

**NEW JERSEY INSTITUTE OF TECHNOLOGY HAZARDOUS  
SUBSTANCES MANAGEMENT RESEARCH CENTER**

**(formerly 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:**

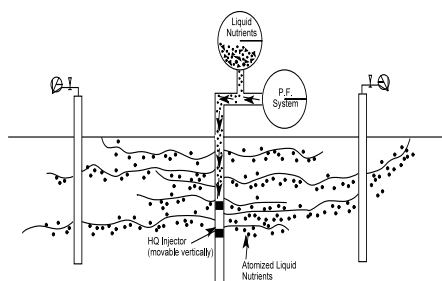
The Hazardous Substance Management Research Center (HSMRC) has developed a technology for the in situ remediation of organic contaminants. The process enhances in situ bioremediation through pneumatic fracturing to establish an extended biodegradation zone supporting aerobic, denitrifying, and methanogenic 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 to 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 which increase formation permeability. In formations with higher permeabilities, the process is still useful for rapid aeration and delivery of amendments to the microorganisms.



Overview of the Integrated Pneumatic Fracturing and Bioremediation Process

## 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. The 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 through comparative analysis 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 concentration levels 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 kilograms 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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**NEW JERSEY INSTITUTE OF TECHNOLOGY  
(GHEA Associates Process)**

**TECHNOLOGY DESCRIPTION:**

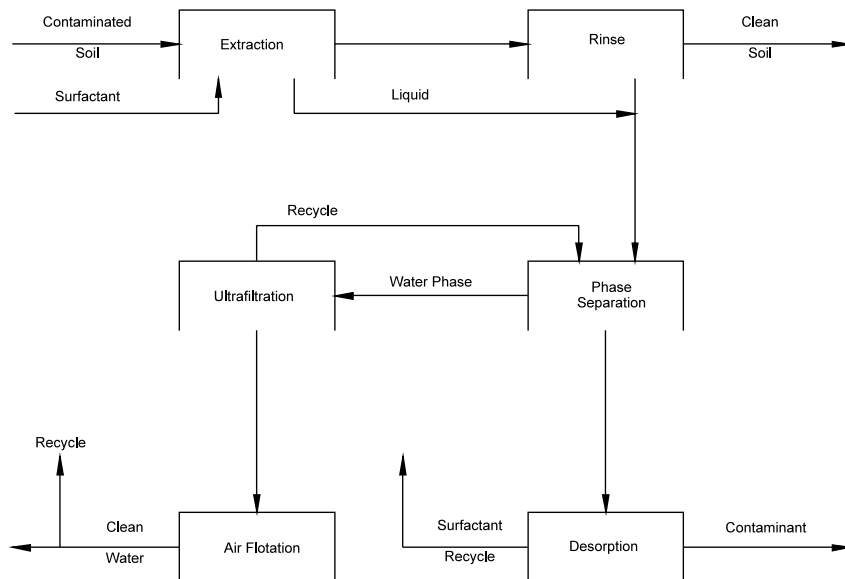
The GHEA Associates process applies surfactants and additives to soil washing and wastewater treatment to make organic and metal contaminants soluble. In soil washing, soil is first excavated, washed, and rinsed to produce clean soil. Wash and rinse liquids are then combined and treated to separate surfactants and contaminants from the water. Next, contaminants are separated from the surfactants by desorption and 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 flushing. Contaminants that can be treated include both organics and heavy metals, nonvolatile and volatile organic compounds, and highly toxic refractory compounds.



GHEA Process for Soil Washing

**.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. The Emerging Technology Bulletin (EPA/540/F-94/509), which details evaluation results, is available from EPA. Costs for treatment range from \$50 to \$80 per ton.

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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) Water, parts per billion (ppb)	20.13 109.0	0.05 2.5	99.7% 97.8%
Total Petroleum Hydrocarbons (TPH): Soil, ppm	13,600	80	99.4%
Polychlorinated Biphenyls (PCB): Soil, ppm Water, ppb	380.00 6,000.0	0.57 <0.1	99.8% >99.9%
Trinitrotoluene in Water, ppm	180.0	<.08	>99.5%
Coal Tar Contaminated Soil (ppm): Benzo[a]pyrene Benzo[k]fluoranthene Chrysene Benzanthracene Pyrene Anthracene Phenanthrene Fluorene Dibenzofuran 1-Methylnaphthalene 2-Methylnaphthalene	28.8 24.1 48.6 37.6 124.2 83.6 207.8 92.7 58.3 88.3 147.3	<0.1 4.4 <0.1 <0.1 <0.1 <0.1 <0.1 <0.1 <0.1 <0.1 1.3 <0.1	>99.7% 81.2% >99.8% >99.7% >99.9% >99.8% >99.9% >99.9% >99.8% 98.5% >99.9%
Heavy Metals In Soil: Chromium, ppm	21,000	640	96.8%
Iron (III) in Water, ppm:	30.8	0.3	99.0%

**PHARMACIA CORPORATION**  
(formerly Monsanto/DuPont)  
(Lasagna™ In Situ Soil Remediation)

**TECHNOLOGY DESCRIPTION:**

The Lasagna™ process, so named because of its treatment layers, combines electroosmosis 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 or horizontally (see figures below). The process is designed to treat soil and groundwater contaminants completely in situ, without the use of injection or extraction wells.

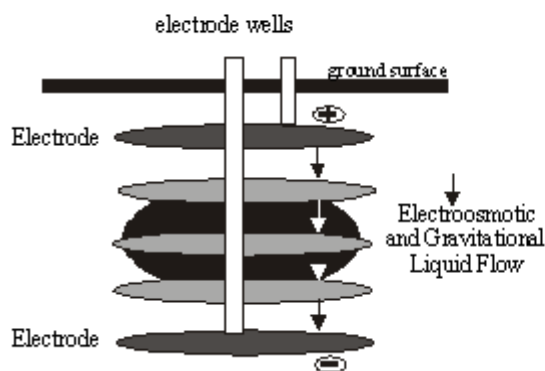
The outer layers consist of either positively or negatively charged electrodes which create an electrical potential field. The electrodes create an electric field which moves contaminants in soil pore fluids into or through treatment layers. In the vertical configuration, rods that are steel or granular graphite and iron filings can 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 methanotropic microorganisms).

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.

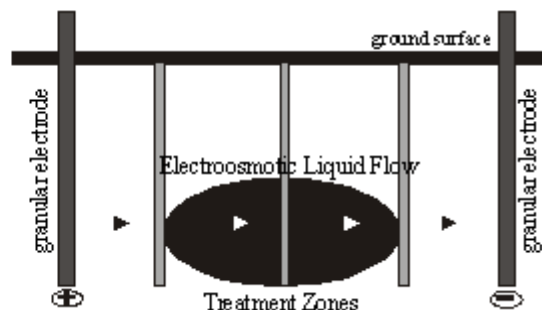
**WASTE APPLICABILITY:**

The process is designed for use in fine-grained soils (clays and silts) where water movement is slow and it is difficult to move contaminants to extraction wells. The process induces water movement to transport contaminants to the treatment zones so the contaminants must have a high solubility or miscibility in water. Solvents such as trichloroethylene and soluble metal salts can be treated successfully while low-solubility compounds such as polychlorinated biphenyls and polyaromatic hydrocarbons cannot.

A. Horizontal Configuration



B. Vertical Configuration



## STATUS:

The Lasagna™ process (vertical configuration) was accepted into the SITE Demonstration Program in 1995. Two patents covering the technology have been granted to Monsanto, and the term Lasagna™ has also been trademarked by Monsanto. Developing the technology so that it can be used with assurance for site remediation is the overall objective of the sponsoring consortium.

## DEMONSTRATION RESULTS:

The vertical configuration demonstration by Pharmacia at the Gaseous Diffusion Plant in Paducah, Kentucky, has been completed. The analysis of trends in TCE contamination of soil before and after Lasagna™ treatment indicated that substantial decreases did occur and the technology can be used to meet action levels.

The horizontal configuration demonstration by the University of Cincinnati and EPA at Rickenbacker ANGB (Columbus, OH) has been completed and both cells decommissioned. The cells were installed in soil containing TCE. The work demonstrated that horizontal Lasagna™ installations are feasible and that the installation results in some treatment of contaminants. The extent of treatment of the TCE-contaminated soil was not clear because of the small size of the cells and transport of TCE into the cells from adjacent contaminated areas.

In cooperation with the U.S. Air Force, EPA installed two horizontal configuration Lasagna™ cells in TCE-contaminated soil at Offutt AFB (Omaha, NE) in November 1998. The cells have been in operation since September 2000. An interim sampling in December 2000 at the four locations with highest concentrations in each cell showed slight decreases in organic chloride in one cell, but these were not statistically different from initial (pretreatment) concentrations. A second interim sampling will be conducted in June 2001 and the final (posttreatment) sampling in September 2001.

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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 plots are intensively cultivated. Plant shoots are cut during the growing



Phytoremediation of Surface Soil



Phytoremediation of the Saturated Zone

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 used 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. A total of 40 hybrid poplar trees were planted using a deep rooting techniques in 1996 and data were collected through 1999 growing season.

### **DEMONSTRATION RESULTS:**

Water removal rates estimated using a water use multiplier and leaf area index to adjust a reference evapo-ranspiration rate was 5 gallons per day per tree in 1998 and 113 gallons per day per tree in 1999. Water removal rates determined using SAP velocity measurements done in September and October of 1998 agreed closely with the estimated values. Although the trees transpired a volume of water equivalent to a 10-ft thickness of the saturated zone, water table elevation data collected in 1999 did not indicate a depression in the water table.

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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 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. The field treatability study was conducted, at the Echo Bay/McCoy Cover mine site near Battle Mountain, Nevada, between June 11, 1997 and August 26, 1997.

### **DEMONSTRATION RESULTS:**

Results from the study are summarized below:

- The average % WAD CN reduction attributable to the Biocyanide process was 89.3 during the period from July 23 to August 26. The mean concentration of the feed over this period was 233 ppm, while the treated effluent from the bioreactors was 25 ppm. A control train, used to detect abiotic loss of cyanide, revealed no destruction of cyanide (average control effluent = 242 ppm).
- Metals that were monitored as part of this study were As, Cd, Co, Cu, Fe, Mn, Hg, Ni, Se, Ag, and Zn. Significant reductions were noted for all metals except Fe and Mn. Average reduction in metals concentration after July 23 for all other

metals were 92.7% for As, 91.6% for Cd, 61.6% for Co, 81.4% for Cu, 95.6% for Hg, 65.0% for Ni, 76.3% for Se, 94.6% for Ag, and 94.6% for Zn. Reductions for As, Cd, Co, and Se are probably greater than calculated due to non-detect levels in some effluent samples. A biomineralization mechanism is proposed for the removal of metals for solution. Biomineralization is a process in which microbes mediate biochemical reactions forming novel mineral assemblages on solid matrices.

- The Aqueous Biocyanide Process was operated for two and one-half months. During the first 42 days (June 11 to July 22) system performance was variable, and occasional downtimes were encountered. This was due to greatly higher cyanide and metals concentration in the feed than was encountered during benchscale and design phases of the project. Once optimized for the more concentrated feed, the system performed well with continuous operation for 35 days (July 23 to August 26). The ability to "re-engineer" the system in the field to accommodate the new waste stream is a positive attribute of the 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.

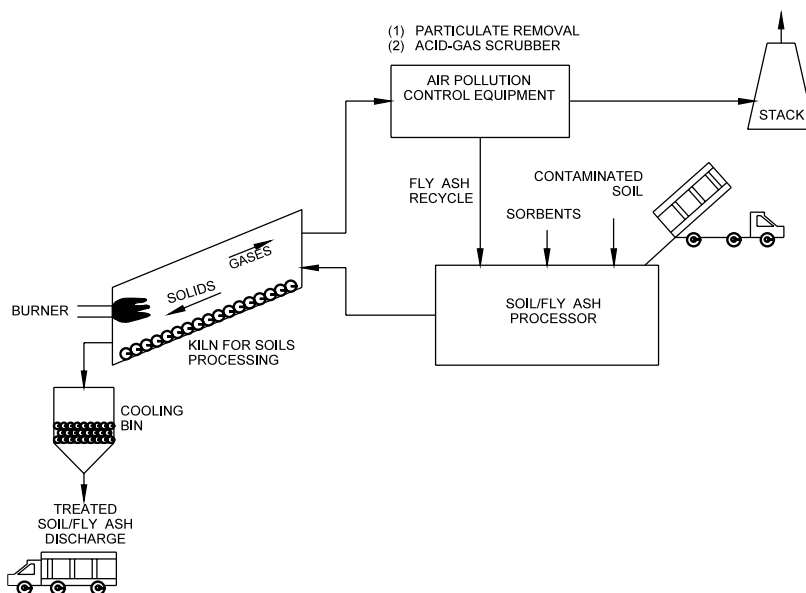
Standard air pollution control devices clean the effluent gas stream. Hydrogen chloride and sulfur dioxide, which may be formed from the oxidation of chlorinated organics and sulfur compounds in the waste, are cleaned by alkaline scrubbers. Fly ash is

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 containing lead paint or leaded gasoline, or chemical or pesticide manufacturing facilities contaminated with organometallics.



MeIDAS Process

**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 occurred 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 absorbing 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-ray processing is estimated to be competitive with alternative processes which decompose the contaminants.

#### **WASTE APPLICABILITY:**

X-ray processing can treat a large number of organic contaminants in aqueous solutions (groundwater, liquids, leachates, or wastewater) without expensive waste extraction or preparation. The technology has successfully treated 17 organic contaminants, listed in 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 completed 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.

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 OH- 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 at the present. The table below summarizes the X-ray treatment results from the SITE evaluation.

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CONTAMINANT	MATRIX	INITIAL CONCENTRATION (ppb) <sup>*</sup>	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 <sub>4</sub> )		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 <sub>4</sub>		Contaminated Well Water	262/400	< 0.5/196	1/0.5
Ethylbenzene/CCl <sub>4</sub>	1,000/430		< 0.5/70.9	680/0.5	33.2/185
Ortho-xylene/CCl <sub>4</sub>	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 <sub>4</sub>		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**

**PULSE SCIENCES, INC.**  
**(X-Ray Treatment of Organically Contaminated Soils)**

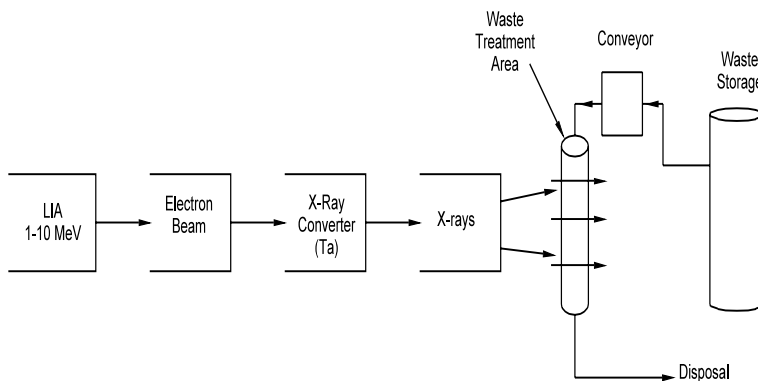
**TECHNOLOGY DESCRIPTION:**

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

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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**RECRA ENVIRONMENTAL, INC.**  
**(formerly Electro-Pure Systems, Inc.)**  
**(Alternating Current Electrocoagulation Technology)**

**TECHNOLOGY DESCRIPTION:**

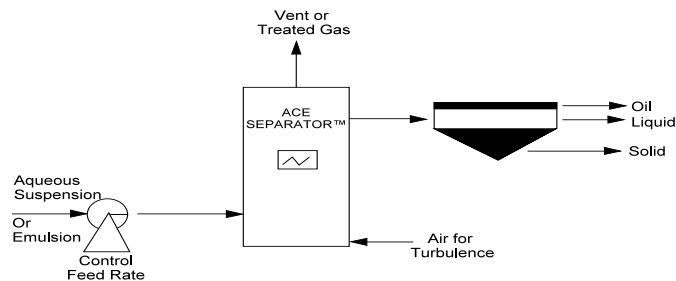
The alternating current electrocoagulation (ACE) technology offers an alternative to the use of metal salts or polymers and polyelectrolyte addition for breaking stable emulsions and suspensions. The technology removes metals, colloidal solids and particles, and soluble inorganic pollutants from aqueous 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.



Alternating Current Electrocoagulation (ACE)

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 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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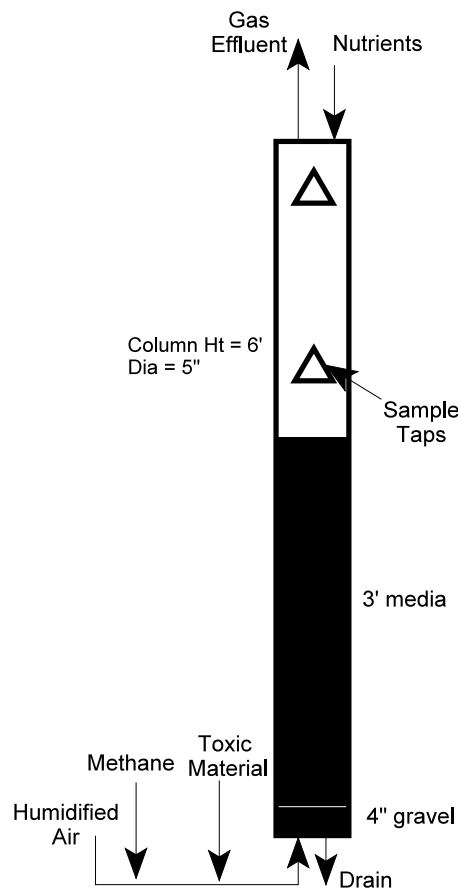
**REMEDIATION TECHNOLOGIES, INC.**  
**(Biofilm Reactor for Chlorinated Gas Treatment)**

**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 Biofilm Reactor

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.

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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**RESOURCE MANAGEMENT & RECOVERY**  
**(formerly Bio-Recovery Systems, Inc.)**  
**(AlgaSORB® Biological Sorption)**

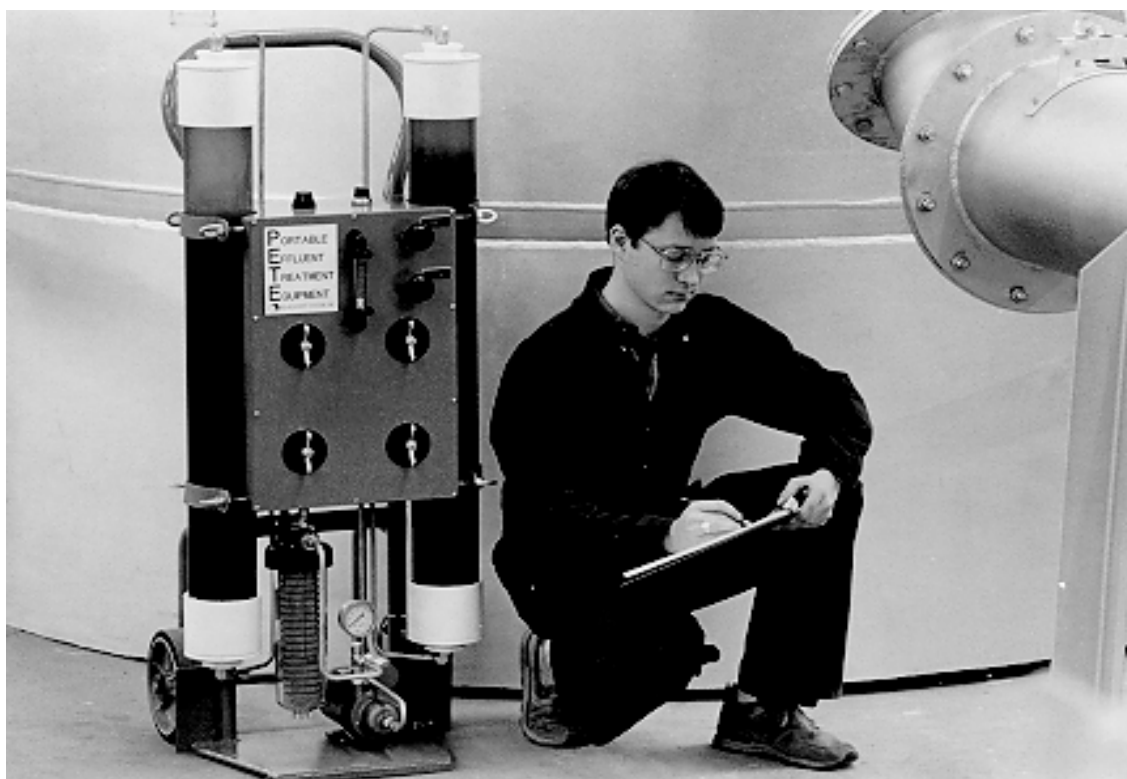
**TECHNOLOGY DESCRIPTION:**

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<sup>+2</sup>]) and metallic oxoanions (negatively charged, large, complex, oxygen-containing ions, such as selenate [SeO<sub>4</sub><sup>-2</sup>]). 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

typical of hard water, such as calcium ( $\text{Ca}^{+2}$ ) and magnesium ( $\text{Mg}^{+2}$ ), or monovalent cations, such as sodium ( $\text{Na}^{+}$ ) and potassium ( $\text{K}^{+}$ ) do not significantly interfere with the binding of toxic heavy metal ions to the algae-silica matrix.

Like ion-exchange resins, AlgaSORB<sup>®</sup> can be regenerated. After the AlgaSORB<sup>®</sup> 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<sup>®</sup> 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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**ROY F. WESTON, INC.**  
**(Ambersorb® 563 Adsorbent)**

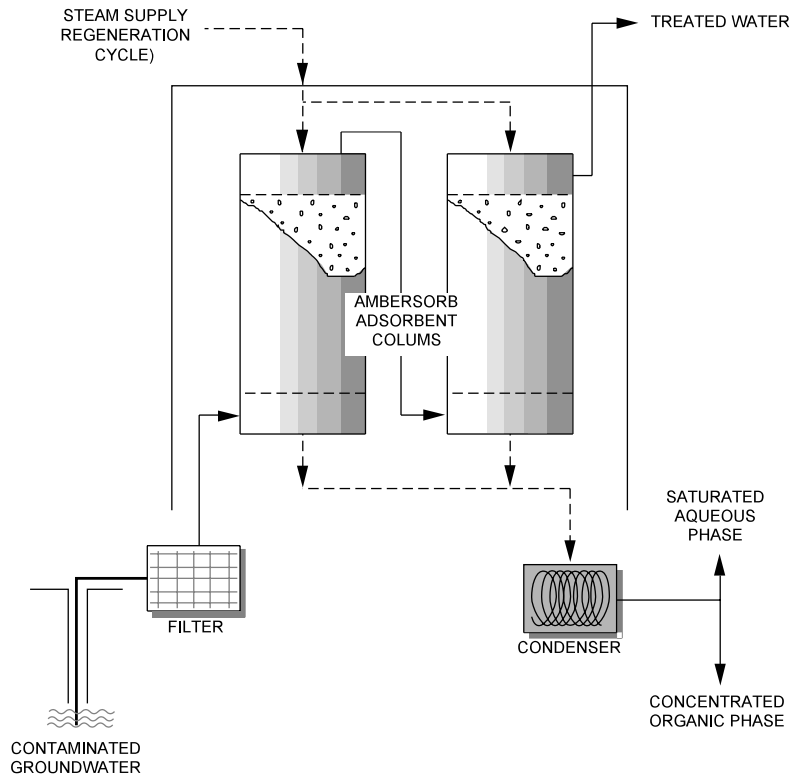
**TECHNOLOGY DESCRIPTION:**

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

- Ambersorb<sup>®</sup> 563 adsorbent can operate at higher flow rate loadings than GAC, which translates into a smaller, more compact system.
- Ambersorb<sup>®</sup> 563 adsorbents are hard, nondusting, spherical beads with excellent physical integrity, eliminating handling problems and attrition losses typically associated with GAC.
- Ambersorb<sup>®</sup> 563 adsorbent is not prone to bacterial fouling.
- Ambersorb<sup>®</sup> 563 adsorbent has extremely low ash levels.

In addition, the Ambersorb<sup>®</sup> 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<sup>®</sup> 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<sup>®</sup> adsorbent system consistently met drinking water standards. On-site steam regeneration demonstrated that the adsorption capacity of the Ambersorb<sup>®</sup> system remained essentially unchanged following regeneration.

### **FOR FURTHER INFORMATION:**

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Note: Ambersorb<sup>®</sup> is a registered trademark of Rohm and Haas Company.



**STATE UNIVERSITY OF NEW YORK AT OSWEGO,  
ENVIRONMENTAL RESEARCH CENTER  
(Electrochemical Peroxidation of PCB-Contaminated Sediments and Waters)**

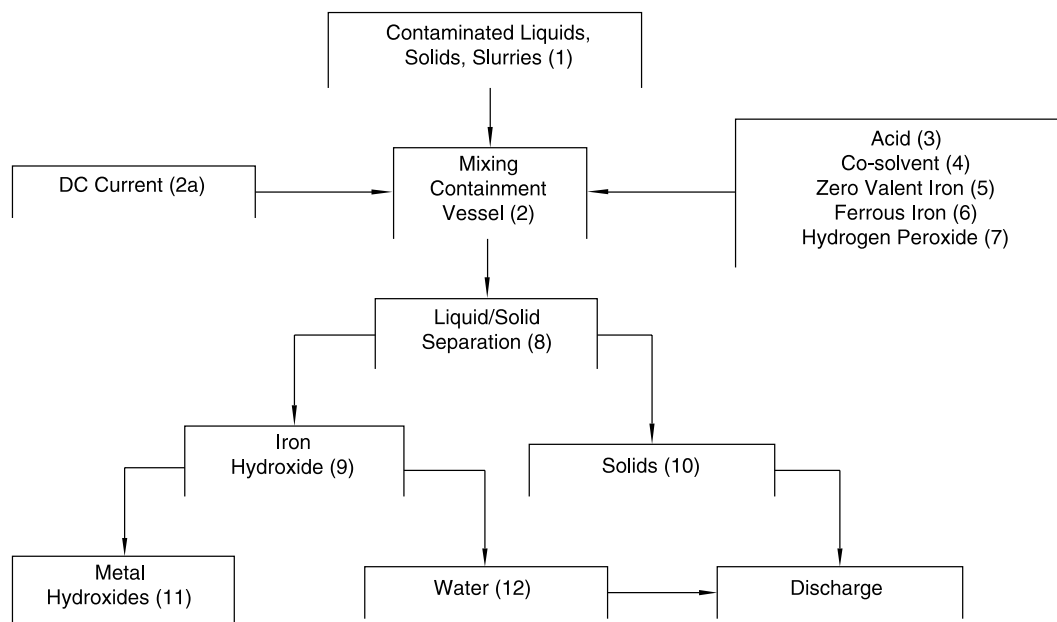
**TECHNOLOGY DESCRIPTION:**

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, MTBE, 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. Hydrogen peroxide and iron are introduced from the electrodes as a low direct current is applied.

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 removed by solids separation. In specific applications, select metals may be plated onto electrodes and recovered.



Pilot-Scale Electrochemical Peroxidation System

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## 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.

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 was tested at a gasoline-contaminated groundwater site in winter of 1998/99. In situ application of the process were conducted at a gasoline spill site during spring, 1999. The process was used to reduce chlorinated solvents (TCE, DCE, PCE) and petroleum hydrocarbons in contaminated groundwater at a large Air Force Base in 1998.

Since completing the SITE project, they have developed and are in the process of patenting a peroxide release system that can be deployed at remote sites to address chlorinated and non-chlorinated organic compounds in situ as well as add oxygen to the groundwater to affect aerobic degradation. This process uses a battery operated pump to inject  $H_2O_2$  into the groundwater to deliver a peroxide solution that readily changes a plume to an aerobic state at a fraction of the cost of other oxygen release

compounds. A pilot scale demonstration conducted at a Saratoga Springs site in New York on about 3,000,000 gallons of BTEX and MTBE contaminated groundwater reduced the contaminant concentrations to below detect within 6 months and increased the dissolved oxygen concentration from  $<0.5$  to  $>9.0$ .

Because  $H_2O_2$  is  $>90\%$  oxygen, the relative cost of the increased dissolved oxygen is about 1/3 that of commercially available oxygen release compounds. Additionally, in well inserts are now available to be used in existing 2.6" monitoring and/or recovery wells to slowly, gravity or pump release a peroxide solution to the groundwater to affect in situ Fenton's Reagent Reactions and alter the redox of the impacted groundwater. These products are currently available through EBSI, a New Jersey based remediation firm.

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