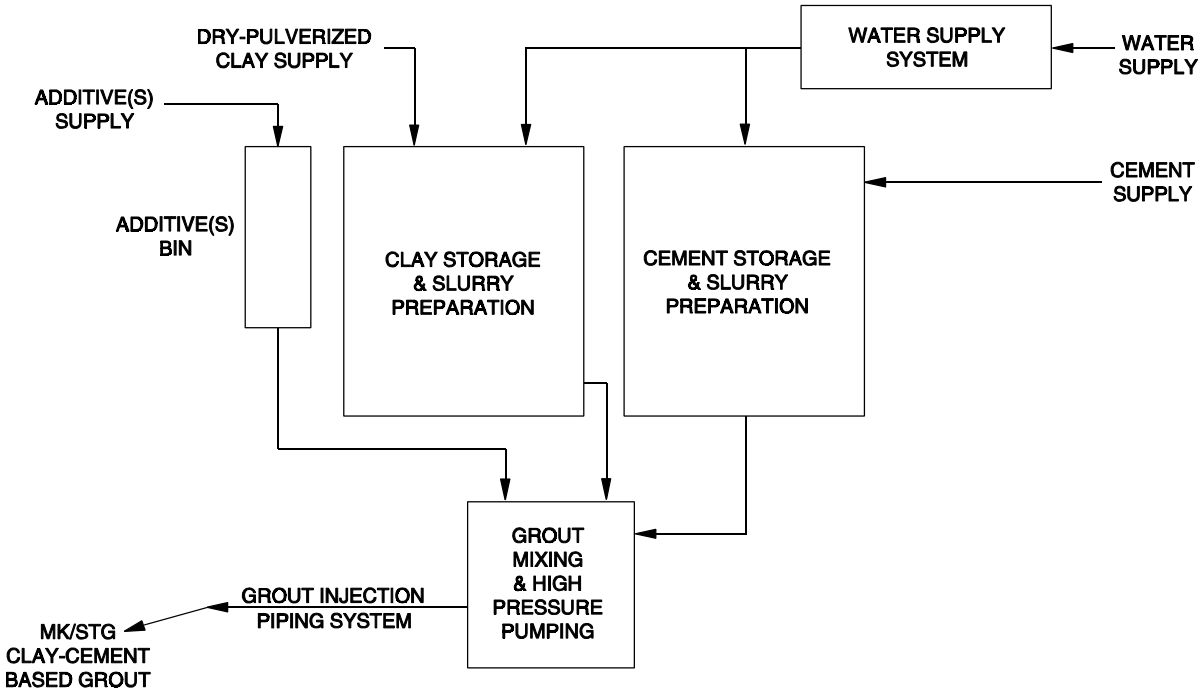
## TECHNOLOGY DESCRIPTION:

Morrison Knudsen Corporation (MK) is working under a joint venture agreement with Spetstamponazhgeologia Enterprises (STG) of Ukraine to demonstrate the effectiveness of a clay-based grouting technology. This technology uses clay slurries as a base for grout solutions, which are injected into bedrock fracture systems to inhibit or eliminate groundwater flow in these pathways. The clay slurries may also be used as a base for slurry wall construction.

The MK/STG clay-based grouting technology is an integrated method involving three primary phases: obtaining detailed site characteristics; developing a site-specific grout formulation; and grout mixing and injection. The first phase, site characterization, includes obtaining geophysical, geochemical, mineralogical, and hydrogeological information about the target area.

The second phase, a site-specific grout formulation, is developed in the laboratory. The overall properties of clay-based grout depend on the physical and mechanical properties of the clay, cement, and other additives. Formulated clay-based grouts are viscoplastic systems composed primarily of clay mineral mortar and structure-forming cement. The clay is normally a kaolin/illite obtained from a local source; other additives may be required. The formulation is laboratory-tested to determine suitability for the desired application.

The third phase is grout mixing and placement. The process for preparing and injecting the clay-based grout is shown in the diagram below. Boreholes drilled during the site characterization phase may be used for grout placement. Additional boreholes may be drilled to complete the injection program. A quality assurance program ensures that placement and project




Process Flow Diagram of the Clay-Based Grouting Technology



The SITE Program assesses but does not approve or endorse technologies.

objectives are met. After injection, the clay-based grout retains its plasticity and does not crystallize, providing permanent underground protection.

## WASTE APPLICABILITY:

This technology is suitable for providing a flow barrier to groundwater contaminated with both heavy metals and organics. The clay-based grout can be formulated to withstand detrimental conditions such as low pH. The technology can be used at inactive mine sites that produce acid mine drainage. Other potential applications include liquid effluent control from landfills, containment of groundwater contaminated with chemicals or radionuclides, and reduction of brine inflows.

## STATUS:

This technology was accepted into the SITE Demonstration Program in winter 1993. It was partially installed in fall 1994 at the abandoned Mike Horse Mine site in Montana; operations were suspended due to winter weather conditions. The third phase, to complete installation of the grout, was canceled due to EPA budget constraints. The demonstration was completed in 1996, but the technology was not fully evaluated due to loss of accessibility to the site.

Over 200 projects using this technology have been completed during the last 20 years in the former Soviet Union and Eastern block countries, as well as in China and Australia. The technology has not been applied in the United States or western hemisphere other than at the Mike Horse Mine site.

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# NORTH AMERICAN TECHNOLOGIES GROUP, INC.
## (Oleophilic Amine-Coated Ceramic Chip)

## TECHNOLOGY DESCRIPTION:

This hydrocarbon recovery technology is based on an oleophilic, amine-coated ceramic chip that separates suspended and dissolved hydrocarbons, as well as most mechanical and some chemical emulsions, from aqueous solutions. The oleophilic chip is manufactured by grafting a hydrophobic amine to a mineral support, in this case a ceramic substrate. Each granule is 0.6 to 1 millimeter in diameter, but is very porous and thus has a large surface area. The hydrophobic property of the amine coating makes each granule more effective for microfiltration of hydrocarbons in an unstable emulsion.

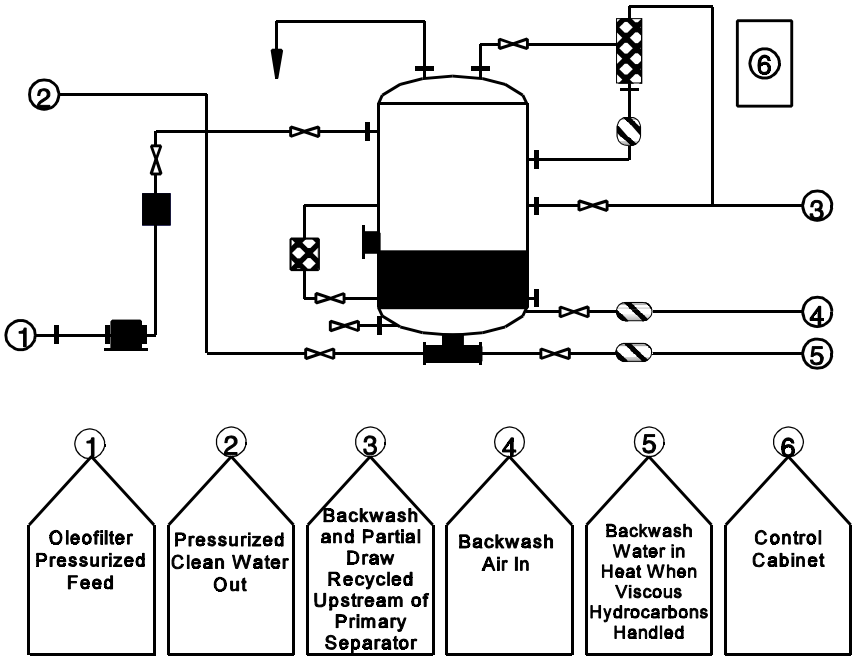
The figure below illustrates the process; the separator, filter, and coalescer unit is shown on the next page. The pressure-sensitive filtering bed is regenerated by automatic backflushing. This automatic regeneration eliminates the expense associated with regeneration of carbon and similar filtration media. Recovered hydrocarbons coalesce and can thus be removed by simple gravity separation.

This technology provides cost-effective oil and water separation, removes free and emulsified hydrocarbon contaminants, and significantly reduces hydrocarbon loading to air strippers and carbon systems. The technology can achieve a concentration of less than 7 parts per million oil and grease in the treated effluent.

## WASTE APPLICABILITY:

The amine-coated granules have proven effective on a wide variety of hydrocarbons, including gasoline; crude oil; diesel fuel; benzene, toluene, ethylbenzene and xylene mixtures; and polynuclear aromatic hydrocarbons. The unit also removes hydrophobic chlorinated hydrocarbons such as pentachlorophenol, polychlorinated biphenyls, and trichloroethene, as well as vegetable and animal oils.

Treatment systems incorporating this technology have been designed for various applications, including (1) contamin ated groundwater pump-and-treat systems; (2) in-process oil and water separation; (3) filtration systems; (4) combined



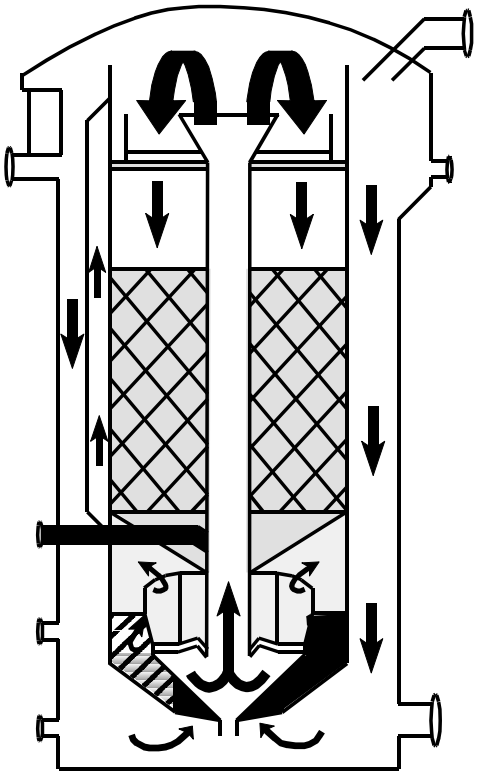

Schematic Diagram of the Oleofilter Technology

oil and water separator-filter-coalescer systems for on-site waste reduction and material recovery; and (5) treatment of marine wastes (bilge and ballast waters).

## STATUS:

This technology was accepted into the SITE Demonstration Program in December 1992. The SITE demonstration was completed in June 1994 at the Petroleum Products Corporation site in Fort Lauderdale, Florida. The site is a former oil recycling facility where groundwater has been contaminated with a variety of organic and inorganic constituents. The Demonstration Bulletin (EPA/540/MR-94/525) and Innovative Technology Evaluation Report (EPA/540/R-94/525) are available from EPA.

The technology has been used for several full-scale projects. Several separator-filter-coalescers (see figure below) are in use treating industrial process waters and oily wash waters.



Separator, Filter, and Coalescer

## DEMONSTRATION RESULTS:

For the demonstration, five separate evaluation periods (runs) were initiated. Each run used the same feed oil, except run four. The oil for run four was a 3:1 mixture of oil to kerosene. The average total recoverable petroleum hydrocarbon (TRPH) concentrations for the feed streams ranged from 422 to 2,267 milligrams per liter (mg/L). Preliminary data indicate that the system removed at least 90 percent of the TRPH from the emulsified oil and water feed stream.

For the runs where the system operated within normal design parameters, TRPH concentrations in the treated water effluent were reduced to 15 mg/L or less. The oleophilic granules achieved a 95 percent reduction of TRPH concentration for the runs with similar feed oil.

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The SITE Program assesses but does not approve or endorse technologies.

# NEW JERSEY INSTITUTE OF TECHNOLOGY
## (GHEA Associates Process)

## TECHNOLOGY DESCRIPTION:

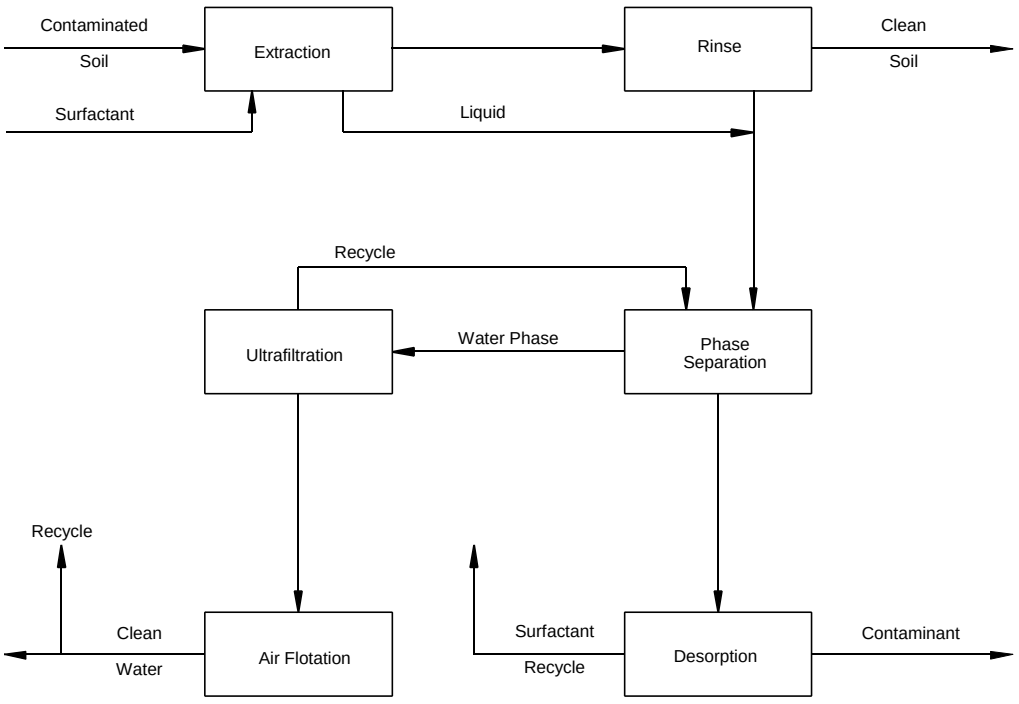
The GHEA Associates process applies surfactants and additives to soil washing and wastewater treatment to make organic and metal contaminants soluble. In soil washing, soil is excavated, washed, and rinsed to produce clean soil. Wash and rinse liquids are then combined and treated to separate surfactants and contaminants from the water. Next, contaminants are separated from the surfactants by desorption and are isolated as a concentrate. Desorption regenerates the surfactants for repeated use in the process.

The liquid treatment consists of a sequence of steps involving phase separation, ultrafiltration, and air flotation (see figure below). The treated water meets all National Pollutant Discharge Elimination System groundwater discharge criteria, allowing it to be (1) discharged without further treatment, and (2) reused in the process itself or reused as a source of high quality water for other users.

In wastewater treatment applications, surfactants added to the wastewater adsorb contaminants. The mixture is then treated in the same manner as described above for (1) water purification, (2) separation of the contaminants, and (3) recovery of the surfactants. The treatment process yields clean soil, clean water, and a highly concentrated fraction of contaminants. No other residues, effluents, or emissions are produced. The figure below illustrates the GHEA process.

## WASTE APPLICABILITY:

This technology can be applied to soil, sludges, sediments, slurries, groundwater, surface water, end-of-pipe industrial effluents, and in situ soil




GHEA Process for Soil Washing



The SITE Program assesses but does not approve or endorse technologies.

flushing. Contaminants that can be treated include both organics and heavy metals, nonvolatile and volatile organic compounds, and highly toxic refractory compounds.

## STATUS:

The technology was accepted into the SITE Emerging Technology Program in June 1990. Treatability tests were conducted on various matrices, including soils with high clay contents, industrial oily sludges, industrial wastewater effluents, and contaminated groundwater (see table below). In situ soil flushing tests have shown a 20-fold enhancement of contaminant removal rates. Tests using a 25-gallon pilot-scale plant have also been conducted. Costs for treatment range from $50 to $80 per ton. The Emerging Technology Bulletin (EPA/540/F-94/509), which details evaluation results, is available from EPA.

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**SUMMARY OF TREATABILITY TEST RESULTS**

| MATRIX | UNTREATED SAMPLE | TREATED SAMPLE | PERCENT REMOVAL |
|---|---|---|---|
| Volatile Organic Compounds (VOC): Trichloroethene; 1,2-Dichloroethene; Benzene; Toluene | | | |
| Soil, parts per million (ppm) | 20.13 | 0.05 | 99.7% |
| Water, parts per billion (ppb) | 109.0 | 2.5 | 97.8% |
| Total Petroleum Hydrocarbons (TPH): Soil, ppm | 13,600 | 80 | 99.4% |
| Polychlorinated Biphenyls (PCB): | | | |
| Soil, ppm | 380.00 | 0.57 | 99.8% |
| Water, ppb | 6,000.0 | <0.1 | >99.9% |
| Trinitrotoluene in Water, ppm | 180.0 | <.08 | >99.5% |
| Coal Tar Contaminated Soil (ppm): | | | |
| Benzo[a]pyrene | 28.8 | <0.1 | >99.7% |
| Benzo[k]fluoranthene | 24.1 | 4.4 | 81.2% |
| Chrysene | 48.6 | <0.1 | >99.8% |
| Benzanthracene | 37.6 | <0.1 | >99.7% |
| Pyrene | 124.2 | <0.1 | >99.9% |
| Anthracene | 83.6 | <0.1 | >99.8% |
| Phenanthrene | 207.8 | <0.1 | >99.9% |
| Fluorene | 92.7 | <0.1 | >99.9% |
| Dibenzofuran | 58.3 | <0.1 | >99.8% |
| 1-Methylnaphthalene | 88.3 | 1.3 | 98.5% |
| 2-Methylnaphthalene | 147.3 | <0.1 | >99.9% |
| Heavy Metals In Soil: Chromium, ppm | 21,000 | 640 | 96.8% |
| Iron (III) in Water, ppm: | 30.8 | 0.3 | 99.0% |

# NOVATERRA ASSOCIATES
## (In Situ Soil Treatment [Steam and Air Stripping])

## TECHNOLOGY DESCRIPTION:

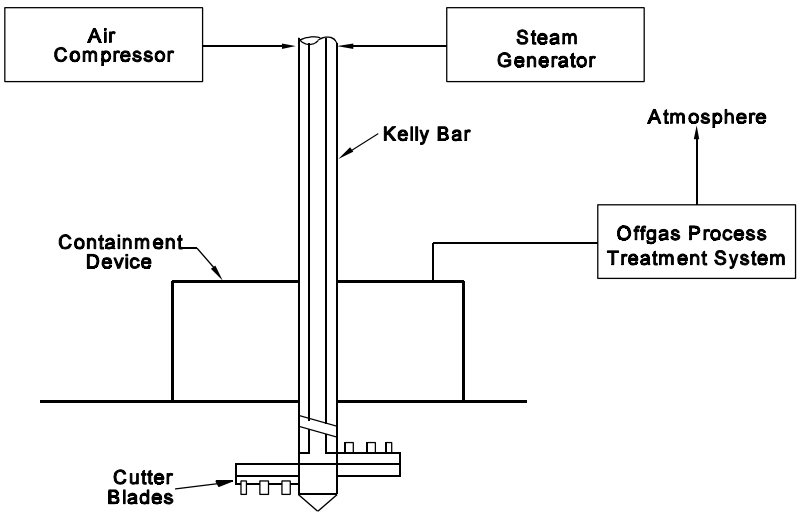
This technology treats contaminated soils and contained groundwater by the simultaneous in situ injection of treatment agents below ground during active mixing by augers or drilling blades (see figure below). The in situ injection of steam and air during mixing strips the volatile organic compounds (VOC) and semivolatile organic compounds (SVOC) from the soil and contained groundwater. The removed organics are captured at the surface and disposed of in an environmentally safe manner.

The technology is implemented by a drill unit that can consist of a single or double blade or auger mounted on a large crane or backhoe. The diameter of the drill or auger can vary from 5 to 8 feet, and it is mounted on a kelly that reaches depths of 60 feet.

The steam and air are carried down the center of the kelly(s) and injected into the ground through jets located on the blade or auger arms. The steam is supplied by an oil- or natural gas-fired boiler at 450 $^{o}$F and 500 pounds per square inch gauge (psig). The air heated by the compressor is injected at 250 $^{o}$F and 200 psig. The steam heats the contaminants in the soil and contained water, increasing the vapor pressure of the VOCs and SVOCs and increasing their removal rates. The direct application of the steam on the soil thermally desorbs the VOCs and SVOCs, increasing their removal percentage. Almost all the VOCs and SVOCs of interest form azeotropes with steam that boil below 212 $^{o}$F and contain low concentrations (such as a few percent) of contaminants. These azeotropes significantly increase contaminant removal rates, especially for the higher-boiling-point SVOCs.

The VOC- and SVOC-laden air and steam vapor stream removes the contamination to the surface where it can be captured, if necessary, in a metal container. The container, which makes a tight seal to the ground surface, is connected to a process stream by piping. A suction blower draws the waste stream to the process stream where it is collected or destroyed. The blower creates a slight vacuum in the container and piping as well as a positive displacement inward to the collection or destruction system, thus protecting the outside environment from contamination.

The simplest form of the process system uses a catalytic oxidizer or thermal oxidizer to destroy the contamination before exhausting to the atmosphere. When treating chlorinated VOCs and SVOCs, an acid scrubber can be added if




In Situ Soil Treatment Process Schematic



The SITE Program assesses but does not approve or endorse technologies.

required by the amount of material being processed. Another simple process uses activated carbon to recover the contamination. For the carbon to work efficiently, a cooling system must precede the carbon bed, so the process must also treat contaminated water. If recovery and reuse of the contamination is important or economically desirable, a process system that condenses the gas stream can be used.

The in situ soil treatment technology has also treated contaminated soil by injecting and mixing other agents. Chemical injection processes include the stabilization and solidification of heavy metals, neutralization of acids and bases, and oxidation. The technology has been successfully used to perform bioremediation. The equipment is capable of injecting cement into the soil and making slurry walls. The technology has the unique feature of being able to inject two materials simultaneously or sequentially.

## WASTE APPLICABILITY:

This technology can treat solid materials which do not contain obstructions, including soils, sludges, lagoons, and the liquids contained within, such as water and dense and light nonaqueous-phase liquids. The technology is applicable to most VOCs and SVOCs, including pesticides. It is particularly applicable to free product and removal of highly concentrated contamination. It is most effective for removals of 95 to 99 percent of the contamination as a result of the low temperature thermal desorption. After treatment is completed, the soil can meet construction engineering requirements by compacting or injecting small amounts of cement.

## STATUS:

This technology was accepted into the SITE Demonstration Program in 1989. A SITE demonstration was performed in September 1989 at the Annex Terminal, San Pedro, California. Twelve soil blocks were treated for VOCs and SVOCs. Liquid samples were collected during the demonstration, and the operating procedures were closely monitored and recorded. In January 1990, six blocks that had been previously treated in the saturated zone were analyzed by EPA methods 8240 and 8270.

The Applications Analysis Report (EPA/540/A5-90/008) was published in June 1991. The technology remediated 30,000 cubic yards at the Annex Terminal after completion of the SITE demonstration and has been used at five other contaminated sites.

## DEMONSTRATION RESULTS:

The SITE technology demonstration yielded the following results:

- Removal efficiencies were greater than 85 percent for VOCs present in the soil.
- Removal efficiencies were greater than 55 percent for SVOCs present in the soil.
- Fugitive air emissions from the process were low.
- No downward migration of contaminants resulted from the soil treatment.
- The process treated 3 cubic yards of soil per hour.

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# NATIONAL RISK MANAGEMENT RESEARCH LABORATORY
## (Base-Catalyzed Decomposition Process)

## TECHNOLOGY DESCRIPTION:

The base-catalyzed decomposition (BCD) process is a chemical dehalogenation technology developed by the National Risk Management Research Laboratory in Cincinnati, Ohio. The process is initiated in a medium-temperature thermal desorber (MTTD) at temperatures ranging from 600 to 950 °F. Sodium bicarbonate is added to contaminated soils, sediments, or sludge matrices containing hazardous chlorinated organics including polychlorinated biphenyls (PCB) and polychlorinated dioxins and furans. Chlorinated contaminants that are thermally desorbed from the matrix are condensed and treated by the BCD process. The BCD process chemically detoxifies the condensed chlorinated organic contaminants by removing chlorine from the contaminants and replacing it with hydrogen.

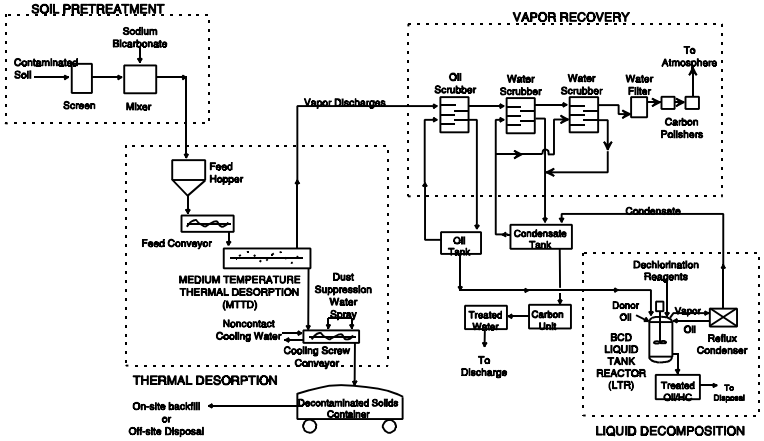
ETG Environmental, Inc. (ETG), and Separation and Recovery Systems, Inc. (SRS), developed the THERM-O-DETOX® and SAREX® systems and combined them with the BCD process chemistry. The combined process begins by initiating solid-phase dechlorination in the MTTD step (see figure below). In addition to the dechlorination that occurs in the MTTD, organics are thermally desorbed from the matrix, and are condensed and sent to the BCD liquid tank reactor (LTR).

Reagents are then added and heated to 600 to 650 °F for 3 to 6 hours to dechlorinate the remaining organics. The treated residuals are recycled or disposed of using standard, commercially available methods. Treated, clean soil can be recycled as on-site backfill.

ETG has continued to develop the THERM-O-DETOX® system and now offers continuous systems and batch vacuum systems. The batch vacuum system offers greater operational flexibility for removal and destruction of high hazard, high boiling point contaminants to ensure that treatment standards are met. The vapor recovery system can be set up to use noncontact condensers or chillers and additional final polishing steps to meet the most stringent air emission standards.

## WASTE APPLICABILITY:

The BCD process can treat soils, sediments, and sludges contaminated with the following chlorinated compounds: halogenated semivolatile organic compounds (SVOC), including herbicides and pesticides; PCBs; pentachlorophenol (PCP) and other chlorinated phenols; and polychlorinated dioxins and furans.




Base-Catalyzed Decomposition (BCD) Process



The SITE Program assesses but does not approve or endorse technologies.

## STATUS:

The combined BCD process was demonstrated under the SITE Program at the Koppers Company Superfund site in Morrisville, North Carolina, from August through September 1993. The process removed PCP from clay soils to levels below those specified in the Record of Decision. The process also removed dioxins and furans from contaminated soil to 2,3,7,8-tetrachlorodibenzo-p-dioxin equivalent concentrations less than the concentration specified in the Record of Decision.

ETG is also currently operating the batch vacuum system at a New York State Department of Environmental Conservation cleanup site in Binghamton, New York. Approximately 1,500 cubic yards of soil contaminated with herbicides pesticides, dioxins, and furans (F027 waste) are being treated. The Michigan Department of Natural Resources has also approved BCD for a project involving treatment of about 200 cubic yards of F027 soils. At another site, multiple systems will treat soils contaminated with chlorinated volatile organic compounds and high boiling point (800-1150 $^{o}$F) organic lubricants. The batch vacuum system has also been used to treat sludges at an operating refinery in Puerto Rico and a chemical company in Texas.

For information on the SAREX® system, see the profile for SRS in the Demonstration Program section (ongoing projects).

## DEMONSTRATION RESULTS:

The SITE demonstration consisted of four test runs in the MTTD and two test runs in the LTR. Feed soil consisted of a dry, clayey silt and had a residence time of 1 to 2 hours in the MTTD, which was heated to 790 $^{o}$F to 850 $^{o}$F. The MTTD off-gases were treated by passing through an oil scrubber, water scrubbers, and carbon filters. The oil from the oil scrubber was transferred to the LTR for BCD treatment. The oil in each LTR test run was batch-processed for 3 to 4 hours at 600 to 630$^{o}$F.

Key findings from the SITE demonstration are summarized as follows:

- The MTTD achieved removal efficiencies of 99.97 percent or better for PCP and 99.56 percent or better for total dioxins and total furans.
- The treated soils were well below toxicity characteristic leaching procedure limits for SVOCs.
- Treated soil met the cleanup goal of 95 parts per million PCP in all test runs. Treated soil also met a cleanup goal of 7 micrograms per kilogram 2,3,7,8-tetrachlorodibenzo-p-dioxin equivalents in all test runs.
- The LTR batch tests reduced PCP concentrations by 96.89 percent or better, and total dioxin and total furan concentrations by 99.97 percent or better.

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# NATIONAL RISK MANAGEMENT RESEARCH LABORATORY and IT CORPORATION
## (Debris Washing System)

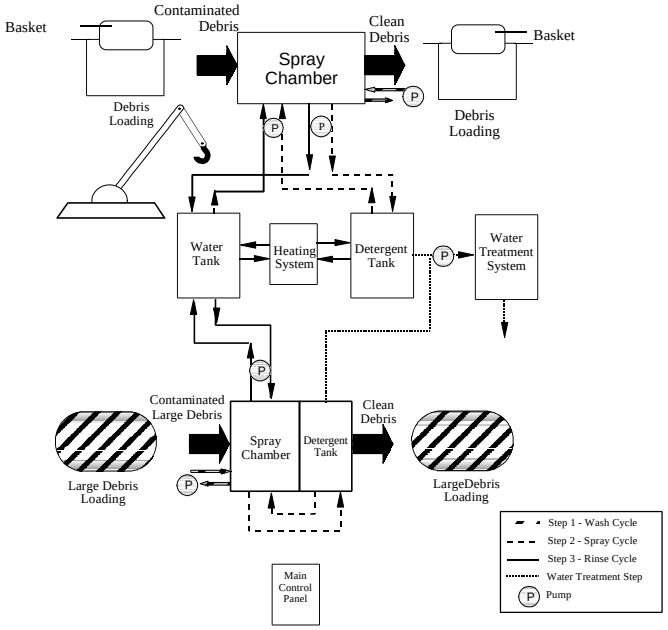
## TECHNOLOGY DESCRIPTION:

This technology was developed by EPA's National Risk Management Research Laboratory and IT Corporation (IT) for on-site decontamination of metallic and masonry debris at Comprehensive Environmental Response, Compensation, and Liability Act sites. The entire system is mounted on three 48-foot flatbed semi-trailers and can be readily transported from site to site.

The full-scale debris washing system (DWS) is shown in the figure below. The DWS consists of dual 4,000-gallon spray-wash chambers that are connected to a detergent solution holding tank and rinse water holding tank. Debris is placed into one of two 1,200-pound baskets, which in turn is placed into one of the spray-wash chambers using a 5-ton crane integral to the DWS. If debris is large enough, the crane places it directly into one of the two chambers. Process water is heated to 160 °F using a diesel-fired, 2,000,000-British-thermal-unit-per-hour (Btu/hr) water heater. The water is continuously reconditioned using particulate filters, an oil-water separator, and other devices such as charcoal columns or ion-exchange columns. About 8,000 to 10,000 gallons of water is required for the decontamination process. The system is controlled by an operator stationed in a trailer-mounted control room.

## WASTE APPLICABILITY:

The DWS can be applied on site to various types of debris (scrap metal, masonry, or other solid debris such as stones) contaminated with hazardous chemicals such as pesticides, dioxins, polychlorinated biphenyls (PCB), or hazardous metals.




Pilot-Scale Debris Washing System



The SITE Program assesses but does not approve or endorse technologies.

## STATUS:

The first pilot-scale tests were performed in September 1988 at the Carter Industrial Superfund site in Detroit, Michigan. An upgraded pilot-scale DWS was tested at a PCB-contaminated Superfund site in Hopkinsville, Kentucky in December 1989. The DWS was also field tested in August 1990 at the Shaver's Farm Superfund site in Walker County, Georgia. The contaminants of concern were benzonitrile and Dicamba. After being cut into sections, 55-gallon drums were decontaminated in the DWS.

Results from the SITE demonstration have been published in a Technology Evaluation Report (EPA/540/5-91/006a), entitled "Design and Development of a Pilot-Scale Debris Decontamination System" and in a Technology Demonstration Summary (EPA/540/S5-91/006).

In 1993, a manual version of the full-scale DWS was used to treat PCB-contaminated scrap metal at the Summit Scrap Yard in Akron, Ohio. During the 4-month site remediation, 3,000 tons of PCB-contaminated scrap metal (motors, cast iron blocks) was cleaned on site. The target level of 7.7 µg/100 $cm^2$ was met, in most cases, after a single treatment with the DWS. The cleaned scrap was purchased by a scrap smelter for $52 per ton. The net costs for the on-site debris decontamination ranged from $50 to $75 per ton. The National Risk Management Research Laboratory and IT estimate that the system can decontaminate 50 to 120 tons of typical debris per day.

## DEMONSTRATION RESULTS:

At the Carter Industrial Superfund site, PCB reductions averaged 58 percent in batch 1 and 81 percent in batch 2. Design changes based on these tests were made to the DWS before additional field testing.

At the Hopkinsville, Kentucky site, PCB levels on the surfaces of metallic transformer casings were reduced to less than or equal to 10 micrograms PCB per 100 square centimeters (µg/$cm^2$). All 75 contaminated transformer casings on site were decontaminated to EPA cleanup criteria and sold to a scrap metal dealer.

At the Shaver's Farm Superfund site, benzonitrile and Dicamba levels on the drum surfaces were reduced from the average pretreatment concentrations of 4,556 and 23 µg/100 $cm^2$ to average concentrations of 10 and 1 µg/100 $cm^2$, respectively.

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# NATIONAL RISK MANAGEMENT RESEARCH LABORATORY and INTECH 180 CORPORATION

**(Fungal Treatment Technology)**

## TECHNOLOGY DESCRIPTION:

This biological treatment system uses lignin-degrading fungi to treat excavated soils. These fungi have been shown to biodegrade a wide catalogue of organic contaminants.

The contaminated soil is inoculated with an organic carrier infested with the selected fungal strain. The fungi break down soil contaminants, using enzymes normally produced for wood degradation as well as other enzyme systems.

This technology has the greatest degree of success when optimal growing conditions for the fungi are used. These conditions include moisture control (at 90 percent of field capacity), and temperature and aeration control. Organic nutrients such as peat may be added to soils deficient in organic carbon.

## WASTE APPLICABILITY:

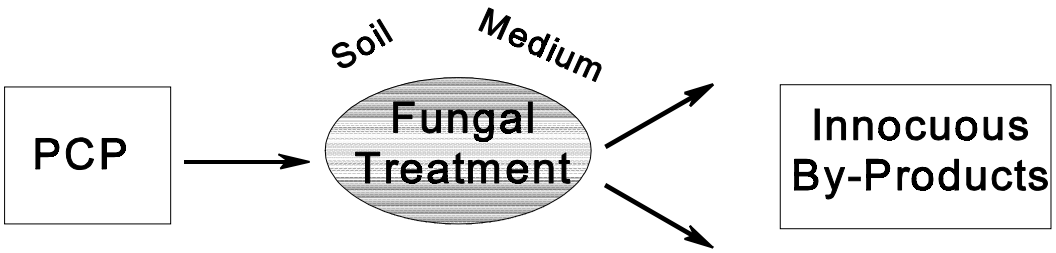
This biological treatment system was initially applied to soil contaminated with organic chemicals found in the wood-preserving industry. These contaminants are composed of chlorinated organics and polynuclear aromatic hydrocarbons (PAH). The treatment system may remediate different contaminants and combinations of contaminants with varying degrees of success. In particular, the SITE Demonstration Program evaluated how well white rot fungi degrade pentachlorophenol (PCP) in combination with creosote PAHs.

## STATUS:

This biological treatment system was accepted into the SITE Demonstration Program in April 1991. In September 1991, a treatability study was conducted at the Brookhaven Wood Preserving site in Brookhaven, Mississippi. Site soils were contaminated with 200 to 5,200 milligrams per kilogram (mg/kg) PCP and up to 4,000 mg/kg PAHs.

A full-scale demonstration of this fungal treatment technology was completed in November 1992 to obtain economic data. The Demonstration Bulletin (EPA/540/MR-93/505) is available from EPA.

The extent of treatment in the full-scale demonstration was disappointing for the time of treatment. The full-scale demonstration was hampered by excessive rainfall which did not permit the treatment beds to be sufficiently tilled. Without this processing, oxygen-depleted conditions developed, leading to loss of fungal biomass and activity. Soil bed applications of this technology may not be suitable in climates of high rainfall.




In Situ White Rot Fungal Treatment of Contaminated Soil



The SITE Program assesses but does not approve or endorse technologies.

Current costs of fungal treatment operation are estimated at $150 to $200 per ton. Lower costs may be achieved with new inoculum formulations which permit reduction in the amount of inoculum mass required for treatment.

## DEMONSTRATION RESULTS:

The full-scale project involved a 0.25-acre plot of contaminated soil and two smaller control plots. The soil was inoculated with *Phanaerochaete sordida*, a species of lignin-degrading fungus. No other amendments were added to the prepared soil. Field activities included tilling and watering all plots. No nutrients were added. The study was conducted for 20 weeks.

Some key findings from the demonstration were:

- Levels of PCP and the target PAHs found in the underlying sand layer and the leachate from each of the plots were insignificant, indicating low leachability and loss of these contaminants due to periodic irrigation of the soil and heavy rainfall.
- Levels of PCP, the target PAHs, and dioxins in the active air samples collected during the soil tilling events were insignificant, indicating a very low potential for airborne contaminant transport.
- Air emissions data showed that soil tilling activities did not pose significant hazards to field technicians. Contaminated soil, underlying sand, and leachate had no significant contamination.

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# NATIONAL RISK MANAGEMENT RESEARCH LABORATORY, UNIVERSITY OF CINCINNATI, and FRX, INC.
## (Hydraulic Fracturing)

## TECHNOLOGY DESCRIPTION:

Hydraulic fracturing is a physical process that creates fractures in soils to enhance fluid or vapor flow in the subsurface. The technology places fractures at discrete depths with hydraulic pressurization at the base of a borehole. These fractures are placed at specific locations and depths to increase the effectiveness of treatment technologies such as soil vapor extraction, in situ bioremediation, and pump-and-treat systems. The technology is designed to enhance remediation in less permeable geologic formations.

The fracturing process begins by injecting water into a sealed borehole until the water pressure exceeds a critical value and a fracture is nucleated (see photograph below). A slurry composed of a coarse-grained sand, or other granular material, and guar gum gel is then injected as the fracture grows away from the well. After pumping, the grains hold the fracture open while an enzyme additive breaks down the viscous fluid. The thinned fluid is pumped from the fracture, forming a permeable subsurface channel suitable for delivering or recovering a vapor or liquid. These fractures function as pathways for fluid movement, potentially increasing the effective area available for remediation.

The hydraulic fracturing process is used in conjunction with soil vapor extraction technology to enhance recovery of contaminated soil vapors. Hydraulic fractures have recently been used to improve recovery of light nonaqueous phase liquids by increasing recovery of free product and controlling the influence of underlying water. Hydraulically induced fractures are used as channels for fluids and nutrients during in situ bioremediation. The technology has the potential to deliver nutrients and other materials to the subsurface solids useful in bioremediation. Solid nutrients or oxygen-releasing granules can be injected into the fractures.

Hydraulic Fracturing Process (Well is at center of photograph)



The SITE Program assesses but does not approve or endorse technologies.

Real-time techniques for measuring ground surface deformation have been developed to monitor the fracture positions in the subsurface.

## WASTE APPLICABILITY:

Hydraulic fracturing is appropriate for enhancing soil and groundwater remediation. The technology can channel contaminants or wastes for soil vapor extraction, bioremediation, or pump-and-treat systems.

## STATUS:

The hydraulic fracturing technology was accepted into the SITE Demonstration Program in July 1991. Demonstrations have been conducted in Oak Brook, Illinois and Dayton, Ohio. The hydraulic fracturing process was integrated with soil vapor extraction at the Illinois site and with in situ bioremediation at the Ohio site. The project was completed in September 1992. The Technology Evaluation and Applications Analysis Reports, which were published under one cover (EPA/540/R-93/505), and the Technology Demonstration Summary (EPA/540/SR-93/505) are available from EPA.

## DEMONSTRATION RESULTS:

The first demonstration was conducted at a Xerox Corporation site in Oak Brook, Illinois, where a vapor extraction system has been operating since early 1991. The site is contaminated with ethylbenzene, 1,1-dichloroethane, trichloroethene, tetrachloroethene, 1,1,1-trichloroethane, toluene, and xylene. In July 1991, hydraulic fractures were created in two of the four wells, at depths of 6, 10, and 15 feet below ground surface. The vapor flow rate, soil vacuum, and contaminant yields from the fractured and unfractured wells were monitored regularly. Results from this demonstration are as follows:

- Over a 1-year period, the vapor yield from hydraulically fractured wells was one order of magnitude greater than from unfractured wells.
- The hydraulically fractured wells enhanced remediation over an area 30 times greater than the unfractured wells.
- The presence of pore water decreased the vapor yield from wells; therefore, water must be prevented from infiltrating areas where vapor extraction is underway.

The technology was also demonstrated at a site near Dayton, Ohio, which is contaminated with benzene, toluene, ethylbenzene, and xylene (BTEX), and other petroleum hydrocarbons. In August 1991, hydraulic fractures were created in one of two wells at 4, 6, 8, and 10 feet below ground surface. Sampling was conducted before the demonstration and twice during the demonstration at locations 5, 10, and 15 feet north of the fractured and unfractured wells. Results from this demonstration are as follows:

- The flow of water into the fractured well was two orders of magnitude greater than in the unfractured well.
- The bioremediation rate near the fractured well was 75 percent higher for BTEX and 77 percent higher for total petroleum hydrocarbons compared to the rates near the unfractured well.

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# NATIONAL RISK MANAGEMENT RESEARCH LABORATORY
## (Volume Reduction Unit)

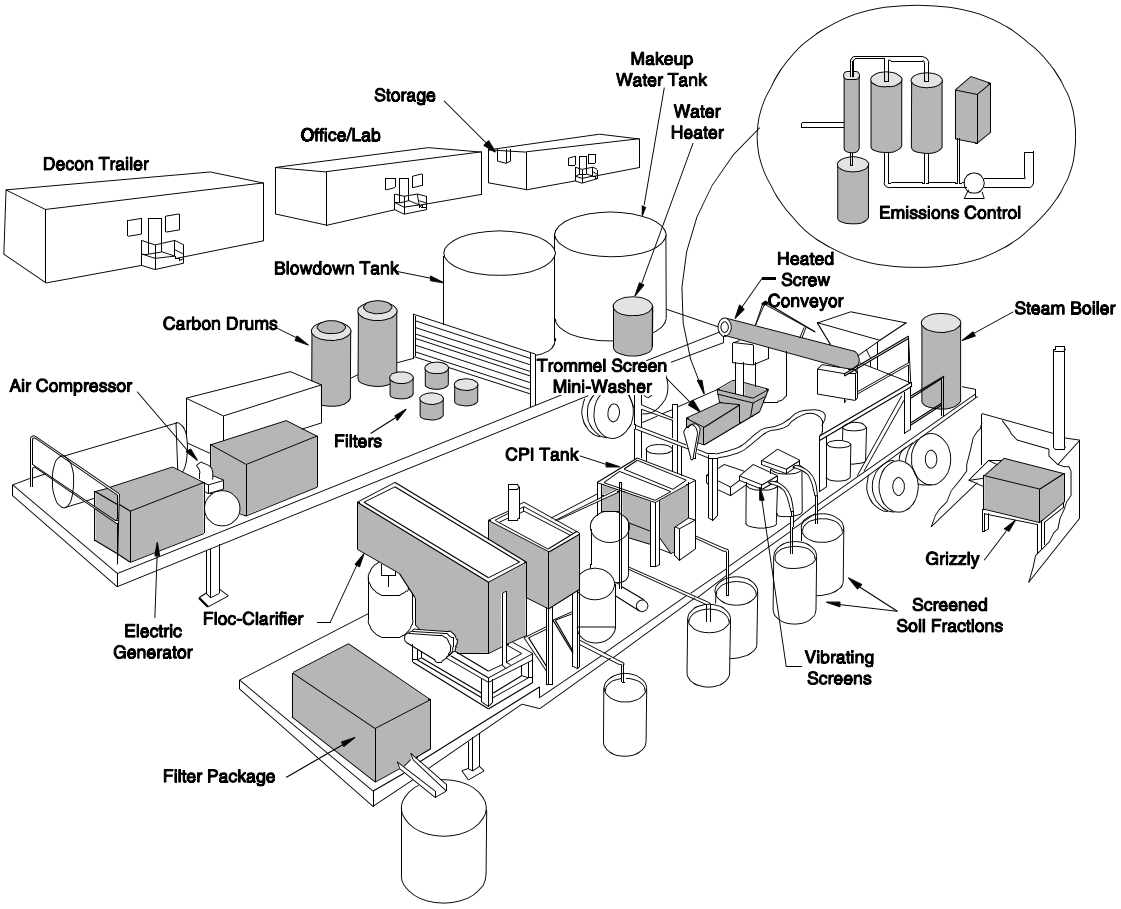
## TECHNOLOGY DESCRIPTION:

The volume reduction unit (VRU) is a pilot-scale, mobile soil washing system designed to remove organic contaminants and metals from soil through particle size separation and solubilization. The VRU can process 100 pounds of soil (dry weight) per hour.

The process subsystems consist of soil handling and conveying, soil washing and coarse screening, fine particle separation, flocculation-clarification, water treatment, and utilities. The VRU is controlled and monitored with conventional industrial process instrumentation and hardware.

## WASTE APPLICABILITY:

The VRU can treat soils that contain organics such as creosote, pentachlorophenol (PCP), pesticides, polynuclear aromatic hydrocarbons (PAH), volatile organic compounds, and semivolatile organic compounds. The VRU also removes metals.




Typical VRU Operational Setup



The SITE Program assesses but does not approve or endorse technologies.

## STATUS:

The VRU was accepted into the SITE Demonstration Program in summer 1992.
The demonstration was conducted in November 1992 at the former Escambia Treating Company in Pensacola, Florida. The facility used PCP and creosote PAHs to treat wood products from 1943 to 1982. The Applications Analysis Report (EPA/540/AR-93/508) is available from EPA.

## DEMONSTRATION RESULTS:

During the demonstration, the VRU operated at a feed rate of approximately 100 pounds per hour and a wash water-to-feed ratio of about six to one. The following physical wash water conditions were created by varying the surfactant, pH, and temperature:

- Condition 1 - no surfactant, no pH adjustment, no temperature adjustment
- Condition 2 - surfactant addition, no pH adjustment, no temperature adjustment
- Condition 3 - surfactant addition, pH adjustment, and temperature adjustment

The table below summarizes the analytical data.

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| | Condition (%) | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| Average PCP removal | 80 | 93 | 97 |
| Average PAH removal | 79 | 84 | 96 |
| Feed soil returned as washed soil | 96 | 96 | 81 |
| Mass balance of total mass | 104 | 113 | 98 |
| Mass balance of PCPs | 108 | 60 | 24 |
| Mass balance of PAHs | 87 | 60 | 17 |

Demonstration Data

# NEW YORK STATE DEPARTMENT OF ENVIRONMENTAL CONSERVATION/ENSR CONSULTING AND ENGINEERING and LARSEN ENGINEERS

**(Ex Situ Biovault)**

## TECHNOLOGY DESCRIPTION:

The Ex Situ Biovault, developed by ENSR Consulting and Engineering (ENSR) and Larsen Engineers (Larsen), is a specially designed, aboveground soil pile designed to treat soils contaminated with volatile organic compounds (VOC) and semivolatile organic compounds (SVOC). The biovault is enclosed by a double liner system; the bottom half of the liner contains a leak detection system. The bottom half of the liner is supported by soil berms that serve as side walls.

To construct a biopile, a layer of gravel containing an air distribution system is placed on the bottom liner. The soil to be treated is then placed over the gravel. After placing the soil, a layer of sand containing a second air distribution system is placed on top of the soil. Soaker hoses are also placed on top of the pile. Finally, the top liner is placed on the pile and sealed at all seams. The air distribution systems are designed to control gas flows throughout the pile while the soaker hoses add water and nutrients. A sump is located in the lowest corner of the biovault with a pump that removes the liquids that drain through the soil pile. This liquid is amended with nutrients as needed and recirculated through the soaker hoses. Together, the sump and soaker hoses form the liquid management system (LMS).

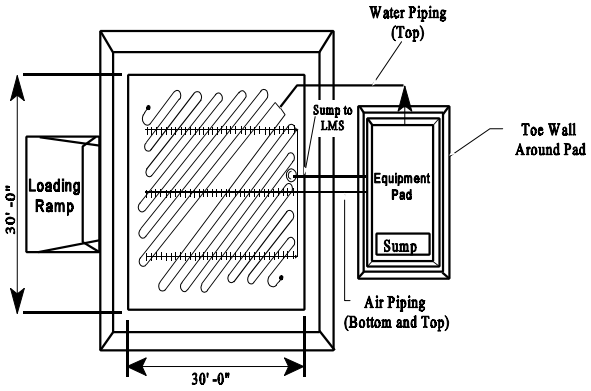
One of the control parameters for biovault operation is the rate of air supply. For the SITE demonstration, two identical vaults were constructed. One vault was operated with a continuous supply of air throughout the course of treatment. In the other biovault, air was supplied intermittently in an effort to cycle the biovault between aerobic and anaerobic conditions.

## WASTE APPLICABILITY:

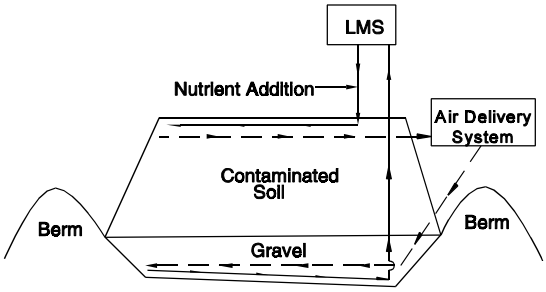
The ex situ biovault is intended to treat soil contaminated with chlorinated and nonchlorinated VOCs, as well as SVOCs. Soil contaminated with VOCs was treated during the demonstration.

## STATUS:

ENSR's and Larsen's ex situ biovault was accepted into the SITE Demonstration Program in June 1994. The pilot-scale, multivendor treatability demonstration (MVTD) was jointly sponsored by the New York State Department of




Schematic of the Ex Situ Biovault System




Cross Section of the Ex Situ Biovault System



The SITE Program assesses but does not approve or endorse technologies.

Environmental Conservation (NYSDEC), the New York State Center for Hazardous Waste Management, and the SITE Program. The objectives of the MVTD were to (1) generate field data for biological processes, and (2) evaluate the performance of each biological process in meeting NYSDEC clean-up goals.

The demonstration was conducted from July to December 1994 at the Sweden 3-Chapman site in Sweden, New York. The soil at the site was contaminated with elevated levels of acetone, trichloroethene, tetrachloroethene, cis-1,2-dichloroethene, 2-butanone, 4-methyl-2-pentanone, and toluene. The final report is available from the vendor.

In addition to the ENSR and Larsen process, the following systems also were demonstrated:

- SBP Technologies, Inc., Vacuum-Vaporized Well System
- R.E. Wright Environmental, Inc., In Situ Bioventing Treatment System

For information on these technologies, refer to the NYSDEC profiles in the Demonstration Program section (completed projects).

The Demonstration Bulletin (EPA/540/MR-95/524) is available from EPA. The Innovative Technology Evaluation Report, which provides more detailed demonstration results, will be available in 1999.

## DEMONSTRATION RESULTS:

The primary objective of the SITE demonstration was to determine the effectiveness of the biovaults in reducing the concentrations of six target VOCs. The results of the ex situ biovault technology demonstration were as follows:

- Soil concentrations of six target VOCs were significantly reduced over the 5-month demonstration period, but the treatment did not meet NYSDEC criteria.
- Analytical results and field measurements indicated that both biovaults supported biological processes.
- The aerobic and aerobic/anaerobic biovaults performed similarly.

The biovault process is sensitive to ambient temperatures, and cool temperatures during the operating period may have negatively impacted microbial activity. The developers suggest initiating biovault operation in the spring and discontinuing operation when weather conditions become too cold to sustain microbial activity.

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# NEW YORK STATE DEPARTMENT OF ENVIRONMENTAL CONSERVATION/R.E. WRIGHT ENVIRONMENTAL, INC.
## (In Situ Bioventing Treatment System)

## TECHNOLOGY DESCRIPTION:

The R.E. Wright Environmental, Inc. (REWEI), process uses bioventing technology to induce aerobic biological degradation of chlorinated compounds. A series of extraction and injection wells is used to amend the soil environment, creating optimum growth conditions for the indigenous bacteria. Anhydrous ammonia and methane are injected into the subsurface to stimulate the growth of methanotrophic microorganisms. Methanotrophs have the enzymatic capabilities to degrade chlorinated solvents through a cometabolic process.

The treatment system consists of an injection and extraction well field and a soil gas extraction-amendment injection blower unit (see photograph below). The blower unit is operated in the vacuum mode long enough to adequately aerate the subsoil and provide oxygen for the aerobic bacteria. Injection wells are located between the extraction wells and are manifolded to the pressure port of the blower unit. Anhydrous ammonia is periodically injected into the subsoil to provide a source of nitrogen for the aerobic bacteria. In addition, methane gas is periodically injected to stimulate the growth of methanotrophs. The positive displacement blower unit is equipped with a moisture knockout tank, an automatic water discharge pump, and a control panel that allows remote operation of the system. Air and water discharges are typically treated with granular activated carbon prior to final discharge.

Normal system monitoring consists of periodic soil sampling and analysis and soil gas monitoring. Soil samples are collected and analyzed for volatile organic compounds (VOC), soil fertility parameters, and microbiological parameters such as trichloroethene (TCE)

In Situ Bioventing Treatment System



The SITE Program assesses but does not approve or endorse technologies.

degraders and methanotrophs. In situ respiration tests are conducted to determine the relative activity of the bacteria in the soil.

## WASTE APPLICABILITY:

The technology can treat both chlorinated and nonchlorinated VOCs and semivolatile organic compounds that are biodegradable. The REWEI process was developed to treat volatile chlorinated aliphatic and aromatic hydrocarbons in the unsaturated soil zone.

## STATUS:

The REWEI process was accepted into the SITE Demonstration Program in June 1994. The REWEI process was part of a pilot-scale, multivendor treatability demonstration (MVTD) that was jointly sponsored by the New York State Department of Environmental Conservation (NYSDEC), the New York State Center for Hazardous Waste Management, and the SITE Program. The objectives of the MVTD were to (1) generate field data for three biological processes, and (2) evaluate the performance of each biological process in meeting NYSDEC cleanup goals.

The demonstration took place from July to December 1994 at the Sweden 3-Chapman site in Sweden, New York and coincided with the ongoing remediation of the site. Soil at the site contained elevated levels of TCE, acetone, tetrachloroethene, dichloroethene, and toluene. The Demonstration Bulletin (EPA/540/MR-95/525) is available from EPA. The Innovative Technology Evaluation Report, which provides more detailed demonstration results, will be available in 1997.

In addition to the REWEI process, the following technologies were also demonstrated:

- SBP Technologies, Inc., Vacuum-Vaporized Well system
- ENSR Consulting and Engineering and Larsen Engineers Ex Situ Biovault

For information on these technologies, refer to the NYSDEC profiles in the Demonstration Program section (completed projects).

## DEMONSTRATION RESULTS:

The SITE demonstration results indicated that the REWEI process reduced contaminants in the soil. The initial mass of TCE in the soil was reduced by 92 percent with 80 percent removal attributed to biodegradation and 12 percent removed by vapor extraction. Results of the microbiological analyses indicate that the number of total heterotrophic, TCE-degrading, and methane-degrading microorganisms increased during treatment. The inorganic soil nitrogen content increased due to the subsurface injection of anhydrous ammonia.

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# NEW YORK STATE DEPARTMENT OF ENVIRONMENTAL CONSERVATION/SBP TECHNOLOGIES, INC.
## (Vacuum-Vaporized Well System)

## TECHNOLOGY DESCRIPTION:

The SBP Technologies, Inc. (SBP), remediation program uses an in situ Unterdruck-Verdampfer-Brunnen (UVB) vertical groundwater circulation well technology, which has been enhanced with an in situ bioreactor to treat soil and groundwater contaminated with chlorinated and non-chlorinated volatile organic compounds (VOC). This process consists of a specially adapted groundwater circulation well, reduced-pressure stripping reactor, an in situ bioreactor, and an aboveground vapor-phase bioreactor.

The UVB technology was developed by IEG mbH in Germany and is distributed in the U.S. by IEG Technologies Corporation. SBP obtained the rights to implement this technology and enhanced it to create a more effective in situ bioremediation technology.

The microbiologically enhanced vertical circulation well technology simultaneously treats the vadose zone, capillary fringe, and saturated zones. During the demonstration, a groundwater convection (circulation) cell was created radially within the aquifer around the 16-inch UVB well. The UVB well consisted of upper and lower screens separated by a solid riser casing. The lower screen was isolated from the upper screen by a packer, creating two separate screened zones. Contaminated groundwater flowed into the lower screen of the UVB well and was pumped to the upper section. The water rose through the in situ fixed film bioreactor, initially reducing the contaminant load. Groundwater then flowed to the in situ aerator/stripping reactor, where fresh ambient air was mixed with the contaminated groundwater.

The convection cell was developed by allowing the treated groundwater to exit into the upper aquifer. The untreated VOCs exiting the in situ bioreactor system were stripped before the groundwater flowed out of the upper screen into the aquifer as clean water. Oxygenated groundwater from the shallow aquifer circulated to the deep aquifer zone and through the fixed film bioreactor to provide for aerobic degradation. This circulation created a remediation circulation cell in a glacial till geologic formation.

In conjunction with the groundwater remediation, the upper double-cased screen in the well allowed for a one-way soil air flow from the vadose zone to the UVB. This one-way soil venting, created by the reduced-pressure developed in the well by the blower, simultaneously remediated the contaminated unsaturated and capillary fringe zones.

The off-gases from the in situ aerator/stripping reactor passed through an ex situ gas-phase bioreactor for further biotreatment followed by granular activated carbon treatment before they were vented. This bioreactor consisted of spirally wound, microporous, polyvinyl chloride-silica sheets that served as a biosupport for *Pseudomonas cepacia* (strain 17616), a known trichloroethene (TCE) degrader. VOCs in the off-gases, such as toluene, benzene, xylene, TCE, and others, were also biologically treated through a cometabolic process in the gas-phase bioreactor.

## WASTE APPLICABILITY:

This technology treats soil and groundwater contaminated with chlorinated and nonchlorinated VOCs.

## STATUS:

The UVB system was accepted into the SITE Demonstration Program in June 1994. The pilot-scale, multivendor treatability demonstration (MVTD) was jointly sponsored by the New York State Department of Environmental Conservation



The SITE Program assesses but does not approve or endorse technologies.

(NYSDEC), the New York State Center for Hazardous Waste Management, and the SITE Program. The objectives of the MVTD were to (1) generate field data for three biological processes, and (2) evaluate the performance of each biological process in meeting NYSDEC cleanup goals.

The demonstration took place at the Sweden 3-Chapman site in Sweden, New York. Field work began in July 1994 and was completed in fall 1995. Final reports from the demonstration are available from EPA.

The UVB demonstration coincided with the remediation of the site. Soil at the site contained elevated levels of TCE, acetone, tetrachloroethene, dichloroethene, and toluene. The contaminants of concern (COC) were monitored at 15 groundwater monitoring wells, across the in situ bioreactor, the vadose zone soils, and the ex situ bioreactor, to evaluate the system's performance. A dye tracer test was conducted to determine the extent of the groundwater circulation cell.

In addition to the SBP process, the following technologies were also demonstrated:

- R.E. Wright Environmental, Inc., In Situ Bioventing Treatment System
- ENSR Consulting and Engineering and Larsen Engineers Ex Situ Biovault

For information on these technologies, refer to the NYSDEC profiles in the Demonstration Program section (completed projects).

## DEMONSTRATION RESULTS:

During the demonstration, an in situ vertical groundwater circulation cell was established with an effective radius of 40 feet. The UVB system reduced the concentration of COCs in groundwater. The in situ bioreactor provided biotreatment of the COCs in the dissolved phase; removal of COCs from soils was also demonstrated. An ex situ bioreactor was effective in treating off-gas vapors from the UVB system prior to final polishing. Mass balance calculations determined that at least 75 percent of the target COCs in soil and groundwater, within the UVB's radius of influence, were removed during the demonstration.

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# OHM REMEDIATION SERVICES CORP.
## (formerly CHEMICAL WASTE MANAGEMENT, INC.)
## (X*TRAX™ Thermal Desorption)

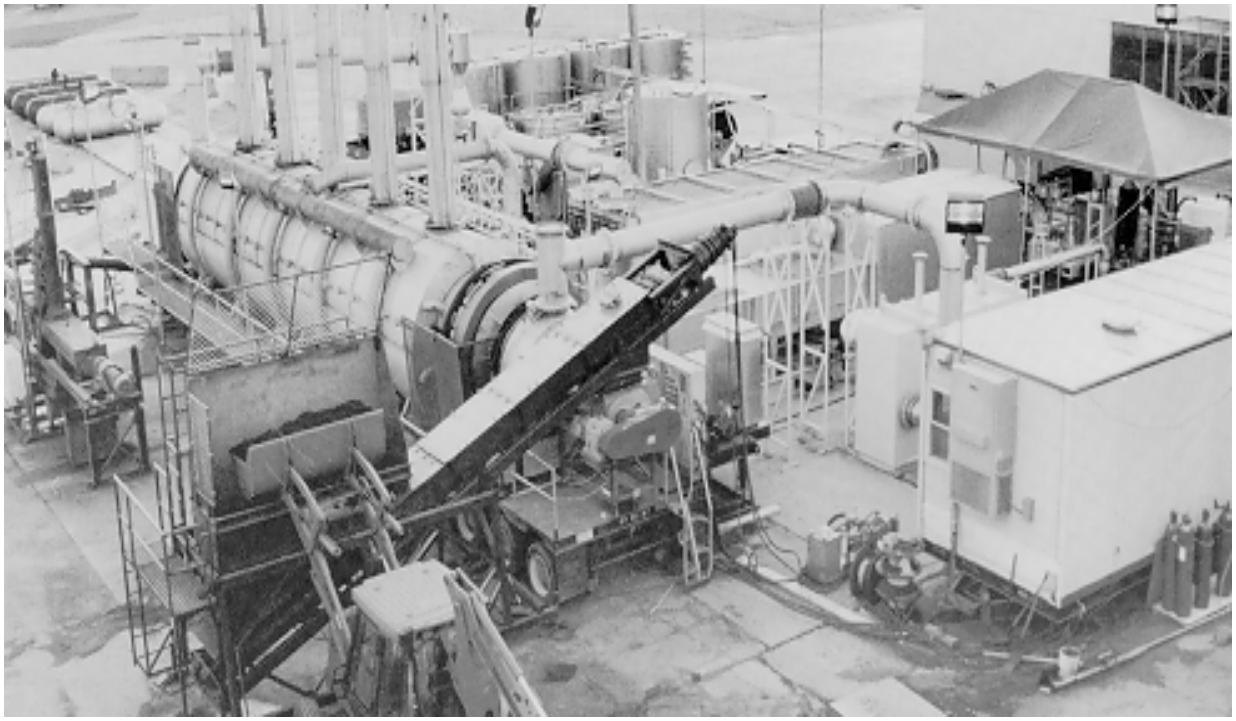
## TECHNOLOGY DESCRIPTION:

The X*TRAX™ technology is a patented thermal desorption process that removes organic contaminants from soils, sludges, and other solid media (see photograph below). X*TRAX™ is not, however, an incinerator or a pyrolysis system. Chemical oxidation and reactions are discouraged by maintaining an inert environment and low treatment temperatures. Combustion by-products are not formed in X*TRAX™, as neither a flame nor combustion gases are present in the desorption chamber.

The organic contaminants are removed as a condensed liquid, which is characterized by a high heat rating. This liquid may then be destroyed in a permitted incinerator or used as a supplemental fuel. Low operating temperatures of 400 to 1,200 $^{o}$F and low gas flow rates optimize treatment of contaminated media.

An externally fired rotary dryer volatilizes the water and organic contaminants from the contaminated media into an inert carrier gas stream. The inert nitrogen carrier gas transports the organic contaminants and water vapor out of the dryer. The carrier gas flows through a duct to the gas treatment system, where organic vapors, water vapors, and dust particles are removed and recovered. The gas first passes through a high-energy scrubber, which removes dust particles and 10 to 30 percent of the organic contaminants. The gas then passes through two condensers in series, where it is cooled to less than 40 $^{o}$F.

Most of the carrier gas is reheated and recycled to the dryer. About 5 to 10 percent of the gas is separated from the main stream, passed through a particulate filter and a carbon adsorption system, and then discharged to the atmosphere. This discharge allows addition of make-up nitrogen to the system to keep oxygen concentrations below 4 percent (typically below 1 percent). The discharge also helps maintain a small negative pressure within the system and prevents potentially contaminated gases from





The SITE Program assesses but does not approve or endorse technologies.

leaking. The volume of gas released from this process vent is approximately 700 times less than from an equivalent capacity incinerator.

## WASTE APPLICABILITY:

The X*TRAX™ process has been used to treat solids contaminated with the following wastes: polychlorinated biphenyls (PCB); halogenated and nonhalogenated solvents; semivolatile organic compounds, including polynuclear aromatic hydrocarbons, pesticides, and herbicides; fuel oils; benzene, toluene, ethylbenzene, and xylene; and mercury.

## STATUS:

This technology was accepted into the SITE Demonstration Program in 1989. The demonstration was conducted in May 1992 at the Re-Solve, Inc., Superfund site in Massachusetts. After the demonstration, the full-scale X*TRAX™ system, Model 200, remediated 50,000 tons of PCB-contaminated soil at the site. The Demonstration Bulletin (EPA/540/MR-93/502), which details results from the demonstration, is available from EPA.

The full-scale system, Model 200, is presently operating at the Sangamo-Weston Superfund site in South Carolina. More than 45,000 tons of PCB-contaminated soil, clay, and sludge have been thermally treated at this site. Feed material with PCB concentrations of more than 8,800 milligrams per kilogram (mg/kg) has been successfully treated to produce (discharge) PCB levels of less than 2 mg/kg. PCB removal efficiency was demonstrated to be greater than 99.97 percent.

Laboratory-, pilot-, and full-scale X*TRAX™ systems are available. Two laboratory-scale, continuous pilot systems are available for treatability studies. More than 108 tests have been completed since January 1988.

## DEMONSTRATION RESULTS:

During the SITE demonstration, X*TRAX™ removed PCBs from feed soil and met the site-specific treatment standard of 25 mg/kg for treated soils. PCB concentrations in all treated soil samples were less than 1.0 mg/kg and were reduced from an average of 247 mg/kg in feed soil to an average of 0.13 mg/kg in treated soil. The average PCB removal efficiency was 99.95 percent.

Polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans were not formed within the X*TRAX™ system. Organic air emissions from the X*TRAX™ process vent were negligible (less than 1 gram per day). PCBs were not detected in vent gases.

X*TRAX™ removed other organic contaminants from feed soil. Concentrations of tetrachloroethene, total recoverable petroleum hydrocarbons, and oil and grease were reduced to below detectable levels in treated soil. Metals concentrations and soil physical properties were not altered by the X*TRAX™ system.

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# PSI TECHNOLOGIES, A DIVISION OF PHYSICAL SCIENCES INC.

## (Metals Immobilization and Decontamination of Aggregate Solids)

## TECHNOLOGY DESCRIPTION:

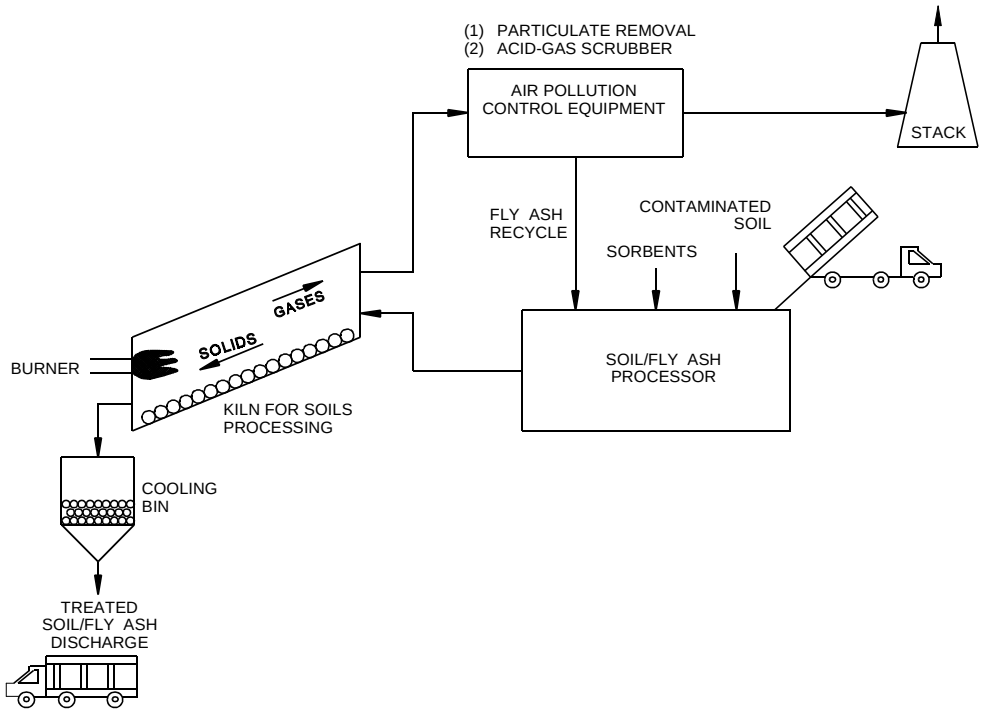
PSI Technologies has developed a technology for metals immobilization and decontamination of aggregate solids (MeIDAS) (see figure below). The technology involves a modified incineration process in which high temperatures destroy organic contaminants in soil and concentrate metals into fly ash. The bulk of the soil ends up as bottom ash and is rendered nonleachable. The fly ash is then treated with a sorbent to immobilize the metals, as determined by the toxicity characteristic leaching procedure. The MeIDAS process requires a sorbent fraction of less than 5 percent by soil weight.

Standard air pollution control devices clean the effluent gas stream. Hydrogen chloride and sulfur dioxide, which may be formed from the oxidation of chlorinated organics and sulfur compounds in the waste, are cleaned by alkaline scrubbers. Fly ash is captured by a particulate removal device, such as an electrostatic precipitator or baghouse. The only solid residues exiting the process are treated soils, which no longer contain organics and will not leach toxic metals.

## WASTE APPLICABILITY:

The MeIDAS process treats organics and heavy metals in soils, sediments and sludges. The process has been effective in treating arsenic, cadmium, chromium, lead, nickel, and zinc.

The MeIDAS process is applicable to wastes contaminated with a combination of volatile metals and complex organic mixtures of low volatility. Possible MeIDAS process applications include battery waste sites and urban sites




MeIDAS Process



The SITE Program assesses but does not approve or endorse technologies.

containing lead paint or leaded gasoline, or chemical or pesticide manufacturing facilities contaminated with organometallics.

## STATUS:

This technology was accepted into the SITE Emerging Technology Program in July 1991. Bench-scale testing under the SITE Program was completed in July 1992. The testing showed that organic, lead, and arsenic wastes could be successfully treated with less sorbent (1 to 10 percent of the soil by weight) than previously anticipated. Pilot-scale testing began in October 1992 and was completed in May 1993. The Emerging Technology Report has been submitted to EPA for review.

Initial testing, conducted under the EPA Small Business Innovative Research program, has demonstrated the feasibility of treating wastes containing arsenic, cadmium, lead, and zinc.

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# PULSE SCIENCES, INC.
## (X-Ray Treatment of Aqueous Solutions)

## TECHNOLOGY DESCRIPTION:

X-ray treatment of organically contaminated aqueous solutions is based on the in-depth deposition of ionizing radiation. X-rays collide with matter, generating a shower of lower energy secondary electrons within the contaminated waste material. The secondary electrons ionize and excite the atomic electrons, break up the complex contaminant molecules, and form highly reactive radicals. These radicals react with the volatile organic compounds (VOC) and semivolatile organic compounds (SVOC) to form nontoxic by-products such as water, carbon dioxide, and oxygen.

An efficient, high-power, high-energy, linear induction accelerator (LIA) plus X-ray converter generates the X-rays used in the treatment process. The LIA energy, which must be small enough to avoid nuclear activation and as large as possible to increase the bremsstrahlung conversion efficiency, will most likely be in the range of 8 to 10 million electron volts (MeV). A repetitive pulse of electrons 50 to 100 nanoseconds long is directed onto a cooled converter of a high atomic number metal to efficiently generate X-rays. The X-rays then penetrate the container and treat the waste materials contained within.

Based on coupled electron-photon Monte Carlo transport code calculations, the effective penetration depth of X-rays produced by converting 10-MeV electrons is 32 centimeters in water (after passing through the side of a standard 55-gallon drum). Large contaminant volumes can be easily treated without being absorbed a significant fraction of the ionizing radiation in the container walls. Either flowing waste or contaminated waste in stationary or rotating containers can be treated. No additives are required for the process, and in situ treatment is feasible. The cost of high throughput X-rayprocessing is estimated to be competitive with alternative processes that decompose the contaminants.

## WASTE APPLICABILITY:

X-ray processing can treat a large number of organic contaminants in aqueous solutions (such as groundwater, liquids, leachates, or wastewater) without expensive waste extraction or preparation. The technology has successfully treated 17 organic contaminants (see the table on the next page). No hazardous by-products are predicted to form or have been observed in the experiments.

## STATUS:

This technology was accepted into the SITE Emerging Technology Program in May 1991 and was evaluated in April 1994. A 1.2-MeV, 800-ampere, 55-nanosecond LIA gave a dose rate of 5 to 10 rads per second. Twelve different VOCs and SVOCs found in Superfund sites were irradiated in 21 aqueous matrices prepared with a neat solution of the contaminant in reagent grade water. The amount of X-ray dose (1 rad = $10^{-5}$ Joules per gram) required to decompose a particular contaminant was a function of its chemical bond structure and its reaction rate with the hydroxyl radical. When carbonate and bicarbonate ions (hydroxyl radical scavengers) were present in contaminated well water samples, approximately five times the X-ray dose was required to decompose contaminants that react strongly with the hydroxyl radical. The remediation rate of carbon tetrachloride, which does not react with hydroxyl radicals, was not affected.

An X-ray dose of 150 kilorads (krad) reduced the moderate contamination levels in a well water sample from a Superfund site at Lawrence Livermore National Laboratory (LLNL) to less than those set by the California Primary Drinking Water Standards. For a more highly contaminated LLNL well water sample, experimental data suggested a 500-krad dose was needed to reduce the contamination levels to drinking water standards.



The SITE Program assesses but does not approve or endorse technologies.

In principle, the rate coefficients determined from the data can be used to estimate the dose level required to destroy mixtures of multiple VOC contaminants and hydroxyl radical scavengers. However, these estimates should be applied judiciously. Only the experimentally determined destruction curves, based on the remediation of test samples of the actual mixture, can be used with confidence. The table below summarizes the X-ray treatment results from the SITE evaluation.

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| CONTAMINANT | MATRIX | INITIAL CONCENTRATION (ppb)* | FINAL CONCENTRATION (ppb) | CPDWS** (ppb) | X-RAY DOSE (krad) |
|---|---|---|---|---|---|
| TCE | Deionized Water | 9,780 | < 0.1 | 5 | 50.3 |
| PCE | | 10,500 | < 0.1 | 5 | 69.8 |
| Chloroform | | 2,000 | 4.4 | -- | 178 |
| Methylene Chloride | | 270 | 3.1 | 5 | 145.9 |
| Trans-1,2-Dichloroethene | | 260 | 0.78 | 10 | 10.6 |
| Cis-1,2-Dichloroethene | | 13 | < 0.5 | 6 | 10.6 |
| 1,1,1-Trichloroethane | | 590 | 54 | 200 | 207.1 |
| Carbon Tetrachloride ($CCl_4$) | | 180 | 14 | 0.5 | 224 |
| Benzene | | 240 | < 0.5 | 1 | 8.8 |
| Toluene | | 150 | < 0.5 | 150 | 4.83 |
| Ethylbenzene | | 890 | 3.6 | 680 | 20.4 |
| Xylene | | 240 | 1.2 | 1,750 | 5.6 |
| Benzene/$CCl_4$ | Contaminated Well Water | 262/400 | < 0.5/196 | 1/0.5 | 39.9/93.8 |
| Ethylbenzene/$CCl_4$ | | 1,000/430 | < 0.5/70.9 | 680/0.5 | 33.2/185 |
| Ortho-xylene/$CCl_4$ | | 221/430 | < 0.5/85 | 1,750/0.5 | 20.5/171 |
| TCE | LLNL Well Water Sample #1 | 3,400 | < 0.5 | 5 | 99.0 |
| PCE | | 500 | < 0.5 | 5 | 99.0 |
| 1,1-Dichloroethane | | < 10 | 1 | 5 | 145.4 |
| 1,1-Dichloroethene | | 25 | < 1 | 6 | 49.9 |
| 1,1,1-Trichloroethane | | 13 | 2.0 | 200 | 145.4 |
| Cis-1,2-Dichloroethene | | 14 | < 0.5 | 6 | 49.9 |
| TCE | LLNL Well Water Sample #2 | 5,000 | < 1.0 | 5 | 291 |
| PCE | | 490 | 1.6 | 5 | 291 |
| Chloroform | | 250 | 81 | -- | 291 |
| $CCl_4$ | | 14 | 4 | 0.5 | 291 |
| 1,2-Dichloroethane | | 38 | 17 | 5 | 291 |
| 1,1-Dichloroethane | | 11 | 6.8 | 5 | 291 |
| Freon | | 71 | 32 | -- | 291 |

* parts per billion
** California Primary Drinking Water Standards

Summary of X-ray Treatment Results

# RADIAN INTERNATIONAL LLC
## (formerly DOW ENVIRONMENTAL, INC.)
## (Integrated AquaDetox Steam Vacuum Stripping and Soil Vapor Extraction/Reinjection)

## TECHNOLOGY DESCRIPTION:

The integrated AquaDetox Steam Vacuum Stripping and soil vapor extraction/reinjection (SVE) system simultaneously treats groundwater and soil contaminated with volatile organic compounds (VOC). The integrated system consists of (1) an AquaDetox moderate vacuum stripping tower that uses low-pressure steam to treat contaminated groundwater, and (2) an SVE process that treats contaminated soil. The two processes form a closed-loop system that simultaneously remediates contaminated groundwater and soil in situ with virtually no air emissions.

AquaDetox is a high-efficiency, countercurrent stripping technology. A single-stage unit can remove up to 99.99 percent of VOCs in water. The SVE system uses a vacuum to treat VOC-contaminated soil, inducing a flow of air through the soil and removing vapor-phase VOCs with the extracted soil gas. Carbon beds remove the VOCs from the soil gas, which is then reinjected into the ground. The AquaDetox and SVE systems share a granular activated carbon (GAC) unit that decontaminates the combined vapors from both systems (see photograph below). By-products of the system are a free-phase recyclable product and treated water. In addition, mineral regenerable carbon requires disposal after about 3 years.

A key element of the closed-loop system is the vent header unit. This unit collects noncondensable gases from the AquaDetox system for treatment in the GAC units. The AquaDetox system then condenses and treats the steam used to regenerate the GAC units.

Integrated AquaDetox/SVE System



The SITE Program assesses but does not approve or endorse technologies.

## WASTE APPLICABILITY:

This technology removes VOCs, including chlorinated hydrocarbons, in groundwater and soil. Sites with contaminated groundwater and soils containing trichloroethene (TCE), tetrachloroethene (PCE), and other VOCs are suitable for this on-site treatment process.

## STATUS:

This technology was accepted into the SITE Demonstration Program in 1990. A SITE demonstration was conducted in September 1991 as part of an ongoing remediation at the San Fernando Valley Groundwater Basin Superfund site in Burbank, California. The Applications Analysis Report (EPA/540/A5-91/002) and Demonstration Bulletin (EPA/540/M5-91/002) are available from EPA.

The AquaDetox/SVE system had been used for over 3 years at the time of the SITE evaluation to treat groundwater and soil gas at the Lockheed Aeronautical Systems Company in Burbank, California. Contaminated groundwater was treated at a rate of up to 1,200 gallons per minute (gpm), while soil gas was removed and treated at a rate of 300 cubic feet per minute. The system occupied about 4,000 square feet. It was operational 95 percent of the time, with 5 percent downtime for scheduled and nonscheduled repairs.

## DEMONSTRATION RESULTS:

During the SITE demonstration, the AquaDetox/SVE system achieved the following results:

- The technology treated groundwater and soil gas contaminated with VOCs.
- Efficiencies ranged from 99.92 to 99.99 percent for removal of VOCs from contaminated groundwater. VOC removal efficiencies for soil gas ranged from 98.0 to 99.9 percent when the GAC beds were regenerated according to the specified frequency (8-hour shifts). VOC removal efficiencies dropped to as low as 93.4 percent when the GAC beds were regenerated less frequently.
- The technology produced effluent groundwater that complied with regulatory discharge requirements for TCE and PCE (5 micrograms per liter for each compound).
- The GAC beds removed VOCs from contaminated soil gas even after 24 hours of continuous operation without steam regeneration.
- The system's steam consumption dropped with decreasing tower pressures. During the demonstration, the system was more efficient at lower operating tower pressures.
- The 500-, 1,000-, and 3,000-gpm systems are estimated to cost about $3.2, $4.3, and $5.8 million, respectively. The total annual operation and maintenance costs are about $410,000, $630,000 and $1,500,000 for the 500-, 1,000-, and 3,000-gpm systems, respectively.

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# RECRA ENVIRONMENTAL, INC.
## (formerly ELECTRO-PURE SYSTEMS, INC.)
## (Alternating Current Electrocoagulation Technology)

## TECHNOLOGY DESCRIPTION:

The alternating current electrocoagulation (ACE) technology offers an alternative to the use of metal salts or polymers and polyelectrolyte addition for breaking stable emulsions and suspensions. The technology removes metals, colloidal solids and particles, and soluble inorganic pollutants from aqueous media by introducing highly charged polymeric aluminum hydroxide species. These species neutralize the electrostatic charges on suspended solids and oil droplets to facilitate agglomeration or coagulation and resultant separation from the aqueous phase. The treatment prompts the precipitation of certain metals and salts.

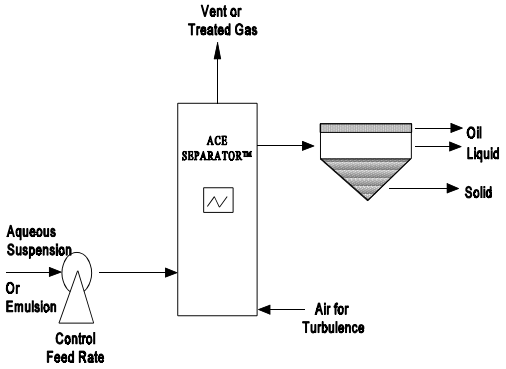
The figure below depicts the basic ACE process. Electrocoagulation occurs in either batch mode, allowing recirculation, or continuous (one-pass) mode in an ACE fluidized bed separator. Electrocoagulation is conducted by passing the aqueous medium through the treatment cells in upflow mode. The electrocoagulation cell(s) consist of nonconductive piping equipped with rectilinearly shaped, nonconsumable metal electrodes between which is maintained a turbulent, fluidized bed of aluminum alloy pellets.

Application of the alternating current electrical charge to the electrodes prompts the dissolution of the fluidized bed and the formation of the polymeric hydroxide species. Charge neutralization is initiated within the electrocoagulation cell(s) and continues following effluent discharge. Application of the electrical field prompts electrolysis of the water medium and generates minute quantities of hydrogen gas. The coagulated solids will often become entrained in the gas, causing their flotation.

Attrition scrubbing of the fluidized bed pellets within the cell inhibits the buildup of scale or coating on the aluminum pellets and the face of the electrodes. Coagulation and flocculation occur simultaneously within the ACE cells as the effluent is exposed to the electric field and the aluminum dissolves from the fluidized bed.

The working volume of the fluidized bed cell, excluding external plumbing, is 5 liters. The ACE systems have few moving parts and can easily be integrated into a process treatment train for effluent, pretreatment, or polishing treatment. The ACE technology has been designed into water treatment systems which include membrane separation, reverse osmosis, electrofiltration, sludge dewatering, and thermo-oxidation technologies.

System operating conditions depend on the chemistry of the aqueous medium, particularly the conductivity and chloride concentration. Treatment generally requires application of low voltage (<135 VAC) and operating currents of




Alternating Current Electrocoagulation (ACE)



The SITE Program assesses but does not approve or endorse technologies.

less than 20 amperes. The flow rate of the aqueous medium through the treatment cell(s) depends on the solution chemistry, the nature of the entrained suspension or emulsion, and the treatment objectives.

Product separation occurs in conventional gravity separation devices or filtering systems. Each phase is removed for reuse, recycling, additional treatment, or disposal.

Current systems are designed to treat waste streams of between 10 and 100 gallons per minute (gpm). RECRA Environmental, Inc., maintains a bench-scale unit (1 to 3 gpm) at its Amherst Laboratory for use in conducting treatability testing.

## WASTE APPLICABILITY:

The ACE technology treats aqueous-based suspensions and emulsions such as contaminated groundwater, surface water runoff, landfill and industrial leachate, wash and rinse waters, and various solutions and effluents. The suspensions can include solids such as inorganic and organic pigments, clays, metallic powders, metal ores, and colloidal materials. Treatable emulsions include a variety of solid and liquid contaminants, including petroleum-based by-products.

The ACE technology has demonstrated reductions of clay, latex, and various hydroxide loadings by over 90 percent. Chemical oxygen demand and total organic carbon content of spiked slurries have been reduced by over 80 percent. The technology has removed heavy metals at between 55 and 99 percent efficiency. Fluoride and phosphate have been removed at greater than 95 percent efficiency. The system has been used to recover fine-grained products which would otherwise have been discharged.

## STATUS:

The ACE technology was accepted into the SITE Emerging Technology Program in July 1988. The laboratory-scale testing was completed in June 1992. The Emerging Technology Bulletin (EPA/540/F-92/011) and Emerging Technology Summary (EPA/540/S-93/504) are available from EPA. The research results are described in the *Journal of Air and Waste Management*, Volume 43, May 1993, pp. 784-789, "Alternating Current Electrocoagulation for Superfund Site Remediation."

Experiments on metals and complex synthetic slurries have defined major operating parameters for broad classes of waste streams. The technology has been modified to minimize electrical power consumption and maximize effluent throughput rates.

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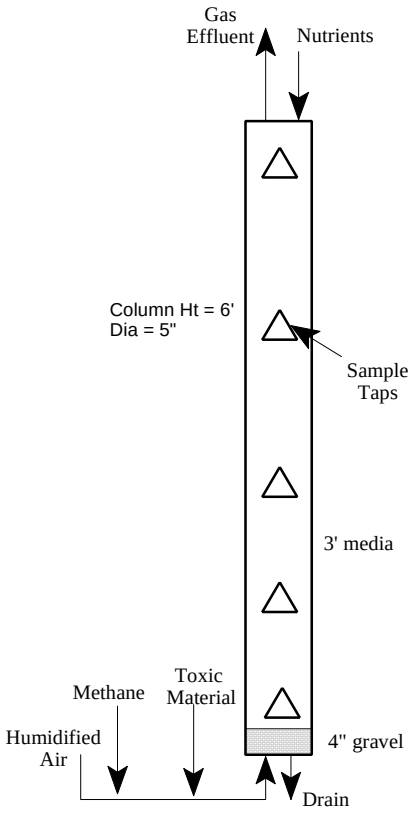
# REMEDIATION TECHNOLOGIES, INC.
## (Biofilm Reactor for Chlorinated Gas Treatment)

## TECHNOLOGY DESCRIPTION:

The Remediation Technologies, Inc., biological treatment technology uses aerobic cometabolic organisms in fixed-film biological reactors to treat gases contaminated with volatile chlorinated hydrocarbons. Contaminated gases enter the bottom of the 6-foot-tall reactor column and flow up through a medium that has a high surface area and favorable porosity for gas distribution. Both methanotrophic and phenol-degrading organisms have been evaluated within the reactor. The figure below illustrates a methanotrophic reactor.

In methanotrophic columns, methane and nutrients are added to grow the organisms capable of degrading volatile chlorinated hydrocarbons. The organisms degrade these compounds into acids and chlorides that can be subsequently degraded to carbon dioxide and chloride. Because of intermediate toxicity and competitive inhibition, methane-volatile organic compound (VOC) feeding strategies are critical to obtain optimum VOC degradation over the long term.

Methanotrophic bacteria from various soils were tested to determine potential VOC compound degradation. The optimal culture from this testing was isolated and transferred to a bench-scale biofilm reactor, where substrate degradation rates per unit of biofilm surface area were determined. Four pilot-scale biofilm reactors were then established, with feeding strategies and retention times based on earlier testing.




Methanotrophic Biofilm Reactor



The SITE Program assesses but does not approve or endorse technologies.

The following issues are investigated in the methanotrophic biofilm reactors:

- Comparison of different media types
- Trichloroethene (TCE) removal across the columns
- TCE degradation rates

In addition to studies of the methanotrophic biofilm reactors, a column was seeded with a filamentous phenol-degrading consortia that grows well on phenol in a nitrogen-limited solution. Phenol also induces enzymes capable of rapid cometabolic degradation of TCE.

## WASTE APPLICABILITY:

This technology can treat gaseous streams of volatile chlorinated hydrocarbons. These waste streams may result from air stripping of contaminated groundwater or industrial process streams, or from vacuum extraction during in situ site remediation.

## STATUS:

This technology was accepted into the SITE Emerging Technology Program in summer 1992; the evaluation was completed in 1995. The Emerging Technology Report, which details results from the evaluation, is being prepared.

TCE degradation rates in the pilot-scale biofilm reactor were well below those previously measured in laboratory testing or those reported in the literature for pure cultures. The phenol-fed column was started on a celite medium. TCE removal was superior to that in the methanotrophic columns, even with sub-optimal biomass development.

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# REMEDIATION TECHNOLOGIES, INC.
## (Liquid and Solids Biological Treatment)

## TECHNOLOGY DESCRIPTION:

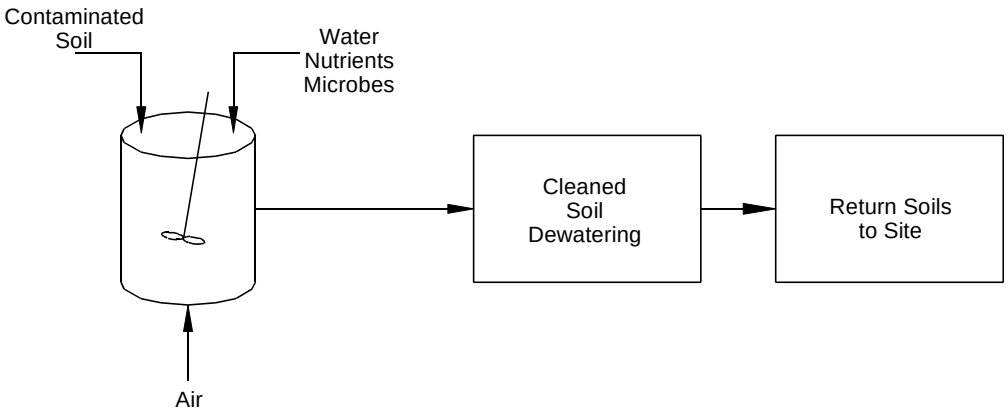
Liquid and solids biological treatment (LST) is a process that remediates soils and sludges contaminated with biodegradable organics (see figure below). The process is similar to activated sludge treatment of municipal and industrial wastewaters, but it treats suspended solids concentrations greater than 20 percent. First, an aqueous slurry of the waste material is prepared, and environmental conditions such as nutrient concentrations, temperature, and pH are optimized for biodegradation. The slurry is then mixed and aerated for a sufficient time to degrade the target waste constituents.

Several physical process configurations are possible, depending on site- and waste-specific conditions. Waste can be treated continuously or in batches in impoundment-based reactors. This configuration is sometimes the only practical option for projects greater than 10,000 cubic yards. Alternatively, tank-based systems may be constructed.Constituent losses due to volatilization must be controlled during LST operations. The potential for emissions is greatest in batch treatment systems and lowest in continuously stirred tank reactor systems, particularly those with long residence times. Technologies such as carbon adsorption and biofiltration can control emissions.

LST may require pre- and posttreatment operations. However, in situ applications that store treated sludge residues do not require multiple unit operations.

Overall bioremediation in a hybrid system consisting of LST and land treatment systems can provide an alternative to landfilling treated solids. This combination rapidly degrades volatile constituents in a contained system, rendering the waste suitable for landfilling.

Remediation Technologies, Inc. (ReTeC), has constructed a mobile LST pilot system for field demonstrations. The system consists of two reactors, two 2,000-gallon holding tanks, and




Liquid and Solids Biological Treatment



The SITE Program assesses but does not approve or endorse technologies.

associated process equipment. The reactors are aerated using coarse bubble diffusers and mixed using axial flow turbine mixers. The reactors can operate separately, or as batch or continuous systems. Oxygen and pH are continuously monitored and recorded. Additional features include antifoaming and temperature control systems.

## WASTE APPLICABILITY:

The technology treats sludges, sediments, and soils containing biodegradable organic materials. To date, the process has mainly treated sludges containing petroleum and wood preservative organics such as creosote and pentachlorophenol (PCP). LST has treated polynuclear aromatic hydrocarbons (PAH), PCP, and a broad range of petroleum hydrocarbons in the laboratory and the field.

## STATUS:

This technology was accepted into the SITE Demonstration Program in 1987. The technology was demonstrated under SITE at the Niagara Mohawk Power Corporation facility at Harbor Point in Utica, New York from June through August 1995. The following equipment was used for the demonstration: (1) a 10,000-gallon cylindrical tank (12-foot diameter) with bottom-mounted air diffusers that provided aeration and assisted in suspending solids; (2) a tank cover outfitted with exhaust piping that contained and channeled air discharge; and (3) a spray system that recircultated liquid from within the tank to disperse foam buildup.

ReTeC has applied the technology in the field over a dozen times to treat wood preservative sludges with impoundment-type LST systems. In addition, LST has treated petroleum refinery impoundment sludges in two field-based pilot demonstrations and several laboratory treatability studies.

## DEMONSTRATION RESULTS:

Analytical results from the SITE demonstration showed a reduction in oil and grease concentrations from 14,500 to 3,100 milligrams per kilogram (mg/kg), or 79 percent; total PAH concentrations were reduced from 137 to 51 mg/kg, or 63 percent; and total benzene, toluene, ethylbenzene, and xylene concentrations were reduced from 0.083 to 0.030 mg/kg, or 64 percent. PAH leachability in the solids was reduced to nondetect levels after treatment. Toxicity of the solids to earthworms was also decreased by the treatment. Only 24 percent of the earthworms survived when added to untreated contaminated soil, while earthworms placed in treated soil showed no toxic effects.

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# RESOURCE MANAGEMENT & RECOVERY
## (formerly BIO-RECOVERY SYSTEMS, INC.)
## (AlgaSORB© Biological Sorption)

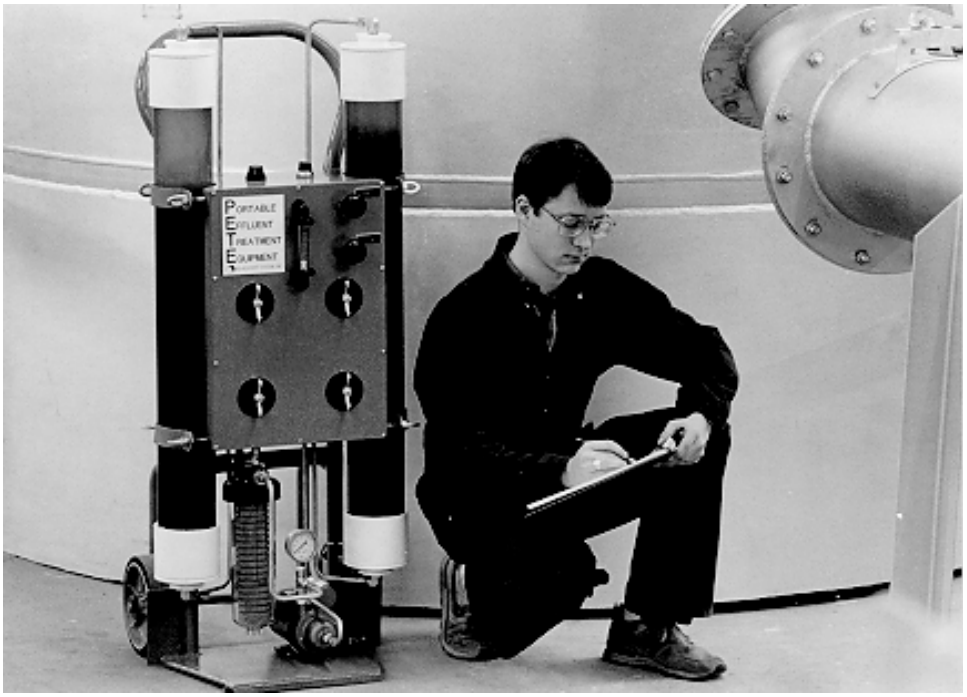
## TECHNOLOGY DESCRIPTION:

The AlgaSORB© sorption process uses algae to remove heavy metal ions from aqueous solutions. The process takes advantage of the natural affinity for heavy metal ions exhibited by algal cell structures.

The photograph below shows a portable effluent treatment equipment (PETE) unit, consisting of two columns operating either in series or in parallel. Each column contains 0.25 cubic foot of AlgaSORB©, the treatment medium. The PETE unit shown below can treat waste at a flow rate of approximately 1 gallon per minute (gpm). Larger systems have been designed and manufactured to treat waste at flow rates greater than 100 gpm.

The AlgaSORB© medium consists of dead algal cells immobilized in a silica gel polymer. This immobilization serves two purposes: (1) it protects the algal cells from decomposition by other microorganisms, and (2) it produces a hard material that can be packed into columns that, when pressurized, still exhibit good flow characteristics.

The AlgaSORB© medium functions as a biological ion-exchange resin to bind both metallic cations (positively charged ions, such as mercury [$Hg^{+2}$]) and metallic oxoanions (negatively charged, large, complex, oxygen-containing ions, such as selenate [$SeO_4^{-2}$]). Anions such as chlorides or sulfates are only weakly bound or not bound at all. In contrast to current ion-exchange technology, divalent cations




Portable Effluent Treatment Equipment (PETE) Unit



The SITE Program assesses but does not approve or endorse technologies.

typical of hard water, such as calcium ($Ca^{+2}$) and magnesium ($Mg^{+2}$), or monovalent cations, such as sodium ($Na^{+}$) and potassium ($K^{+}$) do not significantly interfere with the binding of toxic heavy metal ions to the algae-silica matrix.

Like ion-exchange resins, AlgaSORB© can be regenerated. After the AlgaSORB© medium is saturated, the metals are removed from the algae with acids, bases, or other suitable reagents. This regeneration process generates a small volume of solution containing highly concentrated metals. This solution must undergo treatment prior to disposal.

## WASTE APPLICABILITY:

This technology can remove heavy metal ions from groundwater or surface leachates that are "hard" or that contain high levels of dissolved solids. The process can also treat rinse waters from electroplating, metal finishing, and printed circuit board manufacturing operations. Metals removed by the technology include aluminum, cadmium, chromium, cobalt, copper, gold, iron, lead, manganese, mercury, molybdenum, nickel, platinum, selenium, silver, uranium, vanadium, and zinc.

## STATUS:

This technology was accepted into the Emerging Technology Program in 1988; the evaluation was completed in 1990. Under the Emerging Technology Program, the AlgaSORB© sorption process was tested on mercury-contaminated groundwater at a hazardous waste site in Oakland, California. Testing was designed to determine optimum flow rates, binding capacities, and the efficiency of stripping agents.

The Emerging Technology Report (EPA/540/5-90/005a&b), Emerging Technology Summary (EPA/540/S5-90/005), and Emerging Technology Bulletin (EPA/540/F-92/003) are available from EPA. An article was also published in the *Journal of Air and Waste Management*, Volume 41, No. 10, October 1991. Based on results from the Emerging Technology Program, Resource Management & Recovery was invited to participate in the SITE Demonstration Program.

The process is being commercialized for groundwater treatment and industrial point source treatment.

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# ROCHEM SEPARATION SYSTEMS, INC.
## (Rochem Disc Tube™ Module System)

## TECHNOLOGY DESCRIPTION:

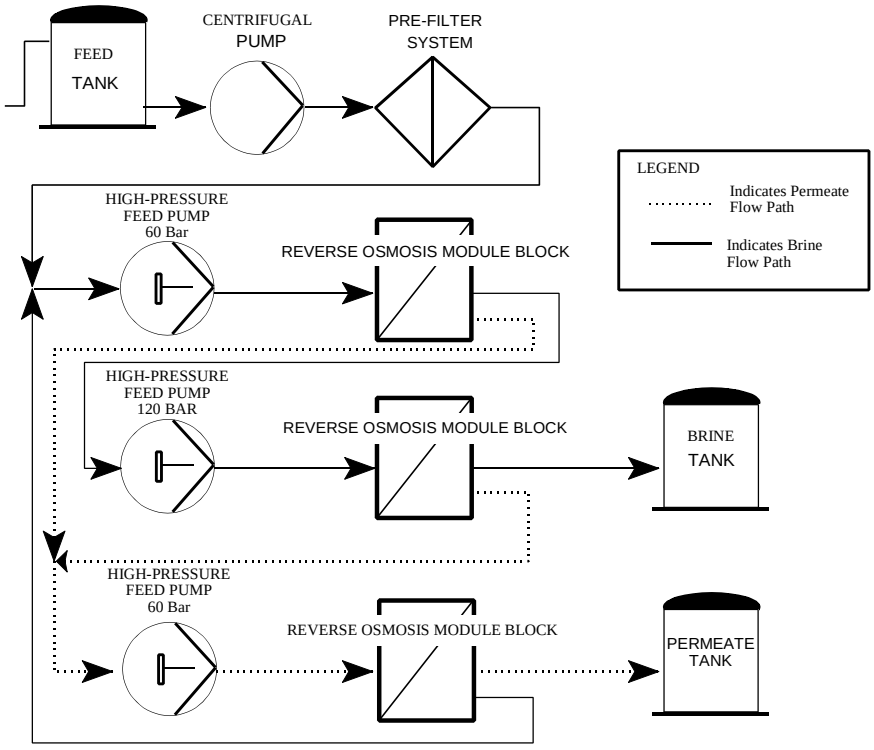
The Rochem Disc Tube™ Module System uses membrane separation to treat aqueous solutions ranging from seawater to leachate contaminated with organic solvents. The system uses osmosis through a semipermeable membrane to separate pure water from contaminated liquids.

Osmotic theory implies that a saline solution may be separated from pure water by a semipermeable membrane. The higher osmotic pressure of the salt solution causes the water (and other compounds having high diffusion rates through the selected membrane) to diffuse through the membrane into the salt water. Water will continue to permeate the salt solution until the osmotic pressure of the salt solution equals the osmotic pressure of the pure water. At this point, the salt concentrations of the two solutions are equal, eliminating any additional driving force for mass transfer across the membrane.

However, if external pressure is exerted on the salt solution, water will flow in the reverse direction from the salt solution into the pure water.

This phenomenon, known as reverse osmosis (RO), can separate pure water from contaminated matrices. RO can treat hazardous wastes by concentrating the hazardous chemical constituents in an aqueous brine, while recovering pure water on the other side of the membrane.

Fluid dynamics and system construction result in an open-channel, fully turbulent feed and water-flow system. This configuration prevents accumulation of suspended solids on the separation membranes, ensuring high efficiency filtration for water and contaminants. Also, the design of the disc tubes allows easy cleaning of the filtration medium, providing a long service life for the membranes.




Three-Stage, Reverse Osmosis Flow Path



The SITE Program assesses but does not approve or endorse technologies.

A general flow path for the Rochem Disc Tube™ Module System as applied at the SITE demonstration is shown on the previous page. Waste feed, process permeate, and rinse water are potential feed materials to the RO modules. The modules are skid-mounted and consist of a tank and a high-pressure feed system. The high-pressure feed system consists of a centrifugal feed pump, a prefilter cartridge housing, and a triplex plunger pump to feed the RO modules. The processing units are self-contained and require electrical and interconnection process piping before operation.

## WASTE APPLICABILITY:

Many types of waste material can be treated with this system, including sanitary and hazardous landfill leachate containing both organic and inorganic chemical species.

## STATUS:

This technology was accepted into the SITE Demonstration Program in July 1991. The demonstration was conducted in August 1994 at the Central Landfill Superfund site in Johnston, Rhode Island. The system was used to treat landfill leachate from a hazardous waste landfill. During the demonstration, approximately 4 gallons per minute of contaminated waste was processed over a 3-week period. All feed and residual effluent streams were sampled to evaluate the performance of this technology. The Innovative Technology Evaluation Report (EPA/540/R-96/507), the Technology Capsule (EPA/540/R-96/507a), and the Demonstration Bulletin (EPA/540/MR-96/507) are available from EPA.

## DEMONSTRATION RESULTS:

Preliminary results from the demonstration suggest the following:

- Over 99 percent of total dissolved solids, over 96 percent of total organic carbon, and 99 percent of all target metals were removed. In addition, the average percent rejection for volatile organic compounds was greater than the test criteria of 90 percent.
- The average water recovery rate for the Rochem Disc Tube™ Module System during the demonstration was approximately 75 percent. The test criterion was 75 percent treated water recovery rate.
- The Rochem Disc Tube™ Module System operated for 19 days at up to 8 hours per day. Daily operation hours were not as long as planned due to weather and field operational difficulties. However, the system operated long enough to evaluate the technology's performance.

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The SITE Program assesses but does not approve or endorse technologies.

# ROY F. WESTON, INC.
## (Ambersorb® 563 Adsorbent)

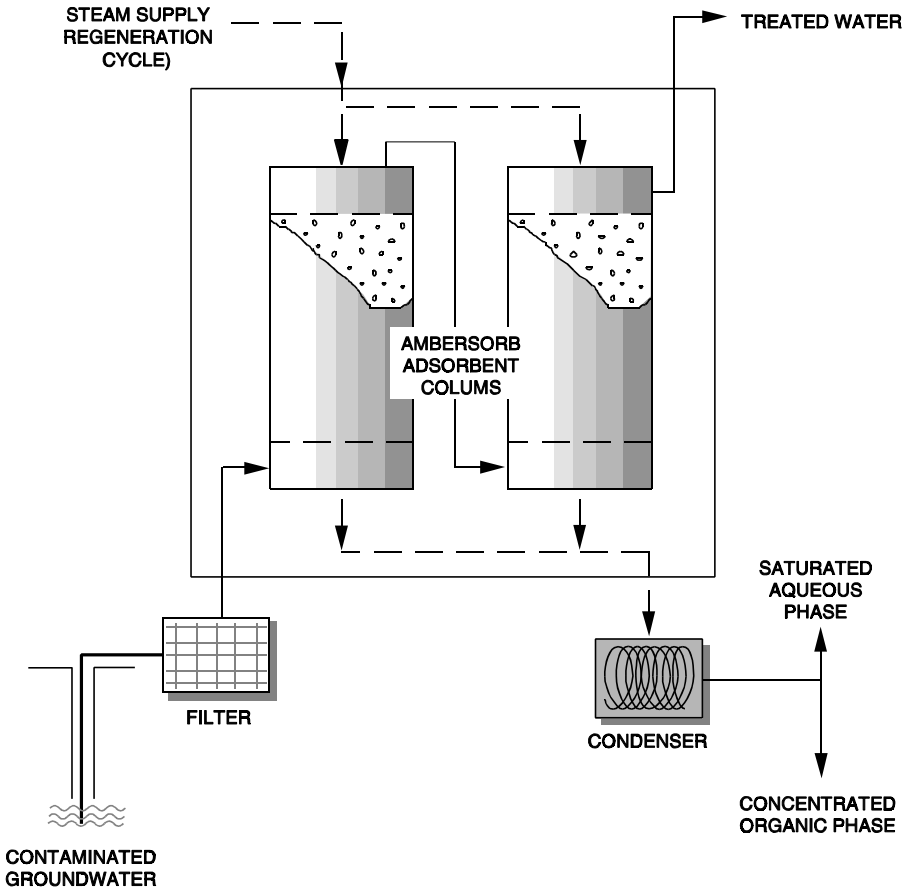
## TECHNOLOGY DESCRIPTION:

Ambersorb® 563 adsorbent is a regenerable adsorbent that treats groundwater contaminated with hazardous organics (see figure below). Ambersorb 563 adsorbent has 5 to 10 times the capacity of granular activated carbon (GAC) for low concentrations of volatile organic compounds (VOC).

Current GAC adsorption techniques require either disposal or thermal regeneration of the spent carbon. In these cases, the GAC must be removed from the site and shipped as a hazardous material to the disposal or regeneration facility.

Ambersorb 563 adsorbent has unique properties that provide the following benefits:

- Ambersorb 563 adsorbent can be regenerated on site using steam, thus eliminating the liability and cost of off-site regeneration or disposal associated with GAC treatment. Condensed contaminants are recovered through phase separation.
- Because Ambersorb 563 adsorbent has a much higher capacity than GAC for volatile organics (at low concentrations), the process can operate for significantly longer service cycle times before regeneration is required.




Ambersorb® 563 Adsorbent



The SITE Program assesses but does not approve or endorse technologies.

- Ambersorb 563 adsorbent can operate at higher flow rate loadings than GAC, which translates into a smaller, more compact system.
- Ambersorb 563 adsorbents are hard, nondusting, spherical beads with excellent physical integrity, eliminating handling problems and attrition losses typically associated with GAC.
- Ambersorb 563 adsorbent is not prone to bacterial fouling.
- Ambersorb 563 adsorbent has extremely low ash levels.

In addition, the Ambersorb 563 carbonaceous adsorbent-based remediation process can eliminate the need to dispose of by-products. Organics can be recovered in a form potentially suitable for immediate reuse. For example, removed organics could be burned for energy in a power plant.

## WASTE APPLICABILITY:

Ambersorb 563 adsorbent is applicable to any water stream containing contaminants that can be treated with GAC, such as 1,2-dichloroethane, 1,1,1-trichloroethane, tetrachloroethene, vinyl chloride, xylene, toluene, and other VOCs.

## STATUS:

This technology was accepted into the SITE Emerging Technology Program in 1993. The Emerging Technology Bulletin (EPA/540/F-95/500), the Emerging Technology Summary (EPA/540/SR-95/516), and the Emerging Technology Report (EPA/540/R-95/516) are available from EPA.

The Ambersorb 563 technology evaluation was conducted at the former Pease Air Force Base in Newington, New Hampshire. The groundwater contained vinyl chloride, 1,1-dichloroethene, and trichloroethene. The field study was conducted over a 12-week period. The tests included four service cycles and three steam regenerations. The effluent from the Ambersorb adsorbent system consistently met drinking water standards. On-site steam regeneration demonstrated that the adsorption capacity of the Ambersorb system remained essentially unchanged following regeneration.

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Note: Ambersorb® is a registered trademark of Rohm and Haas Company.

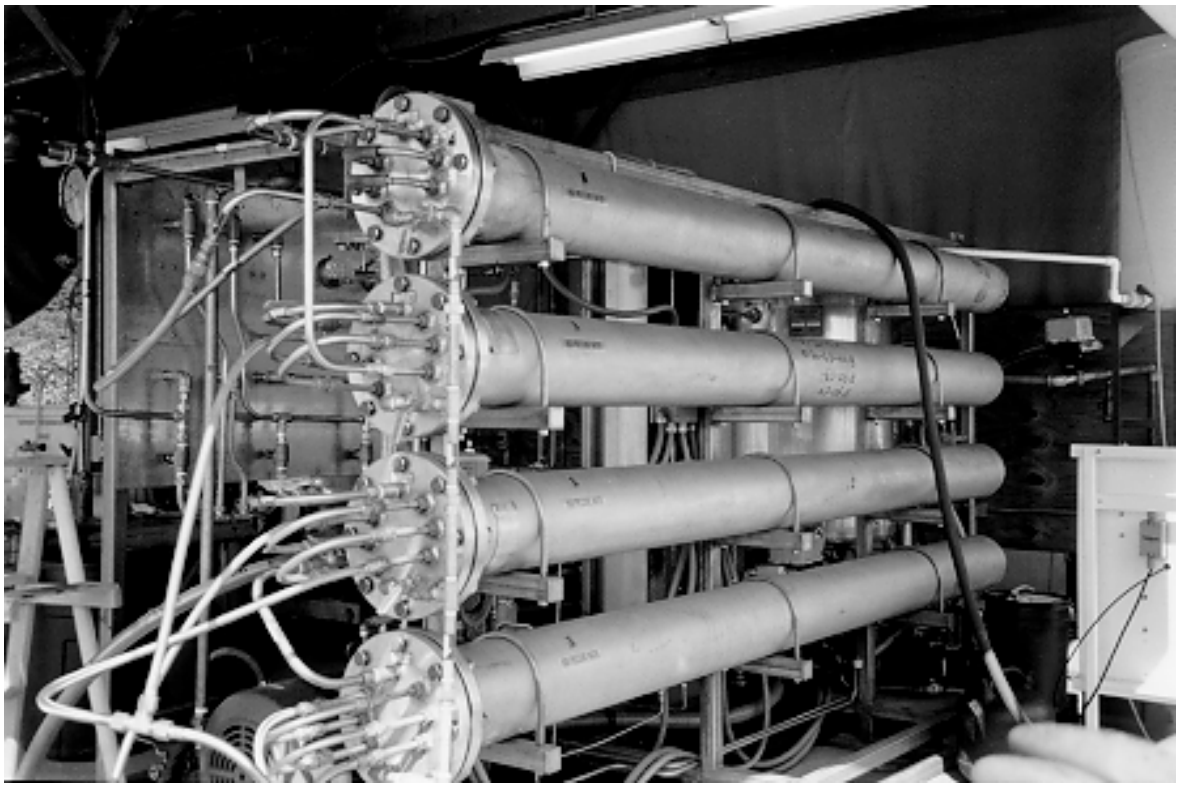
# SBP TECHNOLOGIES, INC.
## (Membrane Filtration and Bioremediation)

## TECHNOLOGY DESCRIPTION:

SBP Technologies, Inc. (SBP), has developed a hazardous waste treatment system consisting of (1) a membrane filtration system that extracts and concentrates contaminants from groundwater, surface water, wash water, or slurries; and (2) a bioremediation system that treats concentrated groundwater, wash water, and soil slurries (see photograph below). These two systems treat a wide range of waste materials separately or as parts of an integrated waste handling system.

The membrane filtration system removes and concentrates contaminants by pumping contaminated liquids through porous stainless steel tubes coated with specifically formulated membranes. Contaminants are collected inside the tube membrane, while "clean" water permeates the membrane and tubes. Depending on local requirements and regulations, the clean permeate can be discharged to the sanitary sewer for further treatment at a publicly owned treatment works (POTW). The concentrated contaminants are collected in a holding tank and fed to the bioremediation system.

Contaminated water or slurry can also flow directly into the bioremediation system and be polished in the membrane filtration system. The bioremediation system consists of one or more bioreactors that are inoculated with specially selected, usually indigenous microorganisms to produce effluent with low to nondetectable contaminant levels. Integrating the two systems allows removal and destruction of many contaminants.



Membrane Filtration and Bioremediation



The SITE Program assesses but does not approve or endorse technologies.

## WASTE APPLICABILITY:

The membrane filtration system concentrates contaminants and reduces the volume of contaminated materials from a number of waste streams, including contaminated groundwater, surface water, storm water, landfill leachates, and industrial process wastewater.

The bioremediation system can treat a wide range of organic contamination, especially wood-preserving wastes and solvents. A modified version can also treat polynuclear aromatic hydrocarbons (PAH) such as creosote and coal tar; pentachlorophenol; petroleum hydrocarbons; and chlorinated aliphatics, such as trichloroethene.

The two technologies can be used separately or combined, depending on site characteristics and waste treatment needs. For example, for waste-waters or slurries contaminated with inorganics or materials not easily bioremediated, the membrane filtration system can separate the material for treatment by another process. Both the membrane filtration system and the bioremediation system can be used as part of a soil cleaning system to handle residuals and contaminated liquids.

## STATUS:

The membrane filtration system, accepted into the SITE Program in 1990, was demonstrated in October 1991 at the American Creosote Works in Pensacola, Florida. The Demonstration Bulletin (EPA/540/MR-92/014) and Applications Analysis Report (EPA/540/AR-92/014) are available from EPA. A full-scale SITE Program demonstration of the bioremediation system was canceledHowever, a smaller-scale field study was conducted at the site; results are available through the developer.SBP is marketing its bioremediation and membrane filtration systems to industrial and governmental clients for on-site treatment of contaminated soil, sludge, and water.

## DEMONSTRATION RESULTS:

Results from the SITE demonstration are summarized as follows:

- The system effectively concentrated the PAHs into a smaller volume.
- The process removed 95 percent of the PAHs found in creosote from the feed and produced a permeate stream that was acceptable for discharge to a POTW.
- The membrane removed 25 to 35 percent of smaller phenolic compounds.
- The system removed an average of about 80 percent of the total concentrations of creosote constituents (phenolics and PAHs) in the feedwater and permeate.

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# SMITH ENVIRONMENTAL TECHNOLOGIES CORPORATION
## (formerly CANONIE ENVIRONMENTAL SERVICES CORPORATION)
## (Low Temperature Thermal Aeration [LTTA®])

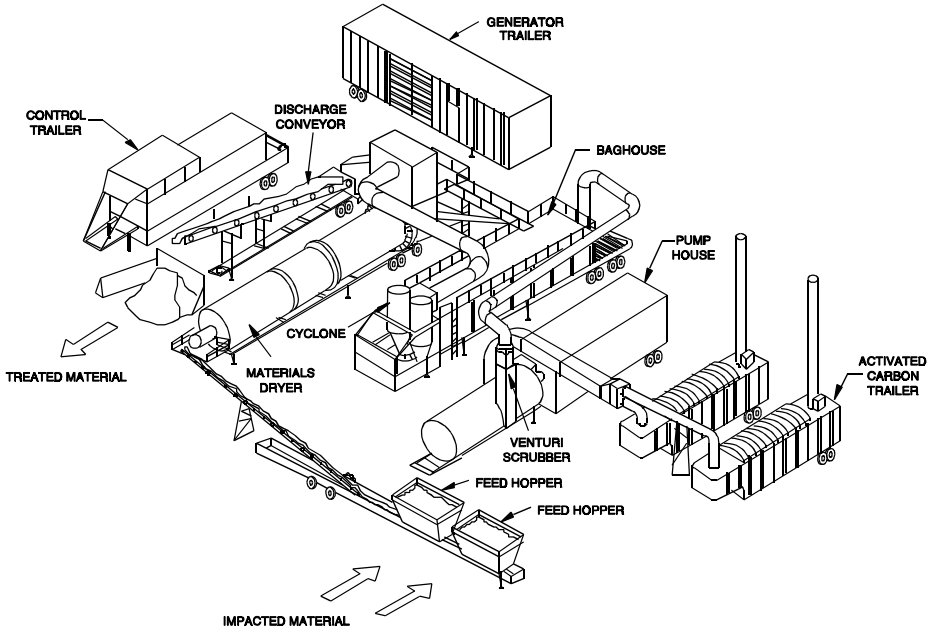
## TECHNOLOGY DESCRIPTION:

The Low Temperature Thermal Aeration (LTTA®) technology is a low-temperature desorption process (see figure below). The technology removes organic contaminants from contaminated soils into a contained air stream, which is extensively treated to collect or thermally destroy the contaminants.

A direct-fired rotary dryer heats an air stream which, by direct contact, desorbs water and organic contaminants from the soil. Soil can be heated to up to 800 °F. The processed soil is quenched to reduce temperatures and mitigate dust problems. The processed soil is then discharged into a stockpile. The hot air stream that contains vaporized water and organics is treated by one of two air pollution control systems. One system removes the organic contaminants from the air stream by adsorption on granular activated carbon (GAC) and includes the following units in series: (1) cyclones and baghouse for particulate removal; (2) wet scrubber for acid gas and some organic vapor removal; and (3) GAC adsorption beds for organic removal.

The second air pollution control system can treat soils containing high concentrations of petroleum hydrocarbons. The system includes the following units in series: (1) cyclones for particle removal; (2) thermal oxidizer-afterburner for destruction of organics; (3) quench tower for cooling of air stream; (4) baghouse for additional particle removal; and (5) wet scrubber for acid gas removal.

The LTTA® technology generates no wastewater or waste soils. Cyclone fines and baghouse dust are combined with treated soil and quenched with treated scrubber water. The treated soil, once verified to meet the treatment criteria, is backfilled on site without restrictions. GAC beds used for air pollution control are regenerated or incinerated when spent.




Low Temperature Thermal Aeration (LTTA®) Technology



The SITE Program assesses but does not approve or endorse technologies.

## WASTE APPLICABILITY:

LTTA® can remove volatile organic compounds (VOC), semivolatile organic compounds (SVOC), organochlorine pesticides (OCP), organophosphorus pesticides (OPP), and total petroleum hydrocarbons (TPH) from soils, sediments, and some sludges. LTTA® has been used at full scale to remove VOCs such as benzene, toluene, tetrachloroethene, trichloroethene, and dichloroethene; SVOCs such as acenaphthene, chrysene, naphthalene, and pyrene; OCPs such as DDT, DDT metabolites, and toxaphene; OPPs such as ethyl parathion, methyl parathion, merphos, and mevinphos; and TPHs.

## STATUS:

The LTTA® technology was accepted into the SITE Demonstration Program in summer 1992. LTTA® was demonstrated in September 1992 on soils contaminated with OCPs during a full-scale remediation at a pesticide site in Arizona. The Demonstration Bulletin (EPA/540/MR-93/504) and Applications Analysis Report (EPA/540/AR-93/504) are available from EPA.

The full-scale LTTA® system has remediated contaminated soils at six sites, including three Superfund sites. The system has treated more than 117,000 tons of soil.

## DEMONSTRATION RESULTS:

Key findings from the demonstration are summarized below:

- The LTTA® system achieved the specified cleanup criteria for the site, a sliding scale correlating the concentrations of DDT family compounds (DDT, DDE, and DDD) with concentrations of toxaphene. The maximum allowable pesticide concentrations in the treated soil were 3.52 milligrams per kilogram (mg/kg) of DDT family compounds and 1.09 mg/kg of toxaphene.
- Residual levels of all the pesticides in the treated soil were generally below or close to the laboratory detection limit, with the exception of 4,4'-DDE, which was found at residual concentrations of 0.1 to 1.5 mg/kg. Removal efficiencies for pesticides found in the feed soil at quantifiable concentrations are summarized below:

| Compound | Efficiency |
|---|---|
| 4,4'-DDD | >99.97% |
| 4,4'-DDE | 90.26% |
| 4,4'-DDT | 99.97% |
| Endrin | >99.85% |
| Toxaphene | >99.83% |

- The LTTA® process did not generate dioxins or furans as products of incomplete combustion or thermal transformation.

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# SOILTECH ATP SYSTEMS, INC.
## (Anaerobic Thermal Processor)

## TECHNOLOGY DESCRIPTION:

The SoilTech ATP Systems, Inc. (SoilTech), anaerobic thermal processor (ATP) uses a rotary kiln to desorb, collect, and recondense contaminants or recyclable hydrocarbons from a wide variety of feed material (see figure below).

The proprietary kiln contains four separate internal thermal zones: preheat, retort, combustion, and cooling. In the preheat zone, water and volatile organic compounds (VOC) are vaporized. The hot solids and heavy hydrocarbons then pass through a proprietary sand seal to the retort zone. The sand seal allows solids to pass and inhibits gas and contaminant movement from one zone to the other. Concurrently, hot treated soil from the combustion zone enters the retort zone through a second sand seal. This hot treated soil provides the thermal energy necessary to desorb the heavy organic contaminants. The vaporized contaminants are removed under slight vacuum to the gas handling system. After cyclones remove dust from the gases, the gases are cooled, and condensed oil and water are separated into their various fractions.

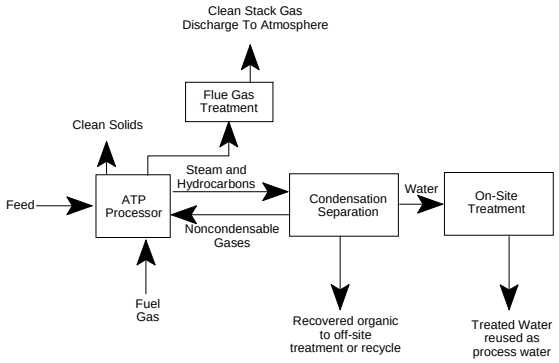
The coked soil passes through a third sand seal from the retort zone to the combustion zone. Some of the hot treated soil is recycled to the retort zone through the second sand seal as previously described. The remainder of the soil enters the cooling zone. As the hot combusted soil enters the cooling zone, it is cooled in the annular space between the outside of the preheat zone and the kiln shell. Here, the heat from the combusted soils is transferred indirectly to the soils in the preheat zone. The cooled, treated soil exiting the cooling zone is quenched with water and conveyed to a storage pile.

Flue gases from the combustion zone pass through the cooling zone to an emission control system. The system consists of a cyclone and baghouse to remove particulates, a wet scrubber to remove acid gases, and a carbon adsorption bed to remove trace organic compounds.

## WASTE APPLICABILITY:

The system treats soils, sediments, and sludges contaminated with compounds that vaporize at temperatures up to 1,100 °F. Treated solids are free of organics and suited for backfill on site. Applicable contaminants include the following:

- Petroleum hydrocarbons: fuel, oil, lube oil, semivolatile organic compounds (SVOC), VOCs
- Halogenated hydrocarbons: polychlorinated biphenyls (PCB), dioxins, furans, pesticides, herbicides




Anaerobic Thermal Processor (ATP)



The SITE Program assesses but does not approve or endorse technologies.

- Aromatic hydrocarbons: coal tar residues polynuclear aromatic hydrocarbons (PAH)
- Volatile metals: mercury

## STATUS:

This technology was accepted into the SITE Demonstration Program in 1991. The ATP has been demonstrated at two sites. At the first demonstration, in May 1991, a full-scale unit dechlorinated PCB-contaminated soil at the Wide Beach Development Superfund site in Brant, New York. At the second demonstration, completed in June 1992, a full-scale unit remediated soils and sediments at the Waukegan Harbor Superfund site in Waukegan, Illinois. Two additional Superfund sites in Ohio and Kentucky have since been remediated by the ATP. Soils at these sites were contaminated with PCBs, PAHs, and pesticides.

The ATP has been used to treat more than 100,000 tons of waste on four separate sites. The system has operated in compliance with state and federal regulations in New York, Illinois, Ohio, and Kentucky. SoilTech is currently negotiating with a confidential client to remediate 25,000 cubic yards of trichloroethene- (TCE) and PCB-contaminated soil at a site located in Pennsylvania.

SoilTech is continuing its research into more diverse organic remediation applications and bitumen recovery.

## DEMONSTRATION RESULTS:

Test results from both SITE demonstrations indicate the following:

- The SoilTech ATP removed over 99 percent of the PCBs in the contaminated soil, resulting in PCB levels below 0.1 part per million (ppm) at the Wide Beach Development site and averaging 2 ppm at the Waukegan Harbor site.
- Dioxin and furan stack gas emissions were below the site-specific standards.
- PCB stack gas emissions were equivalent to 99.99 percent destruction and removal efficiency at the Waukegan Harbor site.
- No volatile or semivolatile organic degradation products were detected in the treated soil. Also, no leachable metals, VOCs, or SVOCs were detected in the treated soil.
- For the Wide Beach Development and Waukegan Harbor remediation projects, soil treatment costs were approximately $265 and $155 per ton, respectively. The regulatory support, mobilization, startup, and demobilization costs totaled about $1,400,000 for each site.

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# SOLIDITECH, INC.
## (Solidification and Stabilization)

## TECHNOLOGY DESCRIPTION:

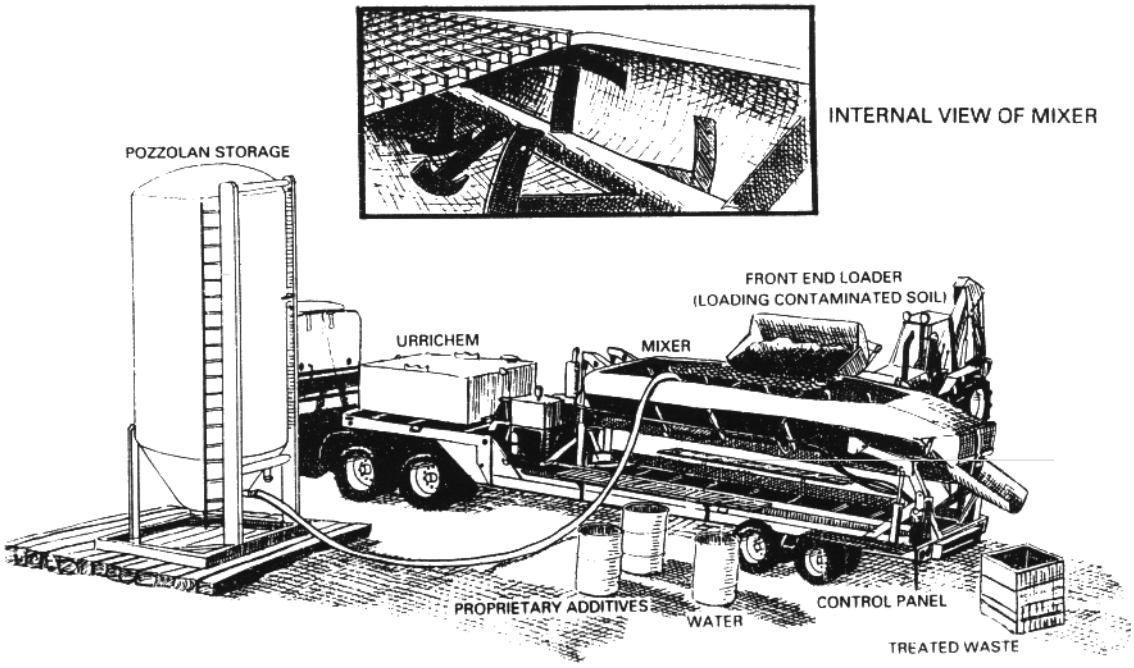
This solidification and stabilization process immobilizes contaminants in soils and sludges by binding them in a concrete-like, leach-resistant matrix. Contaminated waste materials are collected, screened to remove oversized material, and introduced to the batch mixer (see figure below). The waste material is then mixed with water; Urrichem, a proprietary chemical reagent; proprietary additives; and pozzolanic material (fly ash), kiln dust, or cement. After it is thoroughly mixed, the treated waste is discharged from the mixer. Treated waste is a solidified mass with significant unconfined compressive strength (UCS), high stability, and a rigid texture similar to that of concrete.

## WASTE APPLICABILITY:

This process treats soils and sludges contaminated with organic compounds, metals, inorganic compounds, and oil and grease. Batch mixers of various capacities can treat different volumes of waste.

## STATUS:

This technology was accepted into the SITE Demonstration Program in 1988. The solidification and stabilization process was demonstrated in December 1988 at the Imperial Oil Company/Champion Chemical Company Superfund site in Morganville, New Jersey. This site formerly contained both chemical processing




Soliditech Processing Equipment



The SITE Program assesses but does not approve or endorse technologies.

and oil reclamation facilities. Soils, filter cakes, and oily wastes from an old storage tank were treated during the demonstration. These wastes were contaminated with petroleum hydrocarbons, polychlorinated biphenyls (PCB), other organic chemicals, and heavy metals. The Technology Evaluation Report (EPA/540/5-89/005a), Applications Analysis Report (EPA/540/A5-89/005), and Demonstration Bulletin (EPA/540/M5-89/005) are available from EPA. This technology is no longer available through a vendor. Contact the EPA Project Manager for further information.

## DEMONSTRATION RESULTS:

Key findings from the Soliditech demonstration are summarized below:

- Extract and leachate analyses showed that heavy metals in the untreated waste were immobilized.
- The process solidified both solid and liquid wastes with high organic content (up to 17 percent), as well as oil and grease.
- Volatile organic compounds in the original waste were not detected in the treated waste.
- Physical test results of the solidified waste showed (1) UCS ranging from 390 to 860 pounds per square inch (psi); (2) very little weight loss after 12 cycles of wet and dry and freeze and thaw durability tests; (3) low permeability of the treated waste; and (4) increased density after treatment.
- The solidified waste increased in volume by an average of 22 percent. Because of solidification, the bulk density of the waste material increased by about 35 percent.
- Semivolatile organic compounds (phenols) were detected in the treated waste and the toxicity characteristic leaching procedure (TCLP) extracts from the treated waste, but not in the untreated waste or its TCLP extracts. The presence of these compounds is believed to result from chemical reactions in the waste treatment mixture.
- The oil and grease content of the untreated waste ranged from 2.8 to 17.3 percent (28,000 to 173,000 parts per million [ppm]). The oil and grease content of the TCLP extracts from the solidified waste ranged from 2.4 to 12 ppm.
- The pH of the solidified waste ranged from 11.7 to 12.0. The pH of the untreated waste ranged from 3.4 to 7.9.
- PCBs were not detected in any extracts or leachates from the treated waste.
- Visual observation of solidified waste revealed bulk oily material about 1 millimeter in diameter.

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# SOLUCORP INDUSTRIES
# (Molecular Bonding System)

**TECHNOLOGY DESCRIPTION:**

The Molecular Bonding System (MBS) is a process developed for the stabilization of a variety of media, such as soil, sludge, slag, and ash, that is contaminated with heavy metals. The process employs a proprietary mixture of nonhazardous chemicals to convert the heavy metal contaminants from their existing reactive and leachable forms (usually oxides) into insoluble, stable, nonhazardous, metallic-sulfide compounds that will achieve toxicity characteristic leaching procedure (TCLP) levels far below regulatory limits. The MBS process maintains the pH levels in the media within the range where the insolubility of the heavy metal sulfides is assured. The system also provides buffer capacity to ensure that the pH is not significantly altered by the addition of acids or caustics to the media.

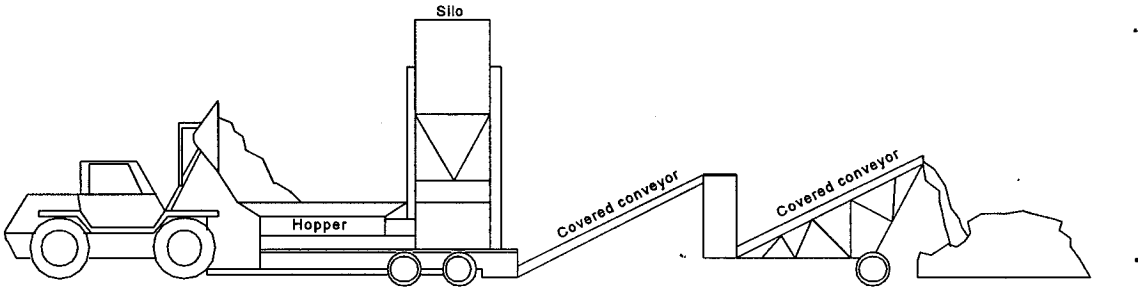
As depicted in the diagram below, the MBS treatment process is completely mobile and easily transportable (to allow for on-site treatment). Waste material is screened and crushed as required to reduce particle sizes to an average 1-inch diameter (particle size reduction increases surface area, which maximizes contact with the reagents). The waste media is then mixed with powdered reagents in a closed-hopper pug mill (the reagent mixture is established through treat ability studies for the site-specific conditions). Water is then added to catalyze the reaction and to ensure homogeneous mixing. There is no curing time and the resulting increase in volume is between 2 to 3 percent. The treated media is then conveyed to a stockpile where it can be either returned to the original site or disposed in a landfill as cover, fill, or contour material.

MBS can also be applied with traditional in situ mixing techniques such as tillers, eliminating the need for excavating and preparing the soil.

The MBS process can also be used to stabilize waste “in line” during the manufacturing process, preventing the waste from being classified as hazardous. Commercial applications on slag from a secondary smelter are underway.

**WASTE APPLICABILITY:**

The MBS process stabilizes heavy metals in soil, sludges, baghouse dust, ash, slag, and sediment. Heavy metals rendered inert by the process include arsenic, cadmium, chromium, copper, lead, mercury, nickel, silver, and zinc. The process can simultaneously stabilize multiple heavy metal contaminants. The presence of organics does not affect treatment by MBS.




Process Flow Diagram of the Molecular Bonding System

**STATUS:**

This technology was accepted into the SITE Demonstration Program in early 1995. A SITE demonstration was conducted at the Midvale Slag Superfund Site in Midvale, Utah in 1997. Three waste streams contaminated with As, Cd, and Pb were treated. Approximately 500 tons of each waste stream was treated. The treated wastes and souls passed EPA's Multiple Extraction Procedure. The MBS process has undergone extensive bench-scale and pilot-scale testing prior to its successful full-scale commercialization. The same reductions in the TCLP levels of hazardous contaminants achieved in the laboratory were achieved at five manufacturing site in five different states.

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# SONOTECH, INC.
## (Frequency-Tunable Pulse Combustion System)

## TECHNOLOGY DESCRIPTION:

The Sonotech, Inc., frequency-tunable pulse combustion system (Sonotech system) is designed to significantly improve batch- and continuous-mode combustion or thermal processes (such as incineration) by creating large-amplitude, resonant pulsations inside the combustion chamber. This technology can be applied to new or existing combustion systems. The technology is used in fossil fuel combustion devices, residential natural gas furnaces, and industrial combustion systems. It should prove similarly beneficial to hazardous waste incineration and soil remediation applications.

The Sonotech system (see photograph below) consists of an air inlet, a combustor section, a tailpipe, a control panel, and safety features. This system is designed to improve an incinerator's performance by (1) increasing mixing rates between the fuel and air, (2) increasing mixing rates between reactive gas pockets and ignition sources, and (3) increasing rates of heat and mass transfer between the gas and the burning waste. These improvements should (1) reduce the amount of excess air required to completely burn the waste, (2) increase destruction and removal efficiencies (DRE) of principal organic hazardous constituents, (3) minimize the formation of products of incomplete combustion, and (4) eliminate or minimize detrimental emissions or "puffs."

The Sonotech system has achieved sound amplitudes as high as 170 decibels and frequencies of 100 to 500 hertz within the combustion chamber. The high frequencies and

Frequency-Tunable Pulse Combustion System Installed at EPA's Research Facility



The SITE Program assesses but does not approve or endorse technologies.

velocities of these gas oscillations help mix the gases in the chamber and thus reduce or eliminate stratification effects.

The Sonotech system can function alone or as a supplemental retrofit to an existing combustion system. In the latter application, the frequency-tunable pulse combustion system can supply as little as 2 to 10 percent of the total energy requirements. The total fuel supplied to the main burner and the Sonotech system should be less than the amount of fuel supplied to the main burner before retrofitting.

## WASTE APPLICABILITY:

This technology can be used with any material that can be treated in a conventional incinerator. Sonotech, Inc., believes that the technology is ready for incineration of hazardous, municipal, and medical wastes.

## STATUS:

This technology was accepted into the SITE Demonstration Program in 1992. The 6-week demonstration evaluated whether the technology improved the performance of a larger scale incineration system. To meet this goal, the pilot-scale rotary kiln incinerator at EPA's Incineration Research Facility in Jefferson, Arkansas was retrofit with a Sonotech system. The demonstration took place from September to October 1994. The retrofit incinerator was used to treat coal- and oil-gasification wastes, traditionally incinerated with conventional technology. The Technology Capsule (EPA/540/R-95/502a) is available from EPA. More detailed results will be available from EPA in early 1997.

## DEMONSTRATION RESULTS:

The Sonotech system increased the incinerator waste feed rate capacity by 13 to 21 percent compared to conventional combustion. As the demonstration waste had significant heat content,the capacity increase was equivalent to a reduction in the auxiliary fuel needed to treat a unit mass of waste from 21,100 British thermal unit/pound (Btu/lb) for conventional combustion to 18,000 Btu/lb for the Sonotech system. Visual observations indicated improved mixing in the incinerator cavity with the Sonotech system operating.

Benzene and naphthalene DREs were greater than 99.99 percent. The average concentration of carbon monoxide exiting the afterburner, corrected to 7 percent oxygen, decreased from 20 parts per million (ppm) with conventional combustion to 14 ppm with the Sonotech system. The average concentration of nitrogen oxides exiting the after burner, corrected to 7 percent oxygen, decreased from 82 ppm with conventional combustion to 77 ppm with the Sonotech system. Average soot emissions exiting the afterburner, corrected to 7 percent oxygen, were reduced from 1.9 milligrams per dry standard cubic meter (mg/dscm) for conventional combustion to less than 1.0 mg/dscm with the Sonotech system. Total air requirements for system combustion, determined from stoichiometric calculations, were lower with the Sonotech system in operation.

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# STATE UNIVERSITY OF NEW YORK AT OSWEGO, ENVIRONMENTAL RESEARCH CENTER

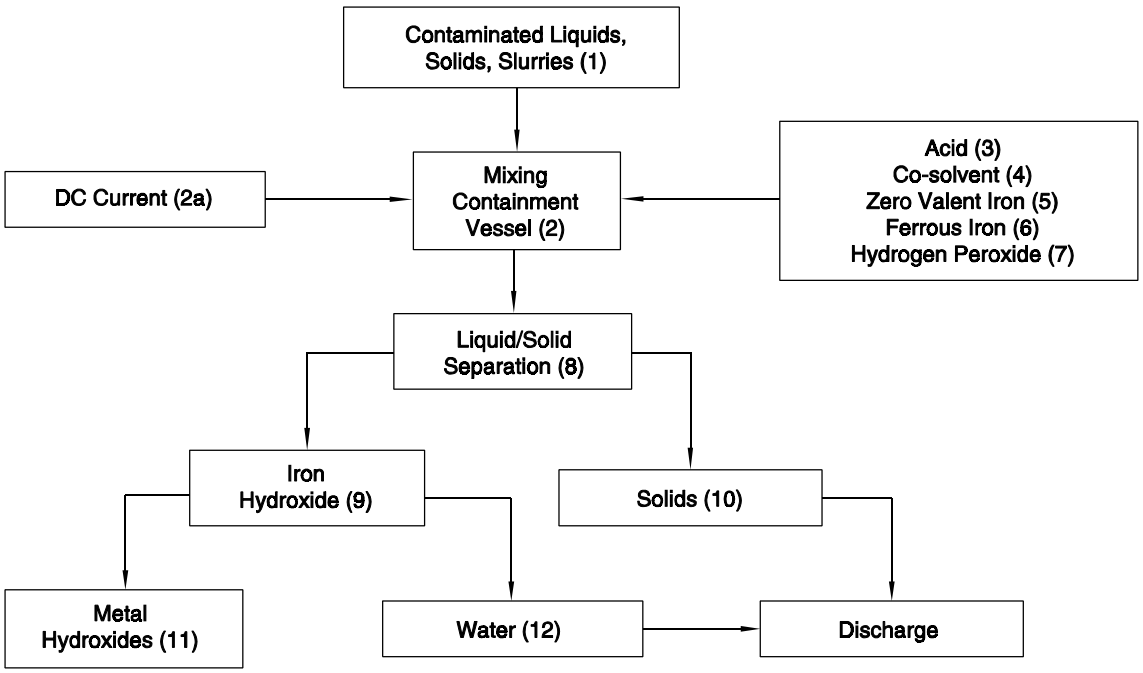
## (Electrochemical Peroxidation of PCB-Contaminated Sediments and Waters)

## TECHNOLOGY DESCRIPTION:

The Environmental Research Center at the State University of New York at Oswego (SUNY) has developed an electrochemical peroxidation process widely applicable for the treatment of liquid wastes and slurries with low solids content. The process treats mixed waste by using (1) oxidative free radicals to attack organic contaminants, and (2) adsorptive removal of metals from liquid waste streams. Initial testing indicates destructive efficiencies greater than 99 percent for a variety of compounds including polychlorinated biphenyls (PCB), volatile organic compounds, benzene, toluene, ethylbenzene, xylene, organic dyes, and microbes.

The process involves combining Fenton's reagent with a small electrical current. In a batch treatment process, steel electrodes are submersed into the waste to be treated; solid particles are suspended by mechanical mixing or stirring. A low direct current is applied to the electrodes, and hydrogen peroxide and a reduced form of iron are added. The iron and hydrogen peroxide instantaneously react to form free radicals, which oxidize organic contaminants. Free radicals are also produced by the reaction of the peroxide with solvated electrons. The process can be significantly enhanced by pH adjustment, periodic current reversal, and use of proprietary enhancements.

Metals readily adsorb to the iron hydroxide by-product, and the metals can then be separated by precipitation or flocculation. The volume of by-products may be reduced and the metals may be immobilized by heating and phase conversion to hematite. In specific applications, select metals may be plated onto electrodes and recovered.




Pilot-Scale Electrochemical Peroxidation System



The SITE Program assesses but does not approve or endorse technologies.

## WASTE APPLICABILITY:

This process is capable of treating liquids and slurries containing a variety of contaminants, including oxidizable organic compounds and metals. The process may be applied to industrial process wastes (textiles, pulp and paper, food industry), landfill leachates, gasoline- or solvent-contaminated groundwater, pesticide rinsates, or other liquid wastes.

## STATUS:

The technology was accepted into the SITE Emerging Technology Program in November 1993 to evaluate photochemical methods of destroying PCBs in water and sediment. The evaluation was complete in 1995. An Emerging Technology Report will be available in late 1996.

During research related to the initial SITE evaluation, which focused on photocatalytic processes, a new technology (electrochemical peroxidation) was discovered. Electrochemical peroxidation has distinct advantages over photochemical processes, and its development was pursued. A pilot-scale continuous flow treatment system has been constructed with a local remediation firm and will be tested at a gasoline-contaminated groundwater site in spring 1997. If initial tests are encouraging, in situ application of the process will be conducted.

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# STC REMEDIATION, INC.
## (formerly SILICATE TECHNOLOGY CORPORATION)
## (Organic Stabilization and Chemical Fixation/Solidification)

## TECHNOLOGY DESCRIPTION:

STC Remediation, Inc. (STC Remediation), has developed both chemical organic stabilization and chemical fixation/solidification technologies that treat inorganic and organic solid hazardous wastes (see photograph below). Leachable organic contaminant concentrations are reduced to well below regulatory limits. The chemical fixation/ solidification technology forms insoluble chemical compounds, reducing leachable inorganic contaminant concentrations in soils and sludges.

STC Remediation's technology has been successfully implemented on numerous full-scale hazardous waste remediation projects, successfully stabilizing more than 750,000 tons of hazardous soils, sediments, and sludges. These sites include Superfund sites and industrial sites across the United States and in Italy.

STC Remediation has evaluated various materials handling and mixing systems for use on full-scale remediation projects. Materials handling processes consist of pretreatment processes for screening and crushing contaminated soils, and placement and conveying systems for handling treated material. Mixing systems consist of various batching plants, pug mills, and high-shear batch mixing systems to properly meter and mix reagents with contaminated soils. STC Remediation provides complete treatability study services during project development and on site technical services and/or contracting services during full scale remediation to ensure effective

Treatment of Contaminated Soil



The SITE Program assesses but does not approve or endorse technologies.

application of the treatment technologies, documentation, and quality assurance/quality control procedures during the treatment process.

## WASTE APPLICABILITY:

STC Remediation's technology can treat a wide variety of hazardous soils, sludges, and wastewaters, including the following:

- Soils and sludges contaminated with inorganics, including most metals, cyanides, fluorides, arsenates, chromates, and selenium
- Soils and sludges contaminated with organics, including halogenated aromatics, polynuclear aromatic hydrocarbons, and aliphatic compounds
- Wastewaters contaminated with heavy metals and emulsified and dissolved organic compounds, excluding low-molecular-weight organic contaminants such as alcohols, ketones, and glycols

## STATUS:

This technology was accepted into the SITE Demonstration Program in 1988, and the demonstration was completed in November 1990 at the Selma Pressure Treating (SPT) Superfund site in Selma, California. STC Remediation was subsequently selected for the full-scale remediation of the SPT site, which is contaminated with organics, mainly pentachlorophenol (PCP), and inorganics, mainly arsenic, chromium, and copper. The Applications Analysis Report (EPA/540/AR-92/010) is available through the National Technology Information Service (Order No. PB93-172948). The Technology Evaluation Report (EPA/540/R-92/010) and Demonstration Bulletin (EPA/540/MR-92/010) are available from EPA.

## DEMONSTRATION RESULTS:

The SITE demonstration yielded the following results:

- The organic stabilization technology reduced total extractable PCP concentrations up to 97 percent. The chemical fixation/stabilization technology stabilized the residual PCP concentrations to very low leachable levels (from 5 to less than 0.3 milligrams per liter).
- STC Remediation's technology immobilized arsenic and copper, while chromium remained well within regulatory limits.
- Long-term monitoring at 18 and 32 months following the demonstration project provided comparable results for PCP, arsenic, and copper, while chromium remained well within regulatory limits.
- The treated wastes had moderately high unconfined compressive strength, averaging 300 pounds per square inch (psi) after 28 days, increasing to more than 700 psi after 18 months.
- Permeability of the treated waste was less than $1.7 \times 10^{-7}$ centimeters per second). The relative cumulative weight loss after 12 wet/dry and 12 freeze/thaw cycles was negligible (less than 1 percent).
- Treatment costs depend on specific waste characteristics.

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# SVEDALA INDUSTRIES, INC.
## (PYROKILN THERMAL ENCAPSULATION Process)

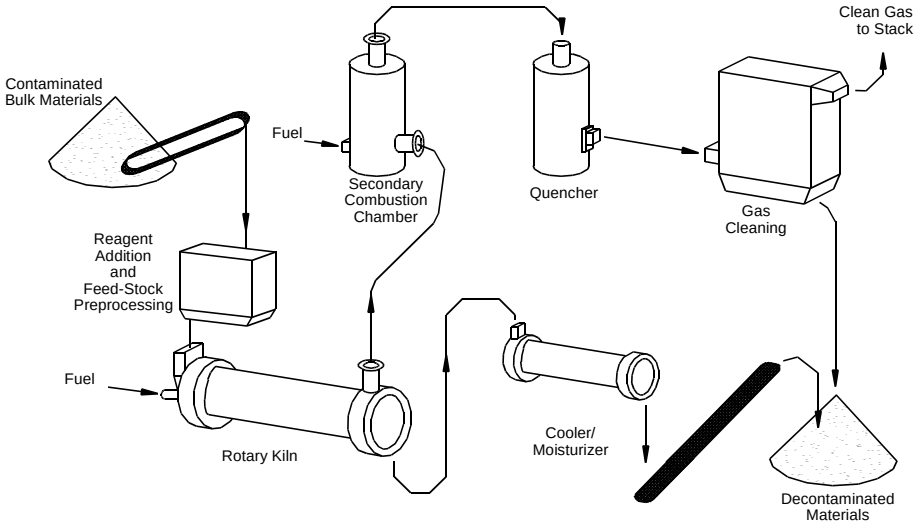
## TECHNOLOGY DESCRIPTION:

The PYROKILN THERMAL ENCAPSULATION process is designed to improve conventional rotary kiln incineration of hazardous waste. The process introduces inorganic additives (fluxing agents) with the waste to promote incipient slagging or thermal encapsulating reactions near the kiln discharge. The thermal encapsulation is augmented using other additives in either the kiln or in the air pollution control (APC) baghouse to stabilize the metals in the fly ash. The process is designed to (1) immobilize the metals remaining in the kiln ash, (2) produce an easily handled nodular form of ash, and (3) stabilize metals in the fly ash, while avoiding the problems normally experienced with higher temperature "slagging kiln" operations.

The basis of this process is thermal encapsulation. Thermal encapsulation traps metals in a controlled melting process operating in the temperature range between slagging and nonslagging modes, producing ash nodules that are 0.25- to 0.75-inch in diameter.

The figure below illustrates the process. Wastes containing organic and metallic contaminants are incinerated in a rotary kiln. Metals (in particular, those with high melting points) are trapped in the bottom ash from the kiln through the use of fluxing agents that promote agglomeration with controlled nodulizing.

The PYROKILN THERMAL ENCAPSULATION process may reduce leaching of metals to levels below EPA toxicity characteristic leaching procedure (TCLP) limits for metals. Metals with low melting and vaporization temperatures, such as arsenic, lead, and zinc, are expected to partially volatilize, partitioning between the bottom ash and the fly ash. Metals concentrated in the fly ash may be stabilized, if necessary, by adding reagents to the kiln and to the APC system to reduce leaching to




PYROKILN THERMAL ENCAPSULATION Process



The SITE Program assesses but does not approve or endorse technologies.

below TCLP limits. This process may also reduce the total dust load to the APC system and the amount of particulate emissions from the stack.

The use of fluxing reagents is a key element in this technology. The fluxing agents are introduced into the kiln in the proper amount and type to lower the ash's softening temperature. Proper kiln design is required to allow the kiln outlet to function as an ash agglomerator. Good temperature control is required to keep the agglomerates at the correct particle size, yielding the desired 0.25- to 0.75-inch nodules. By producing nodules, rather than a molten slag, the process is expected to prevent operating problems such as ash quenching, overheating, and premature refractory failure. The process should also simplify cooling, handling, and conveying of the ash.

The controlled nodulizing process should immobilize metals with high boiling points. Lead, zinc, and other metals with lower volatilization temperatures tend to exit the kiln as fine fumes. Reagents can be injected into the kiln, the APC devices, or a final solids mixer to aid in the collection of these metals from the gas stream.

## WASTE APPLICABILITY:

The technology is intended for soils and sludges contaminated with organics and metals. As with other rotary kiln systems, the process is expected to destroy a broad range of organic species, including halogenated and nonhalogenated organics and petroleum products. Svedala Industries, Inc., claims that metals that may be encapsulated or stabilized include antimony, arsenic, barium, beryllium, cadmium, chromium, copper, lead, nickel, selenium, silver, thallium, and zinc.

## STATUS:

This technology was accepted into the SITE Emerging Technology Program in March 1990.

A final report has been prepared, and a technical paper summarizing the project was presented in 1994 at the Air and Waste Management Association 87th Annual Meeting and Exhibition in Cincinnati, Ohio. The final report was published in the July 1995 issue of the *Journal of the Air and Waste Management Association.*

A synthetic soil matrix was created for the batch rotary kiln tests. Feed preparation was a key element in nodule production. These tests yielded nodules with appropriate crush strength. Test results showed a decrease in TCLP metal leachate levels with increasing crush strength.

An analytical method involving microwave-aided digestion was used to evaluate samples produced in a second batch kiln test program. This method provided excellent, consistent results, indicating leachability below TCLP limits.

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# TERRA-KLEEN RESPONSE GROUP, INC.
## (Solvent Extraction Treatment System)

## TECHNOLOGY DESCRIPTION:

Terra-Kleen Response Group, Inc. (Terra-Kleen), developed the solvent extraction treatment system to remove semivolatile and nonvolatile organic contaminants from soil. This batch process system uses a proprietary solvent blend to separate hazardous constituents from soils, sediments, sludge, and debris.

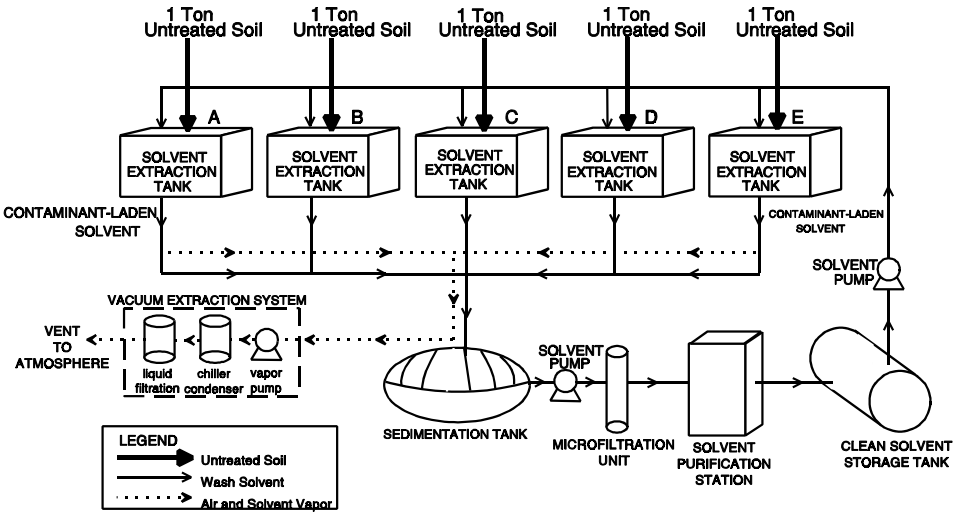
A flow diagram of the Terra-Kleen treatment system is shown below. Treatment begins after excavated soil is loaded into the solvent extraction tanks. Clean solvent from the solvent storage tank is pumped into the extraction tanks. The soil and solvent mixture is held in the extraction tanks long enough to solubilize organic contaminants into the solvent, separating them from the soil. The contaminant-laden solvent is then removed from the extraction tanks and pumped into the sedimentation tank. Suspended solids settle or are flocculated in the sedimentation tank, and are then removed.

Following solvent extraction of the organic contaminants, any residual solvent in the soil is removed using soil vapor extraction and biological treatment. Soil vapor extraction removes the majority of the residual solvent, while biological treatment reduces residual solvent to trace levels. The treated soils are then removed from the extraction tanks.

Contaminant-laden solvents are cleaned for reuse by Terra-Kleen's solvent regeneration process. The solvent regeneration process begins by pumping contaminant-laden solvent from the sedimentation tank through a microfiltration unit and a proprietary solvent purification station. The microfiltration unit first removes any fines remaining in the solvent. The solvent purification station separates organic contaminants from the solvent and concentrates them, reducing the amount of hazardous waste for off-site disposal. The solvent is pumped into the solvent storage tank for use in treating additional soil.

## WASTE APPLICABILITY:

The Terra-Kleen solvent extraction treatment system is a waste minimization process designed to remove the following organic contaminants from soils: polychlorinated biphenyls (PCB), chlorinated pesticides, polynuclear aromatic hydrocarbons (PAH), pentachlorophenol, creosote, polychlorinated dibenzo-p-dioxins (PCDD), chlorinated pesticides, and polychlorinated dibenzofurans (PCDF). The system is transportable and can be configured to treat small quantities of soil (1 to 1,000 cubic




Solvent Extraction Treatment System



The SITE Program assesses but does not approve or endorse technologies.

yards) as well as large volumes generated at remedial sites.

## STATUS:

The solvent extraction treatment system was demonstrated during May and June 1994 at Naval Air Station North Island (NASNI) Site 4 in San Diego, California. Soils at Site 4 are contaminated with heavy metals, volatile organic compounds (VOC), PCBs (Aroclor 1260), and furans. The Technology Capsule (EPA/540/R-94/521a) and Demonstration Bulletin (EPA/540/MR-94/521) are available from EPA. The Innovative Technology Evaluation Report is available from EPA.

Several full-scale solvent extraction units are in operation at this time. Terra-Kleen has removed PCBs from 10,000 tons of soil at three sites within NASNI, and completed cleanup of a remote Air Force Base PCB site in Alaska. A full-scale system has also removed DDT, DDD, and DDE from clay soil at the Naval Communication Station in Stockton, California.

Terra-Kleen has been selected to participate in the Rapid Commercialization Initiative (RCI). RCI was created by the Department of Commerce, Department of Defense, Department of Energy (DOE), and EPA to assist in the integration of innovative technologies into the marketplace. Under RCI, Terra-Kleen is expanding its capabilities to process PCBs and VOCs in low-level radioactive wastes. The pilot project for this effort will begin in early 1997 at DOE's Fernald Plant near Cincinnati, Ohio.

## DEMONSTRATION RESULTS:

Findings from the SITE demonstration are summarized as follows:

- PCB Aroclor 1260 concentrations were reduced from an average of 144 milligrams per kilogram (mg/kg) to less than 1.71 mg/kg, an overall removal efficiency of 98.8 percent.
- NASNI untreated soil contained a moisture content of 0.83 percent; a particle size distribution of 80 percent sand, 15 percent gravel, and 5 percent clay; and an overall oil and grease concentration of 780 mg/kg.
- Hexachlorodibenzofuran and pentachlorodibenzofuran concentrations were reduced by 92.7 percent and 84.0 percent, respectively. Oil and grease concentrations were reduced by 65.9 percent.

Additional data were collected at the Naval Communication Station in Stockton, California. The system treated soil contaminated with chlorinated pesticides at concentrations up to 600 mg/kg. Samples taken during system operation indicated that soil contaminated with DDD, DDE, and DDT was reduced below 1 mg/kg, an overall removal efficiency of 98.8 to 99.8 percent.

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# TERRA VAC
## (In Situ and Ex Situ Vacuum Extraction)

## TECHNOLOGY DESCRIPTION:

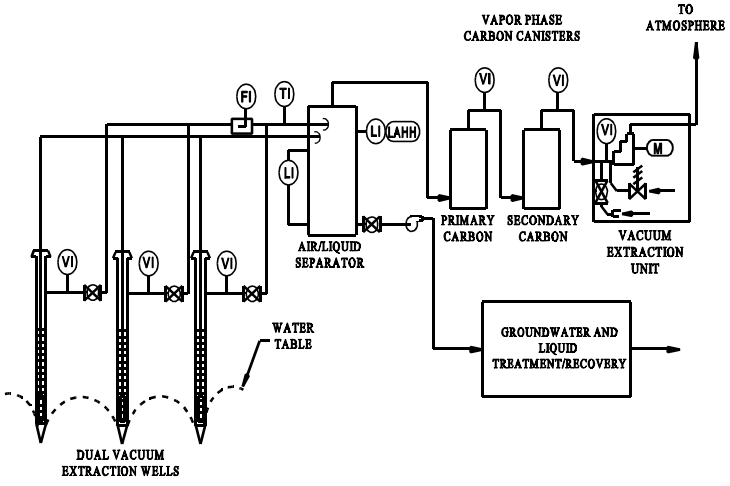
In situ or ex situ vacuum extraction is a process that removes volatile organic compounds (VOC) and many semivolatile organic compounds (SVOC) from the vadose, or unsaturated, soil zone. These compounds can often be removed from the vadose zone before they contaminate groundwater. Soil piles also may be cleaned by ex situ vacuum extraction. The in situ vacuum extraction process has been patented by others and licensed to Terra Vac and others in the United States.

The extraction process uses readily available equipment, including extraction and monitoring wells, manifold piping, air-liquid separators, and vacuum pumps. Vacuum extraction systems may vent directly to the atmosphere or through an emission control device. After the contaminated area is generally characterized, extraction wells are installed and connected by piping to the vacuum extraction and vapor treatment systems.

First, a vacuum pump creates a vacuum in the soil causing in situ volatilization and draws air through the subsurface. Contaminants are removed from the extraction wells and pass to the air-liquid separator. The vapor-phase contaminants may be treated with an activated carbon adsorption filter, a catalytic oxidizer, or another emission control system before the gases are discharged to the atmosphere. Subsurface vacuum and soil vapor concentrations are monitored with vadose zone monitoring wells.

The technology can be used in most hydrogeological settings and may reduce soil contaminant levels from saturated conditions to nondetectable. The process also works in fractured bedrock and less permeable soils (clays) with sufficient permeability. The process may be used to enhance bioremediation (bioventing). It also may be used in conjunction with dual vacuum extraction, soil heating, pneumatic fracturing, and chemical oxidation to recover a wide range of contaminants. The figure below illustrates one possible configuration of the process.

Typical contaminant recovery rates range from 20 to 2,500 pounds (10 to 1,000 kilograms) per day, depending on the degree of site contamination and the design of the vacuum extraction system.




In Situ Dual Vacuum Extraction Process



The SITE Program assesses but does not approve or endorse technologies.

## WASTE APPLICABILITY:

The vacuum extraction technology may treat soils containing virtually any VOC. It has removed over 40 types of chemicals from soils and groundwater, including solvents and gasoline- and diesel-range hydrocarbons.

## STATUS:

The process was accepted into the SITE Demonstration Program in 1987. The process was demonstrated under the SITE Demonstration Program at the Groveland Wells Superfund site in Groveland, Massachusetts, from December 1987 through April 1988. The technology remediated soils contaminated with trichloroethene (TCE). The Technology Evaluation Report (EPA/540/5-89/003a) and Applications Analysis Report (EPA/540/A5-89/003) are available from EPA.

The vacuum extraction process was first demonstrated at a Superfund site in Puerto Rico in 1984. Terra Vac has since applied the technology at more than 20 additional Superfund sites and at more than 700 other waste sites throughout the United States, Europe, and Japan.

## DEMONSTRATION RESULTS:

During the Groveland Wells SITE demonstration, four extraction wells pumped contaminants to the process system. During a 56-day period, 1,300 pounds of VOCs, mainly TCE, were extracted from both highly permeable strata and less permeable ($10^{-7}$ centimeters per second) clays. The vacuum extraction process achieved nondetectable VOC levels at some locations and reduced the VOC concentration in soil gas by 95 percent. Average reductions of soil concentrations during the demonstration program were 92 percent for sandy soils and 90 percent for clays. Field evaluations yielded the following conclusions:

- Permeability of soils is an important consideration when applying this technology.
- Pilot demonstrations are necessary at sites with complex geology or contaminant distributions.
- Treatment costs are typically $40 per ton of soil but can range from less than $10 to $80 per ton of soil, depending on the size of the site and the requirements for gas effluent or wastewater treatment.
- Contaminants should have a Henry's constant of 0.001 or higher.

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# TEXACO INC.
## (Texaco Gasification Process)

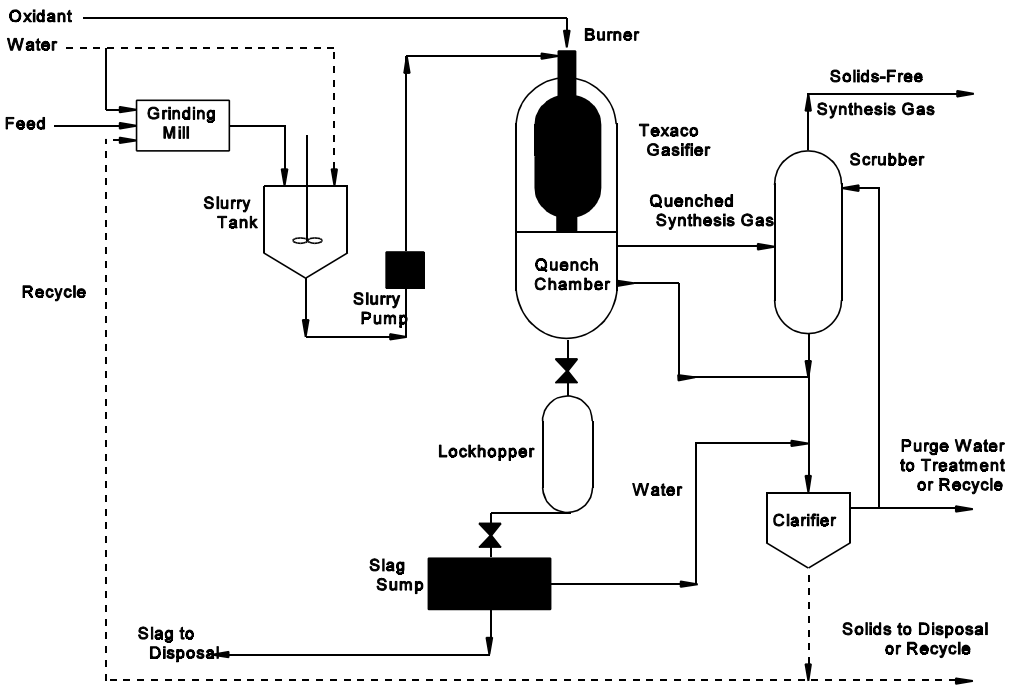
## TECHNOLOGY DESCRIPTION:

The Texaco Gasification Process (TGP) is an entrained-bed, noncatalytic, partial oxidation process in which carbonaceous substances react at elevated temperatures and pressures, producing a gas containing mainly carbon monoxide and hydrogen (see figure below). This product, called synthesis gas, can be used to produce other chemicals or can be burned as fuel. Inorganic materials in the feed melt are removed as a glass-like slag.

This technology has operated commercially for over 40 years with feedstocks such as natural gas, heavy oil, coal, and petroleum coke. The TGP processes waste feedstocks at pressures above 20 atmospheres and temperatures between 2,200 and 2,800 °F.

Slurried wastes are pumped to a specially designed injector mounted at the top of the refractory-lined gasifier. The waste feed, oxygen, and an auxiliary fuel such as coal react and flow downward through the gasifier to a quench chamber that collects the slag. The slag is eventually removed through a lockhopper. A scrubber further cools and cleans the synthesis gas. Fine particulate matter removed by the scrubber may be recycled to the gasifier; a sulfur recovery system may also be added.

After the TGP converts organic materials into synthesis gas, the cooled, water-scrubbed product gas, consisting mainly of hydrogen and carbon monoxide, essentially contains no hydrocarbons heavier than methane. Metals and other ash constituents become part of the glassy slag.




Texaco Gasification Process



The SITE Program assesses but does not approve or endorse technologies.

The TGP can be configured as a transportable system capable of processing about 100 tons of hazardous waste per day. This system would produce about 6 million standard cubic feet of usable synthesis gas per day with a heating value of approximately 250 British thermal units per standard cubic foot.

## WASTE APPLICABILITY:

The TGP can treat the following wastes:

- Contaminated soils, sludges, and sediments that contain both organic and inorganic constituents
- Chemical wastes
- Petroleum residues

Solids in the feed are ground and pumped in a slurry containing 40 to 70 percent solids by weight and 30 to 60 percent liquid, usually water.

Texaco has demonstrated gasification of coal liquefaction residues, petroleum production tank bottoms, municipal sewage sludge, and surrogate contaminated soil. Texaco is operating a gasification facility at its El Dorado, Kansas refinery that will convert up to 170 tons per day of petroleum coke and Resource Conservation and Recovery Act-listed refinery wastes into usable synthesis gas.

## STATUS:

The TGP was accepted into the SITE Demonstration Program in July 1991. A demonstration was conducted in January 1994 at Texaco's Montebello Research Laboratory in California using a mixture of clean soil, coal, and contaminated soil from the Purity Oil Sales Superfund site, located in Fresno, California. The mixture was slurried and spiked with lead, barium, and chlorobenzene. Forty tons of slurry was gasified during three demonstration runs. The Demonstration Bulletin (EPA/540/MR-95/514), Technology Capsule (EPA/540/R-94/514a), and Innovative Technology Evaluation Report (EPA/540/R-94/514) are available from EPA.

## DEMONSTRATION RESULTS:

Findings from the SITE demonstration are summarized below:

- The average composition of the dry synthesis gas product from the TGP consisted of 37 percent hydrogen, 36 percent carbon monoxide, and 21 percent carbon dioxide. The only remaining organic contaminant greater than 0.1 part per million (ppm) was methane at 55 ppm.
- The destruction and removal efficiency for the volatile organic spike (chlorobenzene) was greater than the 99.99 percent goal.
- Samples of the primary TGP solid product, coarse slag, averaged below the Toxicity Characteristic Leaching Procedure (TCLP) limits for lead (5 milligrams per liter [mg/L]) and barium (100 mg/L). Volatile heavy metals tended to partition to and concentrate in the secondary TGP solid products, fine slag and clarifier solids. These secondary products were above the TCLP limit for lead.

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# THERMATRIX, INC.
## (formerly PURUS, INC.)
## (Photolytic Oxidation Process)

## TECHNOLOGY DESCRIPTION:

The photolytic oxidation process indirectly destroys volatile organic compounds (VOC) in soil and groundwater. The process uses a xenon pulsed-plasma flash-lamp that emits short wavelength ultraviolet (UV) light at very high intensities. The process strips the contaminants into the vapor phase, and the UV treatment converts the VOCs into less hazardous compounds.

Photolysis occurs when contaminants absorb sufficient UV light energy, transforming electrons to higher energy states and breaking molecular bonds (see figure below). Hydroxyl radicals, however, are not formed. The process requires the UV light source to emit wavelengths in the regions absorbed by the contaminant. An innovative feature of this technology is its ability to shift the UV spectral output to optimize the photolysis.

The process uses vacuum extraction or air stripping to volatilize VOCs from soils or groundwater, respectively. VOCs then enter the photolysis reactor, where a xenon flashlamp generates UV light. The plasma is produced by pulse discharge of electrical energy across two electrodes in the lamp. Ninety-nine percent destruction occurs within seconds, allowing continuous operation. Because organics are destroyed in the vapor phase, the process uses less energy than a system treating dissolved organics.

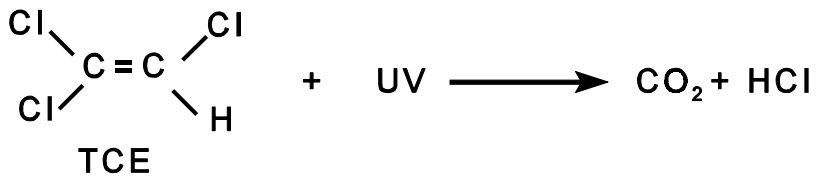
## WASTE APPLICABILITY:

The photolytic oxidation process is designed to destroy VOCs, including dichloroethene (DCE), tetrachloroethene (PCE), trichloroethene (TCE), and vinyl chloride volatilized from soil or groundwater. Destruction of other VOCs, such as benzene, carbon tetrachloride, and 1,1,1-trichloroethane, is under investigation.

## STATUS:

The photolytic oxidation process was accepted into the SITE Emerging Technology Program in March 1991. Field testing of a full-scale prototype began in October 1991. The test was conducted at the Lawrence Livermore National Laboratory Superfund site in California. The site contains soil zones highly contaminated with TCE.

During the field test, a vacuum extraction system delivered contaminated air to the unit at air flows up to 500 cubic feet per minute (cfm). Initial TCE concentrations in the air were approximately 250 parts per million by volume. The contaminant removal goal for the treatment was 99 percent. Vapor-phase carbon filters were placed downstream of the unit to satisfy California Air Quality emission control




UV Photolysis of TCE



The SITE Program assesses but does not approve or endorse technologies.

requirements during the field test. Test results are discussed below. The Final Report (EPA/540/R-93/516), the Summary Report (EPA/540/SR-93/516), and the Technology Bulletin (EPA/540/F-93/501) have been published.

The low-wavelength UV emissions allowed direct photolysis of many VOCs, particularly chlorinated compounds and freons, that would not have been possible with commercial mercury vapor lamps. TCE, PCE, and DCE were quickly destroyed. To be rapidly photolyzed, some VOCs require photosensitization or an even lower-wavelength light source.

TCE results are shown in the table below. TCE removal yielded undesirable intermediates. Greater than 85 percent of the TCE chain photo-oxidation product is dichloroacetyl chloride (DCAC). Further oxidation of DCAC is about 100 times slower than TCE photolysis and forms dichlorocarbonyl (DCC) at about 20 percent yield. At this treatment level, the DCC concentration may be excessive, requiring additional treatment.

Further studies should focus on (1) the effectiveness of dry or wet scrubbers for removing acidic photo-oxidation products, (2) development of thermal or other methods for posttreatment of products such as DCAC, and (3) the use of shorter-wavelength UV lamps or catalysts to treat a broader range of VOCs.

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### TCE PHOTOLYSIS FIELD TEST RESULTS

| Freq. (Hz) | No. of Chambers | Flow (cfm) | Res. Time (sec) | TCE Input (ppmv) | TCE Output (ppmv) | TCE Destruction (%) | DCC Yield (ppmv) | DCAC Yield (ppmv) | Chlorine Balance (Mole%) |
|---|---|---|---|---|---|---|---|---|---|
| 30 | 4 | 103 | 9.6 | 78.4 | dl | ≥99.99 | nd | 20.2 | 78.8 |
| 30 | 4 | 97 | 10.1 | 108.5 | dl | ≥99.99 | 21.3 | 26.5 | 106.2 |
| 30 | 4 | 95 | 10.4 | 98.3 | dl | ≥99.99 | 25.6 | 34 | 114.5 |
| 30 | 2 | 106 | 4.6 | 91.7 | 0.07 | 99.92 | 15.9 | 49.2 | 91.1 |
| 15 | 4 | 97 | 10.1 | 106.8 | dl | ≥99.99 | 22.8 | nd | nd |
| 15 | 2 | 103 | 4.8 | 101.3 | dl | ≥99.99 | 12.6 | 65.3 | 86.2 |
| 5 | 4 | 95 | 10.4 | 104.9 | dl | ≥99.99 | 8.7 | 75.7 | 90.0 |
| 5 | 2 | 103 | 4.8 | 101.4 | dl | ≥99.9 | 9.4 | 76.3 | 88.8 |
| 1 | 4 | 106 | 9.3 | 101.7 | 0.85 | 99.16 | 12.5 | 83.2 | 90.3 |
| 1 | 2 | 103 | 4.8 | 98.5 | 13.23 | 86.57 | 6.8 | 84.9 | 93.3 |

Notes: Hz = Hertz
cfm = cubic feet per minute
sec = seconds
ppmv = parts per million volume
dl = detection limit
nd = not detected

# TORONTO HARBOUR COMMISSION
## (Soil Recycling)

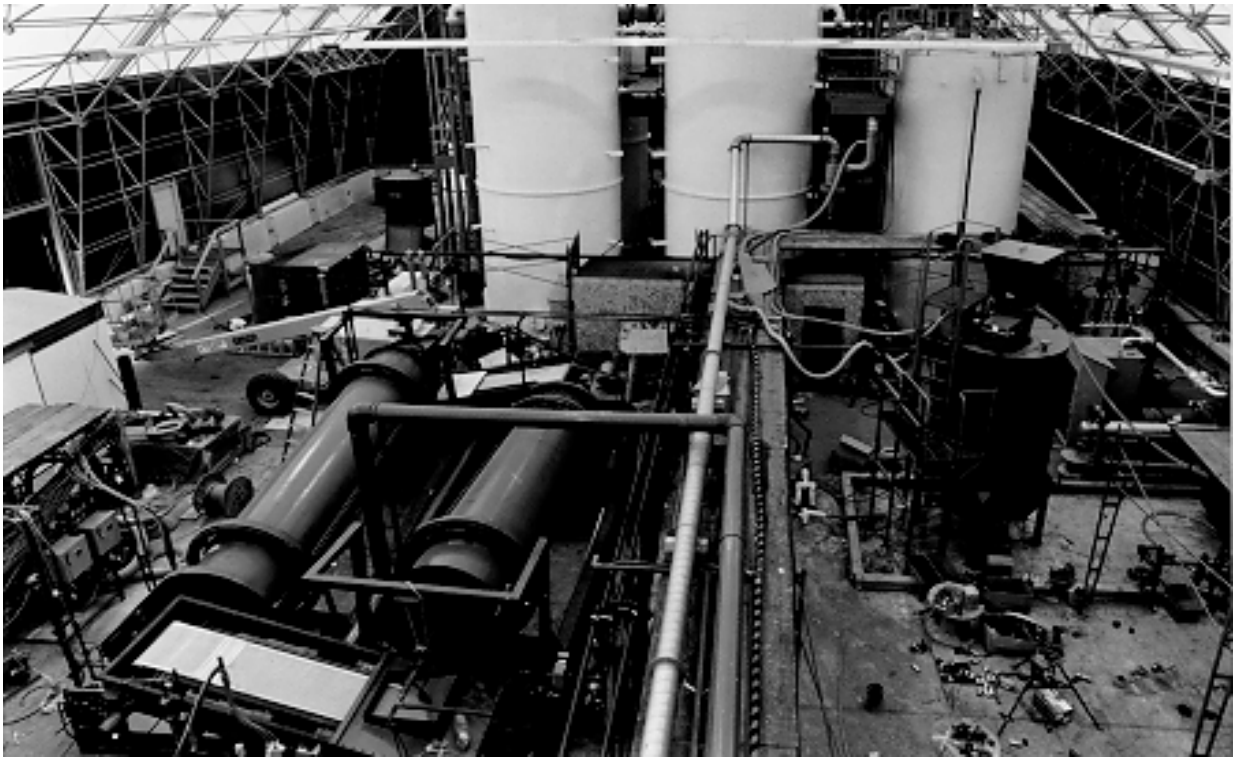
## TECHNOLOGY DESCRIPTION:

The Toronto Harbour Commission's (THC) soil recycling process removes inorganic and organic contaminants from soil to produce a reusable fill material (see photograph below). The process consists of three technologies operating in series: a soil washing technology; a technology that removes inorganic contamination by chelation; and a technology that uses chemical and biological treatment to reduce organic contaminants.

The process uses an attrition soil wash plant to remove relatively uncontaminated coarse soil fractions using mineral processing equipment while concentrating the contaminants in a fine slurry which is routed to the appropriate process for further treatment. The wash process includes a trommel washer to remove clean gravel, hydrocyclones to separate the contaminated fines, an attrition scrubber to free fines from sand particles, and a density separator to remove coal and peat from the sand fraction.

If only inorganic contaminants are present, the slurry can be treated in the inorganic chelator unit. This process uses an acid leach to free the inorganic contaminant from the fine slurry and then removes the metal using solid chelating agent pellets in a patented countercurrent contactor. The metals are recovered by electrowinning from the chelation agent regenerating liquid.

Organic removal is accomplished by first chemically pretreating the slurry from the wash plant or the metal removal process. Next, biological treatment is applied in upflow slurry reactors using the bacteria which have developed



Soil Washing Plant (Metal Extraction Screwtubes in Foreground and Bioslurry Reactors in Background)



The SITE Program assesses but does not approve or endorse technologies.

naturally in the soils. The treated soil is dewatered using hydrocyclones and returned to the site from which it was excavated.

## WASTE APPLICABILITY:

The technology is designed to reduce organic and inorganic contaminants in soils. The process train approach is most useful when sites have been contaminated as a result of multiple uses over a period of time. Typical sites where the process train might be used include refinery and petroleum storage facilities, sites with metal processing and metal recycling histories, and manufactured gas and coal or coke processing and storage sites. The process is less suited to soils with undesirable high inorganic constituents which result from the inherent mineralogy of the soils.

## STATUS:

The THC soil recycling process was accepted into the SITE Demonstration Program in 1991. The soil recycling process was demonstrated at a site within the Toronto Port Industrial District that had been used for metals finishing and refinery products and petroleum storage. Demonstration sampling took place in April and May 1992.

Results have been published in the Demonstration Bulletin (EPA/520-MR-92/015), the Applications Analysis Report (EPA/540-AR-93/517), the Technology Evaluation Report (EPA/540/R-93/517), and the Technology Demonstration Summary (EPA/540/SR-93/517). These reports are available from EPA.

This technology is no longer available through a vendor. For further information on the technology, contact the EPA Project Manager.

## DEMONSTRATION RESULTS:

The demonstration results showed that soil washing produced clean coarse soil fractions and concentrated the contaminants in the fine slurry. The chemical treatment process and biological slurry reactors, when operated on a batch basis with a nominal 35-day retention time, achieved at least a 90 percent reduction in simple polyaromatic hydrocarbon compounds such as naphthalene, but did not meet the approximately 75 percent reduction in benzo(a)pyrene required to achieve the cleanup criteria.

The biological process discharge did not meet the cleanup criteria for oil and grease, and the process exhibited virtually no removal of this parameter. THC believes that the high outlet oil and grease values are the result of the analytical extraction of the biomass developed during the process.

The hydrocyclone dewatering device did not achieve significant dewatering. Final process slurries were returned to the excavation site in liquid form.

The metals removal process achieved a removal efficiency for toxic heavy metals such as copper, lead, mercury, and nickel of approximately 70 percent.

The metals removal process equipment and chelating agent were fouled by free oil and grease contamination, forcing sampling to end prematurely. Biological treatment or physical separation of oil and grease will be required to avoid such fouling.

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# TRINITY ENVIRONMENTAL TECHNOLOGIES, INC.

## (PCB- and Organochlorine-Contaminated Soil Detoxification)

## TECHNOLOGY DESCRIPTION:

This technology uses an aprotic solvent, other reagents, and heat to dehalogenate polychlorinated biphenyls (PCB) in solids to inert biphenyl and chloride salts (see figure below). First, solid material is sized to allow better contact between the reagents and PCBs. In a continuous flow reactor, the soils are heated to drive off excess water. Reagents are then added to destroy the PCBs.

The reagent, consisting of a solvent and an inorganic alkali material, completely strips chlorine from the PCB molecule. Excess alkali can be easily neutralized and is reusable in the process. Treated soil can be returned to the excavation once analytical results show that PCBs have been destroyed.

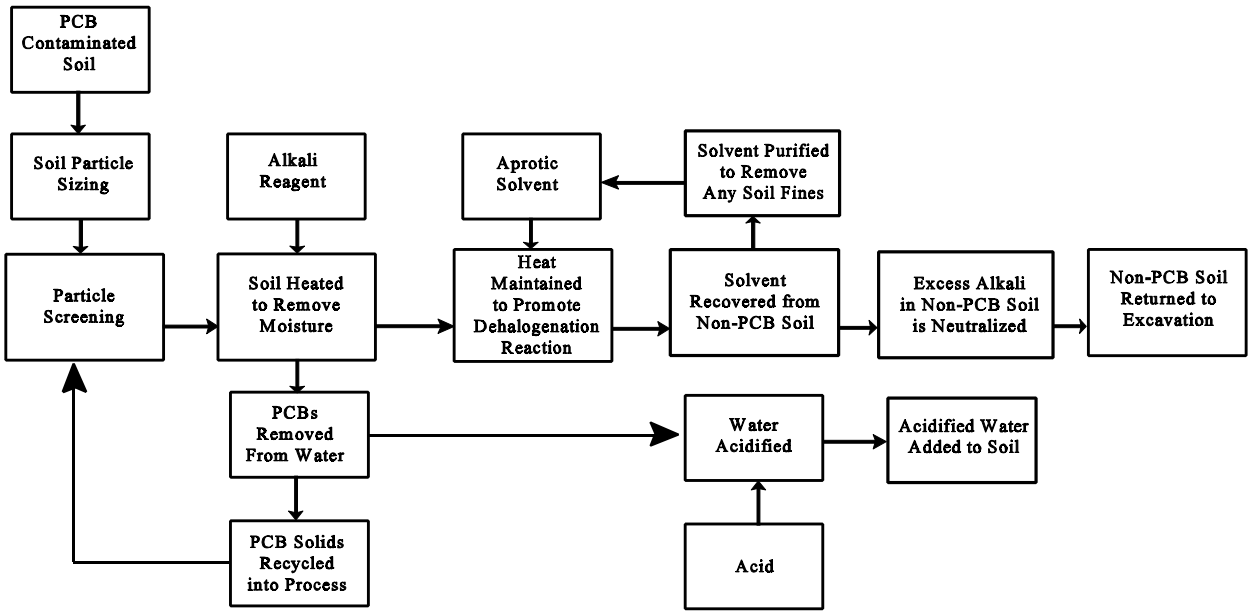
Gas chromatography/mass spectroscopy analyses of processed PCB materials show that the process produces no toxic or hazardous products.

A chlorine balance confirms that PCBs are completely dehalogenated. To further confirm chemical dehalogenation, inorganic and total organic chloride analyses are also used. The average total chloride recovery for treated soils is greater than 90 percent.

The commercial process is expected to be less costly than incineration but more expensive than land disposal. Since no stack emissions are produced, permitting the process for a remediation would be easier than incineration.

## WASTE APPLICABILITY:

The process can treat many different solid and sludge-type materials contaminated with PCB Aroclor mixtures, specific PCB congeners, pentachlorophenol, and individual chlorinated dioxin isomers. However, other chlorinated hydrocarbons such as pesticides, herbicides, and polychlorinated dibenzofurans could also be treated by this technology.




PCB Soil Detoxification Process



The SITE Program assesses but does not approve or endorse technologies.

## STATUS:

This technology was accepted into the SITE Emerging Technology Program in July 1990. The current system was developed by researchers in early 1991, after the original aqueous, caustic-based system proved ineffective at destroying PCBs.

The SITE project was completed in 1992. Trinity is investigating further improvements to the technology. Due to cost limitations, no commercialization of the investigated process is expected. A final report will not be published.

In bench-scale studies, synthetically contaminated materials have been processed to eliminate uncertainties in initial PCB concentration. This chemical process has reduced PCB concentrations from 2,000 parts per million (ppm) to less than 2 ppm in about 30 minutes using moderate power input. Further laboratory experiments are underway to determine the reaction mechanism and to enhance PCB destruction. Through additional experimentation, Trinity Environmental Technologies, Inc., expects to reduce processing time through better temperature control, more efficient mixing, and possibly more aggressive reagents.

A modular pilot-scale processor has been planned that uses several heating zones to preheat and dry the contaminated soil, followed by PCB destruction. The pilot process would be capable of processing 1 ton per hour initially. Additional modules could be added to increase process capacity, as needed. Contaminated soils from actual sites will be used to test the pilot-scale processor instead of the synthetically contaminated soils used in bench-scale testing.

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# UNIVERSITY OF NEBRASKA - LINCOLN
## (Center Pivot Spray Irrigation System)

## TECHNOLOGY DESCRIPTION:

Spray irrigation technology with "center pivots" and "linear" systems can be used to remediate groundwater contaminated with volatile organic compounds (VOC). The technology is commonly used to apply irrigation water to vegetable and row crops. While the systems were introduced to irrigate hilly terrain and excessively well-drained soils, the technology has been adapted in both groundwater quality and quantity management areas as a best management practice. This technology severely reduces water application rates and leaching relative to flood irrigation techniques.

The systems consist of an elevated pipeline with nozzles placed at close intervals. Groundwater is pumped through the pipeline and sprayed uniformly over a field as the pipeline pivots or linearly passes over the cropped area. The typical pump rate is between 800 and 2,000 gallons per minute (gpm). These self-propelled systems are highly mechanized and have low labor and operating requirements. The systems do not require level ground, and start-up costs are low.

The sprinkler method applies water over the irrigated area with a fine spray (see the photograph below). Water coverage over the irrigated area is controlled by the speed with which the "pivot" or "linear" system travels across the field. The heart of the sprinkler irrigation system is the nozzle, which has a small opening through which a high-velocity stream of water is emitted. As the high-velocity water stream leaves the nozzle, it strikes an impact pad and forms a thin film of water. The thin film of water produced by these pads breaks up into small droplets as it leaves the impact pad. Droplet size depends on the stream pressure and design of the impact pad.

The system used in the SITE demonstration program was a center pivot and was located on a seed-corn field in Hastings, Nebraska. The system was equipped with off-the-shelf, fog-

Center Pivot spray Irrigation System



The SITE Program assesses but does not approve or endorse technologies.

producing impact pads for improved volatilization efficiency.

A stratified water droplet collector (SWDC) simultaneously collected spray at four fall heights above ground level, and was specifically contracted for this project by the Dutton-Lainson Company in Hastings, Nebraska. With this device, droplets were collected at heights of 1.5, 4.5, 7.5, and 10.5 feet above the ground surface. Twelve SWDCs were installed parallel to the pivot arm to determine average volatilization efficiencies from the 340 nozzles on the pivot arm.

## WASTE APPLICABILITY:

The sprinkler irrigation system is capable of remediating VOC-contaminated groundwater. Removal rates in excess of 95 percent have been demonstrated for groundwater containing ethylene dibromide (EDB), trichloroethene (TCE), 1,1,1-trichloroethane (TCA), and carbon tetrachloride (CT). The method will efficiently volatilize all common volatiles in groundwater that may originate from landfills, degreasers, dry cleaners, electrical industries, gas stations, or refineries. The residuals are transferred to the atmosphere where they are dispersed and most are rapidly degraded in ultraviolet light.

The technique may be limited to individual groundwater VOC concentrations that are less than 1 part per million if residual concentrations of VOCs are mandated to be near or below the maximum contaminant level prior to reaching the ground surface. Otherwise, the technique can be used in any agricultural setting where sufficient groundwater and irrigatable land are available.

## STATUS:

The Center Pivot Spray Irrigation system was accepted into the SITE Demonstration Program in late 1995. Under a University of Nebraska project funded by the Cooperative State Research Service of the Department of Agriculture, field tests were completed in the summers of 1994 and 1995 in a seed-corn field in Hastings, Nebraska. The technology was demonstrated under the SITE Program in July 1996 at the North Landfill/FAR-MAR-CO Subsite in Hastings, Nebraska. The 50-acre site is a furrow-irrigated corn field underlain by commingled plumes of groundwater containing EDB, TCE, TCA, CT, 1,1-dichloroethene, and chloroform. The primary goal of the demonstration was to determine the efficiency of the system to remediate VOCs in groundwater to concentrations below the maximum contaminant levels. The results of this demonstration are available in the Innovative Technology Evaluation Report (EPA/540/R-09/502).

Clients involved in large pump-and-treat projects at several military bases are investigating the suitability of the system to their specific site situations. Potential clients include the U.S. Navy, the Army Corps of Engineers, and several state agencies. The technology is currently being used at the Lindsey Manufacturing site in Nebraska and near some grain elevators being remediated by Argonne Laboratory.

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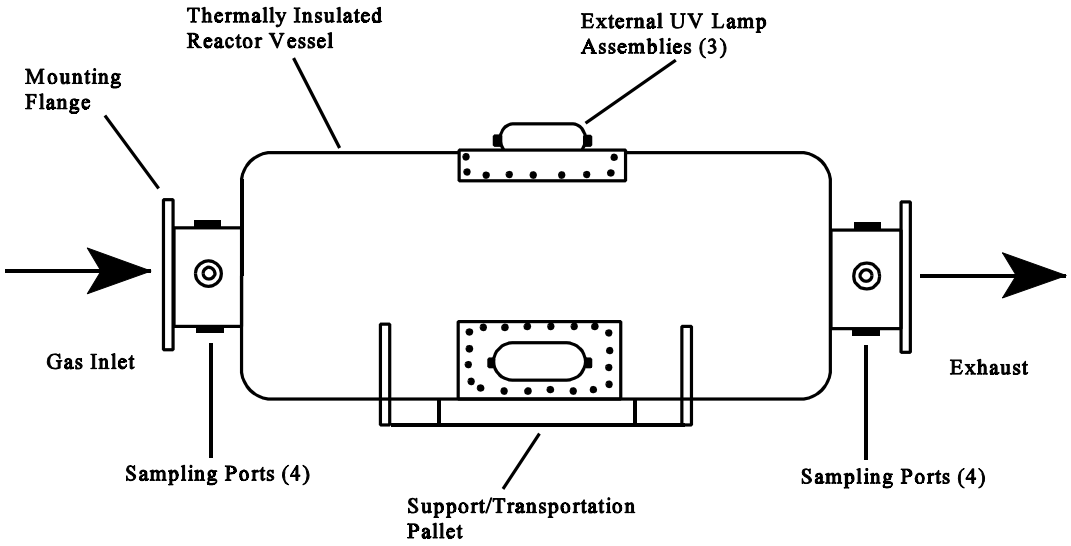
# UNIVERSITY OF DAYTON RESEARCH INSTITUTE
## (Photothermal Detoxification Unit)

## TECHNOLOGY DESCRIPTION:

Photolytic reactions (reactions induced by exposure to ultraviolet [UV] light) can destroy certain hazardous organic wastes at relatively low temperatures. However, most photochemical processes offer relatively limited throughput rates and cannot completely mineralize the targeted wastes. For aqueous waste streams, these problems have been partially addressed by using indirect photochemical reactions involving a highly reactive photolytic initiator such as hydrogen peroxide or heterogeneous catalysts. Recently, the University of Dayton Research Institute (UDRI) developed a photolytic detoxification process to treat the gas waste streams. This process is clean and efficient and offers the speed and general applicability of a combustion process.

The photothermal detoxification unit (PDU) uses photothermal reactions conducted at temperatures higher than those used in conventional photochemical processes (200 to 500 °C versus 20 °C), but lower than combustion temperatures (typically greater than 1,000 °C). At these elevated temperatures, photothermal reactions are energetic enough to destroy many wastes quickly and efficiently without producing complex and potentially hazardous by-products.

The PDU is a relatively simple device, consisting of an insulated reactor vessel illuminated with high-intensity UV lamps. As shown in the figure below, the lamps are mounted externally for easy maintenance and inspection. Site remediation technologies that generate high-temperature gas streams, such as thermal desorption or in situ steam stripping, can incorporate the PDU with only slight equipment modifications. The PDU can be equipped with a pre-heater for use with soil vapor extraction (SVE). Furthermore, the PDU can be equipped with conventional air pollution control devices for removal of acids and suspended particulates from the treated process stream. The PDU shown in the figure below is also equipped with built-in sampling




Photothermal Detoxification Unit (PDU)



The SITE Program assesses but does not approve or endorse technologies.

ports for monitoring and quality assurance and quality control.

## WASTE APPLICABILITY:

According to UDRI, the PDU has proven extremely effective at destroying the vapors of polychlorinated biphenyls, polychlorinated dibenzodioxins, polychlorinated dibenzofurans, aromatic and aliphatic ketones, and aromatic and aliphalic chlorinated solvents, as well as brominated and nitrous wastes found in soil, sludges, and aqueous streams. The PDU can be incorporated with most existing and proposed remediation processes for clean, efficient, on-site destruction of the off-gases. More specifically, high-temperature processes can directly incorporate the PDU; SVE can use the PDU fitted with a preheater; and groundwater remediation processes can use the PDU in conjunction with air stripping.

## STATUS:

The technology was accepted into the Emerging Technology Program in August 1992, and development work began in December 1992. The evaluation was completed in 1994. The Emerging Technology Report (EPA/540/R-95/526), the Emerging Technology Bulletin (EPA/540/F-95/505) and the Emerging Technology Summary (EPA/540/SR-95/526) are available from EPA. An article was also published in the *Journal of Air and Waste Management*, Volume 15, No. 2, 1995.

Emerging Technology Program data indicate that the technology performs as expected for chlorinated aromatic wastes, such as dichlorobenzene and tetrachlorodibenzodioxin, and better than expected for relatively light chlorinated solvents, such as trichloroethene (TCE) and tetrachloroethene. Further tests with selected mixtures, including benzene, toluene, ethyl-benzene, xylene, TCE, dichlorobenzene, and water vapor, show that the process is effective at treating wastes typically found at many remediation sites. Adequate scaling and performance data are now available to proceed with the design and development of prototype full-scale units for field testing and evaluation.

Through prior programs with the U.S. Department of Energy, technology effectiveness has been thoroughly investigated using relatively long wavelength UV light (concentrated sunlight with wavelengths greater than 300 nanometers). Limited data have also been generated at shorter wavelengths (higher energy) using available industrial UV illumination systems.

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# UNIVERSITY OF SOUTH CAROLINA
## (In Situ Mitigation of Acid Water)

## TECHNOLOGY DESCRIPTION:

The in situ acid water mitigation process addresses the acid drainage problem associated with exposed sulfide-bearing minerals from sources including mine waste rock and abandoned metallic mines. Acid drainage forms under natural conditions when iron disulfides are exposed to the atmosphere and water, spontaneously oxidizing them to produce a complex of highly soluble iron sulfates and salts. These salts hydrolyze to produce an acid-, iron-, and sulfate-enriched drainage that adversely affects the environment.

The in situ mitigation strategy modifies the hydrology and geochemical conditions of the site through land surface reconstruction and selective placement of limestone.

Limestone is used as the alkaline source material because it has long-term availability, is generally inexpensive, and is safe to handle. For the chemical balances to be effective, the site must receive enough rainfall to produce seeps or drainages that continually contact the limestone. Rainfall, therefore, helps to remediate the site, rather than increasing the acid drainage.

During mine construction, lysimeters and limestone chimneys are installed to collect surface runoff and funnel it into the waste rock dump. Acidic material is capped with impermeable material to divert water from the

Overview of Site Lysimeters



The SITE Program assesses but does not approve or endorse technologies.

acid cores. This design causes the net acid load to be lower than the alkaline load, resulting in benign, nonacid drainage.

## WASTE APPLICABILITY:

The technology mitigates acid drainage from abandoned waste dumps and mines. It can be applied to any site in a humid area where limestone is available.

## STATUS:

This technology was accepted into the SITE Emerging Technology Program in March 1990. Studies under the Emerging Technology Program are complete. A peer-reviewed journal article has been prepared and submitted.

For the SITE evaluation, six large-scale lysimeters (12 feet wide, 8 feet high, and 16 feet deep) were constructed and lined with 20-mil polyvinyl chloride plastic (see photograph on previous page). The lysimeters drained through an outlet pipe into 55-gallon collection barrels. Piezometers in the lysimeter floor monitored the hydrology and chemistry of the completed lysimeter. During June 1991, 50 tons of acid-producing mine waste rock was packed into each lysimeter.

The effluent from each lysimeter was monitored for 1 year to establish a quality baseline. In the second phase of the study, selected lysimeters were topically treated, maintaining two lysimeters as controls to compare the efficacy of the acid abatement strategy. In addition, a rain gauge was installed at the site for mass balance measurements. An ancillary study correlating laboratory and field results is complete.

In the last phase of the 3-year study, little if any leachate was collected due to drought conditions in the southeast U.S. With the return of normal rainfall, sufficient leachate was collected to compare the treated lysimeters against the controls to evaluate the treatment's effectiveness. The treated lysimeters, in general, showed a 20 to 25 percent reduction in acid formation. The acidities measured about 10,000 milligrams per liter (mg/L) for the untreated lysimeters, while acidities from the treated lysimeters measured about 7,000 mg/L. This study was conducted on a very high acid-producing waste rock, representing a near worst-case situation. The process should be more successful on milder acid sources.

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# UNIVERSITY OF WASHINGTON
## (Adsorptive Filtration)

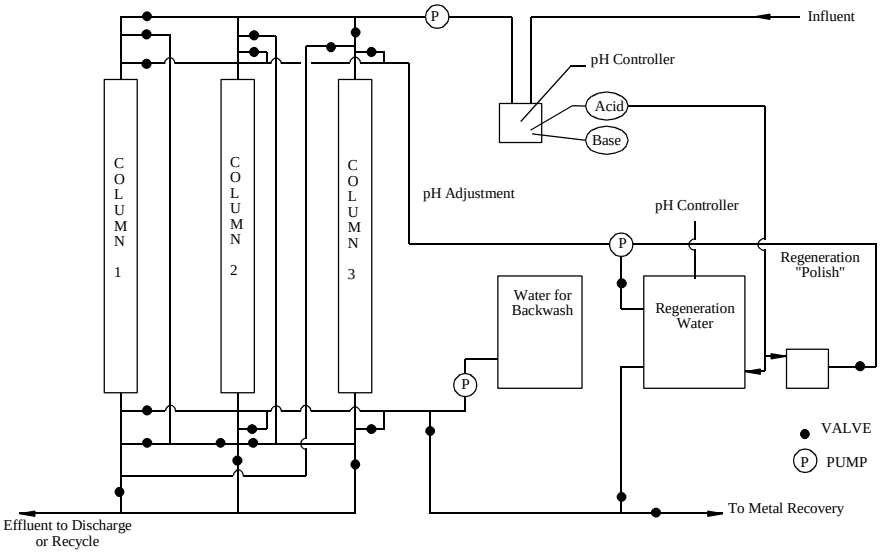
## TECHNOLOGY DESCRIPTION:

Adsorptive filtration removes inorganic contaminants (metals) from aqueous waste streams. An adsorbent ferrihydrite is applied to the surface of an inert substrate such as sand, which is then placed in one of three vertical columns (see figure below). The contaminated waste stream is adjusted to a pH of 9 to 10 and passed through the column. The iron-coated sand grains in the column act simultaneously as a filter and adsorbent. When the column's filtration capacity is reached (indicated by particulate breakthrough or column blockage), the column is backwashed. When the adsorptive capacity of the column is reached (indicated by break-through of soluble metals), the metals are removed and concentrated for subsequent recovery with a pH-induced desorption process.

Sand can be coated by ferrihydrite formed when either iron nitrate or iron chloride salts react with sodium hydroxide. The resulting ferrihydrite-coated sand is insoluble at a pH greater than 1; thus, acidic solutions can be used in the regeneration step to ensure complete metal recovery. The system does not appear to lose treatment efficiency after numerous regeneration cycles. Anionic metals such as arsenate, chromate, and selenite can be removed from the solution by treating it at a pH near 4 and regenerating it at a high pH. The system has an empty bed retention time of 2 to 5 minutes.

This technology offers several advantages over conventional treatment technologies. These advantages are its ability to (1) remove both dissolved and suspended metals from the waste stream, (2) remove a variety of metal complexes, (3) work in the presence of high concentrations of background ions, and (4) remove anionic metals.

This adsorptive filtration process removes inorganic contaminants, consisting mainly of metals, from aqueous waste streams. It can be applied to aqueous waste streams with a wide range of contaminant concentrations and pH values.




Adsorptive Filtration Treatment System



The SITE Program assesses but does not approve or endorse technologies.

## STATUS:

This technology was accepted into the SITE Emerging Technology Program in January 1988; the evaluation was completed in 1992. The Emerging Technology Report (EPA/540/R-93/515), Emerging Technology Summary (EPA/540/SR-93/515), and Emerging Technology Bulletin (EPA/540/F-92/008) are available from EPA.

During the SITE evaluation, synthetic solutions containing cadmium, copper, or lead at concentrations of 0.5 part per million (ppm) were treated in packed columns using 2-minute retention times. After approximately 5,000 bed volumes were treated, effluent concentrations were about 0.025 ppm for each metal, or a 95 percent removal efficiency. The tests were stopped, although the metals were still being removed. In other experiments, the media were used to adsorb copper from wastewater containing about 7,000 milligrams per liter (mg/L) copper.

The first batch of regenerant solutions contained cadmium and lead at concentrations of about 500 ppm. With initial concentrations of 0.5 ppm, this represents a concentration factor of about 1,000 to 1. Data for the copper removal test have not been analyzed. At a flow rate yielding a 2-minute retention time, the test would have taken about 7 days of continuous flow operation to treat 5,000 bed volumes. Regeneration took about 2 hours.

The system has also been tested for treatment of rinse waters from a copper-etching process at a printed circuit board shop. The coated sand was effective in removing mixtures of soluble, complexed, and particulate copper, as well as zinc and lead, from these waters. When two columns were used in series, the treatment system was able to handle fluctuations in influent copper concentration from less than 10 mg/L up to several hundred mg/L.

Groundwater from Western Processing, a Superfund site near Seattle, Washington, was treated to remove both soluble and particulate zinc.

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# UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
## (Excavation Techniques and Foam Suppression Methods)

## TECHNOLOGY DESCRIPTION:

Excavation techniques and foam suppression methods have been developed through a joint EPA effort involving the National Risk Management Research Laboratory (Cincinnati, Ohio), Air and Energy Engineering Research Laboratory (Research Triangle Park, North Carolina), and EPA Region 9 to evaluate control technologies during excavation operations.

In general, excavating soil contaminated with volatile organic compounds (VOC) results in fugitive air emissions. When using this technology, the area to be excavated is surrounded by a temporary enclosure (see photograph below). Air from the enclosure is vented through an emission control system before being released to the atmosphere. For example, in the case of hydrocarbon and sulfur dioxide emissions, a scrubber and a carbon adsorptionunit would be used to treat emissions. As an additional emission control method, a vapor suppressant foam can be applied to the soil before and after excavation.

## WASTE APPLICABILITY:

This technology is suitable for controlling VOC and sulfur dioxide emissions during excavation of contaminated soil.

## STATUS:

This technology was demonstrated at the McColl Superfund site in Fullerton, California, in June and July 1990. An enclosure 60 feet wide, 160 feet long, and 26 feet high was erected over an area contaminated with VOCs and sulfur dioxide. A backhoe removed the overburden and

Excavation Area Enclosure



The SITE Program assesses but does not approve or endorse technologies.

excavated underlying waste. Three distinct types of waste were encountered during excavation: oily mud, tar, and hard coal-like char.

The following documents, which contain results from the demonstration, are available from EPA:

- Applications Analysis Report (EPA/540/AR-92/015)
- Technology Evaluation Report (EPA/540/R-93/015)
- Demonstration Summary (EPA/540/SR-92/015)

## DEMONSTRATION RESULTS:

During excavation, the 5-minute average air concentrations within the enclosed area were up to 1,000 parts per million (ppm) for sulfur dioxide and up to 492 ppm for total hydrocarbons (THC). The air pollution control system removed up to 99 percent of the sulfur dioxide and up to 70 percent of the THCs.

The concentrations of air contaminants inside the enclosure were higher than expected. These high concentrations were due in part to the inability of the vapor suppressant foams to form an impermeable membrane over the exposed wastes. The foam reacted with the highly acidic waste, causing the foam to degrade. Furthermore, purge water from foaming activities made surfaces slippery for workers and equipment.A total of 101 cubic yards of overburden and 137 cubic yards of contaminated waste was excavated. The tar waste was solidified and stabilized by mixing with fly ash, cement, and water in a pug mill. The char wastes did not require further processing.

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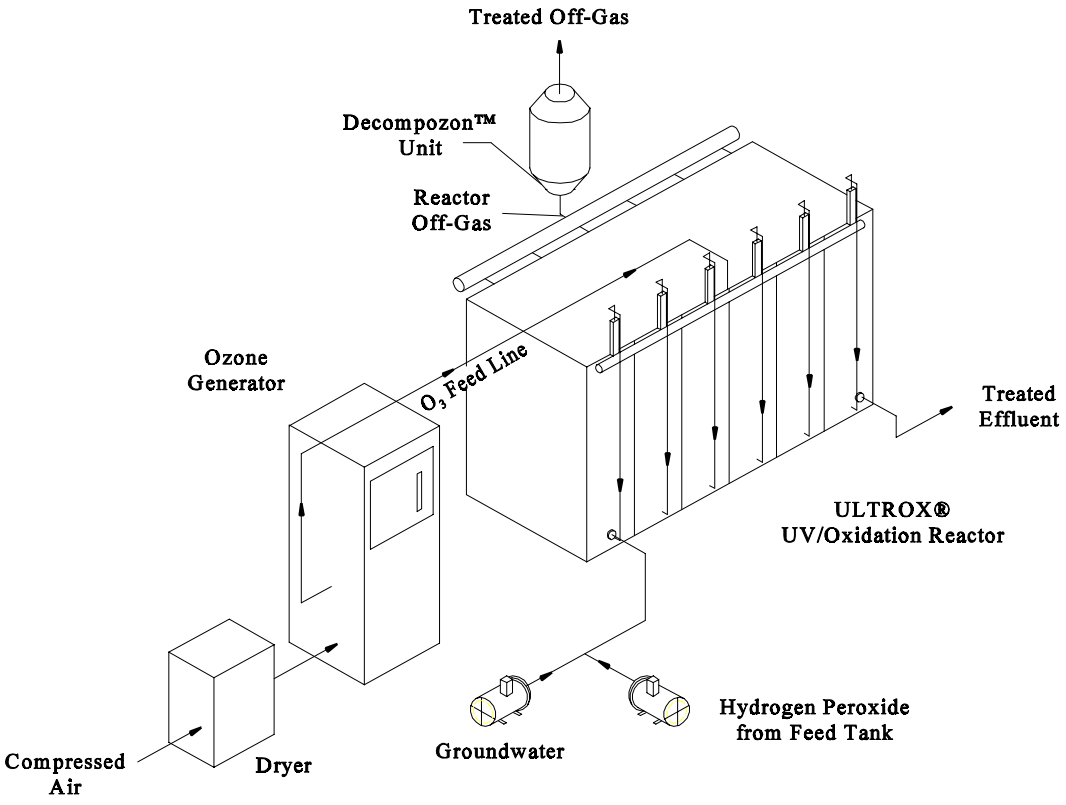
# U.S. FILTER/WTS ULTROX
## (Ultraviolet Radiation and Oxidation)

## TECHNOLOGY DESCRIPTION:

This ultraviolet (UV) radiation and oxidation technology uses UV radiation, ozone, and hydrogen peroxide to destroy toxic organic compounds, particularly chlorinated hydrocarbons, in water. The technology oxidizes compounds that are toxic or refractory (resistant to biological oxidation) to parts per million (ppm) or parts per billion (ppb) levels.

The UV radiation and oxidation system consists of the UV-oxidation reactor, an air compressor and ozone generator module, and a hydrogen peroxide feed system (see figure below). The system is skid-mounted and portable, and permits on-site treatment of a wide variety of liquid wastes. Reactor size is determined by the expected wastewater flow rate and the necessary hydraulic retention time needed to treat the contaminated water. The approximate UV intensity, and ozone and hydrogen peroxide doses, are determined from pilot-scale studies.

Reactor influent is simultaneously exposed to UV radiation, ozone, and hydrogen peroxide to oxidize the organic compounds. Off-gas from the reactor passes through a catalytic ozone destruction Decompozon™ unit, which reduces ozone levels before air venting. The Decompozon™ unit also destroys volatile organic compounds (VOC) stripped off in the reactor.




UV Radiation and Oxidation System (Isometric View)



The SITE Program assesses but does not approve or endorse technologies.

Effluent from the reactor is tested and analyzed before disposal.

## WASTE APPLICABILITY:

The UV radiation and oxidation system treats contaminated groundwater, industrial wastewaters, and leachates containing halogenated solvents, phenol, pentachlorophenol, pesticides, polychlorinated biphenyls, explosives, benzene, toluene, ethylbenzene, xylene, methyl tertiary butyl ether, and other organic compounds. The system also treats low-level total organic carbon and reduces chemical oxygen demand and biological oxygen demand.

## STATUS:

This technology was accepted into the SITE Demonstration Program in 1989. A field-scale demonstration of the system was completed in March 1989 at the Lorentz Barrel and Drum Company site in San Jose, California. The testing program was designed to evaluate system performance while varying five operating parameters: (1) influent pH, (2) retention time, (3) ozone dose, (4) hydrogen peroxide dose, and (5) UV radiation intensity. The Demonstration Bulletin (EPA/540/M5-89/012), Technology Demonstration Summary (EPA/540/S5-89/012), Applications Analysis Report (EPA/540/A5-89/012), and Technology Evaluation Report (EPA/540/5-89/012) are available from EPA.

The technology is fully commercial, with over 30 systems installed. Units with flow rates ranging from 5 gallons per minute (gpm) to 1,050 gpm are in use at various industries and site remediations, including aerospace, U.S. Department of Energy, U.S. Department of Defense, petroleum, pharmaceutical, automotive, woodtreating, and municipal facilities.UV radiation and oxidation technology has been included in records of decision for several Superfund sites where groundwater pump-and-treat remediation methods will be used.

## DEMONSTRATION RESULTS:

Contaminated groundwater treated by the system during the SITE demonstration met regulatory standards at the appropriate parameter levels. Out of 44 VOCs in the wastewater, trichloroethene, 1,1-dichloroethane, and 1,1,1-trichloroethane were chosen as indicator parameters. All three are relatively refractory to conventional oxidation.

The Decompozon™ unit reduced ozone to less than 0.1 ppm, with efficiencies greater than 99.99 percent. VOCs present in the air within the treatment system were not detected after passing through the Decompozon™ unit. The system produced no harmful air emissions. Total organic carbon removal was low, implying partial oxidation of organics without complete conversion to carbon dioxide and water.

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# UV TECHNOLOGIES, INC.
## (formerly ENERGY AND ENVIRONMENTAL ENGINEERING, INC.)
## (PhotoCAT™ Process)

## TECHNOLOGY DESCRIPTION:

The PhotoCAT™ process photochemically oxidizes organic compounds in wastewater using hydrogen peroxide, a chemical oxidant, ultraviolet (UV) radiation, and a photocatalyst. The photochemical reaction has the potential to reduce high concentrations (200,000 or more parts per million [ppm]) of organics in water to nondetectable levels. The energy from UV radiation is predominantly absorbed by the organic compound and the oxidant, making both species reactive. The process can be used as a final treatment step to reduce organic contamination in industrial wastewater and groundwater to acceptable discharge limits.

The existing bench-scale system treats solutions containing up to several thousand ppm of total organic carbon at a rate of 3 gallons per minute. The bench-scale system consists of a photochemical reactor, where oxidation occurs, and associated tanks, pumps, and controls. The UV lamps are high-intensity lamps that penetrate the wastewater more effectively. The portable, skid-mounted system's design depends on the chemical composition of the wastewater or groundwater being treated.

Typically, the contaminated wastewater is pumped through a filter unit to remove suspended particles. Next, the filtrate is mixed with stoichiometric quantities of hydrogen peroxide. Finally, this mixture is fed to the photochemical reactor and irradiated. The overall reaction is as follows:

$$C_aH_bX + [2a + 0.5(b - 1)]H_2O_2 \xrightarrow{h\nu} aCO_2 + [2a + (b - 1)]H_2O + HX$$

where $C_aH_bX$ represents a halogenated contaminant in the aqueous phase. Reaction products are carbon dioxide, water, and the appropriate halogen acid. Reaction kinetics depend on (1) contaminant concentration, (2) peroxide concentration, (3) irradiation dose, and (4) radiation spectral frequency.

## WASTE APPLICABILITY:

The PhotoCAT™ process treats industrial wastewater and groundwater containing organics at concentrations up to several thousand ppm. Destruction efficiencies greater than two orders of magnitude have been obtained for chlorobenzene, chlorophenol, and phenol, with low to moderate dose rates and initial concentrations of 200 ppm. Destruction efficiencies of three orders of magnitude have been demonstrated on simulated industrial waste streams representative of textile dyeing operations, with higher dose rates and an initial concentration of 200 ppm.

## STATUS:

Studies of the PhotoCAT™ process under the SITE Emerging Technology Program are complete, and the technology has been invited to participate in the SITE Demonstration Program. The Emerging Technology Report (EPA/540/SR-92/080), Emerging Technology Bulletin (EPA/540/F-92/004), and Emerging Technology Summary (EPA/540/SR-92/080) are available from EPA.

Work involving the on-line production of oxidants and the effectiveness of the photocatalytic substrate is underway under funding from EPA Small Business Industry Research Phase II and Phase I awards.



The SITE Program assesses but does not approve or endorse technologies.

Representative results from recent trials using the PhotoCAT™ process are summarized in the table below. Results are shown as the electric energy dose per gram-mole of initial contaminant to cause one decade of contaminant destruction.

| Contaminant* | Dose (kW-hr/ gmole/decade)** |
|---|---|
| Chlorobenzene | 7 |
| Trichloroethene | 5 |
| Trichloroethane [500] | 1 |
| Tetrachloroethene | 6 |
| 1,1,1-Trichloroethane | 33 |
| 1,1,1-Trichloroethene [1,000] | 7 |
| Benzene, toluene, ethylbenzene, & xylene | 5 |
| Reactive Black Dye 5 | 26 |
| Direct Yellow Dye 106 | 103 |
| Direct Red Dye 83 | 31 |
| Reactive Blue Dye 19 | 50 |
| 1-Chloronaphthalene [15] | 27 |
| Ethylene, diamine, & triacetic acid | 17 |
| Methanol | 3 |
| Textile waste (sulfur & indigo dyes) [740] | 11 |
| Textile waste (fiber reactive dyes) [270] | 7 |
| Chemical waste (formaldehyde & thiourea) [8,200] | 1 |

* All are 100 parts per million, except as noted
** kilowatt-hour per gram-mole per decade

The technology has been improved since the EPA reports were published. These improvements include (1) using the UV lamp as the energy source; (2) improving the photochemical reactor design; (3) improving the lamp design, including lamp intensity and spectral characteristics; and (4) fixing the catalyst.

A cost-competitive PhotoCAT™ system can be designed and built to treat industrial wastewater with contaminant levels of 10 to 10,000 ppm.

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# WASTECH, INC.
## (Solidification and Stabilization)

## TECHNOLOGY DESCRIPTION:

This technology solidifies and stabilizes organic and inorganic contaminants in soils, sludge, and liquid wastes. First, a proprietary reagent chemically bonds with contaminants in wastes. The waste and reagent mixture is then mixed with pozzolanic, cementitious materials, which combine to form a stabilized matrix. Reagents are selected based on target waste characteristics. Treated material is a nonleaching, high-strength, stabilized end-product.

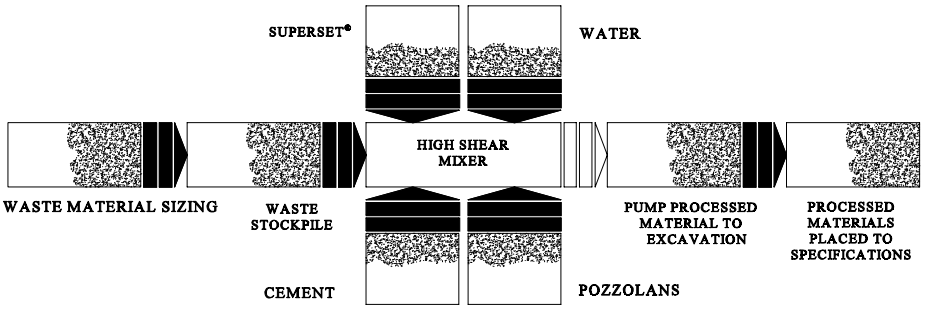
The WASTECH, Inc. (WASTECH), technology uses standard engineering and construction equipment. Because the type and dose of reagents depend on waste characteristics, treatability studies and site investigations must be conducted to determine the proper treatment formula.

Treatment usually begins with waste excavation. Large pieces of debris in the waste must be screened and removed. The waste is then placed into a high shear mixer, along with premeasured quantities of water and SuperSet®, WASTECH's proprietary reagent (see figure below).

Next, pozzolanic, cementitious materials are added to the waste-reagent mixture, stabilizing the waste and completing the treatment process. The WASTECH technology does not generate by-products. The process may also be applied in situ.

## WASTE APPLICABILITY:

The WASTECH technology can treat a wide variety of waste streams consisting of soils, sludges, and raw organic streams, including lubricating oil, evaporator bottoms, chelating agents, and ion-exchange resins, with contaminant concentrations ranging from parts per million levels to 40 percent by volume. The technology can also treat wastes generated by the petroleum, chemical, pesticide, and wood-preserving industries, as well as wastes generated by many other chemical manufacturing and industrial processes. The WASTECH technology can also be applied to mixed wastes containing organic, inorganic, and radioactive contaminants.




WASTECH Solidification and Stabilization Process



The SITE Program assesses but does not approve or endorse technologies.

## STATUS:

The technology was accepted into the SITE Demonstration Program in spring 1989. A field demonstration at Robins Air Force Base in Warner Robins, Georgia was completed in August 1991. WASTECH subsequently conducted a bench-scale study in 1992 under glovebox conditions to develop a detailed mass balance of volatile organic compounds. The Innovative Technology Evaluation Report is available from EPA. The technology is being commercially applied to treat hazardous wastes contaminated with various organics, inorganics, and mixed wastes.

This technology is no longer available from the vendor. For further information about the process, contact the EPA Project Manager.

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# WESTERN PRODUCT RECOVERY GROUP, INC.

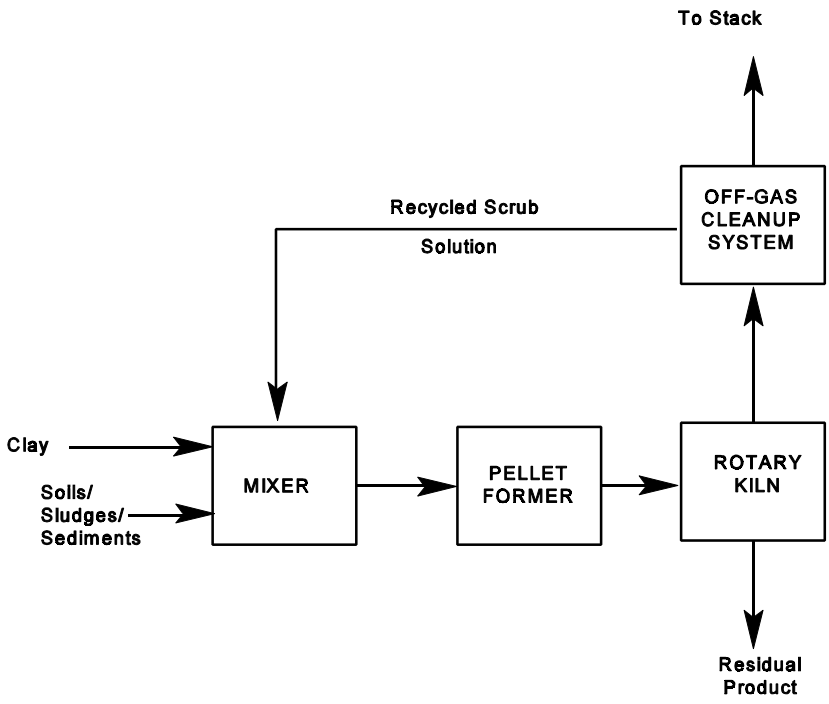
## (Coordinate, Chemical Bonding, and Adsorption Process)

## TECHNOLOGY DESCRIPTION:

The coordinate, chemical bonding, and adsorption (CCBA) process converts heavy metals in soils, sediments, and sludges to nonleaching silicates. The process can also oxidize organics in the waste stream and incorporate the ash into the ceramic pellet matrix (see figure below). The solid residual consistency varies from a soil and sand density and size distribution to a controlled size distribution ceramic aggregate form. The residue can be placed back in its original location or used as a substitute for conventional aggregate. The process uses clays with specific cation exchange capacity as sites for physical and chemical bonding of heavy metals to the clay.

The process is designed for continuous flow. The input sludge and soil stream are carefully ratioed with specific clays and then mixed in a high-intensity mechanical mixer. The mixture is then densified and formed into green or unfired pellets of a desired size. The green pellets are then direct-fired in a rotary kiln for approximately 30 minutes. The pellet temperature slowly rises to 2,000°F, converting the fired pellet to the ceramic state. Organics on the pellet's surface are oxidized, and organics inside the pellet are pyrolyzed as the temperature rises. As the pellets reach 2,000°F, the available silica sites in the clay chemically react with the heavy metals in the soil and sludge to form the final metal silicate product.

The process residue is an inert ceramic product, free of organics, with metal silicates providing a molecular bonding structure that precludes leaching. The kiln off-gas is processed in an afterburner and wet scrub system before it is released into the atmosphere. Excess scrub solution is recycled to the front-end mixing process.




Coordinate, Chemical Bonding, and Adsorption (CCBA) Process



The SITE Program assesses but does not approve or endorse technologies.

## WASTE APPLICABILITY:

The CCBA process has been demonstrated commercially on metal hydroxide sludges at a throughput of 70 wet tons per month, based on an 8-hour day, for a 25 percent solid feed. This process can treat wastewater sludges, sediments, and soils contaminated with most mixed organic and heavy metal wastes.

## STATUS:

The CCBA process was accepted into the SITE Emerging Technology Program in January 1991. Under this program, the CCBA technology has been modified to include soils contaminated with both heavy metals and most organics. The SITE studies were completed at a pilot facility with a capacity of 10 pounds per hour. Proof tests using contaminated soil have been completed. The Emerging Technology Report, Emerging Technology Summary, and Emerging Technology Bulletin will be available from EPA in early 1997.

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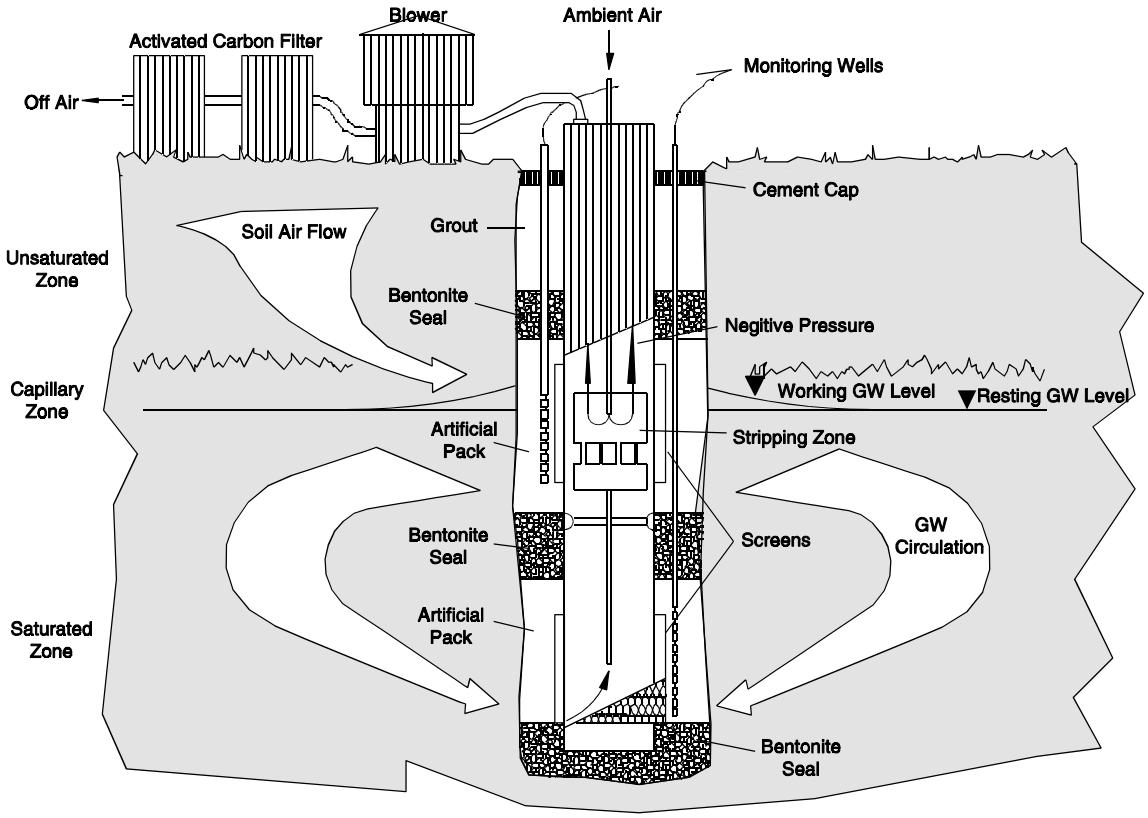
# ROY F. WESTON, INC./IEG TECHNOLOGIES
## (UVB - Vacuum Vaporizing Well)

## TECHNOLOGY DESCRIPTION:

The Unterdruck-Verdampfer-Brunnen (UVB) system is an in situ system for remediating contaminated aquifers. The basic system is simple in design and operation, consisting of a well, a groundwater extraction pump, a negative pressure stripping reactor, and an electric blower. While in operation, the water level rises inside the UVB well casing due to reduced atmospheric pressure generated by the blower, increasing the total hydraulic head in the well. Atmospheric air enters the well through a fresh air pipe connected to the stripping reactor. The incoming fresh air forms bubbles as it jets through the pinhole plate of the stripping reactor and mixes with the influent groundwater in the well casing, creating an "air lift" effect as the bubbles rise and expand to the stripping reactor. After treatment, the movement of water out of the well develops a groundwater circulation cell around a remediation well. The circulating groundwater transports contaminants from the adjacent soils and groundwater to the well, where these contaminants are removed using a combination of physical, chemical and biological treatment processes. The technology is capable of mobilizing and treating contaminants that are water soluble (dissolved phase) or are present as dense non aqueous phase liquids (DNAPL) or light non aqueous phase liquids (LNAPL). The technology also can extract and treat soil gas from the unsaturated zone.

Due to the presence of a natural groundwater flow, the total amount of water circulating around the UVB well at any given time consists of (1) a portion of up gradient groundwatercaptured by the influent screen section, and (2) recirculated groundwater. This




UVB Standard Circulation



The SITE Program assesses but does not approve or endorse technologies.

ratio is typically 15 to 85 percent respectively. Groundwater leaving the circulation cell exits through the downstream release zone in a rate equal to the up gradient groundwater being captured. These flow dynamics and the dimensions of the capture zone, circulation cell, and release zone can be calculated using design aids based on numerical simulations of the groundwater hydraulics and can be validated by monitoring the actual performance results of the system.

The advantage of the UVB technology over external pump-and-treat technologies is its ability to treat contaminants while maintaining a net equilibrium flow in the aquifer, eliminating adverse effects associated with excessive mounding or draw-down of groundwater due to continuous extraction and replacement of equal volumes of water. Additionally, the circulation well serves as a mechanism for flushing contaminants from the soils and aquifer to the well casing for treatment on a continuous basis. As a secondary benefit, because the primary treatment process is physical removal through air stripping, the dissolved oxygen levels in the groundwater passing through the well can theoretically increase up to 10 milligrams per liter within the aquifer, enhancing bioremediation by indigenous microorganisms.

## WASTE APPLICABILITY:

This technology can be used to assist in treating a variety of soil and groundwater pollutants ranging from chlorinated solvents to gasoline constituents, polycyclic aromatic hydrocarbons, heavy metals, and nitrates.

## STATUS:

This technology was accepted into the SITE Demonstration Program in 1993, and a demonstration was completed at March Air Force Base, California, in May 1994. The Demonstration Bulletin (EPA/540/MR-95/500), Technology Capsule (EPA/540/R-95/500a), and Innovative Technology Evaluation Report (EPA/540/R-95/005) will be available from EPAin the fall of 1999.

## DEMONSTRATION RESULTS:

Demonstration results indicate that the UVB system reduced trichloroethene (TCE) in groundwater by an average of 94 percent. The average TCE concentration from the outlet of the UVB system in the treated groundwater was approximately 3 micrograms per liter (µg/L), with only one event above 5 µg/L. The inlet TCE concentration averaged 40 µg/L. Results of a dye tracer study indicated that the radius of the circulation cell was at least 40 feet. Modeling of the study indicated a circulation cell radius of 60 feet. In general, TCE in the shallow and intermediate screened wells showed a concentration reduction both vertically and horizontally during the demonstration. TCE concentrations in these wells appeared to homogenize as indicated by their convergence and stabilization. Variations in TCE concen-trations were noted in the deep screened wells.

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# ROY F. WESTON, INC.
## (Low Temperature Thermal Treatment System)

## TECHNOLOGY DESCRIPTION:

The Roy F. Weston, Inc. (Weston), low temperature thermal treatment (LT³®) system thermally desorbs organic compounds from contaminated soil without heating the soil to combustion temperatures. The transportable system (see photograph below) is assembled on three flat-bed trailers and requires an area of about 5,000 square feet, including ancillary and support equipment. The LT³® system consists of three segments: soil treatment, emissions control, and water treatment.

The LT³® thermal processor consists of two jacketed troughs, one above the other. Each trough houses four intermeshed, hollow screw conveyors. A front-end loader feeds soil or sludge onto a conveyor that discharges into a surge hopper above the thermal processor. Hot oil circulating through the troughs and screws heats the soil to 400 to 500 °F, removing contaminants. A second stage indirect heater is available to achieve 1,000 °F discharge temperatures. Soil is discharged from the thermal processor into a conditioner, where a water spray cools the soil and minimizes dust emissions.

A fan draws desorbed organics from the thermal processor through a fabric filter baghouse. Depending on contaminant characteristics, dust collected on the fabric filter may be retreated, combined with treated material, or drummed separately for off-site disposal. Exhaust gas from the fabric filter is drawn into an air-cooled condenser to remove most of the water vapor and organics. The gas is then passed through a second, refrigerated condenser and treated by carbon adsorption.

Condensate streams are typically treated in a three-phase, oil-water separator to remove light and heavy organic phases from the water phase. The water phase is then treated in a carbon adsorption system to remove residual organic contaminants. Treated condensate is often used

Low Temperature Thermal Treatment (LT³®) System



The SITE Program assesses but does not approve or endorse technologies.

for soil conditioning, and only the organic phases are disposed of off site.

## WASTE APPLICABILITY:

This system treats soils and sludges contaminated with volatile and semivolatile organic compounds (VOC and SVOC). Bench-, pilot-, and full-scale LT³® systems have treated soil contaminated with the following wastes: coal tar, drill cuttings (oil-based mud), No. 2 diesel fuel, JP-4 jet fuel, leaded and unleaded gasoline, petroleum hydrocarbons, halogenated and nonhalogenated solvents, VOCs, SVOCs, polynuclear aromatic hydrocarbons, polychlorinated biphenyls, pesticides, herbicides, dioxins, and furans.

## STATUS:

The LT³® system was accepted into the SITE Demonstration Program in September 1991. In November and December 1991, the LT³® system was demonstrated under the SITE Program as part of a proof-of-process test for full-scale remediation of the Anderson Development Company (ADC) Superfund site in Adrian, Michigan. The system was tested on lagoon sludge from the ADC site. This sludge was contaminated with VOCs and SVOCs, including 4,4-methylene bis(2-chloroaniline) (MBOCA).

The Demonstration Bulletin (EPA/540/MR-92/019) and Applications Analysis Report (EPA/540/AR-92/019) are available from EPA.

## DEMONSTRATION RESULTS:

During the demonstration, the system throughput was approximately 2.1 tons per hour. Six replicate tests were conducted, each lasting approximately 6 hours. The SITE demonstration yielded the following results:

- The LT³® system removed VOCs to below method detection limits (less than 0.060 milligram per kilogram [mg/kg] for most compounds).
- The LT³® system achieved MBOCA removal efficiencies greater than 88 percent; MBOCA concentrations in the treated sludge ranged from 3.0 to 9.6 mg/kg.
- The LT³® system decreased the concentrations of all SVOCs in the sludge, with the exception of phenol, which increased possibly due to chlorobenzene.
- Dioxins and furans were formed in the system, but the 2,3,7,8-tetra-chlorodibenzo-p-dioxin isomer was not detected in treated sludges.
- Stack emissions of nonmethane total hydrocarbons increased from 6.7 to 11 parts per million by volume during the demonstration; the maximum emission rate was 0.2 pound per day (ppd). The maximum particulates emission rate was 0.02 ppd, and no chlorides were measured in stack gases.

The economic analysis of the LT³® system's performance compared the costs associated with treating soils containing 20, 45, and 75 percent moisture. The treatment costs per ton of material were estimated to be $37, $537, and $725, respectively.

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# WHEELABRATOR CLEAN AIR SYSTEMS, INC.
## (formerly CHEMICAL WASTE MANAGEMENT, INC.)
## (PO*WW*ER™ Technology)

## TECHNOLOGY DESCRIPTION:

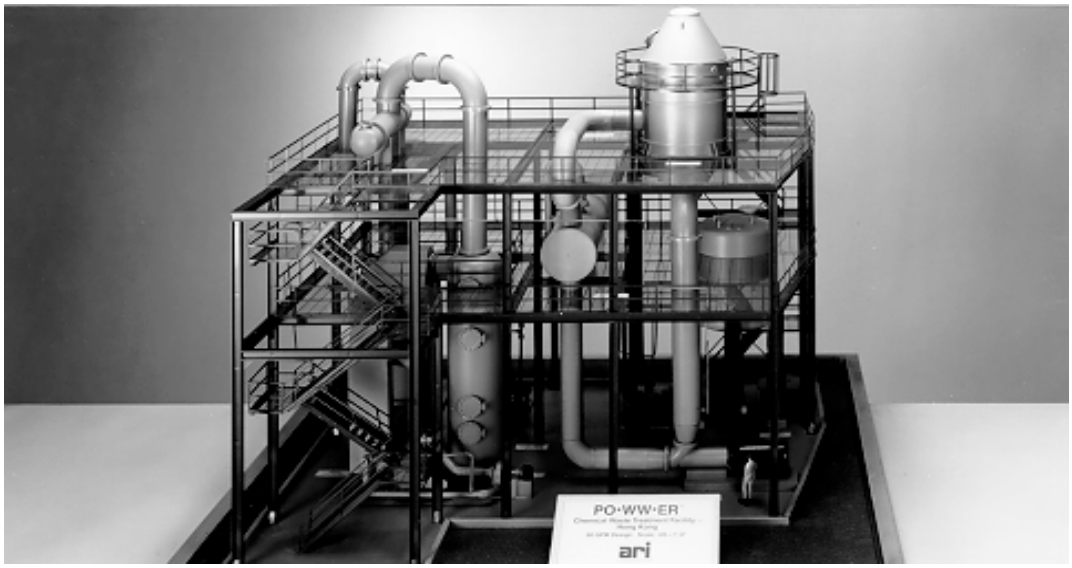
The PO*WW*ER™ technology is used to treat and reduce complex industrial and hazardous wastewaters containing mixtures of inorganic salts, metals, volatile and nonvolatile organics, volatile inorganics, and radionuclides. The proprietary technology combines evaporation with catalytic oxidation to concentrate and destroy contaminants, producing a high-quality product condensate.

Wastewater is first pumped into an evaporator, where most of the water and contaminants are vaporized and removed, concentrating the contaminants into a small volume for further treatment or disposal. The contaminant vapors then pass over a bed of proprietary robust catalyst, where the pollutants are oxidized and destroyed. Depending on the contaminant vapor composition, effluent vapors from the oxidizer may be treated in a scrubber. The vapors are then condensed to produce water (condensate) that can be used as either boiler or cooling tower makeup water, if appropriate. Hazardous wastewater can thus be separated into a small contaminant stream (brine) and a large clean water stream without using expensive reagents or increasing the volume of the total stream. The photograph below illustrates a PO*WW*ER™ - based wastewater treatment plant.

## WASTE APPLICABILITY:

The PO*WW*ER™ technology can treat wastewaters containing a mixture of the following contaminants:

| Organic | Inorganic | Radioactive |
|---|---|---|
| • Halogenated volatiles<br>• Halogenated semivolatiles<br>• Nonhalogenated volatiles<br>• Nonhalogenated semi-volatiles<br>• Organic pesticides/ herbicides<br>• Solvents<br>• Benzene, toluene, ethyl-benzene, and xylene<br>• Organic cyanides<br>• Nonvolatile organics | • Heavy metals<br>• Nonmetallic toxic elements<br>• Cyanides<br>• Ammonia<br>• Nitrates<br>• Salts | • Plutonium<br>• Americium<br>• Uranium<br>• Technetium<br>• Thorium<br>• Radium<br>• Barium |




PO*WW*ER™-Based Wastewater Treatment Plant



The SITE Program assesses but does not approve or endorse technologies.

Suitable wastewaters for treatment by the PO*WW*ER™ technology include landfill leachates, contaminated groundwaters, process wastewaters, and low-level radioactive mixed wastes.

## STATUS:

The technology was accepted into the SITE Demonstration Program in 1991. The demonstration took place in September 1992 at the Chemical Waste Management, Inc., Lake Charles, Louisiana, facility. Landfill leachate, an F039 hazardous waste, was treated in a pilot-scale unit. The Applications Analysis Report (EPA/540/AR-93/506) and Technology Evaluation Report (EPA/540/R93/506) are available from EPA.

A commercial system with a capacity of 50 gallons per minute is in operation at Ysing Yi Island, Hong Kong. A pilot-scale unit, with a capacity of 1 to 1.5 gallons per minute, is available and can treat radioactive, hazardous, and mixed waste streams.

## DEMONSTRATION RESULTS:

The ability of the PO*WW*ER™ system to concentrate aqueous wastes was evaluated by measuring the volume reduction and concentration ratio achieved. The volume of brine produced during each 9-hour test period was about 5 percent of the feed waste volume processed in the same period. The concentration ratio, defined as the ratio of total solids (TS) concentration in the brine to the TS concentration in the feed waste, was about 32 to 1.

The feed waste contained concentrations of volatile organic compounds (VOC) ranging from 320 to 110,000 micrograms per liter ($\mu$g/L); semivolatile organic compounds (SVOC) ranging from 5,300 to 24,000 $\mu$g/L; ammonia ranging from 140 to 160 milligrams per liter (mg/L); and cyanide ranging from 24 to 36 mg/L. No VOCs, SVOCs, ammonia, or cyanide were detected in the product condensate.

The PO*WW*ER™ system removed sources of feed waste toxicity. The feed waste was acutely toxic with median lethal concentrations ($LC_{50}$) consistently below 10 percent. The product condensate was nontoxic with $LC_{50}$ values consistently greater than 100 percent, but only after the product condensate was cooled and its pH, dissolved oxygen level, and hardness or salinity were increased.

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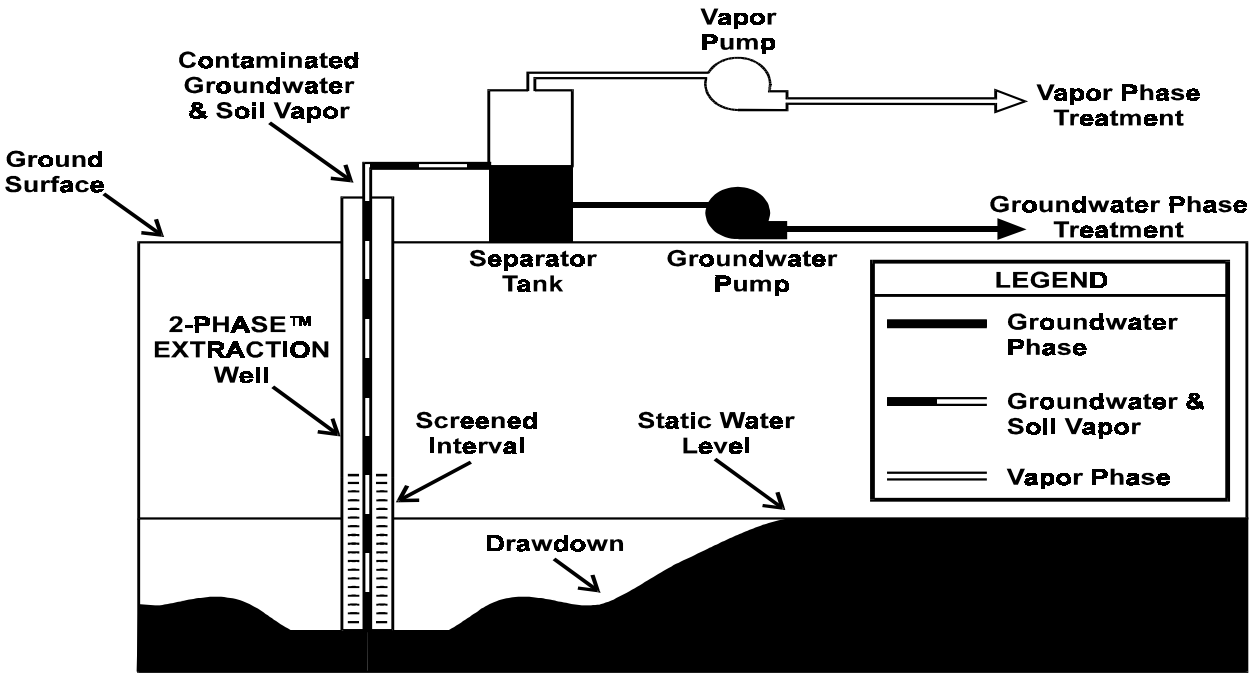
# XEROX CORPORATION
## (2-PHASE™ EXTRACTION Process)

## TECHNOLOGY DESCRIPTION:

The 2-PHASE™ EXTRACTION Process was developed as an alternative to conventional pump-and-treat technology, particularly in low conductivity formations such as silts and clays that are impacted by volatile organic compounds (VOC). 2-PHASE™ EXTRACTION uses a high-vacuum source applied to an extraction tube within a water well to increase groundwater removal rates (consequently the dissolved phase of contamination) and to volatilize and extract that portion of contaminant from the sorbed or free product phases. Vacuum lift of water is not a limiting factor in the application of the technology. Since a mixed vapor-liquid column is extracted from the well, the 2-PHASE™ EXTRACTION technology allows a single piece of equipment (a high vacuum source) to remove contaminants in both the liquid and vapor phases.

To extract both groundwater and soil vapor from a single extraction well, the 2-PHASE™ EXTRACTION process uses a vacuum pump to apply a high vacuum (generally 18 to 29 inches of mercury) through a central extraction tube, which extends down the well. Soil vapor drawn into the well by the vacuum provides for a high velocity vapor stream at the bottom tip of the extraction tube, which entrains the contaminated groundwater and lifts it to ground surface. As groundwater moves through the extraction system, as much as 95 percent of the VOCs in the water phase are transferred to the vapor phase. The vapor and water phases are then separated at the surface in a separator tank. The water phase requires only carbon polishing prior to discharge, provided that the compounds are adsorbable. With some compounds the water carbon treatment can be eliminated. The vapor phase is subjected to carbon treatment, bioremediation, resin regeneration, catalytic oxidation, or other vapor phase treatment (based on contaminant characteristics, mass loadings, and economics) prior to release to atmosphere.

A kick-start system can induce flow and help dewater the well. The flow of atmospheric air can be regulated by adjustment of the gate valve to: (1) optimize the air-to-water flow ratio to




Schematic of the 2-PHASE™ EXTRACTION Process



The SITE Program assesses but does not approve or endorse technologies.

minimize water "slug" production at startup (the term slug refers to an irregular pulsation of water through the extraction tube which indicates irregular water flow); (2) maximize tube penetration into the saturated zone; and (3) maximize the groundwater flow rate by optimizing the applied vacuum to the well's annular space.

Recent technology improvements include a well design that allows for contaminant removal from desired vertical zones within the subsurface. By providing a means to manipulate preferential flow, this innovative well design provides the ability to focus contaminant extraction at shallow zones and deep zones within the same well which results in a thorough removal of contaminants from the impacted area. Xerox and Licensee experience with 2-PHASE™ EXTRACTION typically has shown a reduction in remediation time by 1 to 2 orders of magnitude over conventional pump and treat/soil vapor extraction.

## WASTE APPLICABILITY:

2-PHASE™ EXTRACTION has been successfully demonstrated for the removal of total petroleum hydrocarbons and chlorinated hydrocarbons from groundwater and soils.

## STATUS:

The Xerox 2-PHASE™ EXTRACTION process was accepted into the SITE Demonstration Program in summer 1994. The demonstration began in August 1994 at a contaminated groundwater site at McClellan Air Force Base in Sacramento, California, and was completed in February 1995. Reports of the demonstration are available from EPA.

The Xerox 2-PHASE™ EXTRACTION received eight patents from 1991-1998 and several patents are pending. The technology is available under license and is used extensively in the United States, Canada, South America, Great Britain, and Europe.

## DEMONSTRATION RESULTS:

Results from the demonstration are detailed below:

- The total contaminant (trichloroethene, tetrachloroethene, Freon 133™) mass removal during the 6-month demonstration was estimated at 1,600 pounds, of which 99.7 percent was extracted from the vapor phase.
- The system extracted 1.4 million gallons of groundwater and 24.4 million cubic feet of soil vapor.
- The radius of capture in the groundwater extended from 100 to 300 feet from the extraction well. The radius of influence in the vadose zone extended 200 feet from the extraction well.
- The estimated cost of using the process was $28 per pound compared to an estimated $1370 per pound for a conventional pump and treat system.

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The SITE Program assesses but does not approve or endorse technologies.

# ZENON ENVIRONMENTAL INC.
## (Cross-Flow Pervaporation System)

## TECHNOLOGY DESCRIPTION:

The ZENON Environmental Inc. (ZENON), cross-flow pervaporation technology is a membrane-based process that removes volatile organic compounds (VOC) from aqueous matrices. The technology uses an organophilic membrane made of nonporous silicone rubber, which is permeable to organic compounds, and highly resistant to degradation.

In a typical field application, contaminated water is pumped from an equalization tank through a prefilter to remove debris and silt particles, and then into a heat exchanger that raises the water temperature to about 165°F (75°C). The heated water then flows into a pervaporation module containing the organophilic membranes. The composition of the membranes causes organics in solution to adsorb to them. A vacuum applied to the system causes the organics to diffuse through the membranes and move out of the pervaporation module. This material is then passed through a condenser generating a highly concentrated liquid called permeate. Treated water exits the pervaporation module and is discharged from the system. The permeate separates into aqueous and organic phases. Aqueous phase permeate is sent back to the pervaporation module for further treatment, while the organic phase permeate is discharged to a receiving vessel.

Because emissions are vented from the system downstream of the condenser, organics are kept in solution, thus minimizing air releases. The condensed organic materials represent only a small fraction of the initial wastewater volume and may be subsequently disposed of at significant cost savings. This process may also treat industrial waste streams and recover organics for later use.

## WASTE APPLICABILITY:

Pervaporation can be applied to aqueous waste streams such as groundwater, lagoons, leachate, and rinse waters that are contaminated with VOCs such as solvents, degreasers, and gasoline. The technology is applicable to the types of aqueous wastes treated by carbon adsorption, air stripping, and steam stripping.

ZENON Cross-Flow Pervaporation System



The SITE Program assesses but does not approve or endorse technologies.

## STATUS:

This technology was accepted into the SITE Emerging Technology Program (ETP) in January 1989. The Emerging Technology Report (EPA/540/F-93/503), which details results from the ETP evaluation, is available from EPA. Based on results from the ETP, ZENON was invited to demonstrate the technology in the SITE Demonstration Program. A pilot-scale pervaporation system, built by ZENON for Environment Canada's Emergencies Engineering Division, was tested over a 2-year period (see photograph on previous page). During the second year, testing was carried out over several months at a petroleum hydrocarbon-contaminated site in Ontario, Canada.

A full-scale SITE demonstration took place in February 1995 at a former waste disposal area at Naval Air Station North Island in San Diego, California. The demonstration was conducted as a cooperative effort among EPA, ZENON, the Naval Environmental Leadership Program, Environment Canada, and the Ontario Ministry of Environment and Energy.

Organics were the primary groundwater contaminant at the site, and trichloroethene (TCE) was selected as the contaminant of concern for the demonstration. The Demonstration Bulletin (EPA/540/MR-95/511) and Demonstration Capsule (EPA/540/R-95/511a) are available from EPA.

## DEMONSTRATION RESULTS:

Analysis of demonstration samples indicate that the ZENON pervaporation system was about 98 percent effective in removing TCE from groundwater. The system achieved this removal efficiency with TCE influent concentrations of up to 250 parts per million at a flow rate of 10 gallons per minute (gpm) or less. Treatment efficiency remained fairly consistent throughout the demonstration; however, the treatment efficiency decreased at various times due to mineral scaling problems.

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The SITE Program assesses but does not approve or endorse technologies.

# ZENON ENVIRONMENTAL INC.
## (ZenoGem™ Process)

## TECHNOLOGY DESCRIPTION:

ZENON Environmental Inc.'s, ZenoGem™ Process integrates biological treatment with membrane-based ultrafiltration (see figure below). This innovative system treats high strength wastes at long sludge retention time but short hydraulic residence time. As a result, the bioreactor's size is significantly reduced. Membrane filtration reduces the turbidity of the treated wastewater to less than 1 nephelometric turbidity unit.

In the ZenoGem™ Process, wastewater contaminated with organic compounds first enters the bioreactor, where contaminants are biologically degraded. Next, the process pump circulates the biomass through the ultrafiltration membrane system, or ultrafilter. The ultrafilter separates treated water from biological solids and soluble materials with higher molecular weights, including emulsified oil. The solids and soluble materials are then recycled to the bioreactor. The ZenoGem™ Process captures higher molecular weight materials that would otherwise pass through conventional clarifiers and filters. The ZenoGem™ Process pilot-scale system is mounted on a 48-foot trailer and consists of the following six major components:

- Polyethylene equalization/holding tank: reduces the normal flow concentration fluctuations in the system
- Polyethylene bioreactor tank: contains the bacterial culture that degrades organic contaminants
- Process and feed pumps: ensures proper flow and pressure for optimum system performance
- Ultrafiltration module: contains rugged, clog-free, tubular membranes that remove solids from treated water
- Clean-in-place tank: includes all the necessary valves, instrumentation, and controls to clean the membrane filters

ZenoGem™ Process



The SITE Program assesses but does not approve or endorse technologies.

- Control panel and computer: monitors system performance

The treatment capacity of the pilot-scale, trailer-mounted system is about 500 to 1,000 gallons of wastewater per day; however, a full-scale system can treat much larger quantities of wastewater. The trailer is also equipped with a laboratory that enables field personnel to conduct tests to evaluate system performance. The system is computer-controlled and equipped with alarms to notify the operator of mechanical and operational problems.

## WASTE APPLICABILITY:

The ZenoGem™ Process is designed to remove biodegradable materials, including most organic contaminants, from wastewater to produce a high quality effluent. The process consistently nitrifies organics and can denitrify organics with the addition of an anoxic bioreactor. The process is limited to aqueous media and may be used to treat high strength leachates, contaminated groundwater, and soil washing effluent.

## STATUS:

The ZenoGem™ Process was accepted into the SITE Demonstration Program in summer 1992. The ZenoGem™ Process was demonstrated at the Nascolite Superfund site in Millville, New Jersey, from September through November 1994. Groundwater at this 17.5-acre site is contaminated with methyl methacrylate (MMA) and other volatile organic compounds from manufacturing polymethyl methacrylate plastic sheets, commonly known as Plexiglas. The Demonstration Bulletin (EPA/540/MR-95/503) and Technology Capsule (EPA/540/R-95/503a) are available from EPA. The Innovative Technology Evaluation Report is available from EPA.

Since the development of the ZenoGem™ technology in 1987, ZENON has performed pilot tests for government and private clients on several different types of wastewater, including oily wastewater, metal finishing wastes, cleaning solutions containing detergents, alcohol-based cleaning solutions, landfill leachate, aqueous paint-stripping wastes, and deicing fluids. Information about the two demonstrations conducted in Canada and the United States is available from ZENON.

## DEMONSTRATION RESULTS:

During the 3-month demonstration, sampling results showed that the system achieved average removal efficiencies of greater than 99.9 percent for MMA and 97.9 percent for chemical oxygen demand. MMA concentrations measured in the off-gas emission stream indicated insignificant volatilization. The ultrafiltration system effectively dewatered the process sludge, which yielded a smaller waste volume for off-site disposal. Sludge dewatering resulted in an approximate volume reduction of 60 percent and a solids increase from 1.6 to 3.6 percent. The process effluent was clear and odorless, and accepted for discharge by the local publicly owned treatment works. During the demonstration, the system was left unattended at night and on weekends, demonstrating that computer control is practical for extended operating periods.

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# C-THRU TECHNOLOGIES CORPORATION
## (Formerly SCITEC CORPORATION)
## (Metal Analysis Probe [MAP®] Spectrum Assayer)

## TECHNOLOGY DESCRIPTION:

The C-Thru Technologies Corporation (C-Thru) Metal Analysis Probe Spectrum Assayer (see photograph below) is a field portable X-ray fluorescence (FPXRF) analyzer. This FPXRF analyzer can simultaneously analyze for select metals. It is compact, lightweight, and does not require liquid nitrogen. A rechargeable battery allows the FPXRF analyzer to be used at remote sites where electricity is unavailable.

The instrument is composed of a control console connected to an ambient scanner with a cable. The basic MAP® system also includes a carry pack, rechargeable batteries, operator's manual, target metal standard, and a shipping case. The control console contains a 256-multichannel analyzer with a storage capacity of 325 spectra and analyses. The control console with batteries weighs 11 pounds and the ambient scanner weighs about 2.5 pounds.

The MAP® Spectrum Assayer uses a silicon X-ray detector to provide elemental resolution. The unit demonstrated under the SITE Program used a Cadmium-109 radioisotope as the excitation source. Cobalt-57 and Americium-241 sources are also available.

The MAP® Spectrum Assayer is capable of analyzing 9 to 12 samples per hour based on a 240-second analysis time. The instrument is empirically calibrated by the developer. C-Thru requires a 1-day operator training and radiation safety course prior to obtaining a specific license to operate the instrument. The standard MAP® 3 Portable Assayer package used in the demonstration sold for $32,000.

The MAP® Spectrum Assayer provides high sample throughput and is reportedly easy to operate. Analytical results obtained by this instrument may be comparable to the results obtained by EPA-approved methods.

MAP® Assayer



The SITE Program assesses but does not approve or endorse technologies.

## WASTE APPLICABILITY:

The MAP® Spectrum Assayer can detect select metals in soil and sediment samples and in filter and wipe samples. It can also detect lead in paint. The MAP® Portable Assayer reportedly can quantitate metals at concentrations ranging from parts per million to percentage levels.

## STATUS:

The MAP® Spectrum Assayer has been used at a number of Superfund sites across the country. It was evaluated in April 1995 as part of a SITE demonstration of FPXRF instruments. The results are summarized in Technical Report No. EPA/600/R-97/147, dated March 1998. The instrument was used to identify and quantify concentrations of metals in soils. Evaluation of the results yielded field-based method detection limits, accuracy, and precision data from the analysis of standard reference materials and performance evaluation samples.

Comparability of the FPXRF results to an EPA-approved reference analytical method was also assessed during the demonstration. The Draft Fourth Update to SW-846 includes Method 6200, dated January 1998, which is based on this work.

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# DEXSIL CORPORATION
## (Environmental Test Kits)

## TECHNOLOGY DESCRIPTION:

The DEXSIL Corporation (Dexsil) produces two test kits that detect polychlorinated biphenyls (PCB) in soil: the Dexsil Clor-N-Soil PCB Screening Kit, and the Dexsil L2000 PCB/ Chloride Analyzer. The Dexsil Clor-N-Soil PCB Screening Kit, (see photograph below) extracts PCBs from soil and dissociates the PCBs with a sodium reagent, freeing chloride ions. These ions then react with mercuric ions to form mercuric chloride. The extract is then treated with diphenylcarbazone, which reacts with free mercuric ions to form a purple color. The less purple the color, the greater the concentration of PCBs in the sample.

The Dexsil L2000 PCB/Chloride Analyzer (see photograph on next page) also extracts PCBs from soil and dissociates the PCBs with a sodium reagent, freeing chloride ions. The extract is then analyzed with a calibrated, chloride-specific electrode. The L2000 instrument then translates the output from the electrode into parts per million (ppm) PCB.

These kits produce analytical results at different data quality levels. The Dexsil Clor-N-Soil PCB Screening Kit identifies samples above or below a single concentration, which is generally tied to regulatory action levels. The Dexsil L2000 PCB/ Chloride Analyzer quantifies specific concentrations of PCBs, from 2 to 2,000 ppm, in a sample. The applicability of these methods depends on the data quality needs of a specific project. Both technologies can be used on site for site characterization or a removal action.

Dexsil Clor-N-Soil PCB Screening Kit



The SITE Program assesses but does not approve or endorse technologies.

## WASTE APPLICABILITY:

The Dexsil Clor-N-Soil PCB Screening Kit and the Dexsil L2000 PCB/Chloride Analyzer can detect PCBs in soil, sediment, transformer oils, and water.

## STATUS:

These test kits were demonstrated at a PCB-contaminated facility in EPA Region 7. About 200 soil samples were collected and analyzed on site using the Dexsil test kits. Soil samples were not dried prior to analysis. Split samples were submitted to an off-site laboratory for confirmatory analysis by SW-846 Method 8080. Demonstration data were used to evaluate the accuracy and precision of the test kits relative to internal quality control samples and to formal laboratory data. These data were also used to determine operating costs.

The sampling and field analyses for this technology demonstration were completed in August 1992. The Innovative Technology Evaluation Report (EPA/540/R-95/518) is available from EPA. The Office of Solid Waste has designated the L2000 Method for PCB screening of soil as Method 9078, to be included in the third update to the third edition of SW-846.

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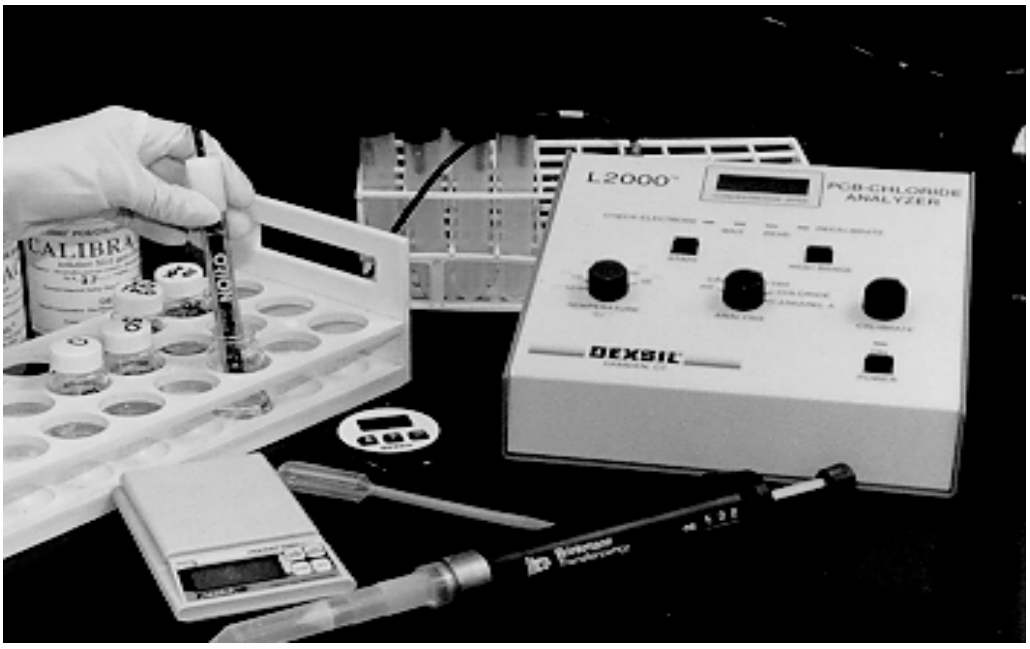


Dexsil L2000 PCB/Chloride Analyzer

# ENVIRONMENTAL TECHNOLOGIES GROUP, INC.
## (AirSentry Fourier Transform Infrared Spectrometer)

## TECHNOLOGY DESCRIPTION:

This air monitoring system (see photograph below) is a field-deployable, open-path Fourier transform infrared (FTIR) spectrometer that measures infrared absorption by infrared-active molecules. The spectrometer system transmits an infrared beam along an open air path to a retroflector target that returns it to the spectrometer. The total air path can be up to 1 kilometer long. Analysis is performed using a quantitative reference spectrum of known concentration, together with classical least squares data fitting software routines. The system does not require acquisition of an air sample; this factor assures that sample integrity is not compromised by interaction between the sample and the collection and storage system.

A measurement over several hundred meters requires only a few minutes, which allows determination of temporal profiles for pollutant gas concentrations. The spectrometer requires performance verification procedures, but does not require calibration.

## WASTE APPLICABILITY:

The AirSentry FTIR spectrometer can collect information on spectral absorption from a number of airborne vapors at one time, including both organic and inorganic compounds. This

AirSentry Fourier Transform Infrared Spectrometer



The SITE Program assesses but does not approve or endorse technologies.

information is processed to obtain the average concentration over the entire pathlength. The system has been used to monitor fugitive emissions from industrial plants and from hazardous waste sites. By combining these measurements with measurements of wind speed, emission rates can be estimated. It can be used to monitor emissions from hazardous waste sites during remediation and removal.

## STATUS:

The AirSentry FTIR spectrometer was demonstrated during a 1990 SITE study at Shaver's Farm, a Superfund site in northwest Georgia. The purpose of this demonstration was to test performance during remedial activities and to develop and test on-site quality assurance procedures. Results of this study were published in a paper titled "Use of a Fourier Transform Spectrometer As a Remote Sensor at Superfund Sites: Proceedings of the International Society for Optical Engineering" --SPIE Vol. 1433, p. 302, Measurement of Atmospheric Gases, Los Angeles, CA, 21-23 January 1991, presented at a 1991 conference.

The AirSentry FTIR spectrometer has been evaluated in several other field studies and has been proven capable of detecting various airborne atmospheric vapors. The AirSentry FTIR gas analysis software, which automatically identifies and quantifies compounds in the presence of background interferences, was evaluated in a 1991 field study sponsored by EPA Region 7. Results of this field evaluation are published in an EPA report entitled "A Field-Based Intercomparison of the Qualitative and Quantitative Performance of Multiple Open-Path FTIR Systems for Measurement of Selected Toxic Air Pollutants."

Another field evaluation of the AirSentry FTIR spectrometer was conducted at a Superfund site in January 1992. During the field evaluation, the FTIR spectrometer was compared with gas chromatography/mass spectrometry techniques using air samples collected in canisters. Results from this field evaluation are published in an EPA report titled "Superfund Innovative Technology Evaluation, The Delaware SITE Study, 1992" (EPA/600/A3-91/071).

A guidance document detailing the steps required for successful field operation of the FTIR-based open path monitoring systems is available from EPA and is referred to as Method TO-16 in the "EPA Compendium of Methods for Determination of Toxic Organic Compounds in the Ambient Air". For a copy of the draft document, contact the EPA Project Manager listed below.

This technology remains available from the Environmental Technologies Group, Inc. as well as other commercial companies. For further information about the technologoy, contact the EPA, contact the EPA Project Manager.

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# FUGRO GEOSCIENCES, INC.
## (formerly LORAL CORPORATION)
## (Rapid Optical Screening Tool)

## TECHNOLOGY DESCRIPTION:

The Fugro Rapid Optical Screening Tool (ROST ™), shown in the figure below, is an insitu screening sensor used in conjunction with Cone opentration Testing (CPT) systems that provides rapid delineation of petroleum hydrocarbons (PHC). ROST ™ characterizes the PHCs from the fluorescence response induced in the polycyclic aromatic hydrocarbon (PAH) compounds contained within the contaminant material. ROST ™ continuously detects separate phase PHCs in the bulk soil matrix in the vadose, capillary fringe, and saturated zones and provides a screening of the relative concentration present. ROST ™ also presents the spectral signature of the detected PHC, which often allows identification of the contaminant type (such as gas, diesel, coal tar,creosote, etc.). CPT testing CPT testing is conducted simultaneously with ROST ™ testing and provides real-time, in situ lithologic data. Fugro can also deploy ROST ™ from percussion-type Direct Push Technology equipment.

The measurements are performed in situ and physical sampling during the delineation phase is not required. However, since ROST ™ is a screening tool, a limited amount of confirmation soil sampling is recommended. The list of petroleum products for which this method is appropriate includes, but is not limited to: gasoline, diesel fuel, crude oil, jet fuel, heating oil, coal tar, kerosene, lubricating oils, and creosote.

Rapid Optical Screening Tool



The SITE Program assesses but does not approve or endorse technologies.

The ROST ™ methodology utilizes laser-induced fluorescence spectroscopy for PHC screening. Pulsed laser light is used to excite PAHs and is delivered via a fiber optic cable to a sub-unit mounted directly behind the CPT penetrometer probe (cone). The light is directed through a sapphire window on the side of the sub-unit and onto the surface of the soil. PAHs present within the soil absorb the excitation light and emit the absorbed energy as fluorescence. A portion of this fluorescence is returned by a collection fiber to the surface and is analyzed by the ROST ™ unit. ROST ™ measures and reports the following three fluorescence parameters in real time:

- Intensity of the fluorescence emitted by the PHC.
- Spectrum of wavelengths of light emitted by the PHC.
- Lifetime of duration of the fluorescence emitted by the PHC.

The fluorescence intensity is generally proportional to concentration and identifies the relative PHC concentration present. The fluorescence intensity is plotted continuously with depth on a computer monitor in the CPT rig as testing proceeds and allows immediate identification of affected soils. The spectral and temporal data are also presented on the computer monitor in real-time and comprise the spectral signature of the contaminant which often allows identification of product type. A log of the fluorescence intensity with depth and contaminant signatures is plotted on a printer in the CPT rig immediately following each test.

## WASTE APPLICABILITY:

The Fugro ROST ™ system is designed to qualitatively detect contaminant materials containing PAH constituents, including, but not limited to gasoline, diesel fuel, crude oil, jet fuel, heating oil, coal tar, kerosene, lubricating oils, and creosote.

## STATUS:

ROST ™ has been commercially available since September 1994 and was evaluated under the U.S. EPA's Environmental Technology Verification (ETV) program. The final report (EPA/600/R-97/020), dated February 1997 is available from EPA or may be downloaded from the EPA's web site (*http://clu-in.com/csct/verstate.htm*).

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# GEOPROBE SYSTEMS
## (Large Bore Soil Sampler)

## TECHNOLOGY DESCRIPTION:

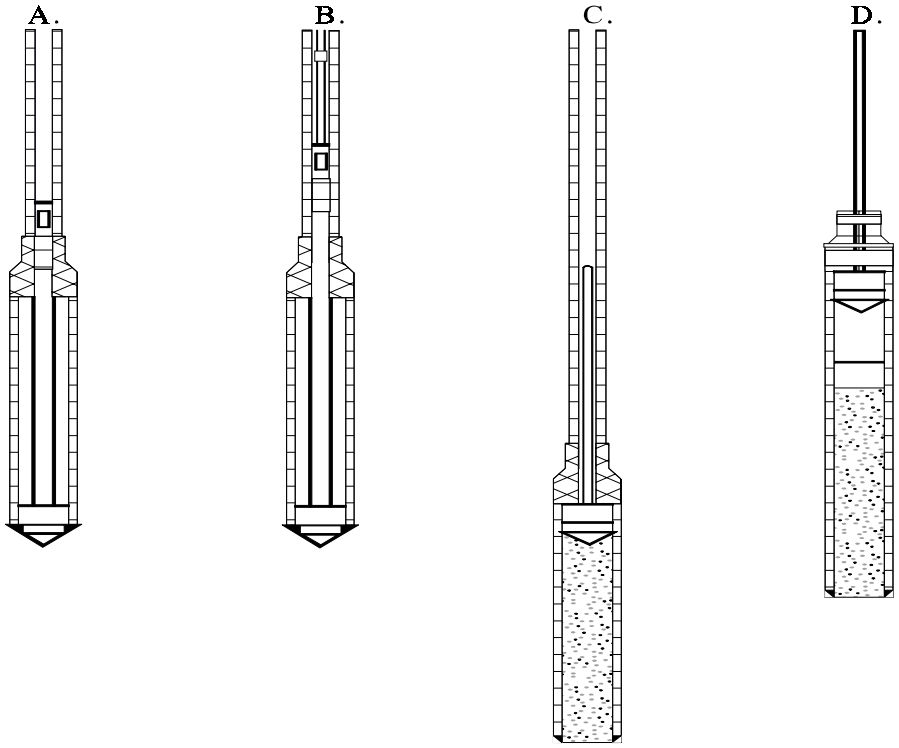
The Large Bore Soil Sampler is a single tube-type, solid barrel, closed-piston sampler (see figure below). It is designed to be driven by the Geoprobe percussion probing machine to collect discrete interval soil samples but can be used for continuous coring if needed. This direct push type sampler is for use in unconsolidated soils. It is capable of recovering a soil core 22 inches long by 1-1/16 inches in diameter (320 millilter (mL) volume). A liner is inserted inside the sampler body to retain the sample after collection and to facilitate removal from the sampler body. Liner materials are available in brass, stainless steel, teflon, and clear plastic (cellulose acetate butyrate).

## WASTE APPLICABILITY:

The Large Bore Soil Sampler can be used to collect soil samples for both organic and inorganic analytes when appropriate liner materials are used. The sampler has been used to collect samples to be analyzed for herbicides, pesticides, polychlorinated biphenyls (PCBs), semivolatile organic compounds, aromatic and halogenated volatile organic compounds (VOCs), petroleum fuels, metals, nitrates, dioxins and furans.

## STATUS:

Geoprobe's Large Bore Soil Sampler was demonstrated under the SITE program during the




A. Driving the sealed Sampler
B. Removing the stop pin
C. Collecting a sample
D. Recovering the sample liner



The SITE Program assesses but does not approve or endorse technologies.

early summer of 1997. The demonstration results indicate that the Large-Bore Soil Sampler can provide useful, cost-effective samples for environmental problem solving. However, in some cases, VOC data collected using the Large Bore Soil Sampler may be statistically different from VOC data collected using the reference sampling method. Also, the integrity of a lined sample chamber may not be preserved when the sampler is advanced through highly contaminatedzones in clay soils. Demonstration results are documented in the "Environmental Technology Verification" report for the sampler dated August 1998 (EPA/600/R-98/092).

There are several hundred Geoprobe owner/operators who use the Large Bore Soil Sampler for geo-environmental investigations. This soil sampler has been used in all 50 states and several foreign countries to complete thousands of projects. It is used primarily for geo-environmental investigations to define soil types and delineate contaminant distribution. The Large Bore Soil Sampler is available in stock from Geoprobe Systems. Geoprobe has developed other soil and groundwater sampling tools that are also widely used in the geo-environmental field.

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# GEOPROBE SYSTEMS
## (Geoprobe Soil Conductivity Sensor)

## TECHNOLOGY DESCRIPTION:

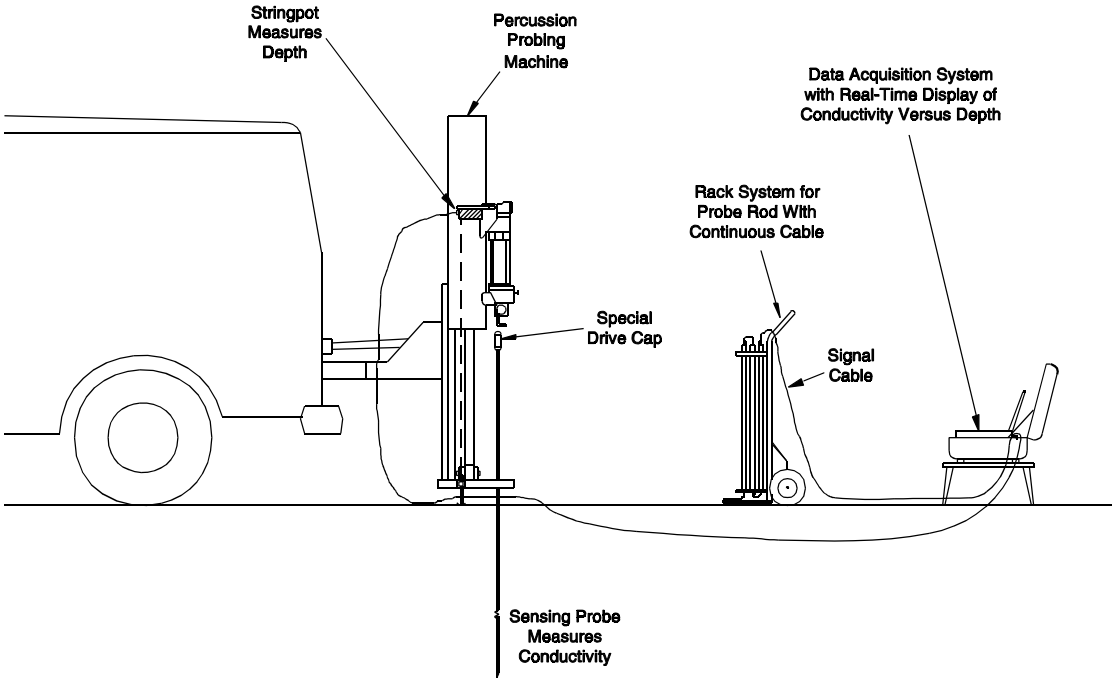
The Geoprobe soil conductivity sensor, shown in the figure below, identifies lithology and potential contamination by measuring the electrical conductivity of soil and hydrogeologic fluids. Soils vary in their electrical conductivity depending on particle size; for example, clays and silts generally have high conductivities, while sand and gravels exhibit low conductivities. Overall, soil and rock are resistant to current. Pore fluids and the amount of dissolved solids in these fluids also influence soil conductivity.

The Geoprobe conductivity sensor uses an isolated array of sensing rings to measure this conductivity. The sensor is principally designed to help determine subsurface stratigraphy. The sensor may also help characterize subsurface contamination, especially where high conductivity leachates or brines are involved.

The principal components of the complete Geoprobe system are as follows:

- A Geoprobe hydraulic soil probing machine
- Standard sampling rods supplied with the system
- A cable, threaded through the sampling rod that introduces the current
- The conductivity sensor
- A data receiver connected to a personal computer to record the sensor's measurements

The hydraulic probing machine uses a combination of pushing and hammering to advance 3-foot-long segments of 2.54-centimeter-diameter hollow steel sampling rods. The conductivity sensor is attached to the lead section of the sampling rod.




Schematic Diagram of the Geoprobe Soil Conductivity Sensor



The SITE Program assesses but does not approve or endorse technologies.

The conductivity sensor consists of four stainless-steel contact rings fitted around a central steel shaft. Plastic electronically isolates the contact rings from the steel shaft. A hollow steel rod extends above the uppermost stainless steel ring, housing a shielded signal cable that connects the contact rings with an external power source, measurement system, and data logging system. The soil conductivity sensor can be used in a dipole array or a Schlumberger array. The dipole array is used when greater resolution is required. The Schlumberger array is generally used when optimal soil-to-probe contact cannot be maintained.

## WASTE APPLICABILITY:

The Geoprobe conductivity sensor is designed to determine subsurface stratigraphy. Only highly conductive contaminants such as oil field brine can be directly measured by the sensor.

## STATUS:

The Geoprobe conductivity sensor field demonstration was conducted in September 1994. The report is available.

Improvements to the unit include the availability of stronger 1.25-inch diameter probe rods, more durable probes, dipole-type probes used for dipole measurements, and expendable probes for use when grouting is required.

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# GRASEBY IONICS, LTD., and PCP, INC.
## (Ion Mobility Spectrometry)

## TECHNOLOGY DESCRIPTION:

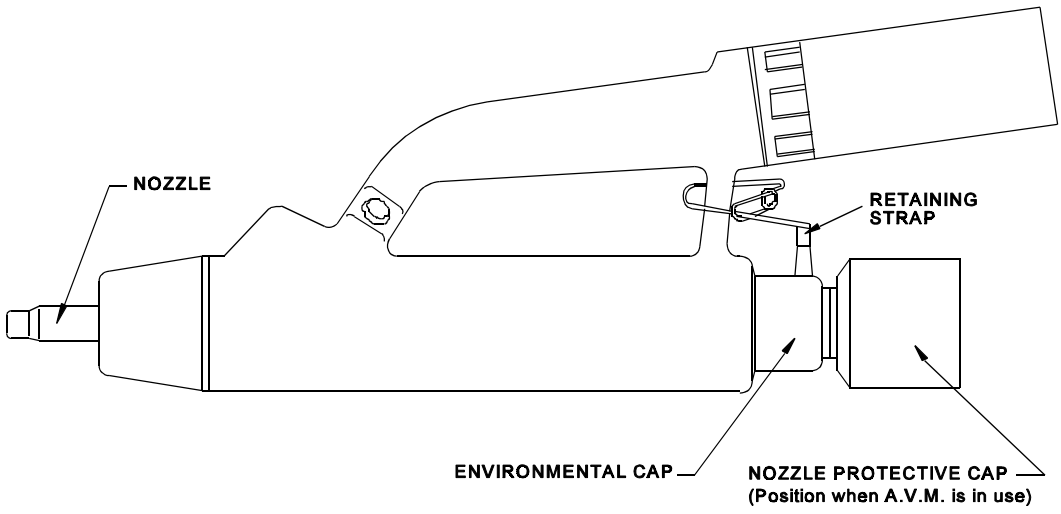
Ion mobility spectrometry (IMS) is a technique used to detect and characterize organic vapors in air. IMS involves the ionization of molecules and their subsequent temporal drift through an electric field. Analysis and characterization are based on analyte separations resulting from ionic mobilities rather than ionic masses; this difference distinguishes IMS from mass spectrometry. IMS operates at atmospheric pressure, a characteristic that has practical advantages over mass spectrometry, allowing a smaller analytical unit, lower power requirements, lighter weight, and easier use. These factors may facilitate use of IMS for mobile, field applications.

## WASTE APPLICABILITY:

The IMS units, which are intended to be used in a preprogrammed fashion, can monitor chloroform, ethylbenzene, and other volatile organic compounds in a defined situation. IMS units can analyze air, vapor, soil, and water samples. However, for analysis of liquid and solid materials, the contaminants must be introduced to the instrument in the gas phase, requiring some sample preparation.

## STATUS:

Graseby Ionics, Ltd. (Graseby), and PCP, Inc. (PCP), participated in a laboratory demonstration in 1990. Graseby used a commercially available,self-contained instrument that weighs about 2 kilograms (kg) (see figure below). PCP used a larger (12 kg) transportable IMS. This laboratory demonstration was the first opportunity to test the instruments on environmental samples. The demonstration results highlighted that the following needs must be satisfied before IMS is ready for field applications:




Airborne Vapor Monitor for IMS



The SITE Program assesses but does not approve or endorse technologies.

- Additional development of sampling or sample preparation strategies for soil and water analysis.
- Improvements in the design and performance of IMS inlets, in conjunction with the development of sampling and presentation procedures.

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# HANBY ENVIRONMENTAL LABORATORY PROCEDURES, INC.

**(Test Kits for Organic Contaminants in Soil and Water)**

## TECHNOLOGY DESCRIPTION:

Hanby Environmental Laboratory Procedures, Inc. (H.E.L.P), field test kits for soil and water (as shown in the figure below) provide rapid, sensitive analyses for a broad range of organic contaminants. The kits have been used at spill and leak sites for petroleum substances including fuels, solvents, oils, pesticides, herbicides, and indirectly wood preservatives such as pentachlorophenols (PCP). The test kit methods are based on simple extraction and colorimetric procedures using Friedel-Crafts (F-C) chemical reactions. During analyses for PCPs suspended in diesel fuel carrier solvent, where the actual analyte does not undergo F-C reactions, it is necessary to perform other analyses to determine the ratio of the target compound to the detected carrier solvent. At locations where the type of contaminant is known, such as gasoline or diesel fuel sites, the appropriate calibration photograph for the substance is used which provides precise quantitative analytical information. Alternatively, H.E.L.P. provides a portable spectrophotometer which reads the sample results, identifying a wider variety of chemicals.

The test kits provide the equipment and reagents to perform 15 soil or water samples. Soil tests are performed using the following steps:

- Using the electronic balance, weigh 5 grams of soil into a beaker.
- Empty one solvent ampule into the beaker.
- Stir the sample for 2 minutes (extraction).
- Pour extract from the beaker into one of the sample test tubes.

Hanby Test Kit



The SITE Program assesses but does not approve or endorse technologies.

- Empty one catalyst powder vial into the test tube, cap and shake for 3 minutes.
- Compare the developed color of the sample to the appropriate calibration photograph, or insert the test tube into the spectrophotometer for readout.

Water testing is performed in a similar manner, except that the extraction procedure is performed on a 500-milliliter water sample in a separatory funnel which comes with the water test kit.

## WASTE APPLICABILITY:

H.E.L.P. field test kits analyze aromatic, halogenated, and other compounds which participate in F-C reactions. These compounds include the complete range of fuel types such as gasoline, diesel fuel, and jet fuel, as well as all types of crude oils. The test kits are also used for the measurement of many other types of substances such as new and used motor oils, transformer oils, hydraulic fluids, and other types of organic liquids which contain only small amounts of F-C reacting compounds. The intense color of these reactions allows sensitivities of detection from 1 to 25 parts per million (ppm).

The availability of two solvent types for the kits provides a range from 1 ppm (with the lower range solvent) to 100,00 ppm (with the high range solvent).

## STATUS:

The H.E.L.P. test kit was used to indirectly screen and quantify PCP contamination in soils for a SITE demonstration in Morrisville, North Carolina in August 1993, using samples collected from a wood preserving site in Winona, Missouri. These samples contained PCP in a diesel carrier solvent. When the ratio of carrier solvent to PCP was constant, the PCP concentration data obtained using the H.E.L.P. test kit correlated well with sample splits analyzed at an off-site laboratory. Results from the demonstration have been published in an Innovative Technology Evaluation Report (EPA/540/R-95/514), which is available from EPA.

The field test kits and the associated spectrophotometer, the H.E.L.P. MATE 2000, were selected by the U.S. Department of Commerce and EPA Rapid Commercialization Initiative (RCI) as representative of "best available demonstrated technology" in March 1996. The technologies selected for RCI was demonstrated and assessed by EPA, the U.S. Departments of Energy, Commerce, and Defense, the California EPA, the Western Governor's Association, and the Southern States Energy Board throughout 1996 and 1997.

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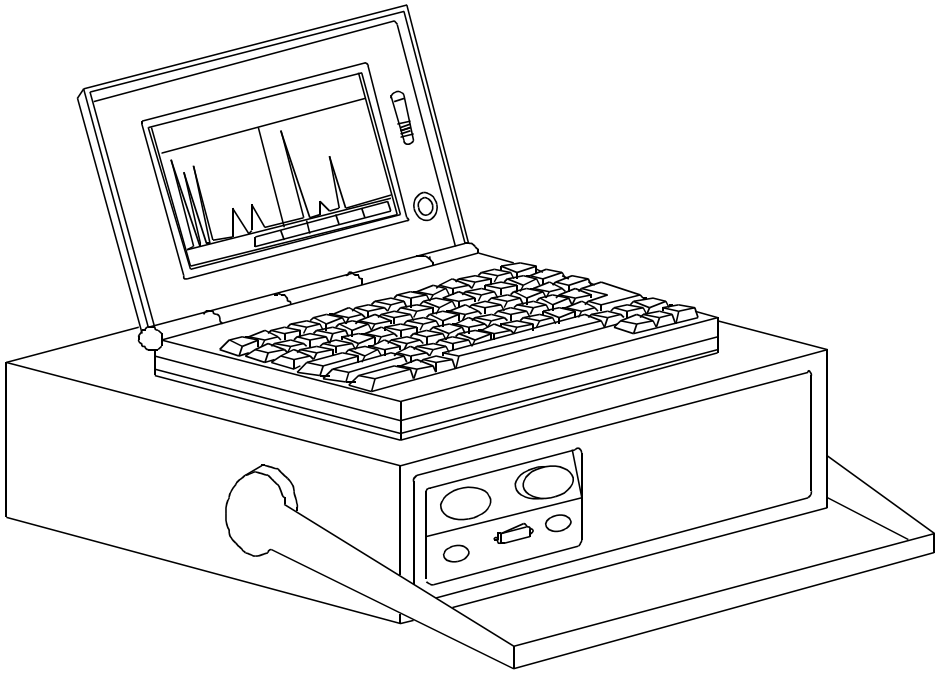
# HEWLETT-PACKARD COMPANY
## (via acquisition of MTI Analytical Instruments, Inc.)
## (Portable Gas Analyzer/HP Micro GC)

## TECHNOLOGY DESCRIPTION:

The Hewlett-Packard (HP) portable gas analyzer, shown below, is a multi-channel, high- speed, portable micro gas chromatograph (GC) that provides isothermal analysis of gas-phase samples. The injector and thermal conductivity detector (TCD) are micro-electromechanical systems (MEMS). That is, they are fabricated from silicon using micro-machining techniques similar to that used to produce microprocessors, microcircuits, etc. As a result these chromatographic components are extremely small and exhibit extremely high reliability and performance. Depending on the analysis requirements, these two components are combined with one of a series of high performance/microbore capillary columns (ranging from 0.25 to 14 meters in length and 0.150-0.32 mm inside diameter [ID]) into an individually programmable analysis channel. Up to four independent, optimized analyses (separations) of a single gas sample can be performed simultaneously in a single instrument.

A gas sample is drawn into a sample loop with an internal vacuum pump. An aliquot of the sample is then introduced into the capillary column using the microvalves contained within the micro-machine injector. The maximum analysis time for components up to C10 is 160 seconds or less, making the HP Micro kGC oneof the fastest commercially available gas chromatographs.



P200 Gas Analyzer



The SITE Program assesses but does not approve or endorse technologies.

The HP portable gas analyzer houses an internal sealed lead acid battery and small refillable carrier gas cylinder providing providing up to 8 hours of continuous operation. When combined with a laptop computer and instrument control/data analysis software, the HP portable gas analyzer is fully capable of field operation.

## WASTE APPLICABILITY:

The HP portable gas analyzer can detect many volatile organic compounds (VOC) at concentrations as low as 1 ppm. A heated sample inlet system enables the gas analyzer to detect higher boiling compounds like naphthalene and hexachlorobutadiene. When combined with an air sampler/pre-concentrator (ex. Entech, Tekmar/Dohrmann) detection limits in the range of 1 to 10 parts per billion for EPA Method TO-14 compounds can be obtained.

The HP portable gas analyzer can be employed for the analysis of soil gases, VOC contaminants in groundwater, and, with the use of an air sampler/pre-concentrator device, VOCs in ambient air. The micro TCD is suitable for analyzing many types of organic and inorganic vapor-phase compounds. The HP portable gas analyzer can be used as part of a system to monitor VOC emissions from hazardous waste sites as part of first site assessment activities and as part of a remediation program. Because of its portability, high analytical speed, and relatively low detection limit, the gas analyzer provides results of comparable quality to laboratory based analysis instruments, including gas chromatography/mass spectrometry (GC/MS).

## STATUS:

The P200 gas analyzer was evaluated during a field study in August 1995. During the study, downwind vapors from an artificial source generator were analyzed. Preliminary results of the demonstration were presented in an article titled "Performance Comparison of Field-Deployable Gas Chromatographs with Canister TO-14 Analyses" in the *Proceeding of the 1996 U.S. EPA/Air and Waste Management Association International Symposium*, VIP-64, 1996.

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# HNU SYSTEMS, INC.
## (HNU GC 311D Portable Gas Chromatograph)

## TECHNOLOGY DESCRIPTION:

The field-deployable HNU GC 311D portable gas chromatograph monitors a wide range of compound emissions from hazardous waste sites and other emissions sources before and during remediation (see photograph below). It has an internal carrier gas supply, operates on 110-volt line power, is microprocessor-controlled, and is temperature programmable. An internal printer plots chromatograms and prints data. Data can also be reported to an external computer, which is connected through an RS-232 outlet.

The instrument has simultaneous dual-detector capability and allows the user to choose from four interchangeable detectors: photoionization, flame ionization, electron-capture, and far ultraviolet absorbance. Capillary columns of all sizes can be installed. The instrument is capable of autosampling.

## WASTE APPLICABILITY:

The HNU GC 311D is applicable to a wide variety of vapor-phase pollutants. The photoionization detector is sensitive to

HNU GC 311D Portable Gas Chromatograph



The SITE Program assesses but does not approve or endorse technologies.

compounds that ionize below 11.7 electron volts, such as aromatic compounds and unsaturated halocarbons. The flame ionization detector is sensitive to hydrocarbons. The electron-capture detector is sensitive to halocarbons and polychlorinated biphenyls. The far ultraviolet absorbance is a universal detector with characteristics similar to that of a thermal conductivity detector (TCD).

## STATUS:

The instrument was evaluated in January 1992 at a Superfund site under remediation. Results from the demonstration are presented in a peer-reviewed article entitled "Evaluation of Portable Gas Chromatographs" in the *Proceedings of the 1993 U.S. EPA/Air and Waste Management Association International Symposium*, VIP-33, Volume 2, 1993. A final report will not be prepared.

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# HNU SYSTEMS, INC.
## (HNU Source Excited Fluorescence Analyzer-Portable [SEFA-P] X-Ray Fluorescence Analyzer)

## TECHNOLOGY DESCRIPTION:

HNU Systems, Inc. developed the Source Excited Fluorescence Analyzer - Portable (SEFA-P), a portable X-ray technology, to selectively determine metals concentrations in soils and other media at hazardous waste sites or industrial locations. Three excitation sources are offered with the SEFA-P X-ray fluorescence (XRF) Analyzer: Iron-55, Cadmium-109, and Americium-241. The SEFA-P is shown in the photograph below.

The SEFA-P in its most basic form consists of the following components: one main cabinet that encloses the sample chamber; the excitation sources; a liquid nitrogen-cooled Si(Li) detector; a preamplifier; spectrometer electronics; a multi-channel analyzer (MCA); and a battery charger. The internal battery can power the MCA for 8 hours. The MCA has an RS-232 interface that allows the SEFA-P to be externally controlled through a PC or laptop computer. The SEFA-P weighs approximately 50 pounds.

Source Excited Fluorescence Analyzer-Portable (SEFA-P) XRF Analyzer



The SITE Program assesses but does not approve or endorse technologies.

The SEFA-P can be calibrated empirically or using the Compton ratio. Quantitative results for samples are displayed on the PC screen in units of parts per million. The SEFA-P only analyzes soil samples in the intrusive mode; soil samples are placed in sample cups prior to analysis. After calibrating the unit, analyzing quality control samples, and preparing samples, it is possible to analyze 30 to 50 samples in an 8- to 10-hour day.

The SEFA-P is sold with a general license, so the operator does not have to be specifically licensed in each state in which it is used. As of 1995, the SEFA-P retailed for approximately $45,000, depending on the options included. This price includes one in-house operational training course.

## WASTE APPLICABILITY:

The SEFA-P can detect elements from aluminum through uranium in soil or other media, such as those elements at mining and smelting sites, drum recycling facilities, or plating facilities. The instrument can provide real-time, on-site analytical results during field screening and remedial operations. XRF analysis is faster and more cost-effective compared to conventional laboratory analysis.

## WASTE APPLICABILITY:

The SEPA-A has been used at a number of Superfund sites across the country. A SITE demonstration of the SEFA-P was conducted in February 1995 and summarized in Technical Report No. EPA/600/R-97/144, dated March 1998. The instrument was used to identify and quantify concentrations of metals in soils. The report gives field-based method detection limits, accuracy, and precision data from the analysis of standard reference materials and performance evaluation samples. Comparability of the XRF results to an EPA-approved reference laboratory method was also assessed. The draft fourth update to SW-846 includes Method 6200, dated January 1998, which incorporates the results of the SITE demonstration.

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# IDETEK, INC.
## (formerly BINAX CORPORATION, ANTOX DIVISION)
## (Equate® Immunoassay)

## TECHNOLOGY DESCRIPTION:

The Equate® immunoassay (see photograph below) uses an anti-benzene, toluene, and xylene (BTX) polyclonal antibody to facilitate analysis of BTX in water. A hapten-enzyme conjugate mimics free BTX hydrocarbons and competes for binding to the polyclonal antibody immobilized on a test tube. After the test tube is washed to remove unbound conjugate, a substrate chromogen mixture is added and a colored enzymatic reaction product forms. The enzymatic reaction is stopped by adding a few drops of sulfuric acid, which colors the enzymatic product yellow.

As with other competitive enzyme-linked immunosorbent assays, the color intensity of the enzymatic product is inversely proportional to the sample analyte concentration. Each sample is run with a reference sample of deionized water. The optical density of the colored enzymatic product is read on a portable digital colorimeter equipped with a filter that passes light at a peak wavelength of 450 nanometers. The ratio of the sample to the reference optical density values is used to estimate the aromatic hydrocarbon level in the low parts per million (ppm) range. The test is sensitive to about 1 ppm and requires 5 to 10 minutes per analysis.

## WASTE APPLICABILITY:

The Equate® immunoassay is designed to measure BTX in water.

Equate® Immunoassay Kit



The SITE Program assesses but does not approve or endorse technologies.

## STATUS:

The National Exposure Research Laboratory-Las Vegas evaluated several versions of the Equate® immunoassay. The evaluation focused on cross-reactivity and interference testing and on analysis of benzene, toluene, ethylbenzene, and xylene and gasoline standard curves.

As a preliminary field evaluation, the Equate® immunoassay was used to analyze in duplicate five well samples and a creek sample, both in the field and the laboratory. Confirmatory analysis was conducted using purge-and-trap gas chromatography with an electron-capture detector, in parallel with a photoionization detector.

A SITE demonstration of the Equate® immunoassay was conducted in 1992. Results from this demonstration were published in June 1994 in an EPA report entitled "Superfund Innovative Technology Evaluation (SITE) Program Evaluation Report for Antox BTX Water Screen (BTX Immunoassay)" (EPA/540/R-93/518).

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# METOREX, INC.
## (Field Portable X-Ray Fluorescence Analyzers)

## TECHNOLOGY DESCRIPTION:

Metorex, Inc. (Metorex), manufactures, sells, leases, and provides analytical and repair services for its X-MET line of field portable X-ray fluorescence (FPXRF) analyzers. The latest X-MET models in this series of instruments are the X-MET 920 and X-MET 2000 systems. The X-MET 920 series includes the X-MET 920-P and 920-MP. The X-MET analyzers are specifically calibrated for on-site or in situ hazardous waste analysis. These analyzers provide rapid, nondestructive measurements of inorganic contaminants in soil, thin film such as lead in paint, or water matrices.

Each X-MET 920 series analyzer is built from modules into systems based on customers' analytical and logistical needs. The X-MET PC System (XPCS) can either be built into the expansion slot of the computer or is provided as a standalone, battery-operated XPCS module for direct interface to a computer's RS-232 port.

The X-MET 920-P is equipped with either a solid state Si(Li) gas-filled proportional counter detector or the other new SIPS detector contained in a hand-held probe. The X-MET 920 MP is equipped with a gas-filled proportional counter detector contained in a hand-held probe.

The 920 X-MET, equipped with a Si(Li) detector, dual radioisotope sources, and a portable sealed computer, sells for $47,950. The X-MET 920 MP sells for $36,325 and the X-MET 2000 sells for $62,430. These prices include factory training for two people at the Metorex facility. The X-MET can also be leased from Metorex.

The basic analyzer configuration includes the PC, XRF software, XPCS, and the analysis probe with excitation source. The XPCS contains a 2,048-channel multichannel analyzer that collects, analyzes, and displays the X-ray pulse-height spectrum. The high-resolution Si(Li) detector is liquid-nitrogen cooled by a 0.5-liter dewar built into the probe. The gas-filled proportional detector and SIPS intrinsic silicon pin diode detector operates at ambient temperatures. Metorex offers iron-55, cadmium-109, and americium-241 radioisotope excitation sources. Dual source configurations are available.

The X-MET 940 was tested as a prototype, which evolved into the X-MET 2000. It is essentially the same instrument as the X-MET 920-P but has a smaller, lighter physical configuration.

The X-MET 2000 is a custom, miniaturized, field-hardened, battery-operated, DOS-based computer that is dedicated to field XRF application. The system uses a flash or electronic hard disk to provide extreme durability under field operating conditions. It is among the smallest, lightest commercially available FPXRF with the full range of analytical capabilities.

All software is menu driven. These instruments are factory-calibrated and can be field-calibrated using either empirical calibration (all probes) or standardless-fundamental parameters (FP). For the Si(Li) probe, empirical calibration requires a set of site-typical or analyzed site-specific samples for the initial calibration. FP calibration requires one certified standard. Metorex claims that 50 or more soil samples can be analyzed in


The SITE Program assesses but does not approve or endorse technologies.

an 8- to 10-hour day with intrusive sampling, rigorous sample preparation, and long measurement times (200 to 300 seconds per sample) and up to 200 samples per day with in situ screening and short (10 to 100 seconds per sample) measurement times. The 920 X-MET, equipped with a Si(Li) detector, dual radioisotope sources, and a portable sealed computer, sells for $47,950. The X-MET 920 MP sells for $36,325 and the X-MET 2000 sells for $62,430. These prices include factory training for two people at the Metorex facility. The X-MET can also be leased from Metorex.

## WASTE APPLICABILITY:

The X-MET 2000 technology is designed to identify more than 60 elements in soil or other matrices, such as those at mining and smelting sites, drum recycling facilities, or plating facilities. The instrument can provide real-time, on-site analytical results during field screening and remediation operations. FPXRF analysis is faster and more cost-effective compared to conventional laboratory analysis.

## STATUS:

The X-MET 920-P, 920-MP, and 940 were evaluated under the SITE Program in April 1995. The evaluation is summarized in technical reports EPA/600/R-97/146 for the 920-P and 940 and EPA/600/R-97/151 for the 920-MP, both dated March 1998. The instruments were used to identify and quantify concentrations of metals in soils. Evaluation of the results yielded field-based method detection limits, accuracy, and precision data from the analysis of standard reference materials and performance evaluation samples. Comparability of the FPXRF results to an EPA-approved reference laboratory method was also assessed. The draft fourth update to SW-846 includes Method 6200, dated January 1998, which incorporates the results of the SITE study.

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# MICROSENSOR SYSTEMS, INCORPORATED
## (MSI-301A Vapor Monitor)

## TECHNOLOGY DESCRIPTION:

The MSI-301A vapor monitor is a portable, temperature-controlled gas chromatograph with a highly selective surface acoustic wave detector and an on-board computer (see photograph below). The MSI-301A vapor monitor performs the following functions:

- Preconcentrates samples and uses scrubbed ambient air as a carrier gas
- Analyzes a limited group of preselected compounds, such as benzene, toluene, and xylenes, at part per billion levels
- Operates by battery and includes an RS-232 interface
- Operates automatically as a stationary sampler or manually as a mobile unit

## WASTE APPLICABILITY:

The MSI-301A vapor monitor can monitor many volatile organic compound emissions from hazardous waste sites and other sources before and during remediation. Some specific applications of the microsensor technology include OSHA compliance monitoring, environmental ambient air analysis, carbon bed breakthrough analysis, and industrial manufacturing area emission monitoring.

MSI-301A Vapor Monitor



The SITE Program assesses but does not approve or endorse technologies.

## STATUS:

In January 1992, the MSI-301A vapor monitor was evaluated in the field at a Superfund site. Results from the demonstration are presented in a peer-reviewed article entitled "Evaluation of Portable Gas Chromatographs" in the *Proceedings of the 1993 U.S. EPA/Air and Waste Management Association International Symposium*, VIP-33, Volume 2, 1993.

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# NITON CORPORATION
## (XL Spectrum Analyzer)

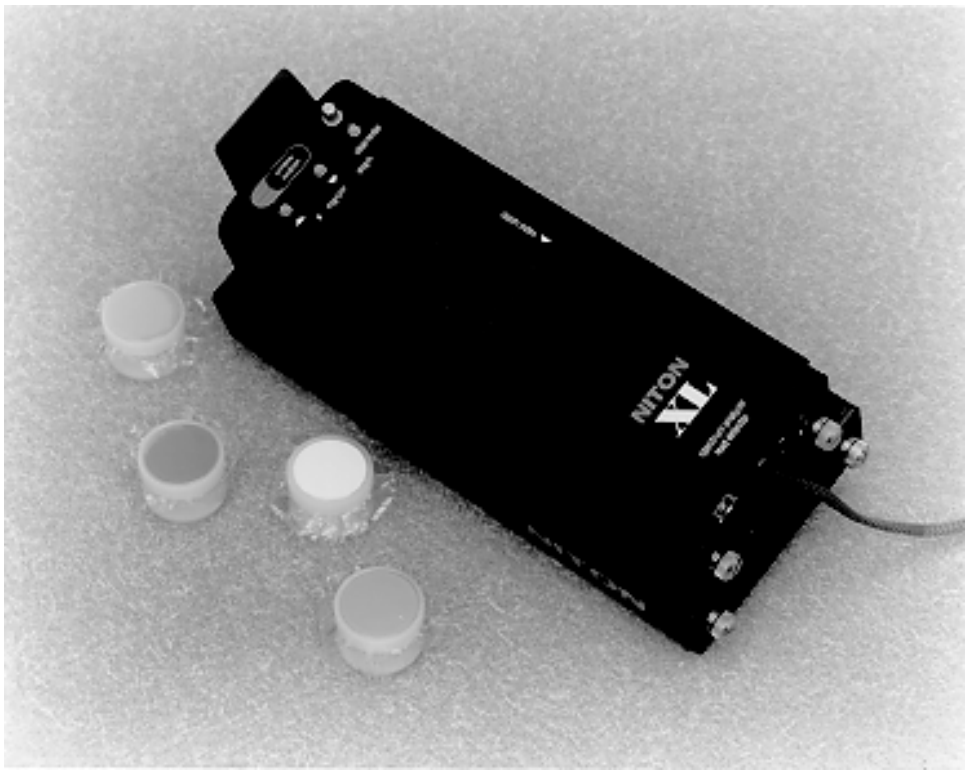
## TECHNOLOGY DESCRIPTION:

NITON Corporation (Niton) manufactures and services the XL Spectrum Analyzer, the XL-309 Lead Detector, the 700Series multi-element analyzers, and the 800Series alloy analyzers. All are hand-held, field portable X-ray fluorescence (FPXRF) instruments.

The XL Spectrum Analyzer allows in situ and prepared-sample, on-site measurement of lead in paint, soils, dust wipes, coatings and air. Lead paint analysis is accepted by EPA, and NIOSH Method 7702 is in place for airborne lead analysis. The 700Series is the multi-element analyzer. This instrument analyzes many elements, including all eight RCRA metals, in soils, filter media, and coatings (see photograph below).

The NITON XL-309 lead detector includes a cadmium-109 radioactive source (10 millicurie) that provides the excitation energy that produces characteristic fluorescent X-rays from a sample The 700Series can be equipped with a cadmium-109 source, americium-241 source, or both. Future releases will also provide an iron-55 source or curium-244 source. All XL-309 instruments can be upgraded to any 700Series instrument at any time. The 800Series alloy analyzers are designed for rapid sorting and identification of metal alloys and scrap metals.

The instrument includes a silicon Pin-diode detector (or a silicon diode plus cadmium-zinc-telluride detector for lead paint analysis), cooled by the thermoelectric Peltier effect. The instrument also includes (1) a multichannel analyzer of 1,024 channels, (2) an RS-232 serial port for data transfer and printing, (3) an internal memory for storing up to 3000 readings with spectra, and (4) a back-lit graphic liquid crystal display.




XL Spectrum Analyzer



The SITE Program assesses but does not approve or endorse technologies.

The instrument self-calibrates its energy scale and uses a Compton backscatter calibration technique for soil testing. Alloy analysis is performed using fundamental parameters. The backscatter calibration compensates for X-ray absorption in the soil matrix. The instrument is equipped with a removable battery pack that provides up to 8 hours of continuous use. It can analyze 20 to 25 samples per hour, based on a 60-second analysis time and minimal sample preparation.

The complete instrument, shown in the photograph above, weighs less than 3 pounds. NITON requires a 1-day operator training and radiation safety at no charge. The course awards a certification maintenance point to Certified Industrial Hygienists who attend. NITON manufactures the Spectrum Analyzers under both general and specific licenses with the State of Rhode Island.

Instrument costs range between $14,000 and $37,000, depending on number of applications and radioactive sources. Prices include two battery packs and charger, automotive power adapter, cable for serial data downloading, waterproof carrying case, operating and safety manual, barcode wand, personal computer software, all necessary hardware accessories and calibration check standards, and a 15-month warranty.

## WASTE APPLICABILITY:

The NITON Spectrum Analyzer can detect more than 20 elements in soil samples, such as those obtained from lead-contaminated residences, mining and smelting sites, drum recycling facilities, and plating facilities.

The instrument can provide real-time, on-site analytical results during field screening and remediation operations. FPXRF analysis is faster and more cost effective compared to laboratory analysis.

## STATUS:

The NITON Spectrum Analyzer was demonstrated under the SITE Program in April 1995. The results are summarized in Technical Report No. EPA/600/R-97/150, dated March 1998. The instrument was used to identify and quantify concentrations of metals in soils. A preliminary evaluation of the results yielded field-based method detection limits, accuracy, and precision data from the analysis of standard reference materials and performance evaluation samples. Comparability of the FPXRF results to an EPA-approved reference laboratory method was also assessed. The Draft Fourth Update to SW-846 includes Method 6200, dated January 1998, which is based on this work.

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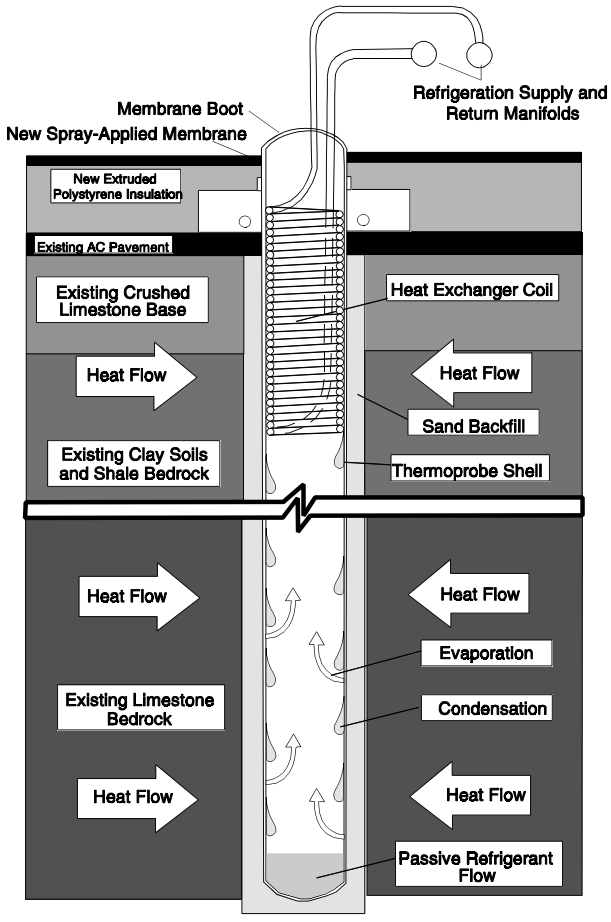
# ARCTIC FOUNDATIONS, INC.
## (Cryogenic Barrier)

## TECHNOLOGY DESCRIPTION:

Long-term containment and immobilization of hazardous wastes using ground freezing technology is a relatively new field, even though ground freezing has been used as a temporary construction aid for several years. Ground freezing is ideally suited to control waterborne pollutants, since changing water from a liquid to a solid has an obvious immobilizing effect. The challenge for conventional ground freezing technologies is to be technically and economically viable in the long-term. Arctic Foundations, Inc. (AFI), has developed a ground freezing technology that can be used as a temporary or permanent, long-term solution for containing and immobilizing hazardous wastes. Buried hazardous waste may be totally confined by surrounding it with a frozen barrier. A frozen barrier is created by reducing the ground temperature around the waste to the appropriate freezing temperature and subsequently freezing the intervening waste. Artificial injection of water is usually unnecessary since moisture is present in sufficient quantities in most soils. The ground freezing process is naturally suited to controlling hazardous waste because in-ground moisture is transformed from serving as a potential waste mobilizing agent to serving as a protective agent.




Cryogenic Barrier Insulation Plan



The SITE Program assesses but does not approve or endorse technologies.

A typical containment system consists of multiple thermoprobes, an active (powered) condenser, an interconnecting piping system, a two-phase working fluid, and a control system. The thermoprobes (AFI's heat removal devices) and piping are inserted into the soil at strategic locations around and sometimes underneath the waste source depending on the presence or absence of a confining layer. Two-phase working fluid circulates through the piping and reduces the temperature of the surrounding soil, creating a frozen barrier around the waste source. The thermoprobes may be installed in any position and spacing to create a frozen barrier wall of almost any required shape and size. The selection of working fluids depends on the specific waste application, site conditions, and desired soil temperatures, and may consist of freon, butane, propane, carbon dioxide, or ammonia.

## WASTE APPLICABILITY:

The cryogenic barrier can provide subsurface containment for a variety of sites and wastes, including the following: underground storage tanks; nuclear waste sites; plume control; burial trenches, pits, and ponds; in situ waste treatment areas; chemically contaminated sites; and spent fuel storage ponds. The barrier is adaptable to any geometry; drilling technology presents the only constraint.

## STATUS:

The AFI cryogenic barrier system was accepted into the SITE Demonstration Program in 1996. The demonstration was conducted over a 5-month period at the U.S. Department of Energy's Oak Ridge National Laboratory (ORNL) in Oak Ridge, Tennessee in 1998. The demonstration was conducted to evaluate the barrier's ability to contain radionuclides from the ORNL Waste Area Grouping 9 Homogeneous Reactor Experiment pond. The system's effectiveness was evaluated through the performance of a groundwater dye tracing investigation. The demonstration was conducted in two phases. Phase one included a background study that was conducted to determine the presence of natural fluorescence and existing dyes in groundwater at the site in order to select a nondetectable dye for use during the dye tracing investigation.

During phase two, the selected dye, Acid Red No. 92, was injected into a standpipe located within the confines of the frozen barrier. Water samples and charcoal packets were then collected at predetermined sampling points outside the barrier wall to determine the presence or absence of dye in groundwater, springs, or seeps. The evaluation of the technology under the SITE Program was completed in July 1998. Preliminary results from the evaluation will be available in early 1999.

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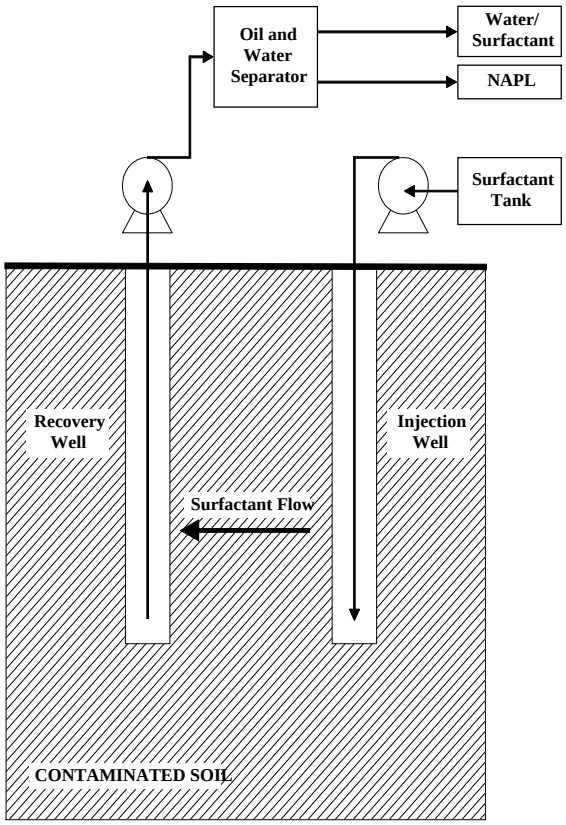
# DUKE ENGINEERING AND SERVICES, INC.
## (Surfactant Enhanced Aquifer Remediation of Nonaqueous Phase Liquids)

## TECHNOLOGY DESCRIPTION:

Surfactant enhanced aquifer remediation (SEAR) technology greatly enhances the removal of residual nonaqueous phase liquids (NAPL) from the subsurface by increasing the solubility of the NAPL and lowering the interfacial tension between the NAPL and aqueous surfactant solution. Increasing the solubility of the NAPL with surfactants substantially enhances the removal of the NAPL mass through pumping. Lowering the interfacial tension between the NAPL and the aqueous surfactant solution reduces the capillary forces that trap the NAPL in the pore spaces of the aquifer. Under certain conditions, the interfacial tension can be lowered sufficiently to drain NAPL from the pore spaces thereby forming an oil bank in the subsurface, which is then recovered at extraction wells.

Before SEAR technology can be implemented, site specific characteristics must be determined. Normal aquifer properties such as stratigraphy, grain size distribution, mineralogy, hydraulic conductivity, vertical and horizontal gradients, depth to ground water, etc., are determined. In addition, a fundamental understanding of the NAPL composition, distribution, and quantity in the subsurface is required. Knowledge of the quantity of NAPL present prior to using SEAR prevents either under- or over-designing the surfactant flood. Laboratory experiments using soil core, contaminant, groundwater, and source water from the site are conducted to determine the optimum surfactant solution mix. A geosystem model is then developed which incorporates all the data gathered. Simulations are run to determine optimum injection and extraction well placement, percent recoveries of




SEAR Technology



The SITE Program assesses but does not approve or endorse technologies.

the compounds injected, contaminant concentration levels in the effluent, percent removal of the contaminant mass, and all other pertinent results of the surfactant flood.

Once the surfactant flood has been fully designed, the surfactant solution is injected into the contaminated zone in the subsurface through one or more wells. The surfactant is drawn through the subsurface by pumping at surrounding extraction wells. As the surfactant moves through the subsurface it solubilizes or, if the design calls for it, mobilizes the NAPL for recovery at the extraction wells. The recovered groundwater and NAPL are then typically sent to a phase separator. The recovered NAPL is either disposed of or recycled, and the groundwater and surfactant is treated. For large scale projects, recovery and reuse of the surfactant from the effluent stream is economical.

## WASTE APPLICABILITY:

SEAR technology is applicable for the rapid removal of residual phase NAPL in the subsurface. Although it does not directly remediate the dissolved phase plume, removal of the source zone contamination can greatly reduce long term liability and risk. SEAR technology can be effective for the removal of a broad range of organic contaminants. This technology may not be suitable for sites with low hydraulic permeabilities ($10^{-5}$ cm/sec or less).

## STATUS:

SEAR technology was accepted into the Superfund Innovative Technology Evaluation (SITE) Demonstration program in 1997. The technology is scheduled for demonstration at the end of November 1998 at the Pearl Harbor demonstration site in Oahu, Hawaii.

SEAR technology has been successfully demonstrated with three separate surfactant floods at a U.S. Air Force base containing chlorinated solvent contamination in an alluvial aquifer.

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# ELECTROKINETICS, INC.
## (In Situ Bioremediation by Electrokinetic Injection)

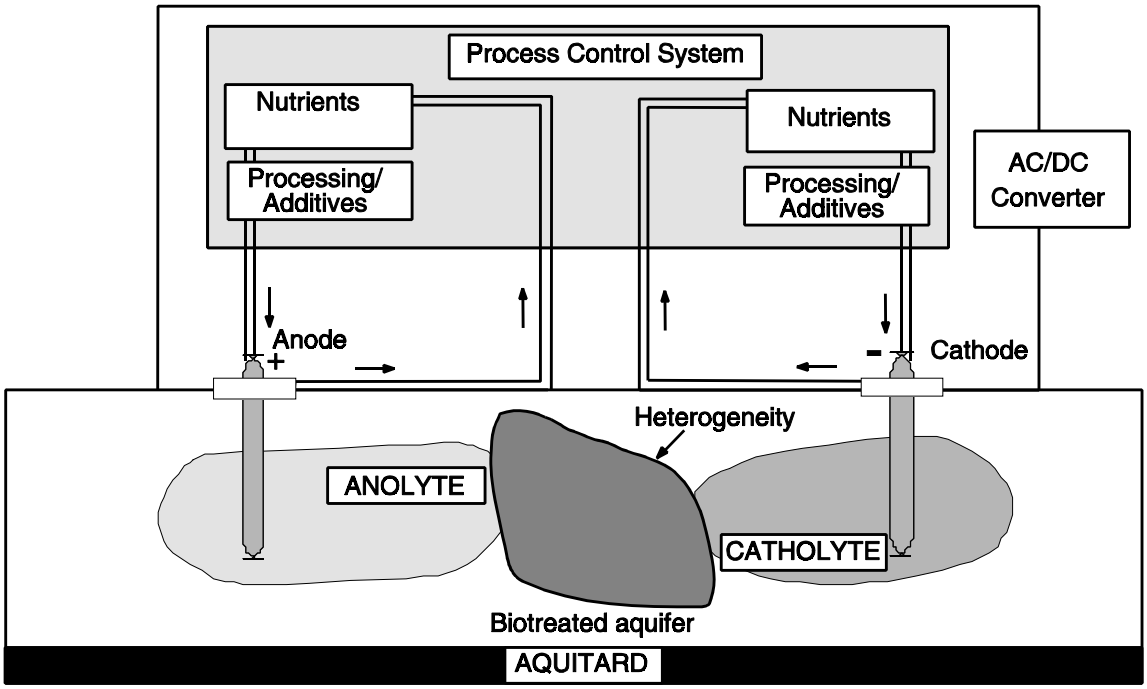
## TECHNOLOGY DESCRIPTION:

In situ bioremediation is the process of introducing nutrients into biologically active zones (BAZ). The nutrients are usually introduced by pumping recirculated groundwater through the BAZ, relying on hydraulic gradients or the permeability of the BAZ. However, heterogeneous aquifers often hinder the introduction of the nutrients. For example, areas with higher permeability result in preferential flow paths, leading to incomplete biological treatment in other areas. The inability to uniformly introduce nutrients and other additives, such as surfactants and cometabolites, is recognized as a hindrance to successful implementation of in situ bioremediation.

Electrokinetics, Inc. (Electrokinetics), has developed an electrokinetic remediation technology that stimulates and sustains in situ bioremediation for the treatment of organics.

The technology involves applying to soil or groundwater a low-level direct current (DC) electrical potential difference or an electrical current using electrodes placed in an open or closed flow arrangement. Groundwater or an externally supplied processing fluid is used as the conductive medium. The low-level DC causes physical, chemical and hydrological changes in both the waste and the conductive medium, thereby enabling uniform transport of process additives and nutrients into the BAZ. The process is illustrated in the diagram below.

Electrokinetic soil processing technologies were designed to overcome problems associated with heterogeneous aquifers, especially those problems that result in incomplete biological treatment. For example, the rate of nutrient and additive transport under electrical gradients is at least one order of magnitude greater than that achieved under hydraulic gradients.




Schematic Diagram of In Situ Bioremediation by Electrokinetic Injection



The SITE Program assesses but does not approve or endorse technologies.

## WASTE APPLICABILITY:

In situ electrokinetic injection can be used for any waste that can be treated by conventional bioremediation techniques. The Electrokinetics, Inc. system facilitates in situ treatment of contaminated subsurface deposits, sediments, and sludges. The technology can also be engineered to remove inorganic compounds through electromigration and electroosmosis, while process additives and nutrients are added to the processing fluids to enhance bioremediation of organic compounds.

## STATUS:

This technology was accepted into the SITE Emerging Technology Program in 1995. Pilot-scale studies under the Emerging Technology Program will be used to develop operating parameters and to demonstrate the efficiency and cost-effectiveness of the technology during a full-scale application. The SITE evaluation may take place in 1999 at a military base or a U.S. Department of Energy (DOE) site.

In a Phase-I study conducted for DOE, Electrokinetics, Inc., demonstrated that nutrient and process additives could be transported in and across heterogeneous areas in aquifers at rates that could sustain in-situ bioremdiation. During the study, ion migration rates, which were on the order of 8 to 20 centimeters per day, exceeded the electroosmotic rate, even in a kaolinite clay. The ion migration also produced a reasonably uniform distribution of inorganic nitrogen, sulfur, and phosphorous additives across the soil mass boundaries. These results are significant and demonstrate that electrokinetic injection techniques may potentially be used for the injection of diverse nutrients in low permeability soils as well as heterogeneous media. Electrokinetics, Inc., recently completed bench- and pilot-scale tests, which determined the feasibility of enhancing the bioremediation of trichloroethylene and toluene by electrokinetic injection. The process of in situ bioremediation by electrokinetic injection was inspired by extensive research work conducted by Electrokinetics, Inc., using the electrochemical process to remediate soils contaminated with heavy metals and radionuclides. In 1994, Electrokinetics, Inc., was commissioned by the U.S. Department of Defense (DoD) to demonstrate its technology in a lead-contaminated creek bed at an inactive firing range in Fort Polk, Louisiana. The study was supported under the U.S. EPA SITE Demonstration Program. This pilot-scale field demonstration represents the first comprehensive scientific study worldwide for the application of electrokinetic separation technology applied to the remediation of heavy metals in soils. Electrokinetics, Inc., successfully removed up to 98 percent of the lead from the firing range soil and received the 1996 Small Business Innovation Research (SBIR) Phase II Quality Award from DoD for technical achievement.

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The SITE Program assesses but does not approve or endorse technologies.

# ENERGIA, INC.

## (Reductive Thermal and Photo-Thermal Oxidation Processes for Enhanced Conversion of Chlorocarbons)

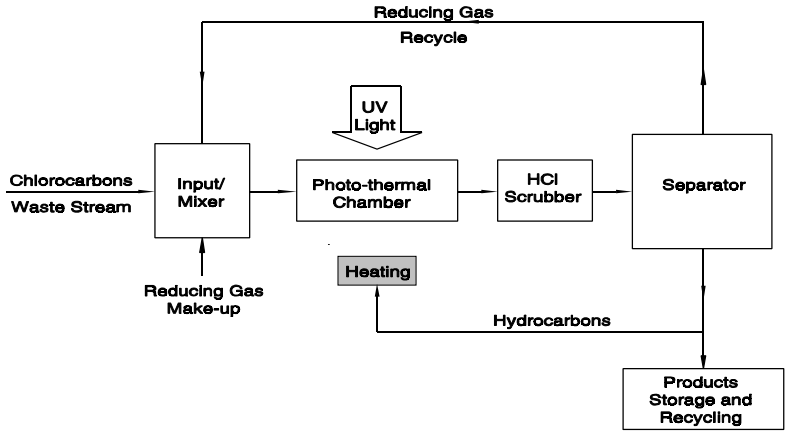
## TECHNOLOGY DESCRIPTION:

Two innovative processes, Reductive Thermal Oxidation (RTO) and Reductive Photo-Thermal Oxidation (RPTO), are designed to safely and cost-effectively convert chlorinated hydrocarbons (ClHC) into environmentally benign and useful materials in the presence of a reducing atmosphere. Both processes have evolved from Energia, Inc.'s, Reductive Photo-Dechlorination (RPD) technology, which does not permit the presence of air (oxygen).

The RTO/RPTO processes treat air streams laden with ClHCs. RTO converts ClHCs at moderate temperatures by cleaving carbon-chlorine bonds in the absence of ultraviolet light. RPTO operates under similar conditions but in the presence of ultraviolet light. Subsequent reactions between ensuing radicals and the reducing gas result in chain-propagation reactions. The presence of air (oxygen) during the conversion process accelerates the overall reaction rate without significant oxidation. The final products are useful hydrocarbons (HC) and environmentally safe materials, including hydrogen chloride, carbon dioxide, and water.

The RTO/RPTO processes are shown in the figure below. The process consists of six main units: (1) input/mixer (2) photo-thermal chamber (3) scrubber (4) separator (5) product storage/sale and (6) conventional catalytic oxidation unit. Air laden with ClHCs is mixed with reducing gas and passed into a photo-thermal chamber, which is unique to the RTO/RPTO technology. In this chamber, the mixture is heated to moderate temperatures to sustain the radical chain reactions. Depending on the physical and chemical characteristics of the particular ClHCs being treated, conversion can take place in two ways: the RTO process is purely thermal, and the RPTO process is photo-thermal. After suitable residence time, HCl is removed by passing the stream through an aqueous scrubber. The stream can then be treated in an optional second stage, or it can be separated and sent to storage.

Excess reducing gas is recycled, and residual ClHCs, HCs, and $CO_2$ are either exhausted, or if needed, treated by catalytic oxidation. Volatile hydrocarbons can also be recycled as an energy source for process heating, if partial oxidation at the photo-thermal chamber does not generate enough heat.




Reductive Thermal Oxidation (RTO)
and Photo-Thermal Oxidation (RPTO) Process



The SITE Program assesses but does not approve or endorse technologies.

## WASTE APPLICABILITY:

The RTO/RPTO processes are specifically applicable to treatment of air streams laden with volatile C1HCs, such as dichloromethane (DCM), methyl chloride, dichloroethane (DCA), trichloroethane (TCA), trichloroethylene (TCE), dichloroethylene (DCE), and chloroform.

These processes provide cost-effective, on-site conversion/dechlorination of C1HCs into environmentally acceptable products. They may be operated as a stand-alone or as an add-on to a remediation train. Potential commercial applications include the following:

- Direct treatment of air streams contaminated with hazardous waste C1HCs discharged from soil vapor extraction (SVE) operations
- Direct treatment of air streams containing volatile organic compounds (VOC) vented from industrial hoods and stacks
- On-site treatment of C1HCs and VOCs released by thermal desorption from contaminated soils
- On-site treatment of groundwater and surface water contaminated with VOCs and C1HCs in conjunction with air-stripping/air-sparging operations
- Regeneration of activated carbon canisters loaded with C1HCs

ENERGIA's innovative gas-phase photo-processes are applicable to: air, water, and soil. They can be used alone or in conjunction with other prospective technologies such as, SVE, thermal desorption, air sparging, and air stripping. In essence, they provide the final stage for environmentally safe destruction of C1HCs or VOCs present in various discharge streams. These compounds are often released to the atmosphere without any treatment.

Laboratory-scale tests were completed on representative C1HCs: two saturated contaminants (DCA and TCA) and two unsaturated compounds (DCA and TCE). Further tests of TCE, DCE, and TCA were conducted on a prototype system. Percent conversion, percent dechlorination, and concentration of parent contaminants and products were determined as a function of reaction time for various compositions at several temperatures. Both processes have exhibited greater than 99 percent conversion/dechlorination with high selectivity towards salable hydrocarbon products (methane and ethane). The RPTO process has always outperformed the RTP one; however, its advantage seemed to diminish with increasing temperature.

A cost analysis based on experimental data was also performed. TCE was used as a representative contaminant. An extremely competitive cost was obtained. For example, the cost of treatment of 1,000 cubic feet of air contaminated with 10 and 1,000 parts per million of TCE is $0.13 and $0.33, respectively.

A pilot-scale field demonstration is expected to take place in 1999. After completion of the field demonstration, these processes will be available for commercialization.

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# ENVIROMETAL TECHNOLOGIES, INC.
## (Reactive Barrier)

## TECHNOLOGY DESCRIPTION:

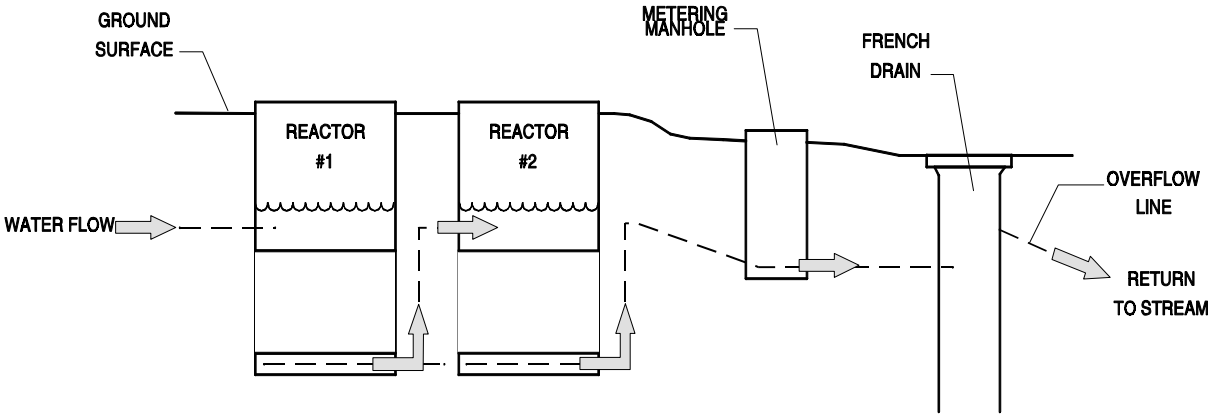
The Reactive Barrier technology is an innovative treatment system that uses the oxidation capacity of zero-valent iron to induce reduction of oxidized metals, reductive dechlorination of chlorinated volatile organic compounds (VOCs), and immobilization of some metals such as uranium by a combination of reduction and sorbtion.

Granular zero-valent iron oxidizes within the reactor vessel or reactive wall. As groundwater containing VOCs flows through the reactor and around these granules, electrons released by oxidation of the iron create a highly reducing environment in solution.

The hydrocarbon-chloride bonds in the chlorinated contaminants become unstable and break down sequentially, forming less chlorinated compounds and releasing nontoxic chloride ions to the groundwater. The completely hydrolyzed hydrocarbon compounds are nontoxic and degrade naturally. The rate of reaction depends primarily on the surface area of the iron or its abundance in the permeable reactive media. The dechlorination reaction is typically accompanied by an increase in groundwater pH and a decrease in oxidation/reduction potential. Inorganic constituents such as calcium, magnesium, and iron combine with carbonate or hydroxide ions in the treated water to form compounds such as metal carbonates and metal hydroxides that precipitate from solution as groundwater moves through the iron. Due to the precipitation of these metallic compounds from solution, the reaction is also typically accompanied by a decrease in total dissolved solids in the groundwater.

## WASTE APPLICABILITY:

The Reactive Barrier technology is applicable to subsurface or above-ground treatment of VOCs and metals in groundwater or wastewater. The technology is adaptable to a variety of sites when used in combination with funnel and gate systems. Depth of the contaminated groundwater is the only constraint on the applicability of the technology.




Schematic of the Reactive Barrier Technology



The SITE Program assesses but does not approve or endorse technologies.

## STATUS:

The technology was accepted into the SITE Demonstration Program in 1996. The demonstration of the technology is currently in progress at the Rocky Flats Environmental Technology Site in Golden, Colorado. The technology's effectiveness will be evaluated through sampling and analysis of untreated and treated groundwater that is collected by a french drain system and transferred to two subsurface reactor tanks through gravity flow. Preliminary results from the evaluation will be available in mid to late 1999.

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# GEOKINETICS INTERNATIONAL, INC.
## (Electroheat-Enhanced Nonaqueous-Phase Liquids Removal)

## TECHNOLOGY DESCRIPTION:

Geokinetics has developed and fully commercialized a novel in-situ process for the extraction and/or destruction of organic materials (nonaqueous phase liquids [NAPL]) from ground and groundwater. The process combines a novel direct electrical heating process with established soil vapor, dual phase and other extraction approaches. Heat is produced directly in the treatment zone by the passage of an AC current through the soil matrix. In effect, the ground and groundwater become the electrical resistor in a conventional resistive heating circuit.

Multi-phase electrical current is supplied to the soil matrix using proprietary high surface area electrodes inserted directly into the ground. Electrical current, heat-up rate, and other operating parameters are regulated by a proprietary computer-based (impedance matching) control system. This system incorporates automated data logging, fault tolerance, and remote operation to minimize field labor requirements.

The process works by gradually and uniformly heating the treatment zone to 60 to 80 °C. This produces the following effects:

- NAPL viscosity is significantly reduced
- A density inversion of many dense nonaqueous-phase liquid (DNAPL) components will occur causing it to float to the top of the saturated zone
- The smear zone will greatly reduce or even collapse
- Nascent biological activity will typically increase dramatically (provided the heat-up rate is managed carefully). This greatly increases natural biodegradation. When the treatment zone has reached its operating temperature, a combination of established extraction techniques are applied as appropriate to remove most or all of the NAPL. Treatment times typically include:

- 1 month for heat-up
- 4 to 8 months for primary extraction

## WASTE APPLICABILITY:

The technology is broadly applicable for enhancing the removal of NAPLs and DNAPLs from a broad range of ground types. Recovered and destroyed contaminants include fuel oil, diesel, kerosene, PAHs, coal tar, hydraulic fluid, TCE, and other chlorinated solvents. ground types treated include clays, silty clays, shale beds, gravel deposits, etc. The technology has been deployed alongside, inside, and underneath existing buildings and structures.

## STATUS:

Geokinetics first developed and commercialized the technology in Europe and has more than 40 projects completed or in progress. In the United States, Geokinetics' technology was accepted in the Superfund Innovative Technology Evaluation (SITE) program in 1997. The technology is scheduled for U.S. demonstration under the SITE program during September and October 1998 at the Pearl Harbor demonstration site in Oahu, Hawaii.



The SITE Program assesses but does not approve or endorse technologies.

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# GEO-MICROBIAL TECHNOLOGIES, INC.
## (Metals Release and Removal from Wastes)

## TECHNOLOGY DESCRIPTION:

Geo-Microbial Technologies, Inc., has developed an anaerobic biotreatment technology to release metals from liquefaction catalyst wastes. Such wastes are derived from spent coal and are also contaminated with complex organic compounds. The anaerobic metals release (AMR) technology may be adapted to treat other wastes contaminated with metals.

Current biohydrometallurgy systems use aerobic acidophilic bacteria, which oxidize mineral sulfides while making metals soluble and forming large amounts of acid. This aerobic process can result in acidic drainage from natural sources of metal sulfides. For example, acidophilic bacteria convert the pyrite and iron-containing minerals in coal into oxidized iron and sulfuric acid. The acid then makes the pyrite and other sulfide minerals more soluble resulting in stream and lake contamination due to acidification and an increase in soluble heavy metals.

The AMR technology operates anaerobically and at a near-neutral pH, employing anaerobic *Thiobacillus* cultures in conjunction with heterotrophic denitrifying bacterial cultures. The diverse culture of denitrifying bacteria consumes and treats multiple carbon sources, including some organic pollutants.

The anaerobic environment can be adjusted by introducing low levels of nitrate salts that function as an electron acceptor in the absence of oxygen. The nitrate salts provide an alternate electron acceptor and selectively enhance the remineralization process of the inherent denitrifying microflora.

This process increases the population of the denitrifying bacterial population that releases the metals. Soils containing the released metals are then flooded with the dilute nitrate solutions. The improved anaerobic leaching solutions permeate the soils, allowing the microbial activity to make the metals soluble in the leachate. The nitrate concentration is adjusted so that the effluent is free of nitrate and the nitrate concentration is monitored so that the process operation can be closely controlled. Soluble metals in the leachate are easily recaptured, and the metal-free effluent is recycled within the process. The nitrate-based ecology of the process also has the added advantage of decreasing levels of sulfate-reducing bacteria and sulfide generation.

The versatility and low operating constraints of the
options. The technology can be adapted for in situ flooding or modified to flood a waste pile in a heap-leaching operation. The elimination of any aeration requirement also allows the process to be designed and considered for bioslurry applications. As a result, the technology offers a greater range of treatment applications for environmental waste situations that are often considered difficult to treat.

## WASTE APPLICABILITY:

The AMR technology targets toxic metal-contaminated soils, sludges, and sediments, which can also be contaminated with other wastes, including hydrocarbons and organic pollutants. While metals are the primary pollutant treated, the biological system is also designed to degrade and remove associated organic contaminants.



The SITE Program assesses but does not approve or endorse technologies.

## STATUS:

The technology was accepted into the SITE Emerging Technology Program in July 1994. Studies under the Emerging Technology Program will evaluate how effectively the AMR technology removes metals from soil.

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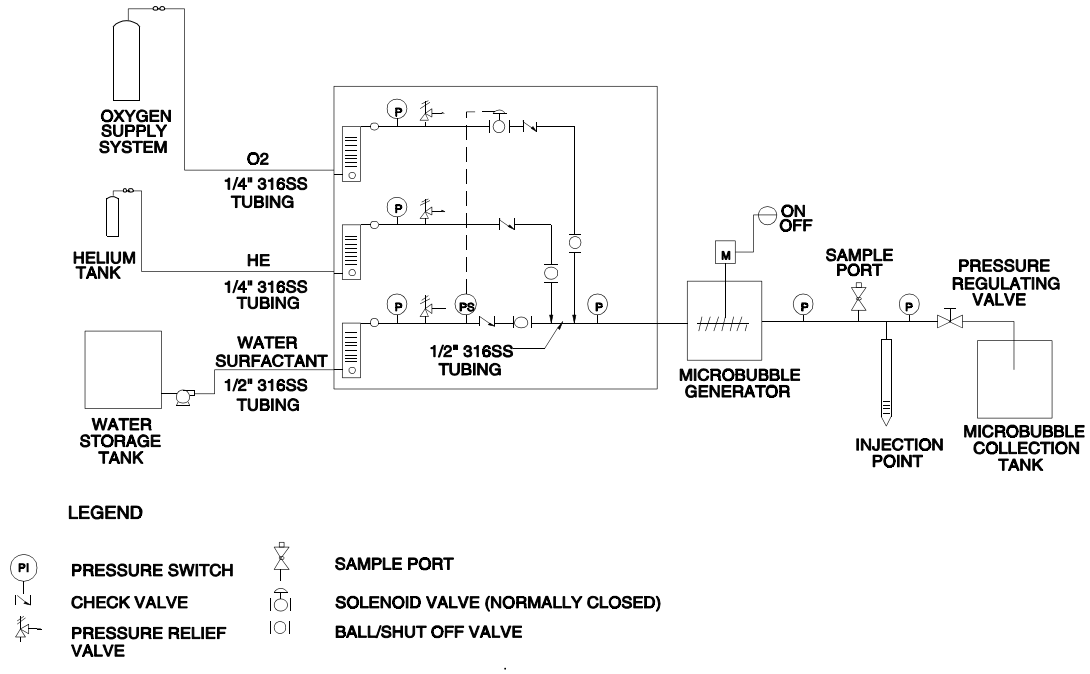
# IT CORPORATION
## (Formerly OHM Remediation Services Corporation)
## (Oxygen Microbubble In Situ Bioremediation)

## TECHNOLOGY DESCRIPTION:

The application of in situ microbial degradation of petroleum hydrocarbons (PHC) has become a common and widespread practice. The most common factor limiting the rate of in situ biodegradation of PHCs is the amount of oxygen available in the saturated and unsaturated zones. Therefore, OHM Remediation Services Corporation (OHM) has focused on developing techniques for delivering oxygen to the subsurface to enhance in situ microbial degradation of PHCs. OHM has extensive experience with oxygen delivery techniques such as bioventing and biosparging to enhance microbial degradation. Injection of oxygen microbubbles is being investigated by OHM as an oxygen delivery system for the in situ biodegradation of PHCs in the unsaturated and saturated zones. OHM has conducted demonstrations of the oxygen microbubble technology in conjunction with the U.S. EPA and the U.S. Armstrong Laboratories. Oygen microbubble technology (see figure elow) uses a continuously generated stream of oxygen and water solution containing low concentrations of a surfactant. A water stream containing about 200 milligrams per liter of surfactant is mixed with oxygen under pressure. The resulting oxygen and water mixture is pumped through a microbubble generator that produces a zone of high-energy mixing. The result is a 60 to 80 percent by volume dispersion of bubbles, with a typical bubble diameter ranging from 50 to 100 microns. The microbubble dispersion is then pumped through an injection well into the treatment zone. The microbubbles deliver oxygen to contaminated groundwater, providing an oxygen source for aerobic biodegradation of the contaminant by the indigenous microflora.




Oxygen Microbubble In Situ Bioremediation



The SITE Program assesses but does not approve or endorse technologies.

## WASTE APPLICABILITY:

The process has successfully treated groundwater contaminated with a number of organic compounds including volatile organic compounds, semivolatile organic compounds, and petroleum hydrocarbons.

## STATUS:

The Oxygen Microbubble In Situ Bioremediation process was accepted into the Emerging Technology Program in summer 1992. This process is being evaluated at a jet fuel spill site at Tyndall Air Force Base in Panama City, Florida.

The overall objective of this project is to evaluate the in situ application of the oxygen microbubble technology for bioremedation. The goals are to determine subsurface oxygen transfer to the groundwater, retention of the microbubble in the soil matrix, and biodegradation of the petroleum hydrocarbons present in the soil and groundwater.

A pilot test was performed at the site in 1995. The objective of the test was to determine the rate at which generated microbubbles could be injected into the surficial aquifer at the site. In addition, changes in the microbubbles and the aquifer during injection were monitored. Specific parameters monitored included the following:

- Microbubble quality, quantity, and stability
- Microbubble injection rate and pressure
- Lateral migration rates of microbubbles
- Lateral extent of migration of surfactant in the aquifer
- Lateral changes in dissolved oxygen concentration in the aquifer
- Rate of migration of tracer gas (helium) in the vadose zone
- Oxygen in the vadose zone

The pilot test verified that microbubbles can be injected into a shallow aquifer consisting of unconsolidated, fine-grained sediments. The study also verified that aquifer characteristics allowed the injection of the microbubble foam at rates of at least 1 gallon per minute. Continued injection of foam after about 45 minutes resulted in coalescence of the foam based on pressure measurements. The microbubble foam was observed to persist in the aquifer for long periods of time. This testing supported the use of oxygen microbubbles as an oxygen delivery system for in situ bioremediation.

The next testing phase at the site began in fall 1996. During this test, multiple injection points will be used to determine the maximum rate of foam injection while maintaining foam stability. Oxygen will be used as the gas for microbubble production. The rentention of oxygen microbubbles will be compared to sparged air to determine oxygen delivery efficiency.

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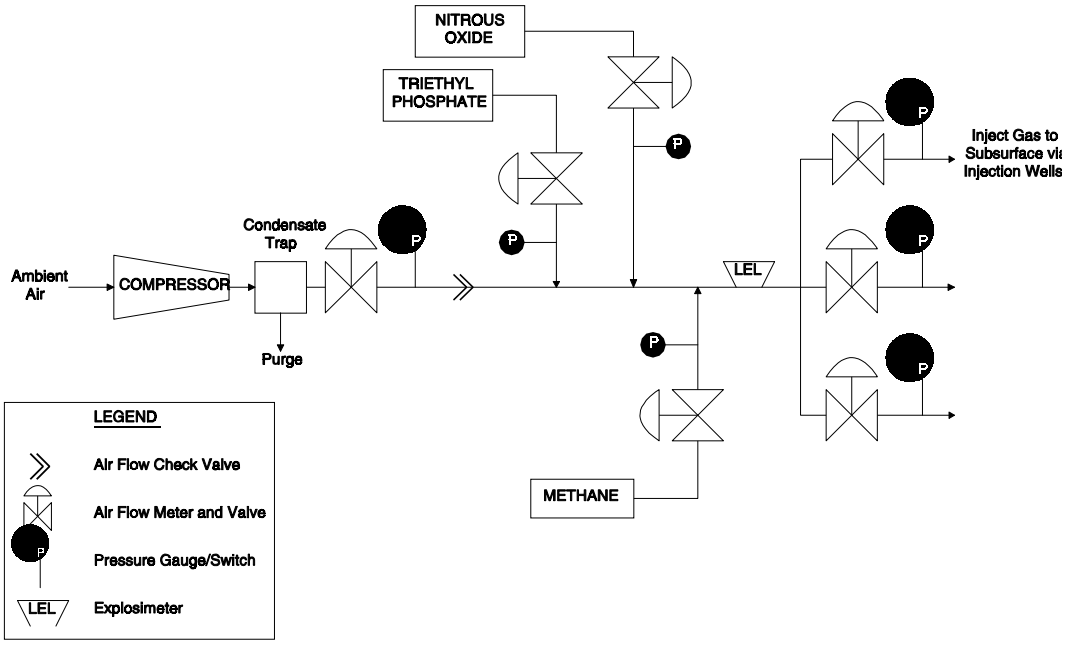
# ITT NIGHT VISION
## (In situ Enhanced Bioremediation of Groundwater)

## TECHNOLOGY DESCRIPTION:

ITT Night Vision is conducting in situ enhanced aerobic bioremediation of contaminated groundwater in fractured bedrock utilizing technologies developed at the U.S. Department of Energy Savannah River Site. This project currently involves remediation of groundwater in the vicinity of one contaminant source area as a pilot-scale operation, with the possibility of applying the technology elsewhere on site. Contaminants of concern in on-site groundwater include chlorinated solvents and their daughter products, plus acetone and isopropanol. To accelerate the intrinsic (natural) biodegradation observed at the site, the selected remedy involves the subsurface injection of air, gaseous-phase nutrients (triethyl phosphate and nitrous oxide), and methane. The amendments are being added to stimulate existing microbial populations (particularly methanotrophs) so that they can more aggressively break down the contaminants of concern. Amendment delivery to the is accomplished through an injection well, and the injection zone of influence is confirmed using surrounding groundwater monitoring wells and soil vapor monitoring points.

The patented PHOSter™ process for injection of triethyl phosphate in a gaseous phase was licensed for use at this site as an integral element of the enhanced bioremediation operation. This technology maximizes the subsurface zone of influence of nutrient injection as compared to technologies injecting nutrients in liquid or slurry form. Monitoring of contaminant (and breakdown product) concentrations in groundwater and soil vapor, measurement of microbiological population density and diversity, and monitoring of nutrient concentrations and groundwater geochemical parameters provides feedback on system effectiveness. This in turn allows adjustments to be made in the sequencing and rate of delivery of air, nutrients, and methane in response to changing subsurface conditions.




Enhanced Bioremediation Technology



The SITE Program assesses but does not approve or endorse technologies.

## WASTE APPLICABILITY:

This enhanced bioremediation technology breaks down volatile organic compounds in groundwater. Compounds which are amenable to intrinsic (natural) biodegradation can be degraded more rapidly when the subsurface microbial populations are stimulated through the injection of air, gaseous-phase nutrients, and methane. By providing an aerobic environment for contaminant degradation, harmless breakdown products are produced and toxic daughter products of anaerobic degradation of chlorinated solvents (such as vinyl chloride) can be broken down completely. This in-situ technology is especially applicable in situation where subsurface infrastructure (for example, networks of utilities) limit or preclude excavation or extraction technologies.

## STATUS:

The enhanced bioremediation system, currently being used in the ongoing RCRA corrective action interim measure at the ITT Night Vision facility, was accepted into the SITE program in 1997, with system start up occurring in March of 1998. The technology had previously been approved by EPA Region 3 as an Interim Measure part of the facility's ongoing RCRA Corrective Action program.

SITE program participants collected groundwater quality and microbiological data prior to system start up (baseline monitoring) and between the air and nutrient injection campaigns (interim monitoring). Baseline monitoring established a statistical reference point for contaminants of concern in groundwater. Interim monitoring suggests that the initial injection campaigns have successfully stimulated the growth of native microbial populations based upon the results of phospholipid fatty acid assays and methanotroph most probable number plate counts. Corresponding decreases in concentrations of contaminants of concern have also been discernible.

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# KSE, INC.
## (Adsorption-Integrated-Reaction Process)

## TECHNOLOGY DESCRIPTION:

The Adsorption-Integrated-Reaction (AIR 2000) process combines two unit operations, adsorption and chemical reaction, to treat air streams containing dilute concentrations of volatile organic compounds (VOC) (see photograph below).

The contaminated air stream containing dilute concentrations of VOCs flows into a photocatalytic reactor, where chlorinated and nonchlorinated VOCs are destroyed. The VOCs are trapped on the surface of a proprietary catalytic adsorbent. This catalytic adsorbent is continuously illuminated with ultraviolet light, destroying the trapped, concentrated VOCs through enhanced photocatalytic oxidation. This system design simultaneously destroys VOCs and continuously regenerates the catalytic adsorbent. Only oxygen in the air is needed as a reactant. The treated effluent air contains carbon dioxide and water, which are carried out in the air stream exiting the reactor. For chlorinated VOCs, the chlorine atoms are converted to hydrogen chloride with some chlorine gas. If needed, these gases can be removed from the air stream with conventional scrubbers and adsorbents.

The AIR 2000 process offers advantages over other photocatalytic technologies because of the high activity, stability, and selectivity of the photocatalyst. The photocatalyst, which is not primarily titanium dioxide, contains a number of different semiconductors, which allows for rapid and economical treatment of VOCs in air. Previous results indicate that the photocatalyst is highly resistant to deactivation, even after thousands of hours of operation in the field.

The particulate-based photocatalyst allows for more freedom in reactor design and more economical scale-up than reactors with a catalyst film coated on a support medium. Packed beds, radial flow reactors, and monolithic reactors are all feasible reactor designs. Because the catalytic adsorbent is continuously regenerated, it does not require disposal or removal for regeneration, as traditional carbon adsorption typically does. The AIR 2000 process produces no residual wastes or by-products needing further treatment or disposal as hazardous waste. The treatment system is self-contained and mobile, requires a small amount of space, and requires less energy than thermal incineration or catalytic oxidation. In addition, it has lower total system costs than

AIR2000



The SITE Program assesses but does not approve or endorse technologies.

these traditional technologies, and can be constructed of fiberglass reinforced plastic (FRP) due to the low operating temperatures.

## WASTE APPLICABILITY:

The AIR 2000 process is designed to treat a wide range of VOCs in air, ranging in concentration from less than 1 to as many as thousands of parts per million. The process can destroy the following VOCs: chlorinated hydrocarbons, aromatic and aliphatic hydrocarbons, alcohols, ethers, ketones, and aldehydes.

The AIR 2000 process can be integrated with existing technologies, such as thermal desorption, air stripping, or soil vapor extraction, to treat additional media, including soils, sludges, and groundwater.

## STATUS:

The AIR 2000 process was accepted into the SITE Emerging Technology Program in 1995. Studies under the Emerging Technology Program are focusing on (1) developing photocatalysts for a broad range of chlorinated and nonchlorinated VOCs, and (2) designing advanced and cost-effective photocatalytic reactors for remediation and industrial service.

The AIR 2000 Process was initially evaluated at full-scale operation for treatment of soil vapor extraction off-gas at Loring Air Force Base (AFB). Destruction efficiency of tetrachloroethene exceeded 99.8 percent. The performance results were presented at the 1996 World Environmental Congress.

The AIR-I process, an earlier version of the technology, was demonstrated as part of a groundwater remediation demonstration project at Dover AFB in Dover, Delaware, treating effluent air from a groundwater stripper. Test results showed more than 99 percent removal of dichloroethane (DCA) from air initially containing about 1 ppm DCA and saturated with water vapor.

A 700 SCFM commercial unit is now operating at a Superfund Site in Rhode Island, destroying TCE, DCE and vinyl chloride in the combined off-gas from a SVE system and a groundwater stripper. Preliminary results show that the system is operating at 99.99% destruction efficiency. The AIR 2000 unit is operating unattended, with the number of UV lamps being illuminated changing automatically in response to changing flow conditions for maximum performance at minimum cost.

The AIR 2000 Process was accepted into the SITE Demonstration program in 1998, with the objective of demonstrating the performance of the system at the Superfund site in Rhode Island.

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# LASAGNA™ PUBLIC-PRIVATE PARTNERSHIP
## (Lasagna™ In Situ Soil Remediation)

## TECHNOLOGY DESCRIPTION:

The Lasagna™ process, so named because of its treatment layers, combines electrokinetics with treatment layers which are installed directly into the contaminated soil to form an integrated, in situ remedial process. The layers may be configured vertically (Figure 1) or horizontally (Figure 2). The process is designed to treat soil and groundwater contaminants completely in situ, without the use of injection or extraction wells.

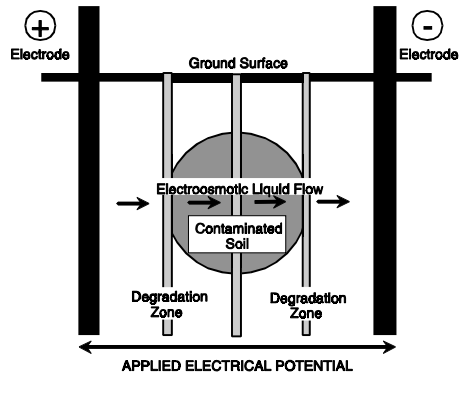
The outer layers consist of either positively or negatively charged electrodes. The electrodes create an electric field which moves contaminants in soil pore fluids into or through the treatment layers. In the vertical configuration, rods that are steel or granular graphite and iron filings may be used as electrodes. In the horizontal configuration, the electrodes and treatment zones are installed by hydraulic fracturing. Granular graphite is used for the electrodes and the treatment zones are granular iron (for zero-valent, metal-enhanced, reductive dechlorination) or granular activated carbon (for biodegradation by methanotrophic microorganisms). The Lasagna™ process can remove contaminants from soil using the following combination:

- Creating treatment zones in close proximity to one another throughout the contaminated soil region, and converting them into sorption/degradation zones by introducing sorbents, catalytic agents, microbes, oxidants, or buffers
- Using electrokinetics to transport contaminants from the soil into the treatment zones for sorption/degradation
- Reversing the direction of transport, if necessary, by switching electrical polarity

The orientation of the electrodes and treatment zones depends on the characteristics of the site and the contaminants. In general, the vertical configuration is probably more applicable to more shallow contamination, within 50 feet of the ground surface. The horizontal configuration, using hydraulic fracturing or related methods, is uniquely capable of treating much deeper contamination.

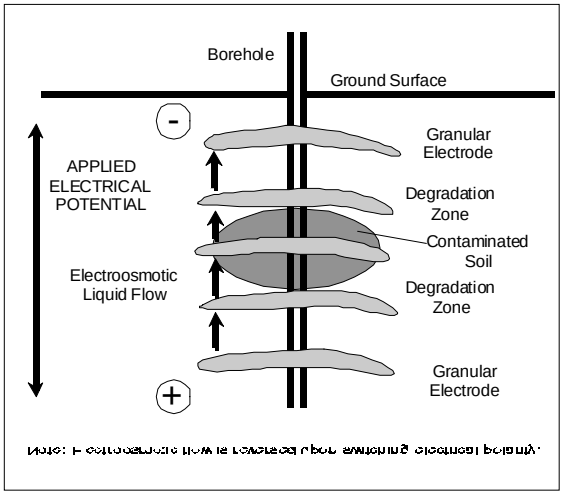
## WASTE APPLICABILITY:

Conceptually, the Lasagna™ process is designed to treat organic and inorganic contaminants and mixed wastes in groundwater and soil. To date, the p
contaminants in low permeability soils.




Note: Electroosmotic flow is reversed upon switching electrical polarity.

Vertical Configuration
of the Lasagna™ Process




Horizontal Configuration
of the Lasagna™ Process



The SITE Program assesses but does not approve or endorse technologies.

## STATUS:

The Lasagna™ process (vertical configuration) was accepted into the SITE Demonstration Program in 1995. Under the SITE Program, with significant funding from the U.S. Department of Energy (DOE), the Lasagna™ process was tested for 120 days in May 1995 on soil contaminated with trichloroethene (TCE) at DOE's Paducah Gaseous Diffusion Plant (PGDP) in Kentucky. One of the key objectives of this test was to successfully demonstrate the coupling of electroosmotic flushing of TCE from the clay soil while removing the TCE from the pore water by in situ adsorption. Steel panels were used as electrodes and granular activated carbon (GAC) served as treatment layers in a vertical configuration.

Sampling and analysis of the GAC at the end of the demonstration revealed a substantial GAC amount of TCE. Soil samples collected before and after the demonstration indicated a 98 percent removal of TCE from tight clay soil, with some samples showing greater than 99 percent removal. TCE soil levels were reduced from the 100 parts per million (ppm) range to an average concentration of 1 ppm.

A second test of the Lasagna™ process in a vertical configuration was started in August 1996 at DOE's PGDP to treat in situ TCE-contaminated soil to 45 feet below ground surface. A sheetpiling method was utilized with hollow mandrels for installing electrodes (granular mixture of coke and iron filings) and treatment zones (iron filings/clay slurry) in thin layers (less than 2 inches thick) through stiff clay soil without generating solid waste. Complications encountered during the operation included contamination levels significantly higherthan anticipated and complex hydrogeology in the subsurface. The overall TCE removal efficiency obtained was in the range of 95 percent for 1 pore volume of water flow to over 99 percent for 2.6 pore volumes between the treatment zones. There are strong indications that some of the TCE was transported and degraded in the dense non-aqueous phase liquid form. Based on the success of this test, DOE has recommended that the Lasagna™ process be used to clean up the rest of this contaminated location at PGDP.

EPA and the University of Cincinnati have installed horizontal configuration cells at Rickenbacker Air National Guard Base (ANGB) near Columbus, Ohio. Support facilities are being installed at Offutt Air Force Base (AFB) near Omaha, Nebraska. Horizontal configuration cells will be installed at Offutt AFB in spring 1997 with funding support from the U.S. Air Force. TCE is the target contaminant at both Rickenbacker ANGB and Offutt AFB.

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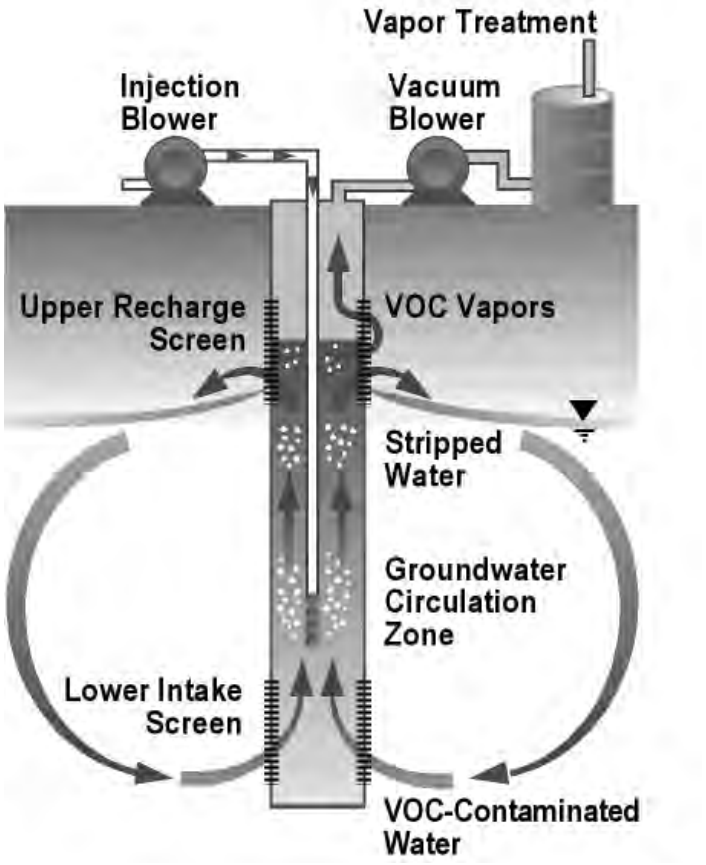
# MACTEC-SBP TECHNOLOGIES COMPANY, L.L.C.
## (formerly EG&G Environmental, Inc.)
## (NoVOCs™ In-Well Stripping Technology)

## TECHNOLOGY DESCRIPTION:

MACTEC-SBP provides the patented NoVOCs™ in-well stripping technology for the in situ removal of volatile organic compounds (VOC) from groundwater (see figure below). NoVOCs™ combines air-lift pumping with in-well vapor stripping to remove VOCs from groundwater without the need to remove, treat, and discharge a wastewater stream. The process also can be adapted to remove both VOCs and soluble metals from groundwater. NoVOCs™ consists of a well screened both beneath the water table and in the vadose zone. An air line within the well runs from an aboveground blower and extends below the water table. Pressurized air injected below the water table aerates the water within the well, creating a density gradient between the aerated water and the more dense water in the surrounding aquifer. As a result, groundwater flows through the lower well screen and forces the aerated water upward within the well, and is in turn accelerated. The result is a




**Schematic Diagram of the NoVOCs™ Technology**



The SITE Program assesses but does not approve or endorse technologies.

rising column of aerated water within the well, essentially acting as an air-lift pump

As the aerated groundwater column rises within the well, VOC mass transfer occurs from the dissolved phase to the vapor phase. Above the water table, a packer is installed at the upper screen to prevent the passage of rising water or bubbles. The rising water column hits the packer, the bubbles burst, and the entrained VOC vapor is stripped off laterally through the screen by an upper vacuum casing. The VOC-rich vapor is brought to the surface for treatment while the laterally deflected water circulates back into the aquifer. Reinfiltrating water creates a toroidal circulation pattern around the well, enabling the groundwater to undergo multiple treatment cycles before flowing downgradient. The VOC-rich vapor is treated using commercially available techniques chosen according to the vapor stream characteristics.

NoVOCs™ also can be used to remove readily reduced metals from groundwater and stabilize them in the vadose zone. Solubilized metals in their oxidized states enter the lower screen by the same route as dissolved VOCs in the groundwater. The nonvolatile metals remain in solution as the VOCs are stripped at the upper screen and the water circulates out of the well. The groundwater and soluble metals then pass through an infiltration and treatment gallery surrounding the upper well screen. This treatment gallery is impregnated with a reducing agent that reduces the soluble metals to an insoluble valence state. The insoluble metals accumulate in the infiltration gallery high above the water table and can be either capped or excavated at the conclusion of remedial action.

## WASTE APPLICABILITY:

The process treats groundwater contaminated with volatile petroleum hydrocarbons including benzene, ethylbenzene, and toluene, as well as chlorinated solvents such as tetrachloroethene and trichloroethene. Highly soluble organics like alcohols and ketones are not easily air-stripped from water but are readily biodegraded in the oxygen-rich environment produced by NoVOCs™.

## STATUS:

The NoVOCs™ technology was accepted into the SITE Demonstration Program in 1995. The demonstration is underway at Naval Air Station North Island in San Diego, California.

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The SITE Program assesses but does not approve or endorse technologies.

# MATRIX PHOTOCATALYTIC INC.
## (Photocatalytic Air Treatment)

## TECHNOLOGY DESCRIPTION:

Matrix Photocatalytic Inc. is developing a titanium dioxide ($TiO_2$) photocatalytic air treatment technology that destroys volatile organic compounds (VOC) and semivolatile organic compounds in air streams. During treatment, contaminated air at ambient temperatures flows through a fixed $TiO_2$ catalyst bed activated by ultraviolet (UV) light. Typically, organic contaminants are destroyed in fractions of a second.

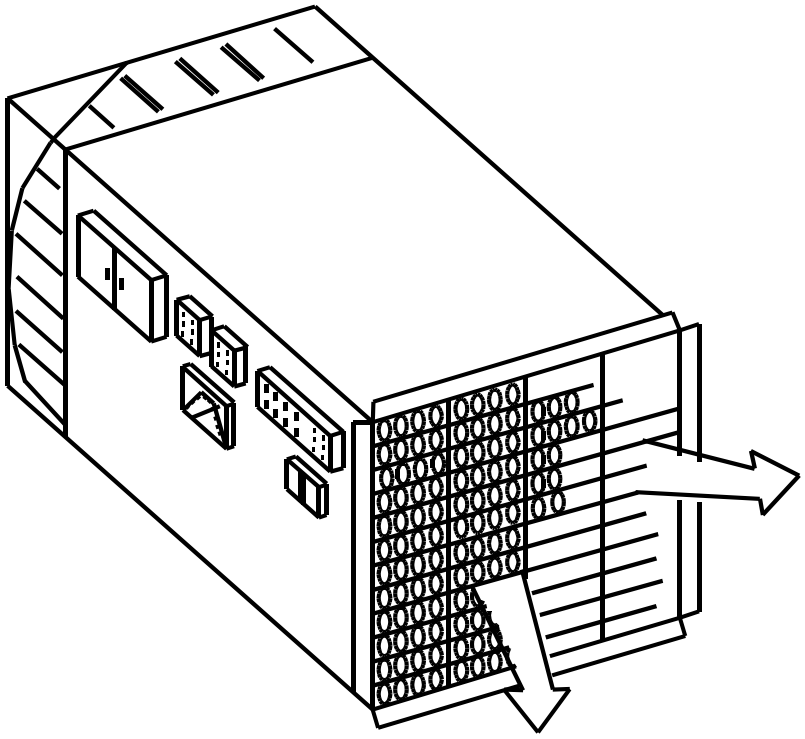
Technology advantages include the following:

- Robust equipment
- No residual toxins
- No ignition source
- Unattended operation
- Low direct treatment cost

The technology has been tested on benzene, toluene, ethylbenzene, and xylene; trichloroethene; tetrachloroethane; isopropyl alcohol; acetone; chloroform; methanol; and methyl ethyl ketone. A field-scale system is shown in the photograph on the next page.

## WASTE APPLICABILITY:

The $TiO_2$ photocatalytic air treatment technology can effectively treat dry or moist air. The technology has been demonstrated to purify contaminant steam directly, thus eliminating the need to condense. Systems of 100 cubic feet per minute have been successfully tested on vapor extraction operations, air stripper emissions, steam from desorption processes, and VOC emissions from manufacturing facilities. Other potential applications include odor removal, stack



Full-Scale Photocatalytic Air Treatment System



The SITE Program assesses but does not approve or endorse technologies.

gas treatment, soil venting, and manufacturing ultra-pure air for residential, automotive, instrument, and medical needs. Systems of up to about 1,000 cubic feet per minute can be cost-competitive with thermal destruction systems.

## STATUS:

The $TiO_2$ photocatalytic air treatment technology was accepted into SITE Emerging Technology Program (ETP) in October 1992; the evaluation was completed in 1993. Based on results from the ETP, this technology was invited to participate in the SITE Demonstration Program. For further information about the evaluation under the ETP, refer to the journal article (EPA/600/A-93/282), which is available from EPA. A suitable demonstration site is being sought.

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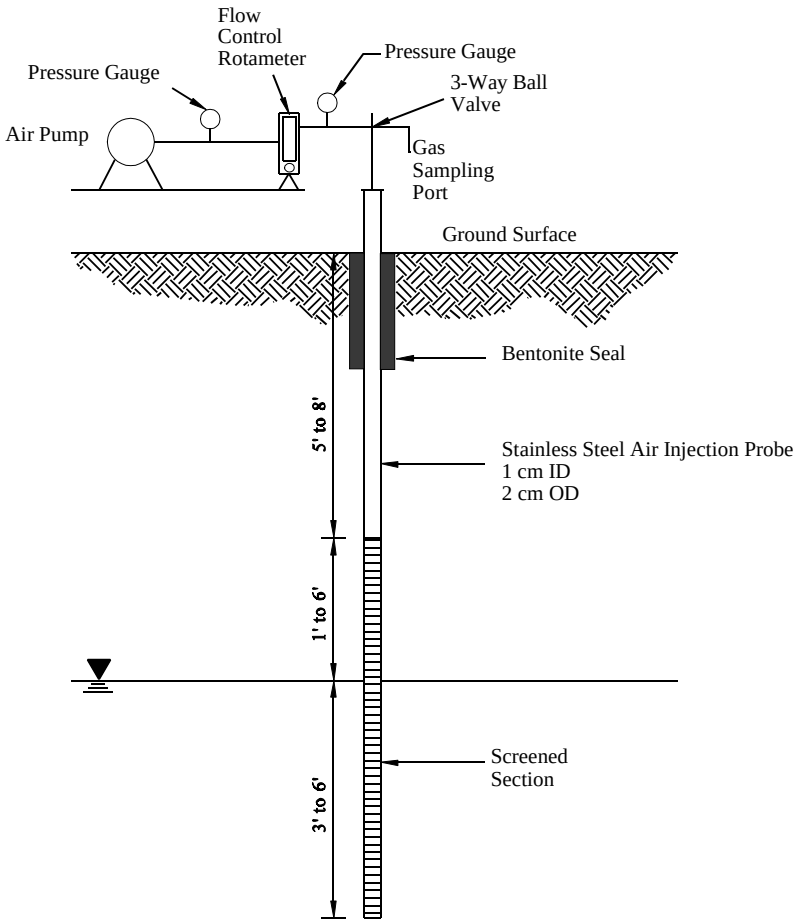
The SITE Program assesses but does not approve or endorse technologies.

# NATIONAL RISK MANAGEMENT RESEARCH LABORATORY
## (Bioventing)

## TECHNOLOGY DESCRIPTION:

Lack of oxygen in contaminated soil often limits aerobic microbial growth. The bioventing biological system treats contaminated soil in situ by injecting atmospheric air. This air provides a continuous oxygen source, which enhances the growth of microorganisms naturally present in the soil. Additives such as ozone or nutrients may be introduced to stimulate microbial growth.

Bioventing technology uses an air pump attached to one of a series of air injection probes (see figure below). The air pump operates at extremely low pressures, providing inflow of oxygen without significantly volatilizing soil contaminants. The treatment capacity depends on the number of injection probes, the size of the air pump, and site characteristics such as soil porosity.




Bioventing System



The SITE Program assesses but does not approve or endorse technologies.

## WASTE APPLICABILITY:

Bioventing is typically used to treat soil contaminated by industrial processes and can treat any contamination subject to aerobic microbial degradation. Bioventing treats contaminants and combinations of contaminants with varying degrees of success.

## STATUS:

This technology was accepted into the SITE Demonstration Program in July 1991. The demonstration began in November 1992 at the Reilly Tar site in St. Louis Park, Minnesota. Soil at this site is contaminated with polynuclear aromatic hydrocarbons. The project will be completed in early 1999.

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# PHYTOKINETICS, INC.
## (Phytoremediation Process)

## TECHNOLOGY DESCRIPTION:

Phytoremediation is the treatment of contaminated soils, sediments, and groundwater with higher plants. Several biological mechanisms are involved in phytoremediation. The plant's ability to enhance bacterial and fungal degradative processes is important in the treatment of soils. Plant-root exudates, which contain nutrients, metabolites, and enzymes, contribute to the stimulation of microbial activity. In the zone of soil closely associated with the plant root (rhizosphere), expanded populations of metabolically active microbes can biodegrade organic soil contaminants.

The application of phytoremediation involves characterizing the site and determining the proper planting strategy to maximize the interception and degradation of organic contaminants. Site monitoring ensures that the planting strategy is proceeding as planned. The following text discusses (1) using grasses to remediate surface soils contaminated with organic chemical wastes (Figure 1), and (2) planting dense rows of poplar trees to treat organic contaminants in the saturated groundwater zone (Figure 2).

Soil Remediation - Phytoremediation is best suited for surface soils contaminated with intermediate levels of organic contaminants. Preliminary soil phytotoxicity tests are conducted at a range of contaminant concentrations to select plants which are tolerant. The contaminants should be relatively nonleachable, and must be within the reach of plant roots. Greenhouse-scale treatability studies are often used to select appropriate plant species.

Grasses are frequently used because of their dense fibrous root systems. The selected species are planted, soil nutrients are added, and the

Phytoremediation of Surface Soil

Phytoremediation of the Saturated Zone



The SITE Program assesses but does not approve or endorse technologies.

plots are intensively cultivated. Plant shoots are cut during the growing season to maintain vegetative, as opposed to reproductive, growth. Based on the types and concentrations of contaminants, several growing seasons may be required to meet the site's remedial goals.

Groundwater Remediation - The use of poplar trees for the treatment of groundwater relies in part on the tree's high rate of water use to create a hydraulic barrier. This technology requires the establishment of deep roots that use water from the saturated zone. Phytokinetics uses deep-rooted, water-loving trees such as poplars to intercept groundwater plumes and reduce contaminant levels. Poplars are often used because they are phreatophytic; that is, they have the ability to use water directly from the saturated zone.

A dense double or triple row of rapidly growing poplars is planted downgradient from the plume, perpendicular to the direction of groundwater flow. Special cultivation practices are use to induce deep root systems. The trees can create a zone of depression in the groundwater during the summer months because of their high rate of water use. Groundwater contaminants may tend to be stopped by the zone of depression, becoming adsorbed to soil particles in the aerobic rhizosphere of the trees. Reduced contaminant levels in the downgradient groundwater plume would result from the degradative processes described above.

## WASTE APPLICABILITY:

Phytoremediation is used for soils, sediments, and groundwater containing intermediate levels of organic contaminants.

## STATUS:

This technology was accepted into the SITE Demonstration Program in 1995. The demonstration will occur at the former Chevron Terminal #129-0350 site in Ogden, Utah. This demonstration will assess the ability of higher plants to reduce the concentration of petroleum hydrocarbons in near-surface soils, and to modify the groundwater gradient and reduce petroleum hydrocarbons in the saturated zone. Alfalfa and fescue plantings will be evaluated for soil remediation, while poplar and juniper trees will be investigated for their ability to treat the saturated groundwater zone.

The primary objectives of the demonstration are to determine whether (1) total petroleum hydrocarbon concentrations in the soil in plots planted with alfalfa and fescue will be reduced by 30 percent annually, and (2) an average annual 3-inch change in the groundwater elevation can be attributed to the trees. The demonstration continued through the 1998 growing season, with reports available in 1999.

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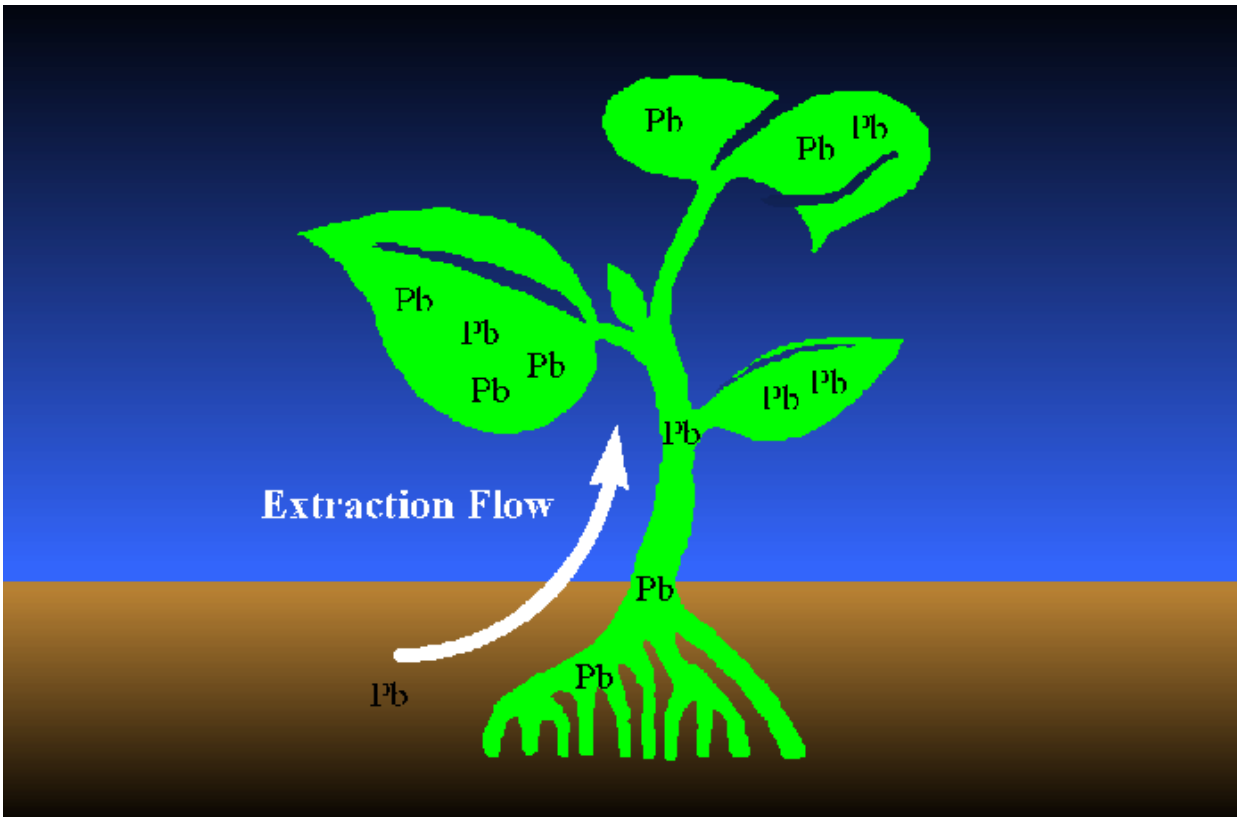
# PHYTOTECH
## (Phytoremediation Technology)

## TECHNOLOGY DESCRIPTION:

Phytotech is an environmental biotechnology company that uses specially selected and engineered plants to treat soil and water contaminated with toxic metals such as lead and cadmium, as well as radionuclides. The treatment of soils or sediments with this technology is referred to as phytoextraction (see figure below).

Phytoextraction offers an efficient, cost-effective, and environmentally friendly way to clean up heavy metal contamination. Plants are grown in situ on contaminated soil and harvested after toxic metals accumulate in the plant tissues. The degree of accumulation varies with several factors, but can be as high as 2 percent of the plants' aboveground dry weight, leaving clean soil in place with metal concentrations that equal or are less than regulatory cleanup levels. After accumulation in the plant tissues, the contaminant metal must be disposed of, but the amount of disposable biomass is a small fraction of the amount of soil treated. For example, excavating and landfilling a 10-acre site contaminated with 400 parts per million (ppm) lead to a depth of 1 foot requires handling roughly 20,000 tons of lead-contaminated soil. Phytoextraction of a 10-acre site to remove 400 ppm of lead from the top 1 foot would require disposal of around 500 tons of biomass - about 1/40 of the soil cleaned. In




Phytoextraction



The SITE Program assesses but does not approve or endorse technologies.

the example cited, six to eight crops would typically be needed, with three or four crops per growing season.

Compared to traditional remedial technologies, phytoextraction offers the following benefits:

- Lower cost
- Applicability to a broad range of metals
- Potential for recycling the metal-rich biomass
- Minimal environmental disturbance
- Minimization of secondary air- and water-borne wastes

## WASTE APPLICABILITY:

Phytotech's phytoextraction technology can be used to clean soil or sediments contaminated with lead, cadmium, chromium, cesium/strontium and uranium. Phytoremediation of other metals such as arsenic, zinc, copper, and thorium is in the research stage.

## STATUS:

Phytotech was accepted into the SITE Demonstration Program in 1997. Under the SITE Program, Phytotech is demonstrating its phytoremediation technology at a former battery manufacturing facility in Trenton, New Jersey. where soil is contaminated with lead. The site has been prepared and characterized, and two crops were planted and harvested in late summer 1998. Phytotech has also conducted several successful field trials of its phytoextraction technology at other contaminated sites in the U.S. and abroad.

Phytotech has conducted several field demonstrations of its rhizofiltration technology for the removal of (1) cesium/strontium at Chernobyl, and (2) uranium from contaminated groundwater at a DOE site in Ashtabula, Ohio. At Chernobyl, sunflowers were shown to extract 95 percent of the radionuclides from a small pond within 10 days. At the Ashtabula site, Phytotech ran a 9-month pilot demonstration during which incoming water containing as much as 450 parts per billion (ppb) uranium was treated to 5 ppb or less of uranium.

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# PINTAIL SYSTEMS, INC.
## (Spent Ore Bioremediation Process)

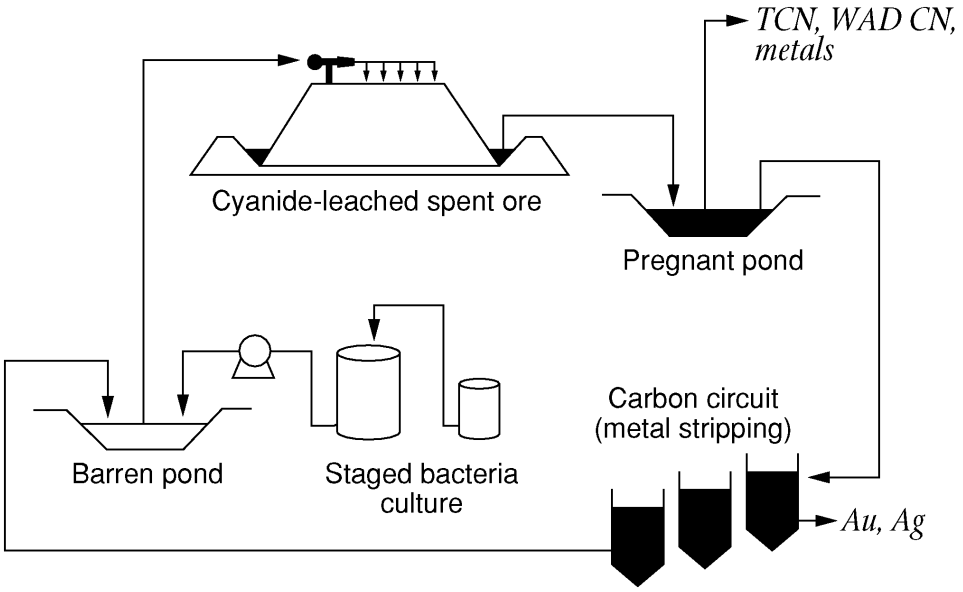
## TECHNOLOGY DESCRIPTION:

This technology uses microbial detoxification of cyanide in heap leach processes to reduce cyanide levels in spent ore and process solutions. The biotreatment populations of natural soil bacteria are grown to elevated concentrations, which are applied to spent ore by drip or spray irrigation. Process solutions are treated with bacteria concentrates in continuous or batch applications. This method may also enhance metal remineralization, reducing acid rock drainage and enhancing precious metal recovery to offset treatment costs.

Biotreatment of cyanide in spent ore and ore processing solutions begins by identifying bacteria that will grow in the waste source and that use the cyanide for normal cell building reactions. Native isolates are ideally adapted to the spent ore environment, the available nutrient pool, and potential toxic components of the heap environment. The cyanide-detoxifying bacteria are typically a small fraction of the overall population of cyanide-tolerant species.

For this reason, native bacteria isolates are extracted from the ore and tested for cyanide detoxification potential as individual species. Any natural detoxification potentials demonstrated in flask cyanide decomposition tests are preserved and submitted for bioaugmentation. Bioaugmentation of the cyanide detoxification population eliminates nonworking species of bacteria and enhances the natural detoxification potential by growth in waste infusions and chemically defined media. Pintail Systems, Inc. (PSI) maintains a bacterial library of some 2,500 strains of microorganisms and a database of their characteristics.

The working population of treatment bacteria is grown in spent ore infusion broths and process solutions to adapt to field operating conditions. The cyanide in the spent ore serves as the primary carbon or nitrogen source for bacteria nutrition. Other required trace nutrients are provided in the chemically defined broths. The bacterial consortium is then tested on spent ore in a 6-inch-by-10-foot column in the field or in the laboratory. The column simulates leach pile




Spent Ore Bioremediation Process



The SITE Program assesses but does not approve or endorse technologies.

conditions, so that detoxification rates, process completion, and effluent quality can be verified. Following column tests, a field test may be conducted to verify column results.

The spent ore is remediated by first setting up a stage culturing system to establish working populations of cyanide-degrading bacteria at the mine site. Bacterial solutions are then applied directly to the heap using the same system originally designed to deliver cyanide solutions to the heap leach pads (see figure on previous page). Cyanide concentrations and leachable metals are then measured in heap leach solutions. This method of cyanide degradation in spent ore leach pads degrades cyanide more quickly than methods which treat only rinse solutions from the pad. In addition to cyanide degradation, biological treatment of heap leach pads has also shown significant biomineralization and reduction of leachable metals in heap leachate solutions.

## WASTE APPLICABILITY:

The spent ore bioremediation process can be applied to treat cyanide contamination, spent ore heaps, waste rock dumps, mine tailings, and process water from gold and silver mining operations.

## STATUS:

This technology was accepted into the SITE Demonstration Program in May 1994. A site located in Battle Mountain, Nevada has been selected for the demonstration. Preliminary treatability tests have been completed. In addition, PSI has completed two full-scale cyanide detoxification projects.

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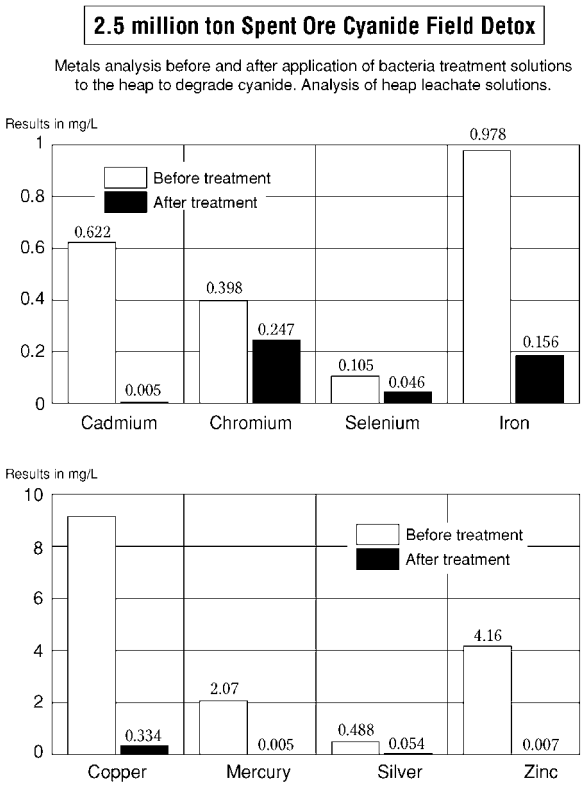
# PINTAIL SYSTEMS, INC.
## (Biomineralization of Metals)

## TECHNOLOGY DESCRIPTION:

Pintail Systems, Inc. (PSI), has evaluated the use of bioremediation processes for in situ biomineralization of heavy metals in mine wastes. Biomineralization processes are part of a natural cycle in which minerals are continuously formed, transformed, and degraded. In situ biomineralization capitalizes on the role that microorganisms play in natural ore formation and involves accelerating the biological reactions to remediate waste.

During biomineralization, microorganisms initiate a complex series of reactions. Effective metal removal mechanisms are influenced by biologically catalyzed remineralization reactions. PSI's research indicates that biomineralization begins when microorganisms attach to the ore's surface, forming a "bioslime" layer. Soluble metals then bind to cell walls and extracellular products. Next, metal hydroxides, oxides, and carbonates precipitate into the bioslime layer as amorphous mineral precursors, which provide a template for further mineralization as they stabilize.

A microbial population for biomineralization may be used in either batch or continuous treatment mode for in situ bioremediation. In batch mode, bacteria and nutrient solutions may be applied directly to contaminated soil, sediments, or




Biomineralization of Metals



The SITE Program assesses but does not approve or endorse technologies.

aqueous solutions to catalyze bioaccumulation and biomineralization. For continuous treatment, microorganisms may be immobilized in a porous matrix or fixed film reactor to remove metals from aqueous solutions.

## WASTE APPLICABILITY:

The PSI biomineralization process is designed to treat solids (soils, sludges, and sediments) that contain heavy metals or organics. It can also be applied to acid rock drainage that occurs naturally or that results from mining or energy production operations. The process can be applied at battery waste sites, urban lead sites, mines, and metal production and fabrication sites.

The PSI technology was accepted into the Emerging Technology Program in 1995. Under the Emerging Technology Program, PSI intends to complete development of its biomineralization process, resulting in a field-ready in situ biomineralization technology. PSI will conduct batch and continuous treatment tests at its laboratory and pilot plant in Aurora, Colorado, using soils, ore, sludges, and tailings from several Superfund sites.

PSI has developed and applied full-scale detoxification processes for spent ore at several mines in the western United States. In addition to cyanide detoxification, metals have been removed or remineralized during treatment at the mines. PSI has also demonstrated biomineralization of metals in laboratory- and pilot-scale tests for mining industry clients at Idaho, Nevada, Arizona, California, Colorado, Mexico, and Canada, including the Summitville Mine Superfund site in Colorado. The results of using biomineralization is shown in the figure on the previous page.

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# PRAXIS ENVIRONMENTAL TECHNOLOGIES, INC.
## (In Situ Thermally Enhanced Extraction (TEE) Process)

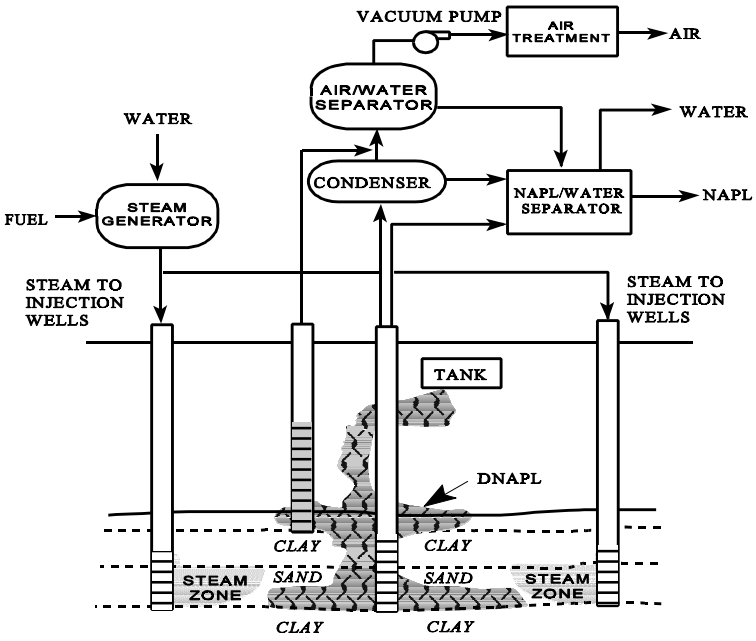
## TECHNOLOGY DESCRIPTION:

The PRAXIS TEE in situ thermal extraction process heats soil with steam injection, enhancing pump-and-treat and soil vapor extraction processes used to treat volatile organic compounds (VOC) and semivolatile organic compounds (SVOC). This process is an effective and relatively inexpensive technique to raise a target soil volume to a nearly uniform temperature.

As illustrated in the figure below, steam is introduced to the soil through injection wells screened in contaminated intervals. The vacuum applied to the extraction wells, during and after steam/hot air injection, forms a pneumatic barrier at the treatment boundaries. This barrier limits lateral migration of steam and contaminants while air sweeping the steam zone boundaries carries contaminants to extraction wells.

Groundwater and liquid contaminants are pumped from the extraction wells; steam, air, and vaporized contaminants are extracted under vacuum. After the soil is heated by steam injection, the injection wells can introduce additional agents to facilitate the cleanup.

Recovered vapors pass through a condenser. The resulting condensate is combined with pumped liquids for processing in separation equipment. Separated nonaqueous phase liquids (NAPL) can be recycled or disposed of, and the water is treated prior to discharge. The noncondensible gases are directed to a vapor treatment system consisting of (1) catalytic oxidation equipment, (2) activated carbon filters, or (3) other applicable vapor technologies. The in situ thermal extraction process uses conventional injection, extraction and monitoring wells, off-the-shelf piping, steam generators,




In Situ Thermal Extraction Process



The SITE Program assesses but does not approve or endorse technologies.

condensers, heat exchangers, separation equipment, vacuum pumps, and vapor emission control equipment.

## WASTE APPLICABILITY:

The in situ thermal extraction process removes VOCs and SVOCs from contaminated soils and groundwater. The process primarily treats chlorinated solvents such as trichloroethene (TCE), tetrachloroethene (PCE), and dichlorobenzene; hydrocarbons such as gasoline, diesel, and jet fuel; and mixtures of these compounds.

The process can be applied to rapid cleanup of source areas such as dense NAPL pools below the water table surface, light NAPL pools floating on the water table surface, and NAPL contamination remaining after using conventional pumping techniques. Subsurface conditions are amenable to biodegradation of residual contaminants, if necessary, after application of the thermal process. A cap is required for implementation of the process near the soil surface. For dense NAPL compounds in high concentrations, a barrier must be present or created to prevent downward percolation of the NAPLs. The process is applicable in less permeable soils with the use of novel delivery systems such as horizontal wells or fracturing.

## STATUS:

This technology was accepted into the SITE Demonstration Program in August 1993. The demonstration occurred at a former waste management area located at Operable Unit 2 at Hill Air Force Base in Ogden, Utah, during June and July 1997. The demonstration site was the location of two former unlined trenches that received unknown quantities of various chlorinated solvent wastes from 1967 to 1975.

The demonstration focused primarily on assessing and recovering dense NAPL from the trough area and reducing TCE and PCE levels in the lower saturated zone so as to meet or exceed the Record of Decision (ROD) cleanup goals and the Preliminary Remedial Goals (PRG) established for the site's soils.

Soil PRGs for TCE and PCE were 58 milligrams per kilogram (mg/Kg) and 12 mg/Kg respectively. A total of 41 post-characterization soil samples were collected to determine if these goals were met by the technology. Thirty-five of the 41 samples had PCE concentrations below the PRG. Thirty-five of the 41 samples also had TCE concentrations below the PRG. There were 33 samples that had both TCE and PCE concentrations below the specified PRGs. Detailed reports on the demonstration are in preparation and will be available from EPA in 1999. The developer is presently seeking patents on various aspects of the system, while continuing to seek opportunities at other U.S. Department of Defense facilities.

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# PROCESS TECHNOLOGIES INCORPORATED
## (Photolytic Destruction of Vapor-Phase Halogens)

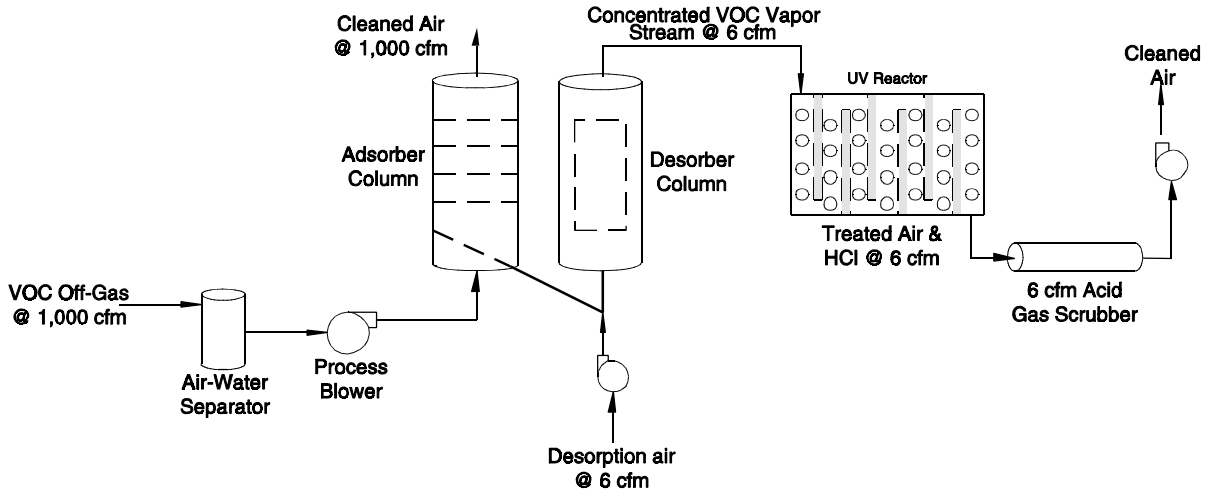
## TECHNOLOGY DESCRIPTION:

The proprietary, nonthermal technology developed by Process Technologies Incorporated (PTI), is a method of photochemically oxidizing gaseous organic compounds within a reaction chamber. PTI's Photolytic Destruction Technology (PDT) uses low-pressure ultraviolet (UV) lamps, with UV emissions primarily at wavelengths in the 185 to 254 nanometer range, located within the reaction chamber. Photons emitted from these lamps break apart the chemical bonds making up the volatile organic compound (VOC) molecule. The process is capable of destroying mixtures of chlorinated and nonchlorinated VOCs.

The PDT system is designed and fabricated in 3- to 12-cubic-feet-per-minute (cfm) modules. The size of the module applied is dependent on the gas flow rate and VOC concentrations in the gas stream. PTI implements a fluid bed concentrator to allow for the treatment of high flow gas streams, or those with rates greater than 1,000 cfm. Significant cost savings can be realized ifthe gas flow can be reduced, and concentration increased prior to destruction.

PTI uses a proprietary reagent that forms a liner within the process chamber. The reagent reacts chemically with the gaseous degradation products formed during the photolytic destruction of halocarbon molecules to form solid, stable reaction products.

Reagent lifetime depends on flow rate, influent concentrations, and specific chemical composition of destruction targets. PTI has performed tests on spent reagent to determine whether the material would be classified as a hazardous waste under federal regulations. Those tests indicated that the spent reagent is likely nontoxic. The spent reagent is also not reactive, corrosive, or flammable, and thus PTI is confident that it is not a hazardous waste under federal law. PTI accordingly believes that the spent reagent material can be disposed of as ordinary solid waste or used as a feedstock for




Simplified Process Flow Diagram
of Photolytic Destruction



The SITE Program assesses but does not approve or endorse technologies.

cement manufacturing. The PTI process is simple in design and easy to operate. The sy stem is designed to run continuously, 24-hours per day.

## WASTE APPLICABILITY:

The technology was developed to destroy a number of groups of compounds, including chlorinated solvents, chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), and halons. Example sources of process off-gas that contains chlorinated and nonchlorinated VOCs, CFCs, and HCFCs include steam vapor extraction, tank vents, air strippers, steam strippers, and building vent systems.

The process is capable of destroying as high as 50,000 parts per million by volume VOC streams. The system is capable of achieving greater than 90 percent on-line availability, inclusive of scheduled maintenance activities.

## STATUS:

The PTI technology was accepted into the SITE Demonstration Program in summer 1994. The demonstration began in September 1994 at McClellan Air Force Base (AFB) in Sacramento, California. The SITE demonstration was postponed shortly thereafter. Activities under the SITE Program were rescheduled in 1997. Additional tests incorporating an improved design for treating soil vapor extraction off-gas were successfully completed at the AFB in January 1996.

PTI completed a four month demonstration of the combined fluid bed concentrator and PDT system at the U.S. Navy's North Island Site 9 in February, 1998. This demonstration was performed to evaluate the effectiveness and cost to remove and destroy VOC vapor from an existing SVE system. The results of the demonstration at the Navy's North Island Site 9 showed the PTI System was capable of achieving greater than 95 percent destruction and removal efficiency of VOCs in the soil vapor at a 250 standard cfm flow rate. Furthermore, the Navy determined that the PTI System provided a 45 percent cost savings over activated carbon or flameless thermal oxidation.

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# PULSE SCIENCES, INC.
## (X-Ray Treatment of Organically Contaminated Soils)

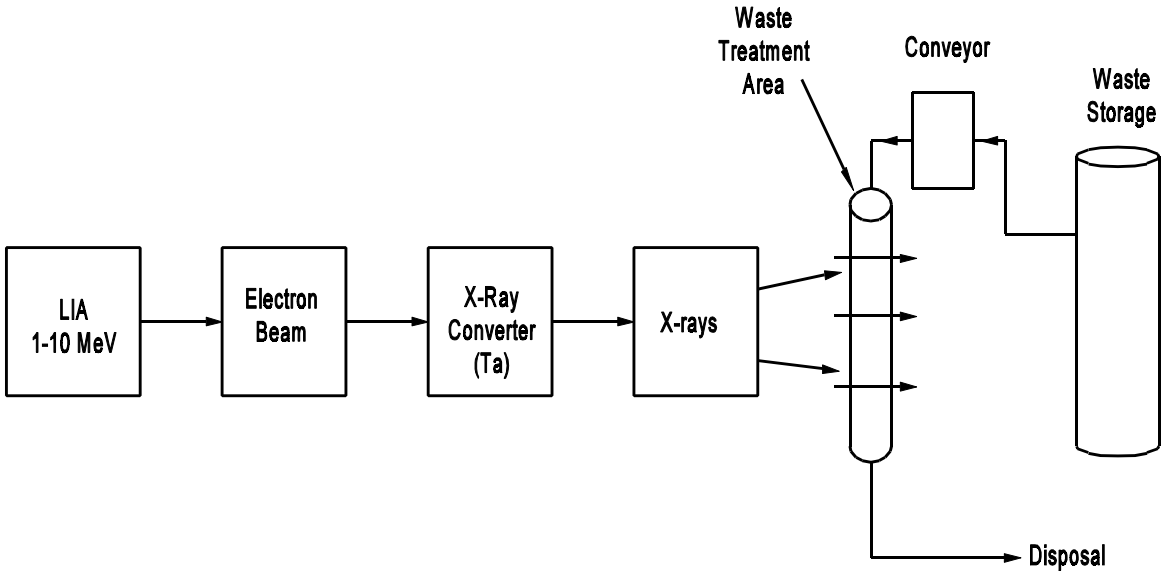
## TECHNOLOGY DESCRIPTION:

X-ray treatment of organically contaminated soils is based on in-depth deposition of ionizing radiation. Energetic photons (X-rays) collide with matter to generate a shower of lower- energy, secondary electrons within the contaminated waste material. These secondary electrons ionize and excite the atomic electrons, break up the complex contaminant molecules, and form highly reactive radicals. These radicals react with contaminants to form nonhazardous products such as water, carbon dioxide, and oxygen.

Other sources of ionizing radiation, such as ultraviolet radiation or direct electron beam processing, do not penetrate the treatable material deeply enough. Ultraviolet radiation heats only the surface layer, while a 1.5-million electron volt (MeV) charge penetrates about 4 millimeters into the soil. X-rays, however, penetrate up to 20 centimeters, allowing treatment of thicker samples. In situ treatment, which reduces material handling requirements, may also be possible with X-ray treatment.

An efficient, high-power, high-energy, linear induction accelerator (LIA) plus X-ray converter generates the X-rays used in the treatment process (see figure below). The LIA energy usually ranges from 8 to 10 MeV. A repetitive pulse of electrons 50 to 100 nanoseconds long is directed onto a cooled converter of high atomic number to efficiently generate X-rays. The X-rays penetrate and treat the organically contaminated soils.

The physical mechanism by which volatile organic compounds (VOC) and semivolatile organic compounds (SVOC) are removed primarily depends on the specific contaminant present. Because of the moisture in contaminated soil, sludge, and sediments, the shower of secondary electrons resulting from X-ray deposition produces both highly oxidizing hydroxyl radicals and highly reducing aqueous electrons. While hazardous by-products may form during X-ray treatment, contaminants and by-products, if found, may be completely converted at sufficiently high dose levels without undesirable waste residuals or air pollution.




X-Ray Treatment Process



The SITE Program assesses but does not approve or endorse technologies.

X-rays can treat contaminated soil on a conveyor or contained in disposal barrels. Because X-rays penetrate about 20 centimeters into soil, large soil volumes can be treated without losing a significant fraction of the ionizing radiation in standard container walls. Pulse Sciences, Inc., estimates that the cost of high throughput X-ray processing is competitive with alternative processes that decompose the contaminants.

## WASTE APPLICABILITY:

X-ray treatment of organically contaminated soils has the potential to treat large numbers of contaminants with minimum waste handling or preparation. Also, X-ray treatment can be applied in situ. In situ treatment may be of significant importance in cases where it is impossible or impractical to reconfigure the waste volume for the ionizing radiation range of electrons or ultraviolet radiation. Treatable organic contaminants include benzene, toluene, xylene, trichloroethene, tetrachloroethene, carbon tetrachloride, chloroform, and polychlorinated biphenyls.

## STATUS:

This technology was accepted into the SITE Emerging Technology Program in 1993. A 1.2-MeV, 800-ampere (amp), 50-watt LIA and a 10.8-MeV, 0.2-amp, 10,000-watt radio frequency (RF) linac will be used in the program. The primary objectives are to (1) demonstrate that X-ray treatment can reduce VOC and SVOC levels in soils to acceptable levels, and (2) determine any hazardous by-product that may be produced.

Samples with identical initial contaminant concentration levels will be irradiated at increasing dose levels to determine (1) the rate (concentration versus dose) at which the contaminants are being destroyed, and (2) the X-ray dose required to reduce organic contamination to acceptable levels. The 10.8-MeV RF linac, which produces more penetrating X-rays, should provide information on the optimum X-ray energy for the treatment process. Increasing the accelerator energy allows a more efficient conversion from electrons to X-rays in the converter, but an upper limit (about 10 MeV) restricts the energy treatment, because higher energy activates the soil. The experimental database will be used to develop a conceptual design and cost estimate for a high throughput X-ray treatment system.

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# RECYCLING SCIENCES INTERNATIONAL, INC.
## (Desorption and Vapor Extraction System)

## TECHNOLOGY DESCRIPTION:

The mobile desorption and vapor extraction system (DAVES) uses a low-temperature fluidized bed to remove organic and volatile inorganic compounds from soils, sediments, and sludges. This system can treat materials with 85 percent solids at a rate of 10.5 tons per hour.

Contaminated materials are fed into a co-current, fluidized bed dryer, where they are mixed with hot air (about 1,000 to 1,400 °F) from a gas-fired heater. Direct contact between the waste material and the hot air forces water and contaminants from the waste into the gas stream at a relatively low fluidized-bed temperature (about 320 °F). The heated air, vaporized water and organics, and entrained particles flow out of the dryer to a gas treatment system.

The gas treatment system removes solid particles, vaporized water, and organic vapors from the air stream. A cyclone separator and baghouse remove most of the particulates. Vapors from the cyclone separator are cooled in a venturi scrubber, countercurrent washer, and chiller section before they are treated in a vapor-phase carbon adsorption system. The liquid residues from the system are centrifuged, filtered, and passed through two activated carbon beds arranged in series (see photograph below).

By-products from the DAVES include (1) treated, dry solids representing about 96 to 98 percent of the solid waste feed, (2) a small quantity of centrifuge sludge containing organics, (3) a small quantity of spent adsorbent carbon, (4) wastewater that may need further treatment, and (5) small quantities of baghouse and cyclone dust that are recycled through the process.

**Desorption and Vapor Extraction System (DAVES)**



The SITE Program assesses but does not approve or endorse technologies.

The centrifuge sludge can be bioremediated, chemically degraded, or treated in another manner. Recycling Sciences International, Inc., has patented an electrochemical oxidation process (ECO) and is developing this process as an adjunct to the DAVES. The ECO is designed to detoxify contaminants within the DAVES in a closed-loop system.

## WASTE APPLICABILITY:

This technology removes the following contaminants from soil, sludge, and sediment: volatile and semivolatile organics, including polychlorinated biphenyls (PCB), polynuclear aromatic hydrocarbons, pentachlorophenol, volatile inorganics such as tetraethyl lead, and some pesticides. In general, the process treats waste containing less than 10 percent total organic contaminants and 30 to 95 percent solids. The presence of nonvolatile inorganic contaminants (such as metals) in the waste feed does not inhibit the process; however, these contaminants are not treated.

This technology was accepted into the SITE Program in April 1995. EPA is selecting a demonstration site for this process. Preferred demonstration wastes include harbor or river sediments containing at least 50 percent solids contaminated with PCBs and other volatile or semivolatile organics. Soils with these characteristics may also be acceptable. About 300 tons of waste is needed for a 2-week test. Major test objectives are to evaluate feed handling, decontamination of solids, and treatment of gases generated by the process.

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# ROCKY MOUNTAIN REMEDIATION SERVICES, L.L.C.
## (ENVIROBOND™ SOLUTION)

## TECHNOLOGY DESCRIPTION:

ENVIROBOND™ is a proprietary solution that binds with metals in contaminated soils and other wastes to form a virtually impenetrable chemical bond. Rocky Mountain Remediation Services, L.L.C., claims that the treatment process effectively prevents metals leaching and can be used with mechanical compaction to reduce the overall volume of contaminated media by 30 to 50 percent. The process generates no secondary wastes and requires minimal handling, transportation, and disposal costs. In addition, unlike some pozzolanic-based reagents, the ENVIROBOND™ liquid is safe to handle and does not generate any emissions.

ENVIROBOND™ consists of a mixture of additives containing oxygen, sulfur, nitrogen, and phosphorous; each additive has an affinity for a specific class of metals. ENVIROBOND™ converts metal contaminants from their leachable form to an insoluble, stable, nonhazardous metallic complex. ENVIROBOND™ is essentially a ligand that acts as a chelating agent. In the chelation reaction, coordinate bonds attachthe metal ion to least two ligand nonmetal ions to form a heterocyclic ring. The resulting ring structure is inherently more stable than simpler structures formed in other binding processes. By effectively binding the metals, the process reduces the waste stream's RCRA toxicity characteristic leaching procedure (TCLP) test results to less than the RCRA-regulated levels, subsequently reducing the risks posed to human health and the environment.

The stabilized waste can then be placed in a pit or compacted into the earth using traditional field compaction equipment, or it can be mechanically compacted to produce a solid, compressed form called ENVIROBRIC™. The machine used to form the ENVIROBRIC™ is designed for mass production of sand-clay "rammed earth" bricks. Unlike conventional construction bricks, rammed earth bricks are produced under extremely high compaction forces and are not heated or fired. As a result, the bricks possess very high compressive strength and a correspondingly low porosity, making them ideal for on-site treatment by solidification/stabilization at industrial sites.
The size of the individual bricks can be adjusteddepending on specific site requirements, and the bricks have successfully passed various tests designed to measure their long-term durability.

## WASTE APPLICABILITY:

The ENVIROBOND™ process does not reduce the overall concentration of metal contaminants; instead it converts them to metal-ligand compounds, rendering them insoluble and stable in the media. The developer claims that the process can be applied to contaminated soils and other media in both industrial and residential use scenarios. At residential sites, contaminated soil can be mixed with ENVIROBOND™ and stabilized before being disposed of off site. At industrial sites, ENVIROBOND™ can be mixed with contaminated waste streams or soils and then compacted in the ENVIROBRIC™ process and backfilled on site to reduce the overall volume of contaminated media.

Bench-scale and field tests indicate that ENVIROBOND™ can be added to waste streams containing more than four metal contaminants at concentrations ranging from 200 to more than 5,000 parts per million (ppm). TCLP tests have


The SITE Program assesses but does not approve or endorse technologies.

shown that metals concentrations in leachate from treated media do not exceed RCRA regulatory levels. Metals that can be stabilized with ENVIROBOND™ include arsenic, barium, cadmium, chromium, lead, mercury, nickel, selenium, silver, and zinc. However, the process is less effective in media containing more than 3 percent by weight of metals such as aluminum, magnesium, calcium, and manganese. These metals may reduce the number of chelating sites available by preferentially binding with the ENVIROBOND™ agent.

The ENVIROBOND process is capable of achieving high processing rates of 20 to 40 tons per hour and can be used with contaminated media containing as much as 10 percent debris and other matter. For acidic wastes with a pH of 3 or less, buffering compounds can be added to the contaminated media before it is mixed with ENVIROBOND™. Volatile organic compounds such as benzene, toluene, ethylbenzene, and xylenes do not affect the process.

## STATUS:

Under a cooperative agreement with the Ohio EPA, the ENVIROBOND™ process was demonstrated in September 1998 at two separate areas of the Crooksville/Roseville Pottery site in Ohio. Soil at the site, some of it adjacent to residential areas, is contaminated with lead from waste disposal practices associated with pottery production operations. Soil at the demonstration areas contains lead in concentrations ranging from 100 ppm to 80,000 ppm. The objective of the demonstration was to determine if the ENVIROBOND™ process can reduce the bioavailability of lead in the soil by 25 percent. Results of the demonstration will be available in early 1999.

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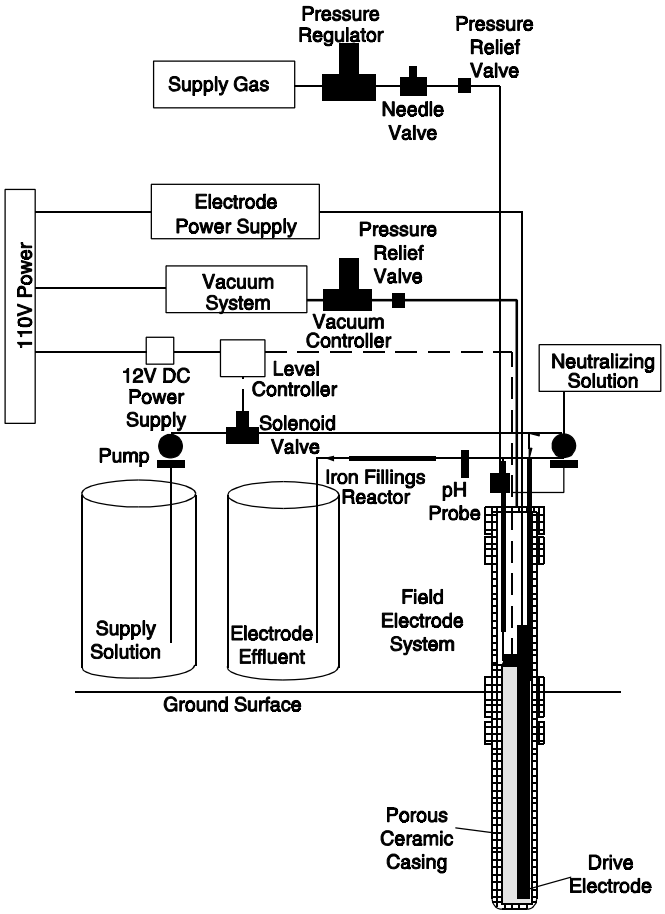
# SANDIA NATIONAL LABORATORIES
## (In Situ Electrokinetic Extraction System)

## TECHNOLOGY DESCRIPTION:

Electrokinetic remediation has been used successfully to treat saturated soils contaminated with heavy metals. At some sites, however, it may not be desirable to add the quantities of water needed to saturate a contamination plume in the vadose zone. Sandia National Laboratories (SNL) has developed an electrokinetic remediation technology that can be used in unsaturated soils without adding significant amounts of water.

The SNL electrokinetic extraction system, shown in the figure below, consists of three main units: the electrode assembly (electrode casing and internal assemblies), the vacuum system, and the power supply. The electrode casing consists of a porous ceramic end that is 5 to 7 feet long and has an outer diameter of 3.5 inches. During field installation, the casing is attached to the required length of 3-inch polyvinyl chloride pipe. The electrode internal assembly consists of the drive electrode, a water level control system, and a pump system. The vacuum system consists of a venturi vacuum pump and vacuum regulator that together supply a constant vacuum for the electrode. Up to four 10,000-watt power supplies can operate in either constant voltage or constant current mode.

When the drive electrode is energized, contaminants and other ions are attracted into the electrode casing. The water level control system




Schematic Diagram of the In Situ Electrokinetic Extraction System



The SITE Program assesses but does not approve or endorse technologies.

adds water to, and extracts water from, the electrodes. Water is supplied to the electrode from a supply solution tank at the ground surface. This solution is either drawn into the electrode by the vacuum maintained in the electrode or by a supply pump. At the same time, water is continuously pumped out from the electrode casing at a constant rate. Part of the contaminated water is sent to an effluent waste tank at the ground surface; the remainder is returned to the electrode to maintain circulation of the fluid surrounding the electrode. A metering pump controlled by in-line pH meters regulates the introduction of neutralization chemicals to each electrode. Process control and monitoring equipment is contained in a 10-foot- by-40-foot instrument trailer.

## WASTE APPLICABILITY:

SNL has developed its electrokinetic extraction system to treat anionic heavy metals such as chromate in unsaturated soil. There is no lower limit to the contaminant concentration that can be treated; however, there may be a lower limit on the ratio of contaminant ions to other ions in the soil.

The technology can be expanded to treat saturated soils. Soil that is highly conductive because of a high salinity content is not suitable for this technology. In addition, sites with buried metal debris, such as pipelines, are not appropriate.

## STATUS:

This technology was accepted into the SITE Demonstration Program in summer 1994. The SITE demonstration began May 1996, at an unlined chromic acid pit within a SNL RCRA regulated landfill. The operation was completed in November 1996 and site closure was completed in April 1997, with a closure report submitted to New Mexico state regulators in September 1997.

The demonstration verified the technology's capability of removing anionic contaminants from vadose zone soil through passive operation. Over 600 grams of hexavalent chromium were removed by the technology during the demonstration, equaling out to about 8 milligrams of chromium removed per kilowatt hour. Reports on the demonstration are in final preparation and should be available from EPA in early 1999.

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# SELENTEC ENVIRONMENTAL TECHNOLOGIES, INC.
## (Selentec MAG*SEP℠ Technology)

## TECHNOLOGY DESCRIPTION:

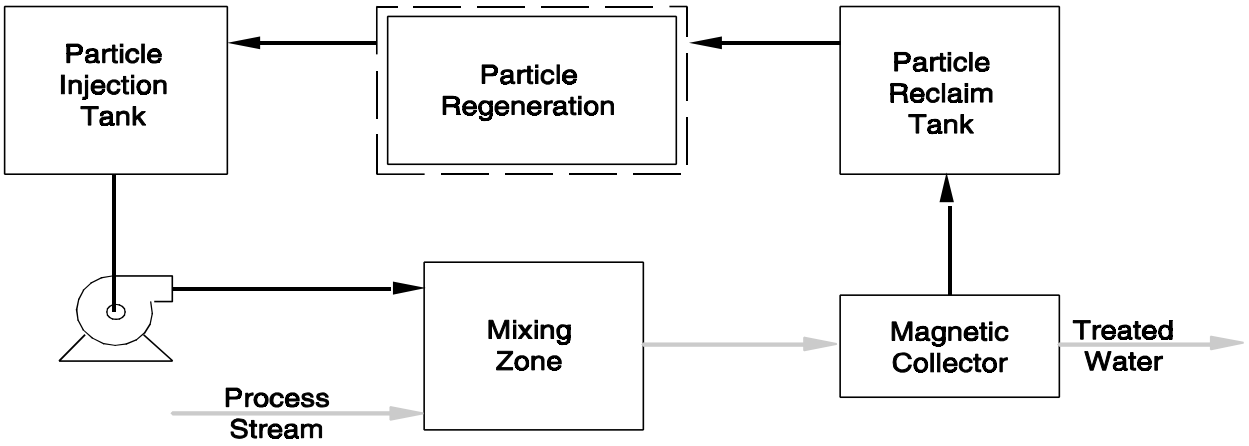
The MAG*SEP℠ process uses the principles of chemical adsorption and magnetism to selectively bind and remove heavy metals or radionuclides from aqueous solutions such as groundwater, wastewater, and drinking water. Contaminants are adsorbed on specially formulated particles which have a core made from magnetic material; these particles are then separated (along with the adsorbed contaminants) from the solution using a magnetic filter or magnetic collector. The magnetic core has no interaction with the contaminant.

The proprietary adsorbing particles are made of a composite of organic polymers and magnetite. The particles can be manufactured in two forms: one with an ion exchanger and/or chelating functional group attached to the particle surface (amidoxime functionalized resin), or one with inorganic adsorbers bound to the surface of the particles (clinoptilolite). These particles have high surface areas and rapid adsorption kinetics.

A typical MAG*SEP℠ treatment system consists of:

- a particle contact zone
- a particle handling system, including particle injection components, a magnetic separator, and particle reclaim components
- a particle regeneration system (where applicable)

The process stream enters a contact zone (usually a tank - other configurations are used for particular applications) where MAG*SEP℠ particles are injected and mixed. The contact zone provides the necessary solution flow characteristics and contact time with the particles to ensure that the contamination will be adsorbed onto the active surface sites of the particles. The mixture then flows through a magnetic collector, where the contaminated particles are retained while the treated process stream passes through (see figure below).




Schematic Diagram of the Mag*SEP℠ Treatment System



The SITE Program assesses but does not approve or endorse technologies.

Depending on the application, type of particle, and contaminant concentration, the particles may be re-injected into the flow stream, collected and disposed of, or regenerated and reused. The regeneration solution is processed to recover (concentrate and remove) the contaminants and may be recycled.

The MAG*SEP[SM] process is able to selectively remove (either ex situ or in situ) the following contaminants from aqueous solutions: titanium, copper, cadmium, arsenic, cobalt, molybdenum, platinum, selenium, chromium, zinc, gold, iodine, manganese, technetium, mercury, strontium, iron, ruthenium, thallium, cesium, cobalt, palladium, lead, radium, nickel, silver, bismuth, thallium, antimony, zirconium, radium, cerium, and all actinides. The process operates at flow rates up to 2,000 gallons per minute (gpm).

## WASTE APPLICABILITY:

The MAG*SEP[SM] technology reduces heavy metal and radionuclide contamination in water and wastewater. The technology has specific applications in environmental remediation and restoration, treatment of acid mine drainage, resource recovery, and treatment of commercial industrial wastewater. MAG*SEP[SM] particles can be produced to incorporate any known ion exchanger or sorbing material. Therefore, MAG*SEP[SM] can be applied in any situation where conventional ion exchange is used.

## STATUS:

The MAG*SEP℠ technology was accepted into the SITE Program in 1996 and is also one of 10 technologies participating in the White House's Rapid Commercialization Initiative. In addition, in 1997 the MAG*SEP[SM] technology received a Research and Development (R&D) 100 Award from the R&D trade publication as one of the 100 Most Technologically Significant New Products of 1997.

Selentec has completed a demonstration of the MAG*SEP℠ technology at the U.S. Department of Energy's Savannah River Site. Heavy metal concentrations in coal pile runoff water were significantly reduced to below drinking water standards. Another demonstration of the technology is planned for Savannah River whereby radioactive cesium will be removed streams. The technology is also being used to remove mercury from heavy water drums at Savannah River.

The first commercial unit of the MAG*SEP℠ technology was put into service on November 18, 1998, at a dairy in Ovruch, Ukraine. For this application, the unit is removing radioactive cesium from contaminated milk produced near the Chernobyl Nuclear Reactor Plant.

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# SEVENSON ENVIRONMENTAL SERVICES, INC.
## (MAECTITE® Chemical Treatment Process)

## TECHNOLOGY DESCRIPTION:

The patented MAECTITE® chemical treatment process for lead and other heavy metals uses reagents and processing equipment to render soils, waste, and other materials nonhazardous when tested by the Resource Conservation and Recovery Act toxicity characteristic leaching procedure (TCLP). The MAECTITE® process reduces leachable lead, hexavalent chromium, and other heavy metals to below treatment standards required by land-ban regulations. Lead in treated material, as determined by approved EPA methods (such as the TCLP, extraction procedure toxicity test, and the multiple extraction procedure), complies with limits established by EPA. The photograph below shows a 500-ton-per-day ex situ unit.

500-Ton-Per-Day MAECTITE® Processing System

Chemical treatment by the MAECTITE® process converts leachable lead into insoluble minerals and mixed mineral forms within the material or waste matrix. MAECTITE® reagents stimulate the nucleation of crystals by chemical bonding to yield mineral compounds in molecular forms. These forms are resistant to leaching and physical degradation from environmental forces. The durability of traditional monolithic solidification-stabilization process end-products is often measured by geotechnical tests such as wet-dry, freeze-thaw, permeability, and unconfined compressive strength. The MAECTITE® process does not use physical binders, is not pozzolanic or siliceous, and does not rely on the formation of metallic hydroxides using hydration mechanisms. Therefore, these tests are not relevant to MAECTITE® product chemical stability, although engineered properties are readily obtained, if required. MAECTITE® is not pH dependent and does not use adsorption, absorption, entrapment, lattice containment, encapsulation, or other physical binding principles. The technology is a true chemical reaction process that alters the structure and properties of the waste, yielding stable compounds.

The MAECTITE® process uses water to assist in dispersing reagents. However, the dehydration characteristic of the process liberates water present in waste prior to treatment (absorbed and hydrated forms) to a free state where it can be removed from the waste matrix by evaporation and capillary drying principles. The ability of treated material to readily lose water, the formation of dense mineral crystals, and the restructuring of the material as a result of MAECTITE® treatment (where interstitial space is minimized), all contribute to reduced waste volume and weight.

Ex situ MAECTITE® processing equipment generally consists of material screening and sizing components, liquid and solid reagent storage delivery subsystems, and a mixing unit such as a pug mill. Equipment is mobile but can



The SITE Program assesses but does not approve or endorse technologies.

be modified for fixed system operations. In situ MAECTITE® processing equipment is also available; system selection is largely dictated by contaminant plume configuration, soil characteristics, and site space limitations.

## WASTE APPLICABILITY:

Materials that have been rendered nonhazardous include soils; sludges; sediments; battery contents, including casings; foundry sands; and firing range soil. Oversized material can be treated with the process as debris, but size reduction often makes processing more efficient. Even sludges with free liquids (as determined by the paint filter test) have been treated to TCLP compliance when excess fluids are present.

The range of lead levels effectively treated has not been fully determined; however, soils with total lead as high as 30 percent by weight and TCLP values over 15,000 milligrams per liter (mg/L) were not problematic. Common lead levels encountered have averaged from 200 milligrams per kilogram to 6,500 with TCLP concentrations averaging 20 to 400 mg/L. Material geochemistry most often dictates final MAECTITE® treatment designs. Furthermore, correlations between total lead and regulated leachable lead levels are inconsistent, with treatment efforts more strongly related to the geochemical characteristics of the waste material.

## STATUS:

The chemical treatment technology was initially accepted into the SITE Demonstration Program in March 1992. EPA is seeking a suitable demonstration site.

Sevenson Environmental Services, Inc. (Sevenson), acquired the MAECTITE® technology in 1993 and was issued second, third and fourth patents in 1995, 1996, and 1997 respectively. Combining ex situ and in situ quantities, over 650,000 tons of material has been successfully processed. Treatability studies have been conducted on over 100 different materials in over 40 states, Canada, Italy, and Mexico. The technology has been applied at full-scale demonstration and remedial projects in over 25 states and in all 10 EPA regions.

The MAECTITE® process has been formally accepted into the EPA PQOPS program for the fixation-stabilization of inorganic species. Proprietary technology modifications have shown promise in rendering radionuclides nonleachable using gamma spectral counting methods on TCLP extract.

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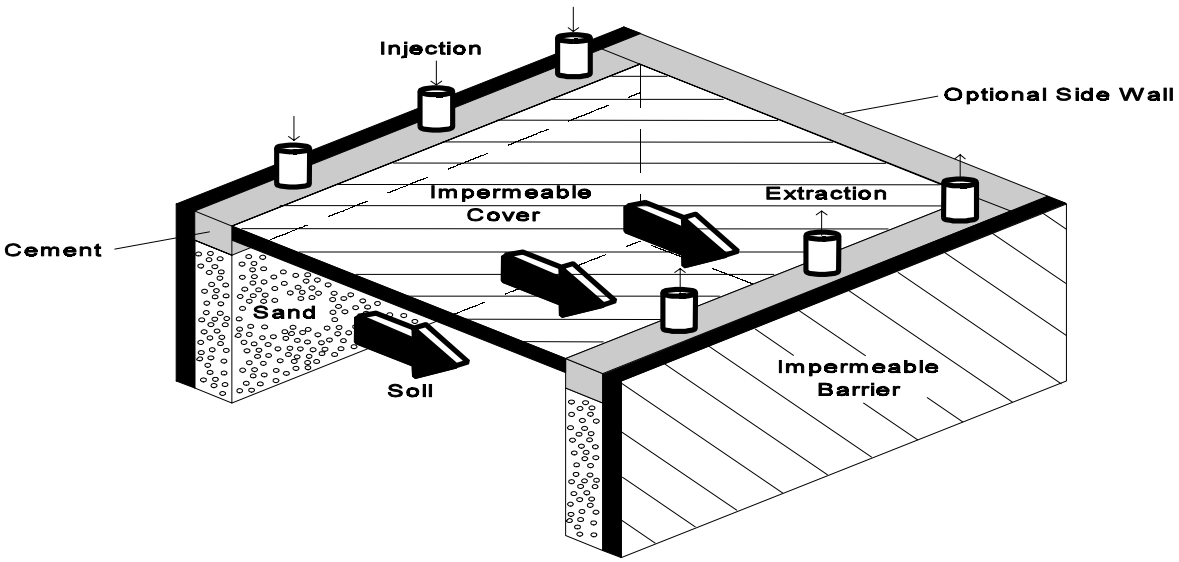
# SIVE SERVICES
## (Steam Injection and Vacuum Extraction)

## TECHNOLOGY DESCRIPTION:

Steam Injection and Vacuum Extraction (SIVE) uses steam injection wells in conjunction with dual-phase extraction wells for in situ treatment of contaminated soil and groundwater. The injected steam strips volatile and semivolatile organic compounds as it permeates the contaminated zones. The steam increases the subsurface temperature, which increases mass transfer and phase exchange rates, reduces liquid viscosities, and accelerates desorption of contaminants from the matrix. The moisture and warmth provided by the steam also accelerates biodegradation of residual contaminants. As a result, contaminants are extracted or degraded at increased rates as compared to conventional isothermal vapor and liquid extraction systems.

SIVE-LF (Linear Flow) is an enhanced SIVE method designed for relatively shallow depths. With the SIVE-LF process, as illustrated in the figure below, steam is forced to flow horizontally and uniformly from one trench, through the contaminant zone, and into another trench, from which the contaminants are extracted. The large open area of the trench faces allow for high injection and extraction rates, which promote low treatment duration. The trenches also allow for installation of an impermeable barrier, such as a polyethylene liner, against one face of the open trench before the trench is backfilled, thus reducing the flow of injected or extracted fluid outside the area of the targeted zones. A surface covering for the treatment area prevents short-circuiting of the flow of injected steam to the atmosphere, and prevents atmospheric air from entering the extraction trench.

Surface equipment for SIVE includes conventional steam generation and delivery systems, and the vacuum extraction system. The vacuum extraction system includes a vacuum blower, steam condenser, other cooling components, and air emission control devices. The condensate generated by the process requires




The SIVE-LF Process



The SITE Program assesses but does not approve or endorse technologies.

further treatment or off-site disposal. The reliability of the equipment and automatic controls allows SIVE to operate without constant direct supervision.

## WASTE APPLICABILITY:

SIVE may be applied to soil or groundwater contaminated with fuels, industrial solvents, oils, and other liquid toxics, and may be applied at any depth. The SIVE-LF process is designed to treat to depths of 30 feet. Because highly volatile contaminants are readily air-stripped without the added effects of steam, the steam-stripping effect will be greatest on the heavier, less volatile contaminants. SIVE also effectively removes floating non aqueous-phase liquids from groundwater.

## STATUS:

This technology was accepted into the SITE Demonstration Program in summer 1994. A suitable site for the demonstration is being sought, although at this time the project is considered inactive.

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# STAR ORGANICS, L.L.C.
## (Soil Rescue Remediation Fluid)

## TECHNOLOGY DESCRIPTION:

Star Organics, L.L.C., has developed a liquid remediation solution that binds heavy metal contaminants in soils, sludges, and aqueous solutions. The liquid, called Soil Rescue, consists of organic acids that occur naturally in trace concentrations in soil. The liquid is typically sprayed onto and then tilled into the contaminated media; the application process can be repeated until the metals concentration in the media are reduced to below the applicable cleanup standards. Laboratory and pilot-scale tests have shown that metals concentrations can be reduced to below Research Conservation and Recovery Act (RCRA) regulatory levels.

The Soil Rescue solution does not destroy or remove toxic concentrations of metals. Instead, organic acids in the solution bond with the metals to form more complex metallic compounds in a process known as chelation. Soil Rescue is essentially a ligand that acts as a chelating agent. In the chelation reaction, coordinate bonds attach the metal ion to least two ligand organic compounds to form a heterocyclic ring. The resulting ring structure is inherently more stable than simpler structures formed in other binding processes.

By effectively binding the metals, the process reduces the waste stream's toxicity characteristic leaching procedure (TCLP) test results to less than the RCRA-regulated levels, subsequently reducing the risks posed to human health and the environment. Once the toxic metals are bound to the ligand, the bond appears to be irreversible. The permanence of the bond has been tested using all recognized EPA test procedures for such determinations, including exposure to boiling acids.

The Soil Rescue process offers the following advantages over some treatment options: (1) it minimizes the handling and transport costs associated with treatment and disposal, (2) it requires no air monitoring because it release no emissions, (3) its liquid application procedure minimizes fugitive dust emissions, (4) it generates no effluent, (5) it requires no stockpiling of contaminated soil, and (6) it minimizes exposure risks for workers because it is sprayed directly onto the contaminated media.

## WASTE APPLICABILITY:

The Soil Rescue solution has been shown to be effective in reducing concentrations of barium, cadmium, chromium, copper, lead, mercury, selenium, and zinc. In situ remediation of heavy metal contaminated soil may be possible in moderately permeable soils. In dense or heavily compacted soils, the remediation procedure may require soil excavation and application of the Soil Rescue solution to moisten the media, followed by mixing in a rotating cylinder. This procedure can be repeated until the metals concentrations in the soil are sufficiently reduced to allow the soil to be replaced as backfill in its original location. At a soil pH of 5.0, a single application can reduce lead concentrations of 1,000 parts per million (ppm) to below the EPA maximum permissible level; with a second application of the remediation fluid, lead concentrations can be reduced to below the RCRA regulatory limit of 5 ppm.

## STATUS:

Under a cooperative agreement with the Ohio EPA, the Soil Rescue technology was demonstrated in September 1998 at two separate areas of the Crooksville/Roseville Pottery site in Ohio. Soil at the site, some of it adjacent to residential areas, is contaminated with lead from waste disposal practices associated with pottery production operations. Soil at the demonstration areas contain lead in concentrations ranging from 100 ppm to 80,000 ppm. The objective of the demonstration was to determine if the Soil Rescue process can reduce the bioavailability of lead in the soil by 25 percent. Results of the demonstration will be available in early 1999.



The SITE Program assesses but does not approve or endorse technologies.

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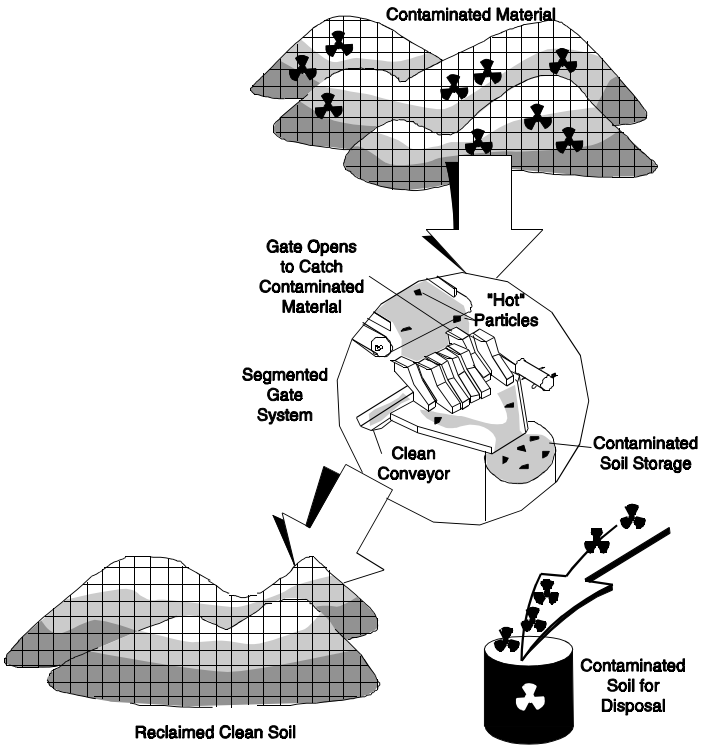
# THERMO NUTECH, INC.
## (formerly TMA THERMO ANALYTICAL, INC.)
## (Segmented Gate System)

## TECHNOLOGY DESCRIPTION:

Thermo NUtech, Inc. (Thermo), has conducted many radiological surveys of soil contaminated with low and intermediate levels of radioactivity. Cleanup of these sites is a highly labor-intensive process requiring numerous personnel to conduct radiological surveys with portable hand-held instruments. When small areas of contamination are encountered, they are typically removed manually. When surveys disclose larger areas of contamination, heavy equipment is used to remove the contaminated material. Because pinpoint excision with earthmoving equipment is difficult, large amounts of uncontaminated soil are removed with the contaminant. Few sites have been characterized to be uniformly and/or homogeneously contaminated above release criteria over the entire site area.

As a result, Thermo developed the Segmented Gate System (SGS) to physically separate and segregate radioactive material from otherwise "clean" soil (see figure below). The SGS removes only a minimal amount of clean soil when radioactive particles are removed, significantly reducing the overall amount of material requiring disposal. The SGS works by conveying radiologically contaminated feed material on moving conveyor belts under an array of sensitive, rapidly reacting radiation detectors. The moving material is assayed, and radioactivity content is logged. Copyrighted computer software tracks the radioactive material as it is transported by the conveyor. The software then triggers a diversion by one or more of the SGS chutes when the material reaches the end of the conveyor. Clean soil goes in one direction, and contaminated material in another.




TMA's Segmented Gate System



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The key advantage to this system is automation, which affords a much higher degree of accuracy compared to manual methods. Contaminants can be isolated and removed by locating small particles of radioactive material dispersed throughout the soil. All of the soil is analyzed continuously during processing to document the level of radioactivity in the waste and to demonstrate that cleaned soil meets release criteria. This automation and analysis results in a significant cost reduction for special handling, packaging, and disposal of the site's radioactive waste.

## WASTE APPLICABILITY:

The SGS locates, analyzes, and removes gamma ray-emitting radionuclides from soil, sand, dry sludge, or any host matrix that can be transported by conveyor belts. The SGS can identify hot particles, which are assayed in units of picoCuries, and can quantify distributed radioactivity, which is assayed in units of picoCuries per gram (pCi/g) of host material. The lower limit of detection (LLD) for the system depends on the ambient radiation background, conveyor belt speed, thickness of host material on conveyor, and contaminant gamma ray energy and abundance. However, LLDs for americium-241 of 2 pCi/g and for radium-226 of 5 pCi/g have been successfully demonstrated.

## STATUS:

This technology was accepted into the SITE Emerging Technology Program in July 1994. Pilot- and field-scale tests using Thermo-owned mobile equipment began at a U.S. Department of Energy facility in March 1995.

A field test at a DOE site in Ashtabula, Ohio was scheduled for October 1998. Soil containing throrium-232, radium-226, and uranium-238 will be processed.

A similar system has been used on Johnston Atoll in the mid-Pacific since January 1992; Thermo is currently under contract to the U.S Defense Nuclear Agency to process coral soil contaminated with plutonium and americium using the SGS.

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# UNIVERSITY OF HOUSTON
## (Concentrated Chloride Extraction and Recovery of Lead)

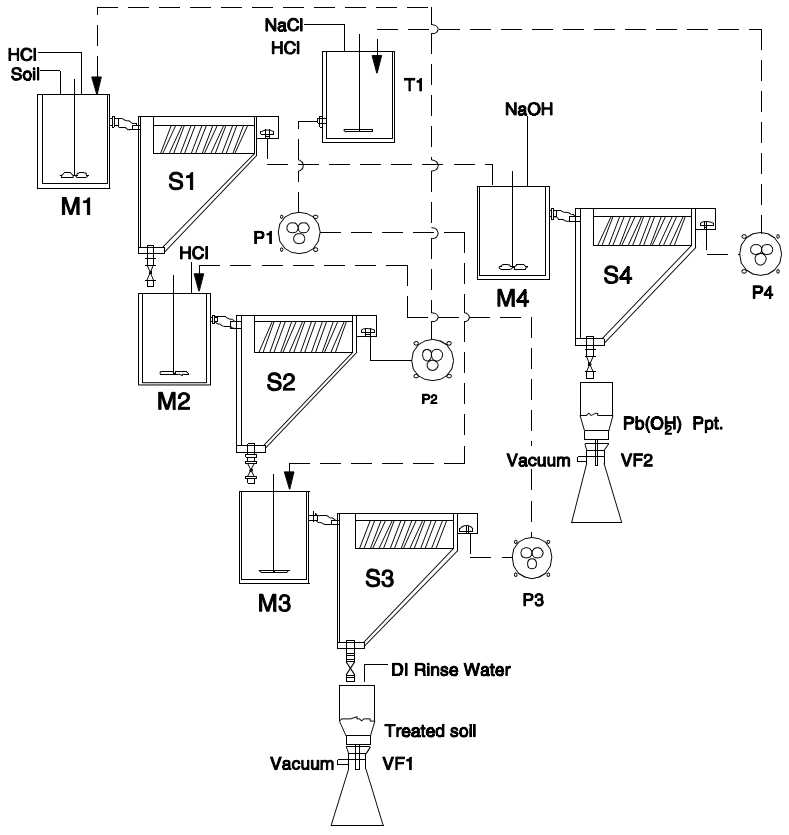
## TECHNOLOGY DESCRIPTION:

This technology recovers lead from soils using an aqueous solvent extraction process that takes advantage of the high solubility of chlorocomplexes of lead. The extract solution contains greater than 4 molar sodium chloride and operates at a pH of 4. The figure below depicts a bench-scale model of the three-stage continuous countercurrent pilot plant used to study the process.

To operate the pilot plant, soil is sieved to remove particles greater than 1.12 millimeters in diameter. The soil is then placed in the first chloride extraction tank (M1) for extraction with concentrated chloride solution. The resulting soil and solvent slurry passes into a thickener (S1). The soil and solvent slurry has an average residence time of 1 hour in each extraction tank in the system.

The bottoms of the thickener flow by gravity to the second chloride extraction tank (M2). The solution exiting the second chloride extraction tank flows to the second thickener (S2). The bottoms of the second thickener feed the third stage.

The third stage is the last soil stage and the first solvent stage; fresh solvent enters the system at stage three. The bottoms of the third thickener




Concentrated Chloride Extraction and Recovery of Lead (Bench-Scale Process)



The SITE Program assesses but does not approve or endorse technologies.

(S3) flow by gravity into the soil rinse system (VF1) to remove excess salt. Soil rinsed in VF1 is clean product soil. The overflows from S3 pass to M2, the overflows from S2 pass to the M1, and the overflows from S1 pass to the lead precipitation system (M4/S4). In M4/S4, lead hydroxide [$(Pb(OH)_2$] is recovered by simply raising the pH of the spent extraction solution to 10. After $Pb(OH)_2$ removal, the spent chloride solution flows to the solvent makeup unit (T1) where it is acidified to pH 4 in preparation for reuse.

This technology produces (1) treated soil, suitable for replacement on site, and (2) $Pb(OH)_2$ that may be suitable for reprocessing to recover pure lead. The ease of solvent regeneration minimizes waste disposal. Solvent recycling is very successful, and pilot-plant tests have required little or no salt or water makeup.

The pilot plant has treated soil from two lead battery waste sites (LBWS). One LBWS soil contained a high percentage of fines (about 50 percent clay and silt), and the other contained a low percentage of fines (less than 20 percent clay and silt). The pilot plant's method of transferring soil by gravity eases much of the soil handling problems typical of high clay soils. After treatment, both soils easily passed the Toxicity Characteristic Leaching Procedure test. The total lead concentration in the high fines and low fines soil was reduced from 7 percent to about 0.15 percent and from 1.5 percent to 0.07 percent, respectively.

## WASTE APPLICABILITY:

This technology removes high concentrations of lead from soil, particularly at LBWS, while producing a treated soil that can be used as backfill and a recyclable, concentrated lead salt.

## STATUS:

This technology was accepted into the SITE Emerging Technology Program in September 1994. Batch extraction testing was completed in 1995. Treatability tests using the pilot plant to process high and low fines soils were completed in August 1996. The high fines soil came from a LBWS located in Houston, Texas, and the low fines soil came from the Sapp Battery National Priority List site in Florida. Future plans include expanding the applications of the technology by studying its effect on other wastes in soils. The technology evaluation is expected to be completed by August 1998.

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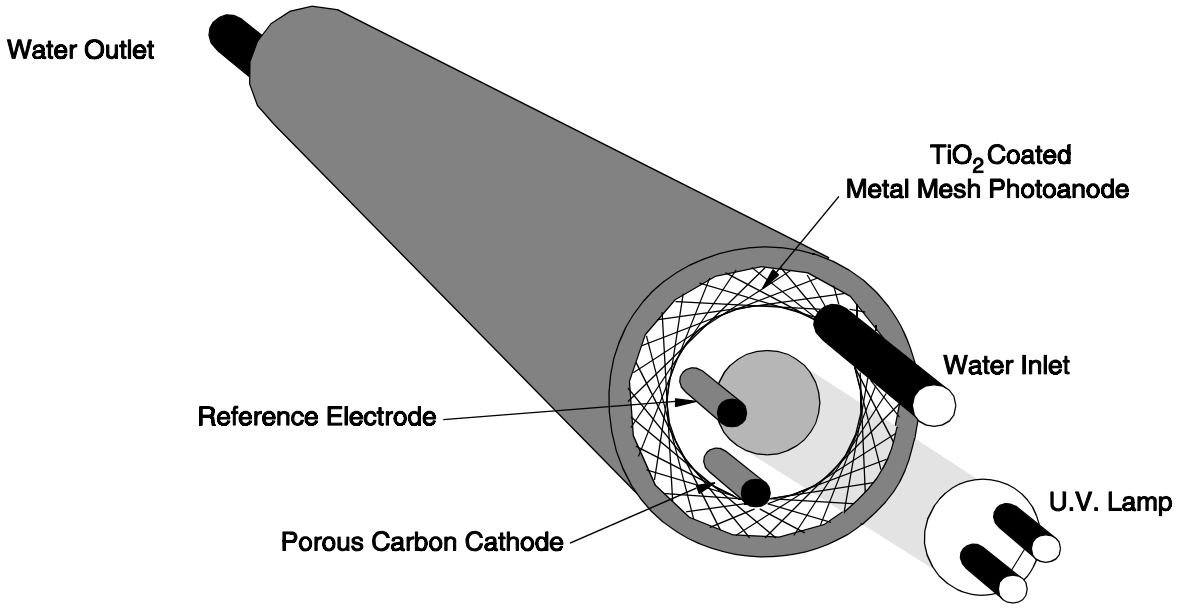
# UNIVERSITY OF WISCONSIN-MADISON
## (Photoelectrocatalytic Degradation and Removal)

## TECHNOLOGY DESCRIPTION:

The University of Wisconsin-Madison (UW-Madison) is developing a photocatalytic technology that uses titanium dioxide ($TiO_2$) suspensions to coat various supporting materials used in treatment applications. For this application, the suspensions are used to coat a conductive metallic or carbon mesh. Coating the mesh with a suitable thickness of $TiO_2$ catalyst provides the basis for a photoreactor that uses most of the available ultraviolet (UV) radiation. An electrical field can also be applied across the catalyst to improve its performance.

The figure below shows a possible photoreactor design that uses a ceramic film. In this design, the $TiO_2$ coating on the porous metal acts as a photoanode. An electric potential can then be placed across the coating to direct the flow of electrons to a porous carbon counter-electrode that has a high surface area and is capable of collecting collect any heavy metal ions present in the liquid. In addition, an applied electric potential can improve the destruction efficiency of organic contaminants by reducing electron-hole recombination on the catalyst surface. This recombination is seen as a primary reason for the observed inefficiency of other UV/$TiO_2$ systems used to treat organics in groundwater. Lastly, the electric potential has been shown to reduce the interference of electrolytes on the oxidation process. Electrolytes such as the bicarbonate ion are known hydroxyl radical scavengers and can be problematic in the UV/$TiO_2$ treatment of contaminated groundwater.




Photoreactor Design using Ceramic Film



The SITE Program assesses but does not approve or endorse technologies.

This technology represents and improvement on liquid-phase photocatalytic technologies by distributing radiation uniformly throughout the reactor. Also, the technology does not require additional oxidants, such as peroxide or ozone, to cause complete mineralization or to improve reaction rates. It also eliminates the need for an additional unit to separate and recover the catalyst from the purified water after the reaction is complete.

## WASTE APPLICABILITY:

This particular technology is designed to treat groundwater and dilute aqueous waste streams contaminated with organics and heavy metals. Organics are completely oxidized to carbon dioxide, water, and halide ions. Heavy metals are subsequently stripped from the cathode and recovered.

## STATUS:

The UW-Madison photocatalytic technology was accepted into the SITE Emerging Technology Program in 1995. The overall objective of the Emerging Technology Program study is to refine the reactor design, enabling it to treat heavy metals as well as organic contaminants. Testing of a bench-scale unit is currently underway.

UW-Madison has tested its photocatalytic reactor at the laboratory scale on aqueous solutions of several organic contaminants, including polychlorinated biphenyls, chlorosalicylic acid, salicylic acid, and ethylenediamine tetraacetate. UW-Madison has also used similar reactors to remove volatile organic compounds, such as trichloroethene, tetrachloroethene, benzene, and ethylene from air streams. Photooxidation of trichloroethene and tetrachloroethene has been successfully field-tested at low flow rates (less than 0.1 standard cubic feet per minute).

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The SITE Program assesses but does not approve or endorse technologies.

# U.S. AIR FORCE
## (Phytoremediation of TCE-Contaminated Shallow Groundwater)

## TECHNOLOGY DESCRIPTION:

The U. S. Air Force (USAF) has initiated a field demonstration designed to evaluate the effectiveness of eastern cottonwood trees in remediating shallow groundwater contaminated with trichloroethene (TCE). Using vegetation to remediate contaminated soil and groundwater is known as phytoremediation.

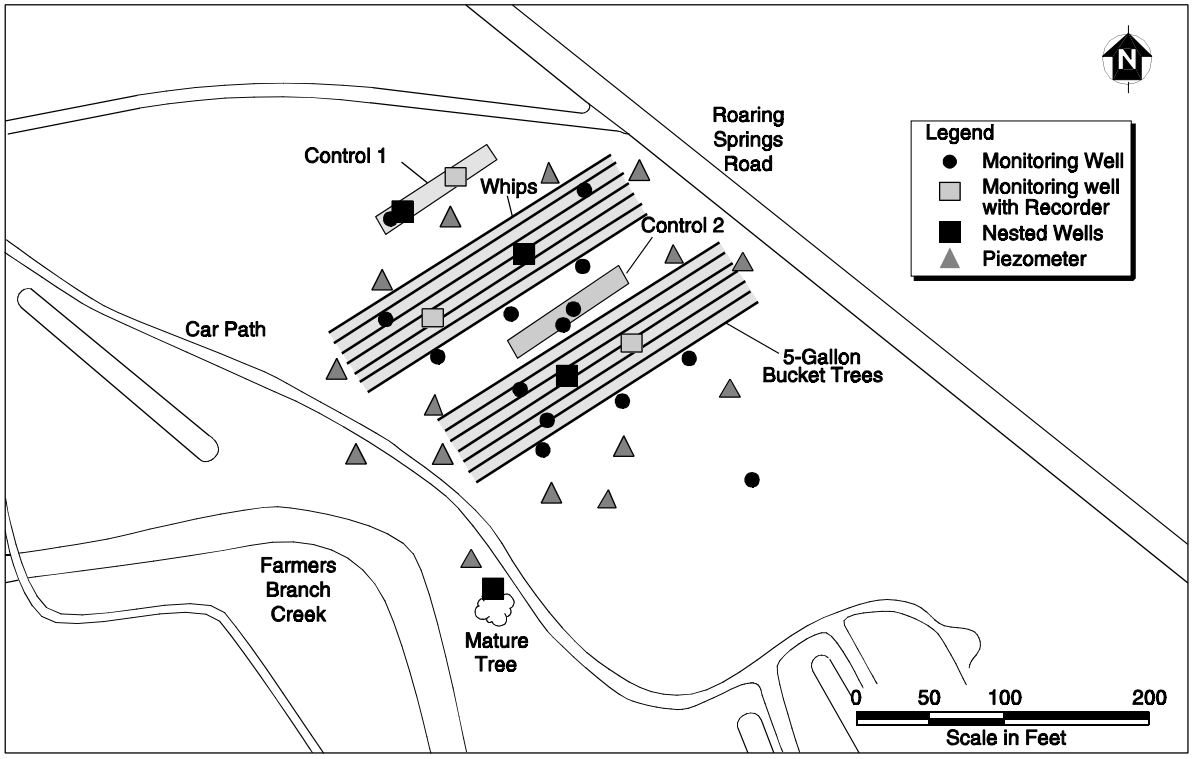
Phytoremediation of groundwater involves planting deep-rooted, water-loving vegetation to reduce contaminant levels in the saturated zone. The USAF's demonstration entails planting and cultivating eastern cottonwood trees over a dissolved TCE plume in a shallow (6 to 11 feet below grade) alluvial aquifer.

The cottonwood trees are expected to bioremediate the contaminated groundwater and any contaminated soil through one or more of the following mechanisms:

- Release of root exudates and enzymes stimulating microbial activity in the rhizosphere and enhancing biochemical transformations of contaminants
- Metabolism or mineralization of contaminants within the vegetative tissues; the contaminated water enters the vegetative tissues by root uptake from the aquifer
- Transpiration of water by the leaves

In essence, the trees are expected to serve as a natural pump-and-treat system.

TCE concentrations in the groundwater, soil from the rhizosphere, and tree tissues will be




Schematic Diagram of the Site Layout at Navel Air Station Ft. Worth



The SITE Program assesses but does not approve or endorse technologies.

monitored during the demonstration. In general, data will be gathered and interpreted to identify the overall effect of the planted trees on the dissolved TCE plume in the aquifer. Groundwater levels and TCE concentrations in the aquifer will be measured initially to establish baseline conditions and subsequently to map changes in the aquifer throughout the demonstration period. Changes in the flow field and the position of the TCE plume will also be modeled.

TCE concentrations will also be monitored in the soil from the rhizosphere and in the tree tissues. Ratios of daughter and parent compounds will be calculated for groundwater, soil, and tissue samples collected throughout the demonstration period. Microbial activity in the rhizosphere will be monitored and transpiration rates will be measured. These data will be used to determine the fate of the TCE at the site, including those processes that affect its fate.

## WASTE APPLICABILITY:

The USAF's phytoremediation technology may be used to remediate shallow groundwater and soil contaminated with TCE, as well as other contaminants common to USAF installations. Such contaminants include petroleum, munitions, and halogenated hydrocarbons. Costs of the technology are limited to initial site preparation, planting, and occasional maintenance (irrigation).

## STATUS:

The technology was accepted into the SITE Demonstration Program in 1996. The USAF is currently demonstrating its phytoremediation technology on a TCE plume near Air Force Plant 4 at the Naval Air Station Ft. Worth, formerly Carswell Air Force Base in Fort Worth, Texas.

Initial site characterization and final site selection were completed in January 1996. Site development, which included planting trees and installing the irrigation system, was completed in April 1996. The figure on the previous page details the layout of the site. Baseline sampling began in June 1996, and demonstration sampling is scheduled to continue until 2000. Preliminary data may be obtained from either of the below listed contacts.

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# VORTEC CORPORATION
## (Vitrification Process)

## TECHNOLOGY DESCRIPTION:

Vortec Corporation (Vortec) has developed an oxidation and vitrification process for remediating soils, sediments, sludges, and mill tailings contaminated with organics, inorganics, and heavy metals. The process can vitrify materials introduced as dry granulated materials or slurries.

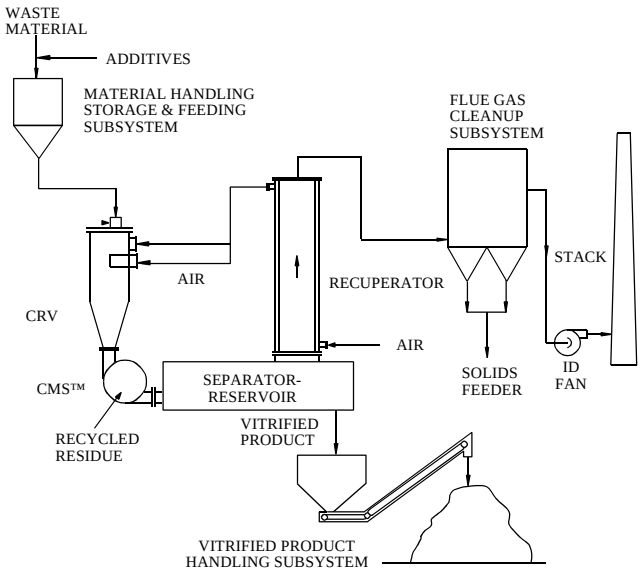
The figure below illustrates the Vortec vitrification process. Its basic elements include (1) a cyclone melting system (CMS™); (2) a material handling, storage, and feeding subsystem; (3) a vitrified product separation and reservoir assembly; (4) an air preheater (recuperator); (5) an air pollution control subsystem; and (6) a vitrified product handling subsystem.

The Vortec CMS™ is the primary system and consists of two major assemblies: a counterrotating vortex (CRV) reactor and a cyclone melter. First, slurried or dry-contaminated soil is introduced into the CRV.

The CRV (1) provides a high temperature environment; (2) preheats the suspended waste materials along with any glass-forming additives mixed with soil; and (3) destroys any organic constituents in the soil. The average temperature of materials leaving the CRV reactor chamber is between 2,200 and 2,800 °F, depending on the melting characteristics of the processed soils.

The preheated solid materials exit the CRV and enter the cyclone melter, where they are dispersed to the chamber walls to form a molten glass product. The vitrified, molten glass product and the exhaust gases exit the cyclone melter through a tangential exit channel and enter a glass- and gas-separation chamber.

The exhaust gases then enter an air preheater to heat the incoming air and are subsequently delivered to the air pollution control subsystem for particulate and acid gas removal. The molten glass product exits the glass- and gas-separation chamber through the tap and is delivered to a water quench assembly for subsequent disposal.




Vortec Vitrification Process



The SITE Program assesses but does not approve or endorse technologies.

Unique features of the Vortec vitrification process include the following:

- Processes solid waste contaminated with both organic and heavy metal contaminants
- Handles waste quantities ranging from 5 to more than 400 tons per day
- Recycles particulate residue collected in the air pollution control subsystem into the CMS™. These recycled materials are incorporated into the glass product.
- Produces a vitrified product that is nontoxic according to EPA toxicity characteristic leaching procedure (TCLP) standards. The product has long- term stability.

## WASTE APPLICABILITY:

The Vortec vitrification process treats soils, sediments, sludges, and mill tailings containing organic, inorganic, and heavy metal contamination. Organic materials included with the waste are successfully destroyed by the high temperatures in the CRV. The inorganic constituents in the waste material determine the amount and type of glass-forming additives required to produce a vitrified product. This process can be modified to produce a glass cullet that consistently meets TCLP requirements.

## STATUS:

The Vortec vitrification process was accepted into the SITE Emerging Technology Program in May 1991. Research under the Emerging Technology Program was completed in winter 1994, and Vortec was invited to participate in the SITE Demonstration Program.

Construction of a 1.5-ton-per-hour, transportable system for treating contaminated soil at a Department of Energy site in Paducah, Kentucky, was initiated in October 1996. A SITE demonstration is expected to occur in early 1999.

A 50-ton-per-day system has been purchased by Ormet Aluminum Corporation of Wheeling, West Virginia for recycling aluminum spent pot liners, which are considered cyanide- and fluoride-containing wastes (K088). The recycling system became operational in 1996. Vortec is offering commercial systems and licenses for the CMS™ system.

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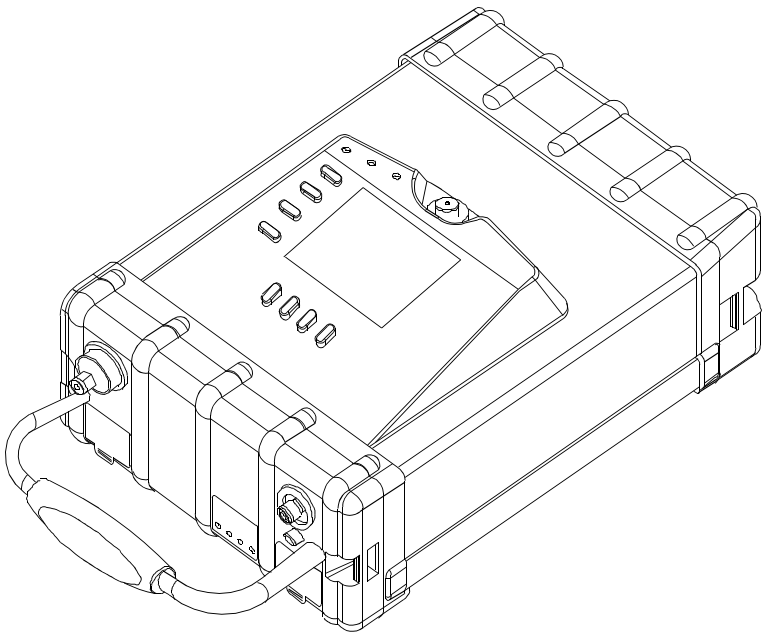
# PHOTOVAC MONITORING INSTRUMENTS
## (formerly PHOTOVAC INTERNATIONAL, INC.)
## (PE Photovac Voyager Portable Gas Chromatograph)

## TECHNOLOGY DESCRIPTION:

The PE Photovac Voyager Portable Gas Chromatograph (GC) is a lightweight, battery powered, isothermal GC (see figure below). The Voyager GC is designed to replace the Photovac 10S Plus GC and incorporates the following advanced features:

- A miniature analytical engine containing a precolumn with backflush capability; three analytical columns dedicated for "light", "middle", and "heavy" compounds; an isothermal oven with an operating temperature range of 30-80 $^{o}$C; a miniature all-stainless steel valve array; and a syringe/valve injection port. The whole engine is maintained at the set isothermal temperature.
- The Voyager photoionization detector (PID) provides superior sensitivity to volatile organic compounds (VOC) such as benzene, toluene, xylenes, and chlorinated ethylenes.
- High sensitivity to chlorinated compounds is achieved using a Voyager equipped with an electron capture detector (ECD).
- A VOC function acts as a fast screening tool for pre-GC analysis; the VOC mode supports either syringe or automatic "sample injections."
- A factory-programmed assay for analysis of up to 40 VOCs listed in EPA Method 601, 602, 624, and 8260.
- A "simplified" operating mode designed to detect a subset of VOCs selected from the preprogrammed assay.
- A user mode, simple point-and-press operation, to analyze preselected compounds from the factory programmed assay.
- Total weight with PID is 15 pounds.



PE-Photovac Portable Gas Chromatograph



The SITE Program assesses but does not approve or endorse technologies.

## WASTE APPLICABILITY:

The Voyager GC can monitor VOC emissions from hazardous waste sites and other emission sources before, during, and after remediation. PC Sitechart LX software provides the user with data downloading, integration and GC customization capabilities. This enables a user to generate data onsite, with confidence.

## STATUS:

The Photovac 10S PLUS GC was evaluated in January 1992 at a Superfund site under remediation. Results from this demonstration are presented in a peer-reviewed article entitled "Evaluation of Portable Gas Chromatographs" in the *Proceedings of the 1993 U.S. EPA/Air and Waste Management Association International Symposium*, VIP-33, Volume 2, 1993.

The Voyager GC was evaluated during a field study in August 1995. During the study, downwind vapors from an artificial source generator were analyzed. Preliminary results of the demonstration were presented in an article titled "Performance Comparison of Field-Deployable Gas Chromatographs with Canister TO-14 Analyses" in the *Proceeding of the 1996 U.S. EPA/Air and Waste Management Association International Symposium*, VIP-64, 1996.

## FOR FURTHER INFORMATION:

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# QUADREL SERVICES, INC.
## (Emflux® Soil-Gas Survey System)

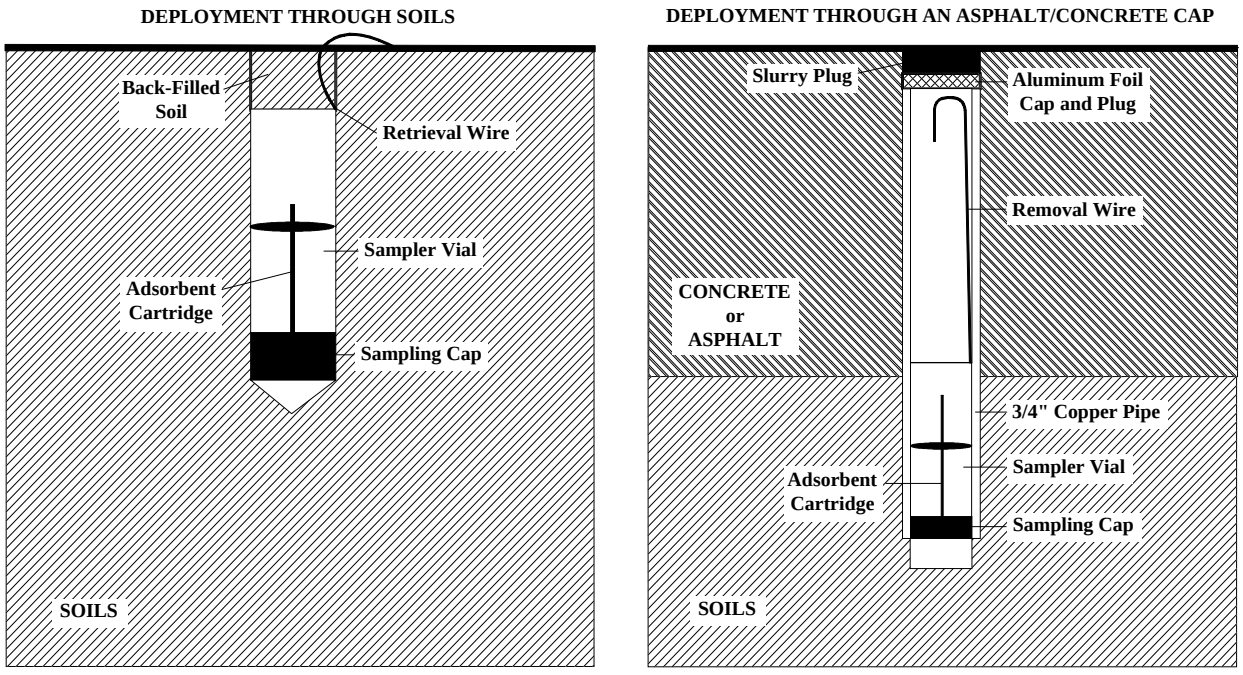
## TECHNOLOGY DESCRIPTION:

Quadrel's EMFLUX® System is a fully operational, passive, near-surface investigative technology capable of identifying buried VOCs and SVOCs at concentrations in the low parts-per-billion range.

EMFLUX® exploits the crustal effects of gravity (generally referred to as "earth tides") through a predictive computer model. These geophysical forces dominate vertical soil-gas velocities, increasing them by three to five orders of magnitude. The ability to predict such velocity changes (which dwarf influences of barometric pressure, temperature, moisture, and other phenomena) allows EMFLUX® to take advantage of maximum gas emissions at ground surface through simultaneous, cumulative sampling, thereby enhancing detection accuracy and survey reliability. As a result, EMFLUX® survey results are reproducible in excess of 90 percent of the time in terms of both correct identification of individual VOCs and SVOCs and proportional duplication at ground surface of changes in subsurface concentrations of targeted compounds.

Deployment, by individuals or two-person teams, takes less than two minutes per point (exclusive of initial sample location surveying); retrieval requires half that time; and collectors remain in the field for 72 hours. Field components of the system (9-inch stainless steel shells used above ground, or 3.5-inch glass vials for shallow subsurface placement) are completely portable. Available analytical methods range from EPA Methods 8020 and 8021, using gas chromatography and a variety of detectors, to Methods 8260 and 8270, using mass spectrometry.

**EMFLUX® COLLECTOR**






The SITE Program assesses but does not approve or endorse technologies.

## WASTE APPLICABILITY:

The EMFLUX® System has been employed with great effectiveness in detecting a broad range of VOCs and SVOCs (from vinyl chloride through hexachlorobutadiene) in soil, groundwater and air. The technology has also been successful in identifying and mapping methane, non-methane landfill gases, mercury, certain types of high explosives, and chemical surety materials.

## STATUS:

Quadrel participated in the SITE Program (Environmental Technology Verification Program) in May and June 1997, when EMFLUX® was deployed at two sites (one in Colorado, the other in Iowa) to detect, among other VOCs, vinyl chloride, 1,2-DCE, 1,1-DCA, 1,1,1-TCA, TCE and PCE. The demonstration results indicate that the EMFLUX® system can provide useful, cost-effective data for environmental problem-solving. The EMFLUX® system successfully collected soil gas samples in clay and sandy soils. The sampler provided positive identification of target VOCs and may be able to detect lower concentrations of VOCs in the soil gas than the reference method. The results of the demonstration did not indicate consistent proportional comparability between the EMFLUX® data and the reference method's data. Currently, the final report and verification statement is being completed by the National Risk Management Research Laboratory in Las Vegas, Nevada. The EMFLUX® system has been commercially operational since 1990. EMFLUX® has been used on 350 major projects in 46 U.S. states, in Guam, Canada, Great Britain, South America, Poland, and the Czech Republic.

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# RADIOMETER ANALYTICAL GROUP
## (Anodic Stripping Voltammetry for Mercury in Soil)

## TECHNOLOGY DESCRIPTION:

The Radiometer Analytical Group (Radiometer) anodic stripping voltammetry (ASV) method is a field-portable technique that uses a programmed electrochemical apparatus to measure total mercury in soil and sediment. The Radiometer method is more complex than immunoassay methods, but it can generate quantitative results, while immunoassay methods generate only semiquantitative or screening level results. Each Radiometer ASV apparatus can analyze up to about 40 samples per day for mercury.

Mercury in soil or sediment samples is first extracted using a heated 1:6:17 mixture of hydrochloric acid, nitric acid, and deionized water. The extract is then cooled, buffered, and centrifuged. The extracted samples are then analyzed by ASV using a Radiometer PSU 20 unit.

The ASV method has two steps. In the first step, mercury ions are plated out of solution onto a glassy carbon electrode that is coated with a gold film and placed under a negative potential. In the second step, the negative potential is removed and the mercury is stripped off the electrode. The change in electrode potential is measured with a high impedance voltmeter and is proportional to the mercury concentration.

## WASTE APPLICABILITY:

The Radiometer method has been used to analyze soil and sediment samples containing mercury. The effect of soil texture on this method's performance is unknown. Soil moisture content of up to 31 percent had minimal to no effect on performance. The ASV method can measure mercury in soil or sediment at the parts per million (ppm) level.

## STATUS:

The Radiometer ASV method was field demonstrated in August 1995 at two southwestern state sites: the Carson River Mercury site in Reno, Nevada; and the Sulphur Bank Mercury Mine site in Clear Lake, California. During the demonstration, the method was used to analyze 145 samples (55 samples from each site and 35 archived samples), 20 field duplicate samples, 17 weak digestion samples, and 13 performance evaluation samples. Duplicate samples underwent confirmatory analysis using inductively coupled plasma with mass spectrometry (ICP-MS) at an off-site laboratory. The ASV method provided reproducible quantitative results comparable to those generated by ICP-MS down to 2 ppm. Additional results from the field demonstration will be available in the Innovative Technology Evaluation Report. According to Radiometer, the PSU 20 unit has been improved to achieve detection limits at the parts per billion level (Radiometer PSU 22 unit).



The SITE Program assesses but does not approve or endorse technologies.

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# SENTEX SYSTEMS, INC.
## (Scentograph Plus II Portable Gas Chromatograph)

## TECHNOLOGY DESCRIPTION:

The Scentograph Plus II Portable Gas Chromatograph is designed to monitor volatile organic compound (VOC) emissions from hazardous waste sites and other emission sources. It operates by drawing air through a sorbent bed, followed by rapid thermal desorption into the carrier stream. The instrument operates in either Micro Argon Ionization or Micro Electron Capture modes.

The Scentograph Plus II Portable Gas Chromatograph can operate for several hours on internal batteries and has internal carrier gas and calibration tanks. It can be fitted with capillary columns (30 meters, 0.32 or 0.53 millimeter) or packed columns. The instrument can be operated isothermally at temperatures ranging from ambient to 179 °C. Oven temperatures can be programmed at a desired rate. The 11.7- electron-volt ionization energy allows a detection limit of about 1 part per billion. The instrument is controlled by a detachable IBM compatible laptop computer (see photograph below). Purge and Trap Accessories enable on-site, on-line determinations of various VOCs in water.

## WASTE APPLICABILITY:

The Scentograph Plus II portable gas chromatograph can monitor VOC emissions from hazardous waste sites and other emission sources.

Scentograph Plus II Portable Gas Chromatograph



The SITE Program assesses but does not approve or endorse technologies.

## STATUS:

The Scentograph Plus II portable gas chromatograph was evaluated in January 1992 at a Superfund site under remediation. Results from this demonstration are presented in a peer-reviewed article titled "Evaluation of Portable Gas Chromatographs" in the *Proceedings of the 1993 U.S. EPA/Air and Waste Management Association International Symposium*, VIP-33, Volume 2, 1993.

The technology was also evaluated in June 1994 at a landfill adjacent to a residental area. Results from this demonstration are presented in a peer-reviewed article titled "On-Site Monitoring of Vinyl Chloride at Parts Per Trillion Levels in Air" in the *Proceedings of the 1995 U.S. EPA/Air and Waste Management Association International Symposium*, VIP-47, Volume 1, 1995.

The Scentograph Plus II portable gas chromatograph was also evaluated during a field study in August 1995. During the study, downwind vapors from an artificial source generator were analyzed. Preliminary results of the demonstration were presented in an article titled "Performance Comparison of Field-Deployable Gas Chromatographs with Canister TO-14 Analyses" in the *Proceeding of the 1996 U.S. EPA/Air and Waste Management Association International Symposium*, VIP-64, 1996.

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# SIMULPROBE® TECHNOLOGIES, INC.
## (Core Barrel Soil Sampler)

## TECHNOLOGY DESCRIPTION:

The SimulProbe® Technologies, Inc. (SimulProbe®), core barrel sampler consists of a split core barrel similar to a split-spoon sampler, a drive shoe, and a core barrel head.

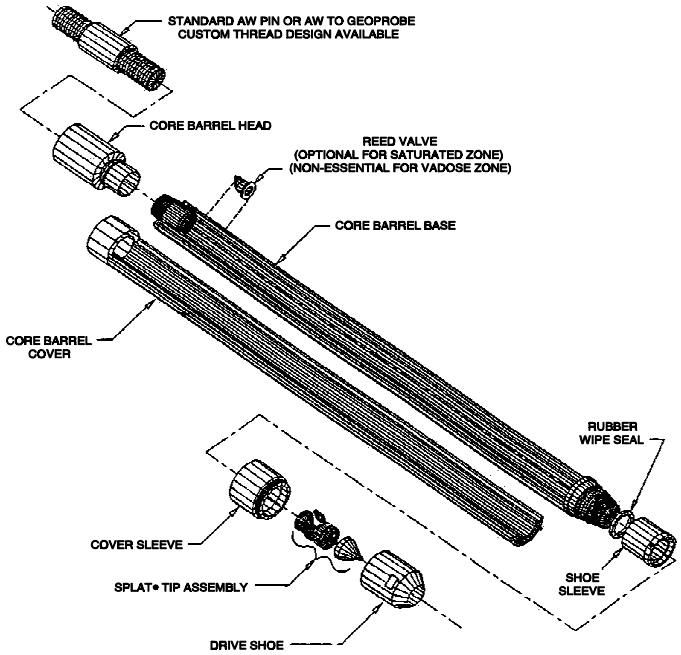
The sampler is constructed of steel, has a uniform 2-inch outer diameter, and is 27 inches long. It is capable of recovering a discrete sample 1.25 inches in diameter and 27 inches long. Multiple 5.25-inch-long stainless-steel liners or a single full-length plastic liner can be used inside the sampler to contain the soil core. The drive shoe of the sampler is equipped with a slide mechanism and has an optional drive tip for direct-push, discrete sampling applications.

The drive tip, known as the SimulProbe® Latch Activated Tip (SPLAT™), seals the sample chamber until the target depth is reached. The SPLAT™ is then released at the target depth to collect the sample.

The core barrel sampler decreases the likelihood of cross-contamination, preserves sample intergrity when used with a liner, can collect either discrete or continuous soil samples of unconsolidated materials, does not need specialized training to use, and does not generate drill cuttings.

## WASTE APPLICABILITY:

The SimulProbe® core barrel sampler can be used to collect unconsolidated, subsurface soil samples at depths that depend on the capability of the advancement platform. The sampler can be advanced into the subsurface using a direct-push platform, drill rig, or manual methods. The sampler has been used to collect samples of sandy and clayey soil contaminated with high concentrations of volatile organic compounds (VOC). It can also be used to collect samples for semivolatile organic compounds, metals, general minerals, and pesticides analyses.




Simulprobe Core Barrel Sampler



The SITE Program assesses but does not approve or endorse technologies.

## STATUS:

The SimulProbe® core barrel sampler was demonstrated under the Superfund Innovative Technology Evaluation (SITE) program in May and June 1997 at two sites: the Small Business Administration (SBA) site in Albert City, Iowa, and the Chemical Sales Company (CSC) site in Denver, Colorado. Samples collected during the demonstrations were analyzed for VOCs to evaluate the performance of the samplers.

Demonstration results indicate that the core barrel sampler had higher sample recoveries and yielded samples with higher VOC concentrations in the clayey soil present at the SBA site than the standard methods. Conversely, the sampler had lower recoveries and yielded samples with lower VOC concentrations than the standard methods in the sandy soil present at the CSC site. Sample integrity using the core barrel sampler was not preserved in highly contaminated soil, and the use of sample liners was found to be required to preserve sample integrity. The core barrel sampler's reliability and throughput were not as good as those of the standard methods; however, the developer claims that the sampler used during the demonstrations was incorrectly manufactured. Costs for the core barrel sampler were lower than costs related to the standard sampling method.
Demonstration results are documented in the "Environmental Technology Verification" report for the sampler dated August 1998 (EPA/600/R-98/094).

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# SPACE AND NAVAL WARFARE SYSTEMS CENTER
## (formerly Naval Command, Control and Ocean Surveillance Center)
## (SCAPS Cone Penetrometer)

## TECHNOLOGY DESCRIPTION:

The Site Characterization and Analysis Penetrometer System (SCAPS) was developed by the space and naval warfare systems center. SCAPS is mounted on a cone penetrometer testing (CPT) platform for field use; it can be fitted with a laser-induced fluorescence (LIF) sensor to provide in situ field screening of petroleum hydrocarbons in subsurface soils. CPT technology has been widely used in the geotechnical industry for determining soil strength and soil type from measurements of tip resistance and sleeve friction on an instrumented probe. The SCAPS CPT platform equipped with LIF sensors can provide real-time field screening of the physical characteristics of soil and chemical characteristics of petroleum hydrocarbon contamination at hazardous waste sites.

SCAPS is primarily designed to quickly and cost-effectively distinguish hydrocarbon-contaminated areas from uncontaminated areas. SCAPS also provides geologic information and reduces the amount of investigation-derived waste. This capability allows further investigation and remediation decisions to be made more efficiently and reduces the number of samples that must be submitted for laboratory analysis.

The LIF system uses a pulsed laser coupled with an optical detector to measure fluorescence through optical fibers. Fluorescence is measured through a sapphire window on a probe that is pushed into the ground with a truck-mounted CPT. LIF provides data on the in situ distribution of petroleum hydrocarbons, measured by the fluorescence response induced in the polynuclear aromatic hydrocarbons (PAH) that comprise the petroleum hydrocarbon. LIF detects PAHs in the bulk soil matrix throughout the vadose, capillary fringe, and saturated zones. LIF also provides a detect-nondetect field screening capability relative to a specified detection limit derived for a specific fuel product on a site-specific soil matrix. In addition, LIF provides qualitative data derived from spectrographic data at depths up to 150 feet.

## WASTE APPLICABILITY:

SCAPS CPT technology equipped with LIF sensors can provide real-time qualitative analysis of subsurface soils. This technology may be useful in screening soils at oil refineries, tank farms, and shipyards. The combined technologies provide substantial cost savings and quicker analyses compared to conventional laboratories.

## STATUS:

The SCAPS CPT and LIF technologies were demonstrated at two hydrogeologically distinct field sites under the SITE Characterization and Monitoring Program. The demonstrations were conducted at the Hydrocarbon National Test Site at the Naval Construction Battalion Center in Port Hueneme, California in May 1995, and the Steam Plant Tank Farm, Sandia National Laboratories in Albuquerque, New Mexico in November 1995. An Innovative Technology Evaluation Report (ITER) (EPA/540/R-95/520) was published by EPA.



The SITE Program assesses but does not approve or endorse technologies.

The SCAPS project is meeting the Navy's goals of (1) expedited development and regulatory acceptance, (2) performance of urgently needed petroleum, oil, and lubricant (POL) field screening at Navy facilities, and (3) technology transfer to industry for widespread use. The SCAPS LIF technology is certified and verified. The technology has matured to become a platform with state-of-the-art sensor technology and a suite of the latest CPT tools for sampling and direct push well installations. On August 5, 1996, the California EPA Department of Toxic Substance Control certified the SCAPS LIF as a site characterization technology for real-time, in situ subsurface field screening for POL contaminants, pursuant to California Health and Safety Code, Section 25200.1.5.

Three SCAPS units are performing POL field screenings at Navy facilities on a prioritized basis. These screenings include plume chasing and plume edge delineation on a finer scale than has been feasible in the past.

## DEMONSTRATION RESULTS:

The results of the SCAPS demonstrations at Port Hueneme and Sandia National Laboratories were presented in the ITER and are summarized below:

- SCAPS met the demonstration objective of providing real-time screening of the physical characteristics of soil and chemical characteristics of petroleum hydrocarbon contamination.
- SCAPS achieved better than 90 percent agreement with the discrete soil samples and analytical results.
- SCAPS is capable of mapping the relative magnitude and the vertical and horizontal extent of subsurface fluorescent petroleum hydrocarbon contaminant plumes in soil and groundwater.

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# SRI INSTRUMENTS
## (Compact Gas Chromatograph)

## TECHNOLOGY DESCRIPTION:

The SRI Instruments (SRI) line of compact single- and dual-oven portable gas chromatographs (GC) are designed for on-site and laboratory analysis of organic compounds in soil, water, air, and other matrices. SRI GCs are equipped with ambient-to-400 °C programmable column ovens and electronic pressure/pneumatic control (EPC) of all system gases. These GCs include built-in, serially interfaced (RS-232) data acquisition unit that permits use of desktop, notebook, and palmtop PCs and software versions for Windows 3.11/Windows NT 4.00, and Windows '95/'98 (Y2K compliant). SRI GCs are equipped with a standard on-column injection port that accepts packed and capillary columns, and systems may be equipped with multiple injectors and detectors for series or independent operation, as required by the application. Automated gas sampling, split/splitless injection, Method 5035/5030 compliant purge-and-trap concentration, and liquid autosampling carousels are available as options. SRI also manufactures external detector units that may be connected to other host GCs by means of a heated transfer line (provided), or used in stand-alone monitoring applications such as continuouis monitoring of stack THC emissions and chlorinated compounds.

## WASTE APPLICABILITY:

The SRI GCs can monitor airborne emissions from hazardous waste sites and other emission sources before, during, and after remediation. They can also analyze soil, water, and gas samples for organic contaminants such as benzene, toluene, ethylbenzene, xylene, polychlorinated biphenyls, and pesticides. Their performance characteristics in the field have been proven by a large private, commercial, and government user base.

Compact Gas Chromatograph



The SITE Program assesses but does not approve or endorse technologies.

## STATUS:

The SRI model 8610 GC was evaluated in January 1992 at a Superfund site under remediation. Results from this demonstration are presented in a peer-reviewed article entitled "Evaluation of Portable Gas Chromatographs" in the *Proceedings of the 1993 U.S. EPA/Air and Waste Management Association International Symposium*, VIP-33, Volume 2, 1993.

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# STRATEGIC DIAGNOSTICS, INC.
## (formerly ENSYS ENVIRONMENTAL PRODUCTS, INC.)
## (EnSys Penta Test System)

## TECHNOLOGY DESCRIPTION:

The Ensys Penta Test System is designed to quickly provide semiquantitative results for pentachlorophenol (PCP) in soil and water samples. The system is shown in the photograph below. The technology uses immunoassay chemistry to produce compound-specific reactions that detect and quantify PCP. Polyclonal antibodies are fixed to the inside wall of a test tube, where they offer binding sites for PCP. An enzyme conjugate containing a PCP derivative is added to the test tube to compete with sample PCP for antibody binding sites. Excess sample and enzyme conjugate are washed from the test tube. Reagents are then added to the test tube to react with the enzyme conjugate, forming a color. After a designated time period, a solution is added to the test tube to stop color formation. The sample color is compared to the color formed by a PCP standard. A differential photometer compares the colors. The results obtained from soil samples are compared against a standard to determine the detection levels.

The system can be affected by extremes of naturally occurring matrix effects such as humic acids, pH, or salinity. Site-specific matrix effects that can affect the system include PCP carriers such as petroleum hydrocarbons or solvents; and other chemicals used in conjunction with PCP, including creosote, copper-chromium-arsenate, or herbicides. Specific chemicals similar in structure to PCP can provide positive results, or cross reactivity.

## WASTE APPLICABILITY:

The PCP immunoassay measures PCP concentrations in soil and water. For semiquantitative soil analysis, the concentration ranges are as follows: greater than 50 parts per million (ppm),

EnSys Penta Test System



The SITE Program assesses but does not approve or endorse technologies.

between 50 and 5 ppm, between 5 and 0.5 ppm, and less than 0.5 ppm. For water analysis, the concentration ranges are as follows: greater than 5,000 parts per billion (ppb), between 5,000 and 500 ppb, between 500 and 5 ppb, and less than 5 ppb. These ranges can be customized to a user's needs.

## STATUS:

The SITE demonstration occurred in summer 1993 at Morrisville, North Carolina. Samples collected from Winona, Missouri were transported to the demonstration location for testing. Samples from both sites were analyzed to evaluate the effects of different sample matrices and of different PCP carriers such as diesel fuel and isopropyl ether-butane. During the demonstration, the PENTA RISc Test System analyzed 112 soil samples and 16 water samples. The Innovative Technology Evaluation Report (EPA/540/R-95/514), which details results from the demonstration, is available from EPA.

The PENTA RISc Test System has been accepted under Solid Waste Method 4010 (SW-846, third edition, second update). In the 4 years that it has been available, more than 12,000 immunoassay-based tests have been used on wood preserving sites.

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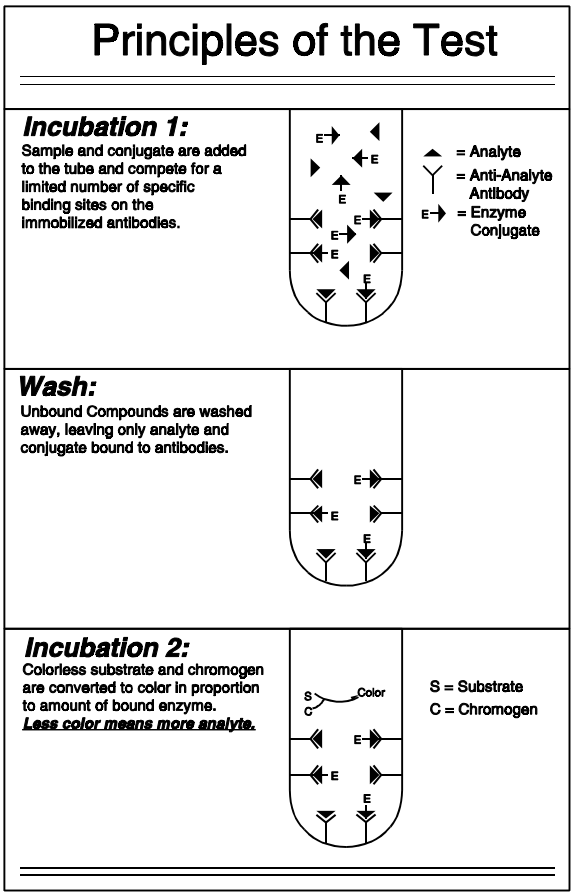
# STRATEGIC DIAGNOSTICS INC. (Formerly EnviroGard Corporation)

## (EnviroGard™ PCB Immunoassay Test Kit)

## TECHNOLOGY DESCRIPTION:

The EnviroGard™ polychlorinated biphenyl (PCB) immunoassay test kit rapidly analyzes for PCB concentrations in samples of soil or sediment. The operating procedure for this competitive enzyme-linked immunoassay kit is shown in the figure below.

Soil sample extracts are prepared using the EnviroGard™ Soil Extraction Kit and methanol. These extracts and assay calibration solutions are added to plastic test tubes coated with antibodies. PCB-enzyme conjugate is added to each test tube. The test tubes then stand for 15 minutes. The antibodies in each test tube bind with either PCB molecules or enzyme conjugate. Next, the tubes are washed to remove any material not bound to the antibodies. A clear substrate/chromogen solution is then added to each tube, and the tubes are allowed to stand for 5 minutes. Any enzyme conjugate bound to the tubes colors the clear substrate blue. A deeper shade of blue in the test tube indicates a lower PCB concentration.The color intensity in the test tubes is measured at 450 nanometers using a small portable photometer. The color intensity is compared to one or more of the four calibrator solutions included in the kit




Test Kit Procedure



The SITE Program assesses but does not approve or endorse technologies.

to yield data allowing classification above or below 1, 5, 10, or 50 parts per million (ppm). Up to 18 sample extracts can be analyzed in less than 30 minutes. Millipore Corporation (Millipore) can provide optional protocols for quantitative analysis of specific Aroclors or for testing sediment, water, or soil samples.

## WASTE APPLICABILITY:

The EnviroGard™ PCB test kit measures PCB concentrations in soil or sediment. The test is calibrated to screen for Aroclors 1016, 1232, 1242, 1248, 1254, and 1260 at greater than 95 percent confidence interval.

## STATUS:

In 1991, the EnviroGard™ PCB test kit was used to screen and quantify PCB contamination in soils at a SITE demonstration of a solvent extraction system in Washburn, Maine. Soil containing over 50 ppm PCB was required for the demonstration at the Washburn, Maine site. Calibrators at the 5 and 50 ppm level were used to evaluate the kit's potential for segregating soils. Additional tests were performed on dilutions of the soil extracts to evaluate quantitative performance. Highly contaminated soils were easily identified, and quantitative tests provided correlation to contaminant levels obtained by off-site laboratory analysis using EPA Method 8080.

The Innovative Technology Evaluation Report (EPA/540/R-95/517) is available from EPA. The kit was also demonstrated at a U.S. Department of Energy (DOE) site in Kansas City, Missouri. Soils contaminated with Aroclor 1242 in ranges from nondetectable to greater than 1,000 ppm were analyzed with the test kit at the DOE facility. Over 200 assays of environmental samples and calibrators were performed to evaluate correlation with both on-site and off-site laboratory gas chromatograph data. Final evaluation of the data is presented in the Technology Evaluation Report.

The EnviroGard™ PCB test kit has been accepted by the EPA Office of Solid Waste for inclusion in SW-846 as Method 4020.

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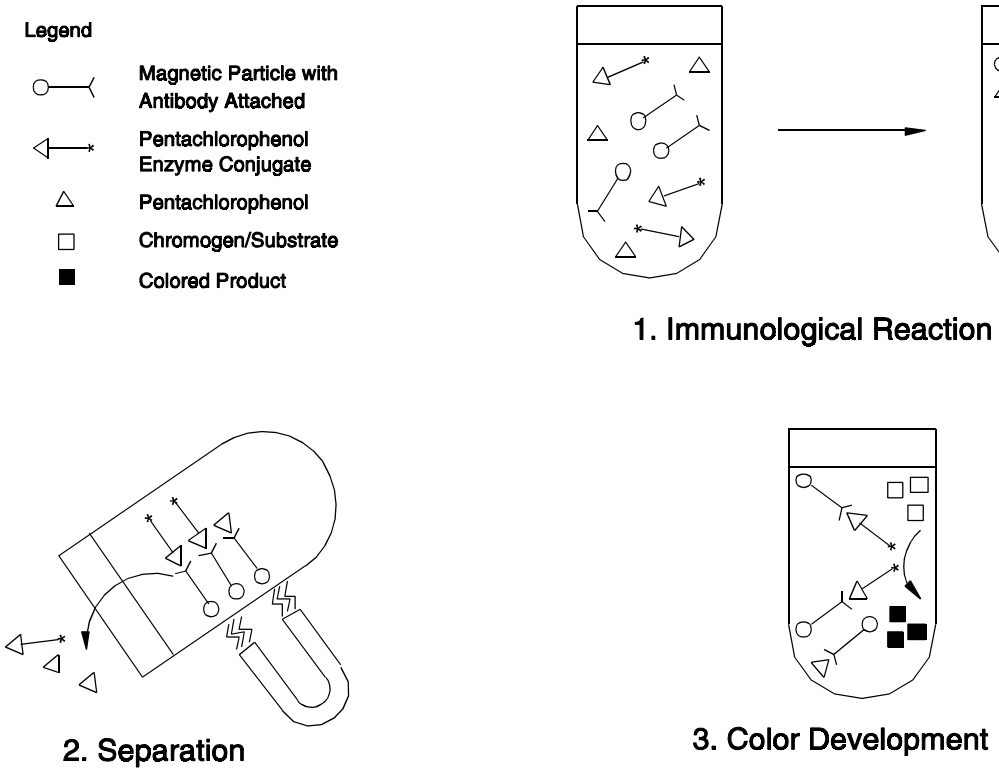
# STRATEGIC DIAGNOSTICS,INC.
## (formerly OHMICRON CORPORATION)
## (RaPID Assay®)

## TECHNOLOGY DESCRIPTION:

The RaPID Assay® kit is designed to quickly provide quantitative results for pentachlorophenol (PCP) concentrations in soil and water samples. The kit uses immunoassay chemistry to produce detectable and quantifiable compound-specific reactions for PCP, as shown in the figure below. Polyclonal antibodies bound to paramagnetic particles are introduced into a test tube where they offer binding sites for PCP. An enzyme conjugate containing a PCP derivative is added to the test tube, where it competes with PCP from samples for antibody binding sites. A magnetic field is applied to each test tube to hold the paramagnetic particles containing PCP and enzyme conjugate, while excess sample and enzyme conjugate are washed from the test tube. Reagents are then added to the test tube, where they react with the enzyme conjugate and form a color. The color formed in the sample is compared to the color formed by PCP calibration standards. The comparison is made with a spectrophotometer. Samples with PCP concentrations above the calibration range can be diluted and reanalyzed.

The RaPID Assay® kit has several advantages and limitations when used under field conditions. The method is field portable, easy and fast to operate, and inexpensive. The RaPID Assay® kit is limited in that (1) electricity is required to operate the spectrophotometer, (2) the immunoassay method may be affected by temperature fluctuations, and (3) cross-reactivity may occur for compounds similar to PCP.




RaPID Assay®



The SITE Program assesses but does not approve or endorse technologies.

## WASTE APPLICABILITY:

The RaPID Assay® kit can be used to identify and quantify PCP in soil and water samples. The developer reports the detection limit for soils at 0.1 part per million and water samples at 0.06 part per billion.

## STATUS:

The RaPID Assay® kit was evaluated during a SITE field demonstration in Morrisville, North Carolina in August 1993. A photograph of the kit is shown below. In addition, samples collected from a location in Winona, Missouri were analyzed to evaluate the effects of different matrices and PCP carriers. The Innovative Technology Evaluation Report (EPA/540/R-95/514), which details results from the demonstration, is available from EPA.

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RaPID Assay Used During the SITE Demonstration

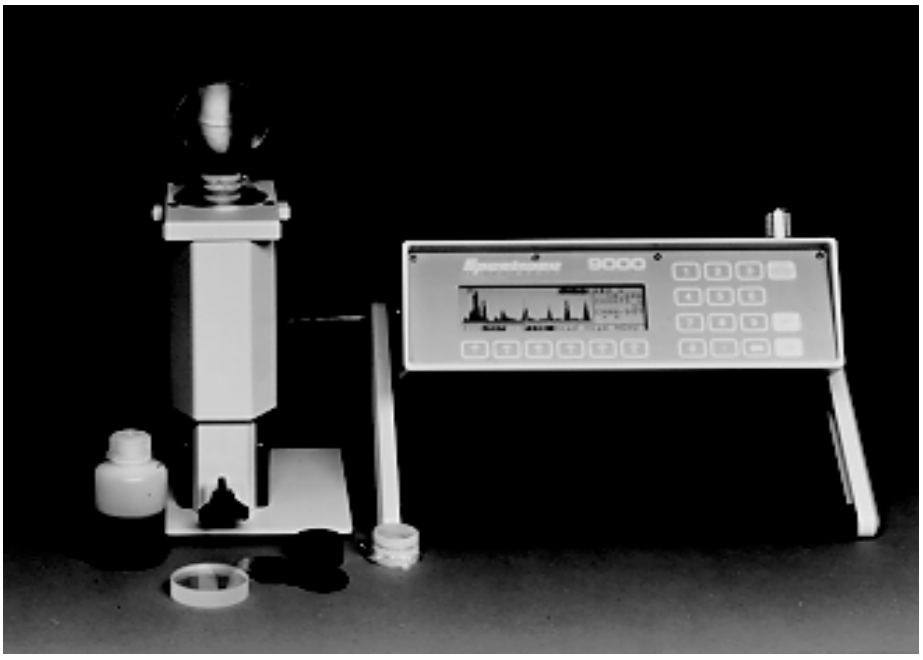
# TN SPECTRACE
## (TN 9000 and TN Pb X-Ray Fluorescence Analyzers)

## TECHNOLOGY DESCRIPTION:

The TN 9000 X-ray Fluorescence (XRF) Analyzer (see photograph below) is a field portable unit that simultaneously analyzes elements ranging from sulfur to uranium. The TN Pb Analyzer was designed to analyze for lead in soil, paint and paint chips, and other matrices. It can also measure arsenic, chromium, iron, copper, manganese, and zinc in soils. Both instruments are compact, lightweight, and do not require liquid nitrogen. A rechargeable battery allows the XRF analyzers to be used at remote sites where electricity is unavailable.

The TN 9000 Analyzer and the TN Pb Analyzer both use a high-resolution mercuric iodide detector to provide elemental resolution and low detection limits. The TN 9000 Analyzer is equipped with the radioisotope sources iron-55, cadmium-109, and americium-241, which allow for identification and quantification of 26 elements. The TN Pb Analyzer is equipped only with the cadmium-109 source, which allows for the quantification and identification of the seven elements listed above.

The TN 9000 Analyzer and TN Pb Analyzer consist of two main components: a probe and an electronics unit. The probe is connected to the electronics unit by a flexible cable that allows analysis of soil samples in the in situ or intrusive modes. The probe contains the detector and excitation sources and weighs approximately 4 pounds. The electronics unit contains a 2,048-multichannel analyzer for spectral analysis. A maximum of 300 sets of results and 120 spectra can be stored in the TN 9000 before downloading



TN 9000 X-Ray Fluorescence Analyzer



The SITE Program assesses but does not approve or endorse technologies.

to a personal computer (PC). A maximum of 600 sets of results and 100 spectra can be stored in the TN Pb Analyzer before downloading to a PC.

All elemental concentrations are displayed in parts per million on the liquid crystal display (LCD) of the electronic console. The electronics unit weighs approximately 15 pounds and can be carried in the field in a water- repellant carrying case. The electronic unit is battery-powered and can run up to 8 hours on a full charge.

Both instruments incorporate user-friendly, menu-driven software to operate the instrument. The TN 9000 Analyzer and TN Pb Analyzer are calibrated using fundamental parameters, which is a standardless calibration technique. At the time of the SITE demonstration, the TN 9000 and TN Pb Analyzers cost $58,000 and $39,500, respectively. These costs included all equipment necessary to operate the instrument. Leasing and rental options are also available. The TN 9000 Analyzer, using all three excitation sources, is capable of analyzing 100 samples per day. The TN Pb Analyzer is capable of analyzing 20 to 25 samples per hour using a 60-second count time for the cadmium-109 source.

## WASTE APPLICABILITY:

The TN 9000 and TN Pb Analyzers can detect select elements in soil, sediment, filter, and wipe samples. The TN Pb Analyzer can also detect lead in paint. Both units can identify select elements at concentrations ranging from parts per million to percentage levels in soil samples obtained from mining and smelting sites, drum recycling facilities, and plating facilities. These instruments can provide real-time, on-site analytical results during field screening and remediation operations. XRF analysis is faster and more cost-effective compared to conventional laboratory analysis.

## STATUS:

The TN 9000 and TN Pb Analyzers were demonstrated under the SITE Program in April 1995. The results were summarized in Technical Report No. EPA/600/R-97/145, dated March 1998. The instruments were used to identify and quantify concentrations of metals in soils. Evaluation of the results yielded field-based method detection limits, accuracy, and precision data from the analysis of standard reference materials and performance evaluation samples.

Comparability of the XRF results to an EPA-approved reference laboratory method was also assessed. The draft fourth update to SW-846 includes Method 6200, dated January 1998, which is based on this demonstration.

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# TRI-SERVICES
## (Site Characterization and Analysis Penetrometer System [SCAPS])

## TECHNOLOGY DESCRIPTION:

The Tri-Services Site Characterization and Analysis Penetrometer System (SCAPS) was developed by the U.S. Army (U.S. Army Corps of Engineers, Waterways Experiment Station [WES] and the Army Environmental Center [AEC]), Navy (Naval Command, Control and Ocean Surveillance Center), and the Air Force (Armstrong Laboratory). The U.S. Army holds a patent for the application of laser sensors combined with cone penetrometry. The laser-induced fluorescence (LIF) system used in the SCAPS was modified from a design developed by the Navy to detect petroleum, oil, and lubricant fluorescence in seawater.

A complete cone penetrometer (CPT) truck system consists of a truck, hydraulic rams andassociated controllers, and the CPT itself (see photograph below). The weight of the truck provides a static reaction force, typically 20 tons, to advance the CPT. The hydraulic system, working against the static reaction force, advances 1-meter-long, 3.57-centimeter-diameter threaded push rod segments into the ground. The CPT, which is mounted on the end of the series of push rods, contains LIF sensors that continuously log tip stress and sleeve friction.

The data from these sensors are used to map subsurface stratigraphy. Conductivity or pore pressure sensors can be driven into the ground simultaneously. The 20-ton truck is designed with protected work spaces.

The SCAPS has been modified to provide automatic grouting of the penetrometer hole during retraction of the CPT. It can also decontaminate the push rods as they are retracted from the soil. The 20-ton CPT system is capable of pushing standard push rods to depths of approximately 50 meters.

The main LIF sensor components are as follows:

- Nitrogen ($N_2$) laser
- Fiber optic cable
- Monochromator to resolve the fluorescence emission as a function of wavelength
- Photodiode array (PDA) to detect the fluorescence emission spectrum and transduce the optical signal into an electrical signal
- optical multichannel analyzer (OMA) to interface between the optic system and the computer system
- Computer system

Site Characterization and Analysis Penetrometer System (SCAPS)



The SITE Program assesses but does not approve or endorse technologies.

To operate the SCAPS LIF sensor, the CPT is positioned over a designated penetration point. The LIF sensor response is checked using a standard rhodamine solution held against the sapphire window; sensor response is checked before and after each penetration. The CPT is then advanced into the soil.

The SCAPS LIF system is operated with a $N_2$ laser. The PDA accumulates the fluorescence emission response over 10 laser shots, and the PDA retrieves an emission spectrum of the soil fluorescence and returns this information to the OMA and computer system. The LIF sensor and stratigraphy data collection are interpreted by the on-board computer system.

The spectral resolution of the LIF system under these operating conditions is 2 centimeters. The fluorescence intensity at peak emission wavelength for each stored spectrum is displayed along with the soil classification data.

## WASTE APPLICABILITY:

The Tri-Services SCAPS was designed to qualitatively and quantitatively identify classes of petroleum, polynuclear aromatic hydrocarbon, and volatile organic compound contamination in subsurface soil samples.

## STATUS:

The technology field demonstration was held in EPA Region 7 during September 1994. The Innovative Technology Evaluation Report (EPA/540/R-95/520) is available from EPA. Since the SITE demonstration in 1994, the U.S. Army has developed the SCAPS Petroleum Sensor (for detection of fluorescing petroleum,oil and lubricant contaminants in groundwater and soil), SCAPS Explosives Sensor (for detection of nitrogen-based explosive compounds), SCAPS Hybrid VOC Sensor/Sampler (for detection of VOCs in soil), SCAPS Metals Sensor (for in situ detection of meal contaminants in subsurface media), and a SCAPS Radionuclide Sensor (for detection of gamma emitting radionuclides in groundwater, mixed tank wastes, and soil). These technologies have not been demonstrated in the SITE Program.

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# UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
## (Field Analytical Screening Program - PCB method)

## TECHNOLOGY DESCRIPTION:

The field analytical screening program (FASP) polychlorinated biphenyl (PCB) method uses a temperature-programmable gas chromatograph (GC) equipped with an electron-capture detector (ECD) to identify and quantify PCBs in soil and water. Gas chromatography is an EPA-approved method for determining PCB concentrations. The FASP PCB method is a modified version of EPA SW-846 Method 8080.

In the FASP PCB method for soil samples, PCBs are extracted from the samples, injected into a GC, and identified and quantified with an ECD. Soil samples must be extracted before analysis begins. Hexane and sulfuric acid are used during the extraction process, which removes potential interferences from the soil sample. Chromatograms for each sample are compared to the chromatograms for PCB standards. Peak patterns and retention times from the chromatograms are used to identify and quantify PCBs in the soil sample extract. In addition to the GC, the operator may use an autosampler that automatically injects equal amounts of the sample extract into the GC column. The autosampler ensures that the correct amount of extract is used for each analysis and allows continual analysis without an operator. The FASP PCB method quickly provides results with statistical accuracy and detection limits comparable to those achieved by formal laboratories. The method can also identify individual Aroclors.

Instrumentation and equipment required for the FASP PCB method are not highly portable. When mounted in a mobile laboratory trailer, however, the method can operate on or near most sites relatively easily. Use of this method requires electricity, and Aroclor standards require refrigeration. An exhaust hood and carrier gases also are needed.

## WASTE APPLICABILITY:

The FASP PCB method can identify and quantify PCBs in soil and water samples.

## STATUS:

The FASP PCB method was demonstrated under the SITE Program at a well-characterized, PCB-contaminated site. During the demonstration, the method was used to analyze 112 soil samples, 32 field duplicates, and two performance evaluation samples. Split samples were submitted to an off-site laboratory for confirmatory analysis by SW-846 Method 8080. Data generated by the FASP PCB method were directly compared with the data from the off-site laboratory to evaluate the method's accuracy and precision. In addition, the operational characteristics and performance factors of the FASP PCB method were evaluated.

The stated detection limit for the FASB PCB method is 0.4 parts per million (ppm). During the demonstration, the method achieved a detection limit as low as 0.1 ppm. In addition, up to 21 samples were analyzed by the method in
period. The Innovative Technology Evaluation Report (EPA/540/R-95/516) contains additional details on the method's demonstration and evaluation and is available from EPA.



The SITE Program assesses but does not approve or endorse technologies.

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# UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
## (Field Analytical Screening Program - PCP method)

## TECHNOLOGY DESCRIPTION:

The field analytical screening program (FASP) pentachlorophenol (PCP) method uses a gas chromatograph (GC) equipped with a megabore capillary column and either a flame ionization detector (FID) or an electron-capture detector (ECD) to identify and quantify PCPs. Gas chromatography is an EPA-approved method for determining PCP concentrations in soil, water, and waste samples. The FASP PCP method is an abbreviated, modified version of these methods.

Soil and water samples require extraction before GC analysis. To remove interferences caused by petroleum hydrocarbons, including PCP carriers such as mineral spirits, kerosene, diesel fuel, and fuel oil, an acid-base partition clean-up step is used. In this step, the method includes petroleum hydrocarbons that are removed from the reagent water, while potassium phenates remain in the reagent water. Sample extracts are injected onto a GC, separated with a DB-5 megabore capillary column, and the PCP is identified and quantified using a FID. The sample extracts are then compared to standards to determine whether PCP is present in the sample and, if so, at what concentration. The FASP PCP method will only provide high parts per billion detection levels of PCP in water when an FID is used. To achieve a lower detection limit, the sample extracts are reanalyzed using an ECD.

The FASP PCP method is field-portable only in a mobile laboratory. It should be used indoors in a temperature-controlled environment. Reagents required for soil and water sample analyses require refrigeration and the GC extraction fume hood requires electricity.

## WASTE APPLICABILITY:

The FASP PCP method is designed to provide quantitative screening results for PCP in water and soil samples. The FASP PCP method is best used at sites where PCP is a known contaminant, where petroleum products are not the carrier solvents, and where large concentrations of other organic chemicals are not present in the sample.

## STATUS:

The FASP PCP method was demonstrated under the SITE Program at a well-characterized PCP-contaminated site. During the demonstration, the method was used to analyze 98 soil samples, 14 soil field duplicates, 10 water samples, and six water sample field duplicates. Split samples were submitted to an on-site laboratory for confirmatory analysis by the standard EPA-approved analytical methods. Data generated by the FASP PCP method were directly compared with the data from the off-site laboratory to evaluate the method's accuracy and precision. In addition, the specificity of the technology was evaluated.



The SITE Program assesses but does not approve or endorse technologies.

The demonstration results indicate that the FASP PCP method requires experienced GC operators to produce reliable results. The average number of demonstration samples extracted, concentrated, and analyzed in one 10-hour day during the demonstration was 14. The detection limit reported by this method for soil samples is 0.8 parts per million and 1.0 ppb for water samples. Generally, if 10 to 20 percent of the soil samples (not contaminated with petroleum) are sent to a confirmatory laboratory, the results from the other 80 to 90 percent can be corrected. This approach could yield significant savings in analytical costs. The water analysis portion of this demonstration produced similar results.

The FASP PCP method was found to be most affected by the diesel fuel used as a PCP carrier solvent. A specificity study performed during the demonstration showed that diesel fuel would provide a positive response when present at a concentration of 10 ppm. The Innovative Technology Evaluation report (EPA/540/R-95/528) contains additional details on the method's demonstration and evaluation and is available from EPA.

## FOR FURTHER INFORMATION:

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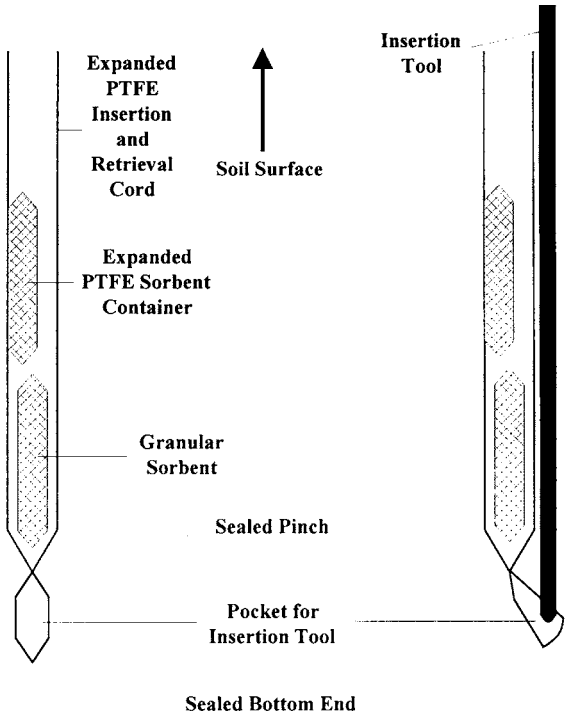
# W.L. GORE AND ASSOCIATES, INC.
## (GORE-SORBER® Screening Survey)

## TECHNOLOGY DESCRIPTION:

The GORE-SORBER® Screening Survey employs the use of patented passive soil vapor sampling devices (GORE-SORBER Modules), which are made of an inert, hydrophobic, microporous expanded polytetrafluoroethylene (ePTFE, similar to Teflon® brand PTFE) membrane. The membrane transfer of soil and liquid, but allows the soil gases to move across the membrane for collection onto engineered sorbents. These sorbents are designed to minimize the affects of water vapor and to detect a broad range of VOCs and SVOCs.

GORE-SORBER® Screening Surveys have been used successfully at thousands of sites for determining subsurface areas impacted by VOCs and SVOCs. Organic compounds commonly detected include halogenated solvents, straight- and branched-chain aliphatics, aromatics, and polycyclic aromatic hydrocarbons (PAH). Many of these compounds are associated with a wide range of petroleum products, including gasoline, mineral spirits, heating oils, creosotes, and coal tars. GORE-SORBER® Screening Surveys have also been used successfully to screen fornitroaromatic explosives, chemical warfare agents, precursors, breakdown products, and pesticides.

The GORE-SORBER® Screening Survey is a service that includes the manufacturing of the samplers, the analysis of the samplers (through thermal desorption, gas chromatography, and mass selective detection), and a final report that includes color contour plots of the compounds detected.




GORE-SORBER®



The SITE Program assesses but does not approve or endorse technologies.

## STATUS:

Common applications of the GORE-SORBER® Screening Surveys include detection of compounds to (1) trace soil and groundwater plumes in porous and fractured media, (2) monitor progress of subsurface in situ remedial actions, (3) provide baseline data for real estate transfer assessments, and (4) reduce groundwater monitoring costs. Prudent use of this technology can optimize and reduce soil and groundwater sampling efforts, resulting in significant cost savings over the life of site assessment and remedial action programs.

The GORE-SORBER® Screening Survey was accepted into the SITE Demonstration Program in November 1996. The SITE field demonstration was completed in May 1997. Since this technology has been accepted into the SITE program, water quality monitoring and the design of the GORE-SORBER Module have been improved.

The SITE demonstration showed that the GORE-SORBER® Screening Survey is more sensitive than active soil gas sampling, and therefore more accurate in terms of detecting and reporting low concentrations of some compounds. The technology demonstration also revealed that this survey is more accurate when the soil conditions would otherwise restrict the use of active soil gas methods, for example, where the soil is very dense or nearly saturated. Additionally, this sorbent based method provides a more robust system for sample collection and analysis for those projects that have more stringent data quality objectives.

Demonstration results are documented in the "Environmental Technology Verification" report for the sampler dated August 1998 (EPA/600/R-98/095).

## FOR FURTHER INFORMATION:

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# XONTECH INCORPORATED
## (XonTech Sector Sampler)

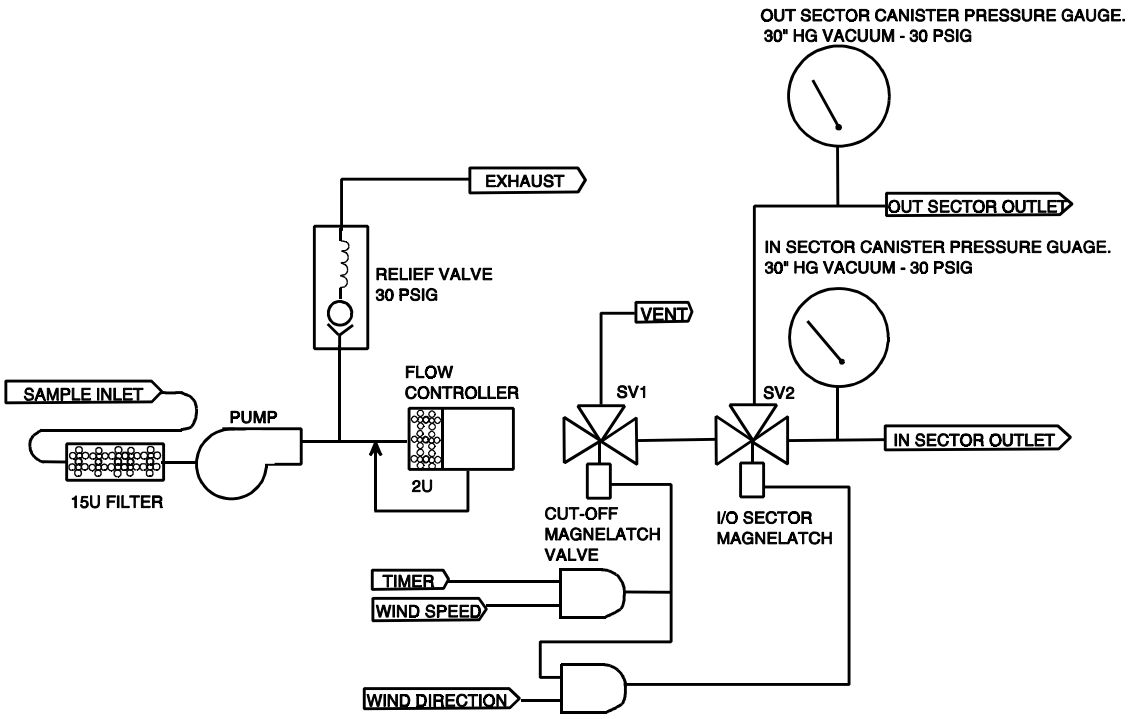
## TECHNOLOGY DESCRIPTION:

The XonTech Incorporated (XonTech) sector sampler collects time-integrated whole air samples in Summa™-polished canisters (see diagram below). The wind sensor directs whole air, sampled at a constant rate, into either an "in" sector canister or an "out" sector canister. When wind velocity exceeds 0.37 meter per second (m/s) from the direction of the suspected emissions area (the target), the first canister is filled. When the wind velocity exceeds 0.37 m/s from any other direction, the other canister is filled. When the wind velocity falls below 0.37 m/s, either canister or neither canister may receive the sample. Over an extended period of time, a target sample and a background sample are collected. This method is analogous to upwind-downwind sampling but does not require two distinct sites or manual sampler control.

The sampler is portable and can be battery- or AC-powered. The air samples are analyzed by gas chromatograph (EPA Method TO-14) for volatile organic compounds (VOC). The use of sector samplers enables identification of VOCs originating from the source and differentiation between other sources in the vicinity.

## WASTE APPLICABILTY:

The XonTech sector sampler can monitor VOC emissions from hazardous waste sites and other emission sources before and during remediation. Short-term sampling can determine which high concentration compounds are emitted from a site. Long-term monitoring can assess an emission source's potential effects on the local population, providing data to support risk analyses.




Schematic Diagram of the XonTech Sector Sampler



The SITE Program assesses but does not approve or endorse technologies.

## STATUS:

The XonTech sector sampler's usabililty has been demonstrated in two short-term field studies. This technology has been applied to industrial emissions as well as emissions from landfill sites. Mathematical methods for processing data have been developed and shown to be appropriate. The sampler is now commercially available.

## FOR FURTHER INFORMATION:

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