

**ACTIVE ENVIRONMENTAL TECHNOLOGIES, INC.**  
(formerly EET, Inc.)  
(TechXtract® Decontamination Process)

**TECHNOLOGY DESCRIPTION:**

The TechXtract® process employs proprietary 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 wood. Each formulation consists of chemicals from up to 14 separate chemical groups, and formulation can be specifically tailored to individual 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.

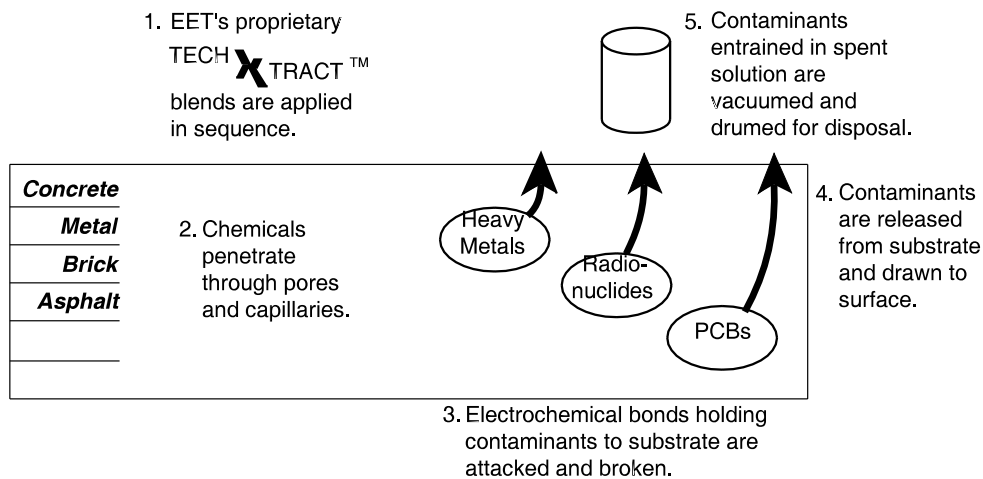
The surface preparation step uses a solution that contains buffered organic and inorganic acids, sequestering agents, wetting agents, and special hydrotrope chemicals. The extraction formula includes macro- and microemulsifiers in addition to electrolyte, flotation, wetting, and sequestering agents. 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 or vacuumed from the surface with a wet/dry, barrel-vacuum. No major capital equipment is required.

Contaminant levels can be reduced from 60 to 90 percent per cycle. The total number of cycles is determined from initial contaminant concentrations and final remedial action objectives.

**WASTE APPLICABILITY:**

The TechXtract® process is designed to treat porous solid materials contaminated with PCBs; toxic hydrocarbons; heavy metals, including lead and arsenic; and radionuclides. Because the contaminants are extracted from the surface, the materials can be left in place, reused, or recycled. After treatment, the contaminants are concentrated in a small volume of liquid waste. The liquid can be disposed as is, incinerated, or solidified for landfill. It will carry the waste characteristics of the contaminant.



Process Flow Diagram of the TECHXTRACT® Process

In commercial applications, the process has reduced PCB concentrations from 1,000,000 micrograms per 100 square centimeters ( $\mu\text{g}/100\text{ cm}^2$ ) to concentrations less than  $0.2\ \mu\text{g}/100\text{ cm}^2$ . The TechXtract<sup>®</sup> process has been used on concrete floors, walls, and ceilings, tools and machine parts, internal piping, valves, and lead shielding. The TechExtract<sup>®</sup> process has removed lead, arsenic, technetium, uranium, cesium, tritium, and throrium, chrome (+3,+6), gallium, copper, mercury, plutonium, and strontium.

### **STATUS:**

This technology was accepted into the SITE Demonstration Program in summer 1994. EAT Demonstrated the TechXtract<sup>®</sup> technology from February 26, 1997 to March 6, 1997. During the demonstration, AET competed 20 TechXtract<sup>®</sup> 100 cycles and 12 300/200 cycles. Post-treatment samples were collected on March 6, 1997. In April 1997 a demonstration project was completed at the Pearl Harbor Naval Complex.

The technology has been used in over 200 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. Further research is underway to apply the technology to soil, gravel, and other loose material. AET also plans to study methods for removing or concentrating metals in the extracted liquids.

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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.

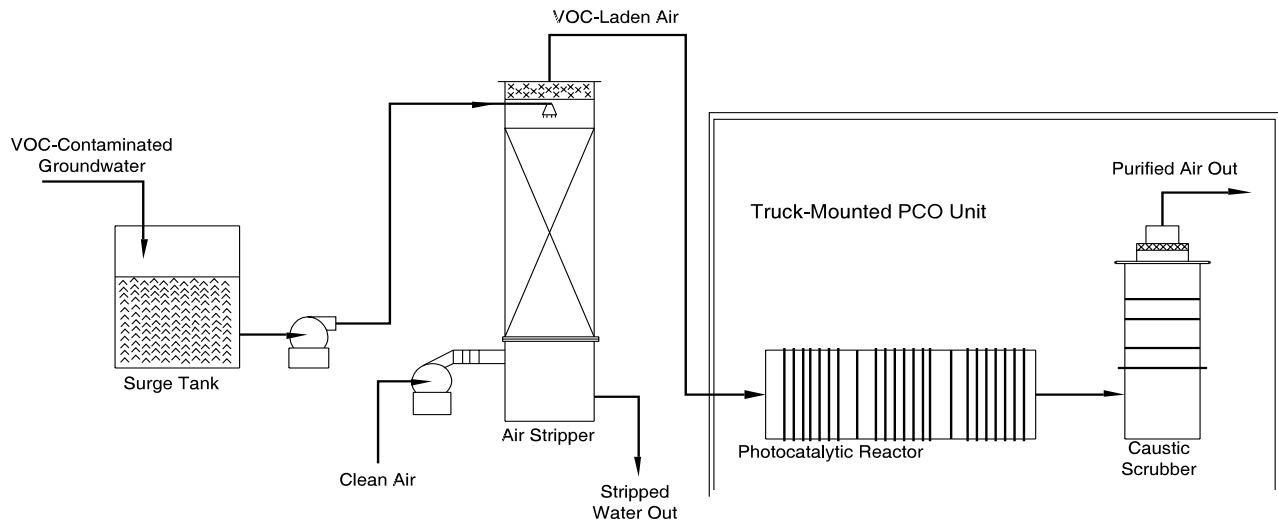
In gas-solid photocatalytic oxidation (PCO), the VOC-laden air stream is exposed to a titania catalyst in near-ultraviolet (UV) light. The UV light activates the catalyst, producing oxidizing radicals. The radicals promote rapid chain reactions that completely destroy VOCs to carbon dioxide and water; 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.
- 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.



Photocatalytic Oxidation with Air Stripping

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**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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**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.

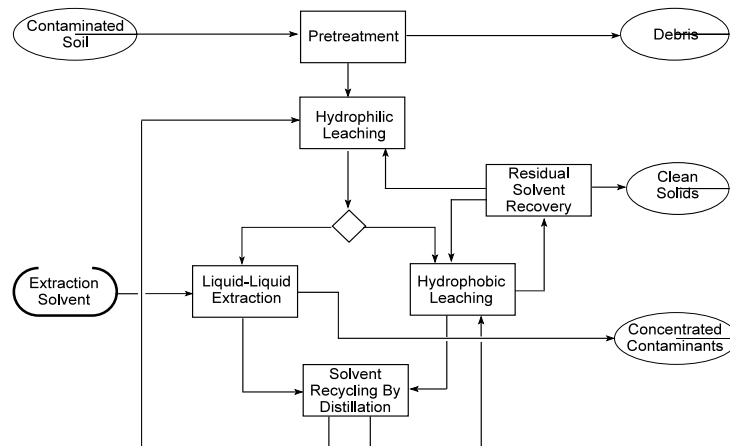
After pretreatment, the solid matrix is washed in a unique, dual solvent process that uses both hydrophilic and hydrophobic solvents. The combination of these proprietary solvents guarantees efficient contaminant removal.

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



LEEP® Process Flow Diagram

experiments have shown that 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)**

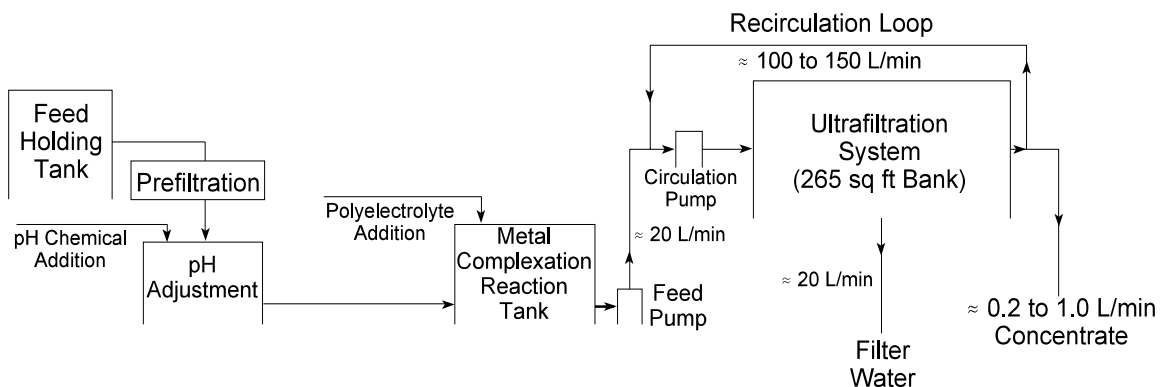
**TECHNOLOGY DESCRIPTION:**

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 (concentrate), while allowing uncomplexed ions to pass through the membrane with the filtered water. The filtered water (permeate) is continuously withdrawn, while the concentrate stream, containing most of the contaminants, is recycled through the recirculation loop 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

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**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. In addition, the process 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-scale 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 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)**

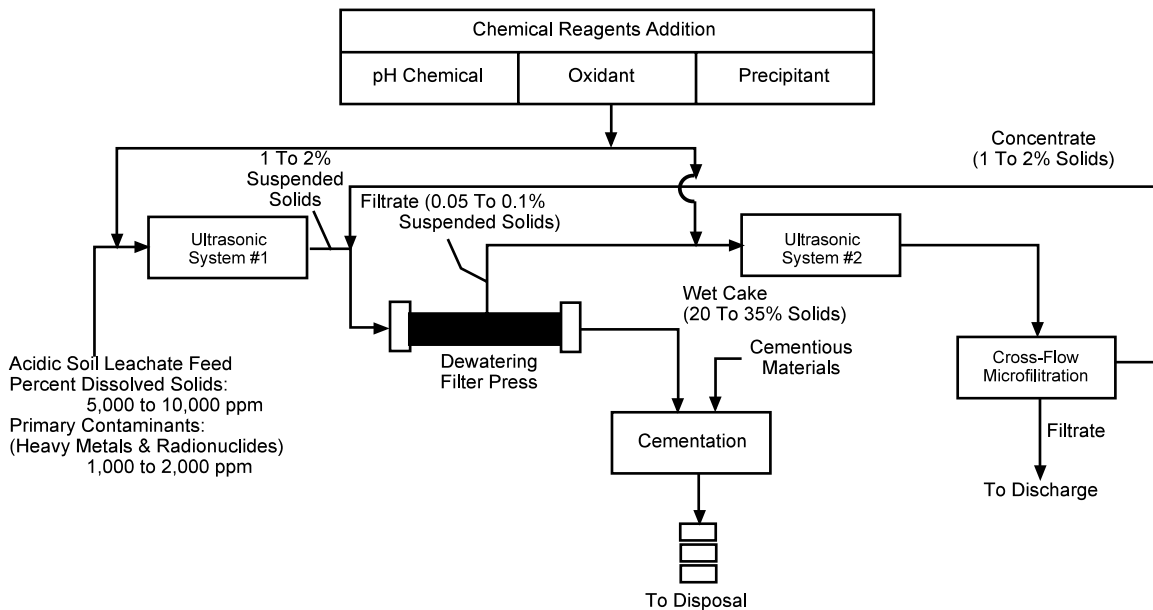
**TECHNOLOGY DESCRIPTION:**

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. 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.



Single-Stage Chemical Treatment and Ultrafiltration Process

## **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).

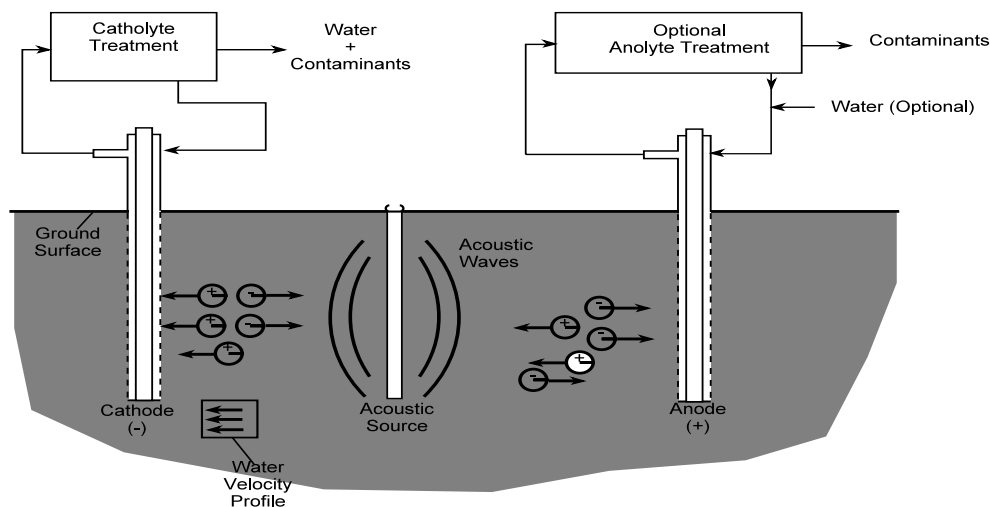
The double-layer boundary theory is important when an electric potential is applied to soils. For soil particles, the double layer consists of (1) a fixed layer of negative ions that are firmly held to the solid phase, and (2) a diffuse layer of more loosely held cations and anions. Applying an electric 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. The technology's potential for improving



In Situ Electroacoustic Soil Decontamination (ESD) Technology

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; it is only marginally effective for hydrocarbon removal. A modified ESD process for more effective hydrocarbon removal has been developed but not 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 EPA.

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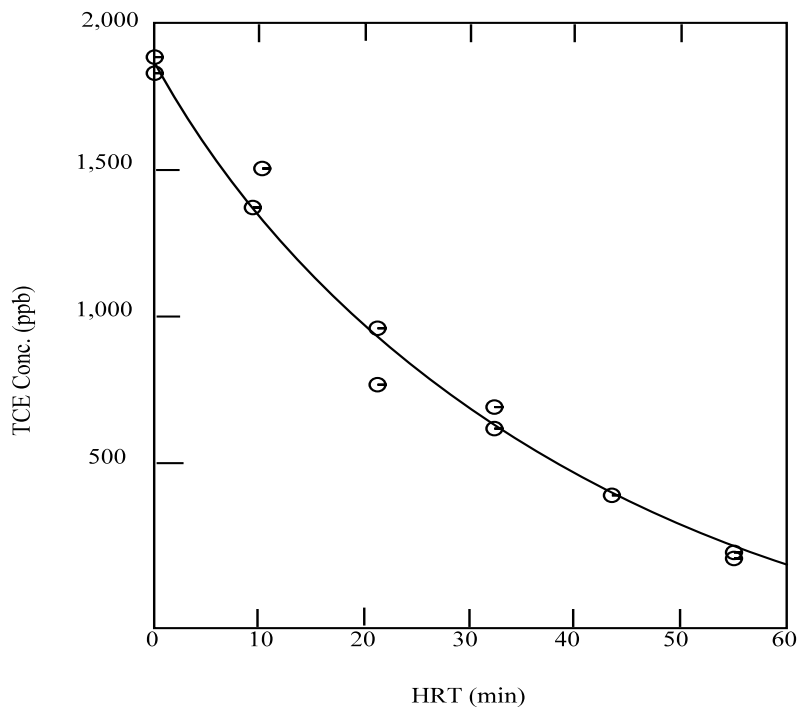
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**BIOTROL®**  
(Methanotrophic Bioreactor System)

**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.



Results for Pilot-Scale, Continuous-Flow Reactor

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, dichloroethane isomers, chloroform, dichloromethane (methylene chloride), and others. In the case of groundwater treatment, bioreactor effluent can either be reinjected or discharged to a sanitary sewer or a National Pollutant Discharge Elimination System.

### **STATUS:**

This technology was accepted into the SITE Emerging Technology Program in July 1990. Both 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 EPA.

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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).

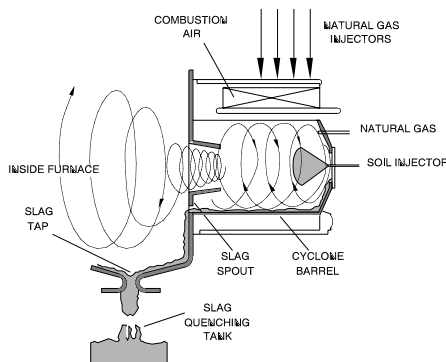
Natural gas and preheated combustion air are heated to 820 °F and enter tangentially into the cyclone burner. For dry soil processing, the soil matrix and natural gas enter tangentially along the cyclone furnace barrel. For wet soil processing, an atomizer uses compressed air to spray the soil slurry 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 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.



Cyclone Furnace

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## 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.

## STATUS:

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

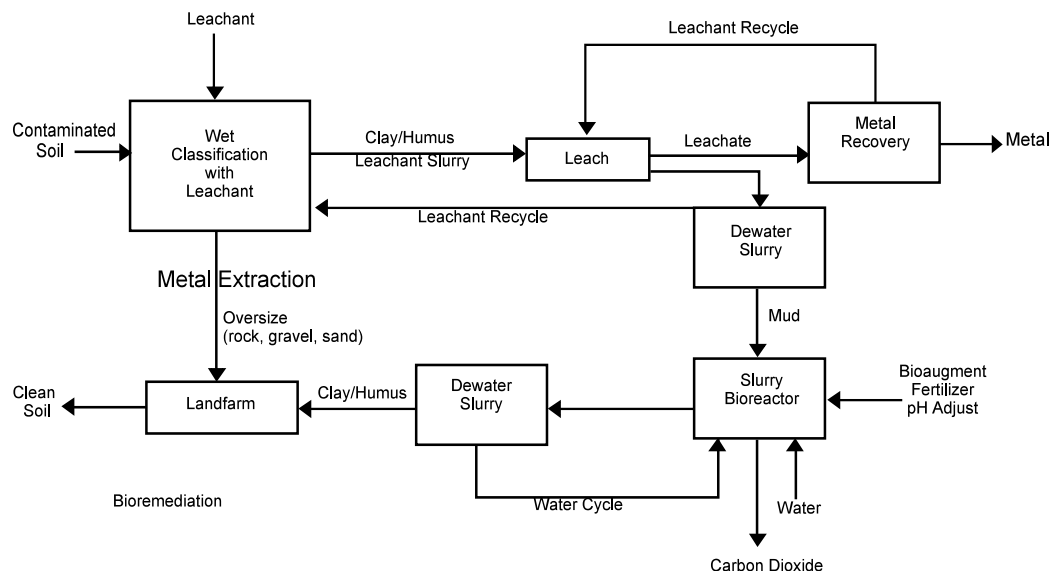
**TECHNOLOGY DESCRIPTION:**

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



Metal Leaching and Bioremediation Process

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 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.

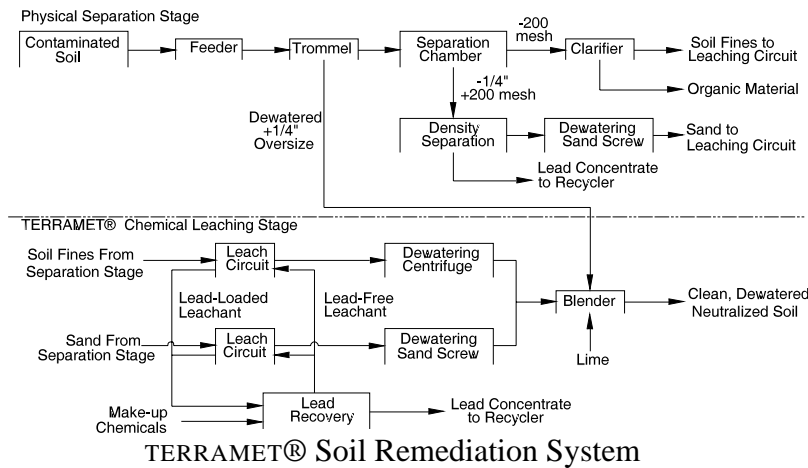
The figure below illustrates the process. A pretreatment, physical separation stage may involve dry screening to remove gross oversized material. The soil can be separated into oversized (gravel), sand, and fine (silt, clay, and humus) fractions. Soil, including the oversized fraction, is first washed. 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 metal;
- (6) no waste is generated during processing.



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## 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  
(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.

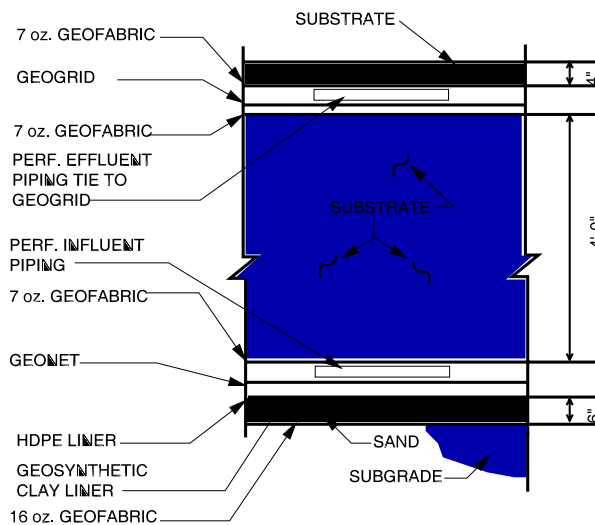
Influent waters with high metal concentrations flow through the aerobic and anaerobic zones of the wetland ecosystem. Metals are removed by ion exchange, adsorption, absorption, and precipitation through geochemical and microbial oxidation and reduction. Ion exchange occurs as metals in the water contact 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.

**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-



Schematic Cross Section of Pilot-Scale Upflow Cell

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.

This technology was in operation from 1993 to May 1999. It has been discontinued.

### **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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**CONCURRENT TECHNOLOGIES**  
(formerly 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.

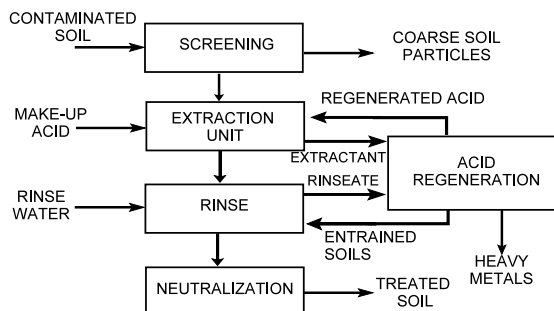
After coarse particle removal, the remaining soil is scrubbed in an attrition scrubber to break up agglomerates and cleanse surfaces. Hydrochloric acid is then introduced into the soil in the extraction unit. The residence time in the unit varies depending on the soil type, contaminants, and contaminant 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.



Acid Extraction Treatment System (AETS) Process

## 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 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.

## FOR FURTHER INFORMATION:

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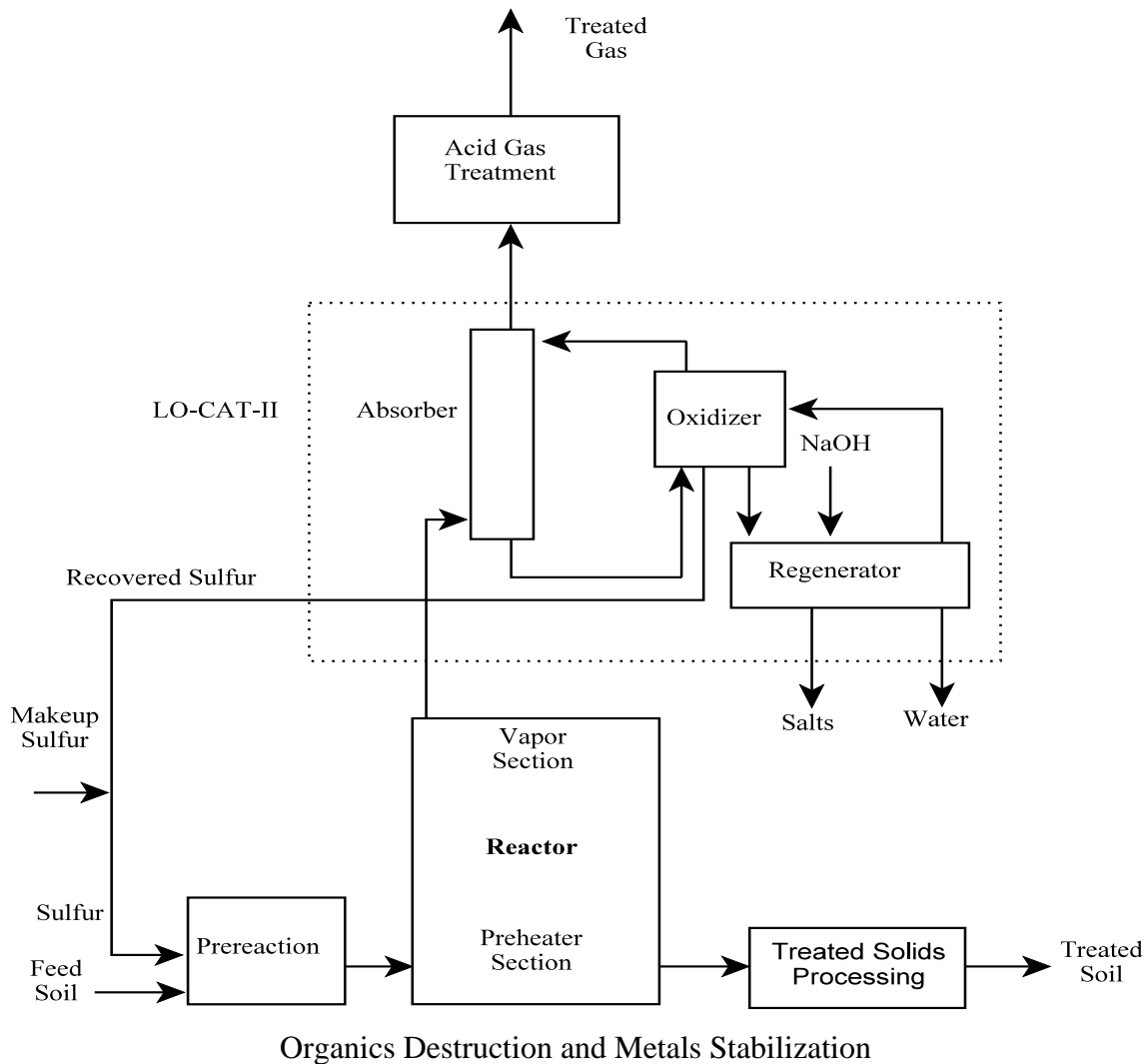
**CONCURRENT TECHNOLOGIES**  
(formerly Center for Hazardous Materials Research)  
(Organics Destruction and Metals Stabilization)

**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 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 was made available in 1997.

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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.

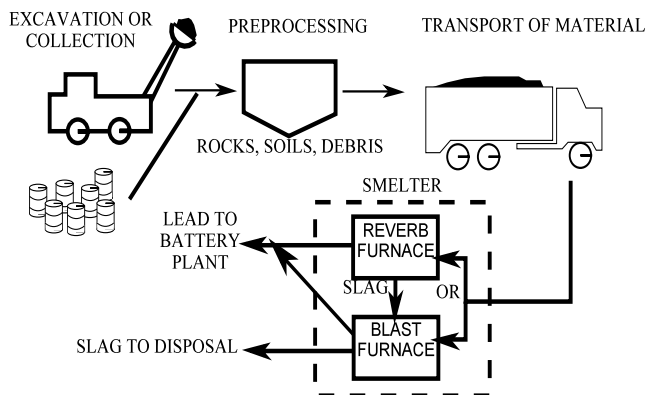
At the smelter, waste is fed to reverberatory or blast furnaces, depending on particle size or lead content. The two reverberatory furnaces normally treat lead from waste lead-acid batteries, as well as other lead-containing material. The furnaces are periodically tapped to remove slag, which contains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



Smelting Lead-Containing Waste Process

**STATUS:**

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

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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<b>Source of Material/ Type of Material Tested</b>	<b>% Lead</b>	<b>Economical *</b>	<b>Test Results</b>
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.

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