CALGON CARBON ADVANCED OXIDATION TECHNOLOGIES

(formerly Vulcan Peroxidation Systems, Inc.)

(perox-pure™ Chemical Oxidation Technology)

TECHNOLOGY DESCRIPTION:

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

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

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

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

WASTE APPLICABILITY:

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

perox-pure™ Model SSB-30

combination of the **perox-pure™** technology with activated carbon, air stripping, or biological treatment will provide a more economical approach than would be obtained by using only one technology.

STATUS:

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

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

DEMONSTRATION RESULTS:

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

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

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CF SYSTEMS CORPORATION

(Liquified Gas Solvent Extraction [LG-SX] Technology)

TECHNOLOGY DESCRIPTION:

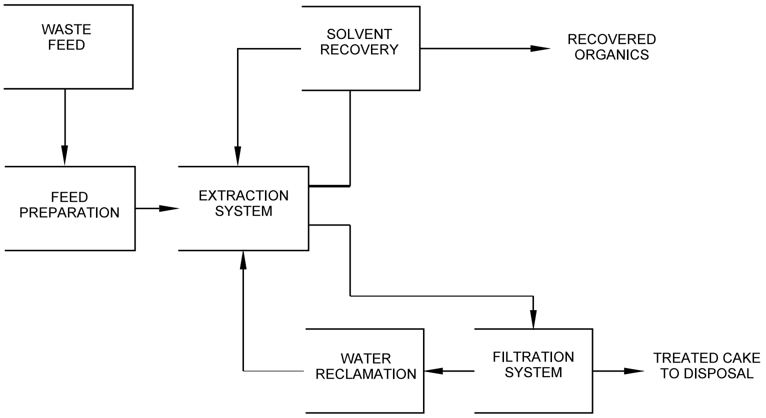
The CF Systems Corporation (CF Systems) liquified gas solvent extraction (LG-SX) technology uses liquified gas solvents to extract organics from soils, sludges, sediments, and wastewaters. Gases, when liquified under pressure, have unique physical properties that enhance their use as solvents. The low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

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

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

WASTE APPLICABILITY:

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



Liquified Gas Solvent Extraction (LG-SX) Technology

STATUS:

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

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

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

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

DEMONSTRATION RESULTS:

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

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

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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.

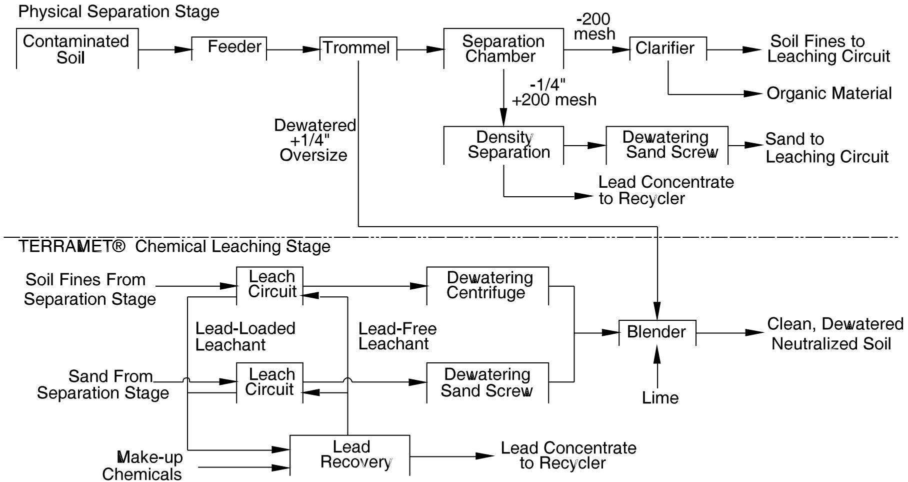
The figure below illustrates the process. A pretreatment, physical separation stage may involve dry screening to remove gross oversized material. The soil can be separated into oversized (gravel), sand, and fine (silt, clay, and humus) fractions. Soil, including the oversized fraction, is first washed.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

WASTE APPLICABILITY:

The COGNIS TERRAMET® soil remediation system can treat soil, sediment, and sludge contaminated by lead and other heavy metals or metal mixtures. Appropriate



TERRAMET® Soil Remediation System

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. A Demonstration Bulletin (EPA/540/MR-93/03) and Applications Analysis Report (EPA/540/AR-93-93/503) are available from the EPA.

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).

DEMONSTRATION RESULTS:

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

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COLORADO DEPARTMENT OF PUBLIC HEALTH AND ENVIRONMENT

(Developed by Colorado School of Mines)
(Constructed Wetlands-Based Treatment)

TECHNOLOGY DESCRIPTION:

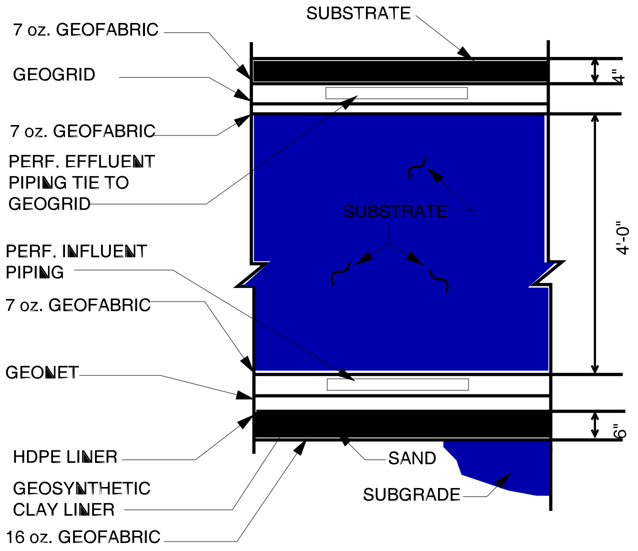
The constructed wetlands-based treatment technology uses natural geochemical and microbiological processes inherent in an artificial wetland ecosystem to accumulate and remove metals from influent waters. The treatment system incorporates principal ecosystem components found in wetlands, such as organic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

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

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 test 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 test 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/R-93/523), or the Emerging Technology Bulletin (EPA/540/F-92/001), which are available from EPA.



Schematic Cross Section of Pilot-Scale Upflow Cell

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 pilots-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 to 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 sentabout 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 was to be available in 1999. Information on the technology can be obtained through below-listed sources.

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COMMODORE ADVANCED SCIENCES, INC.

(Solvated Electron Technology, SET™ Remediation System)

TECHNOLOGY DESCRIPTION:

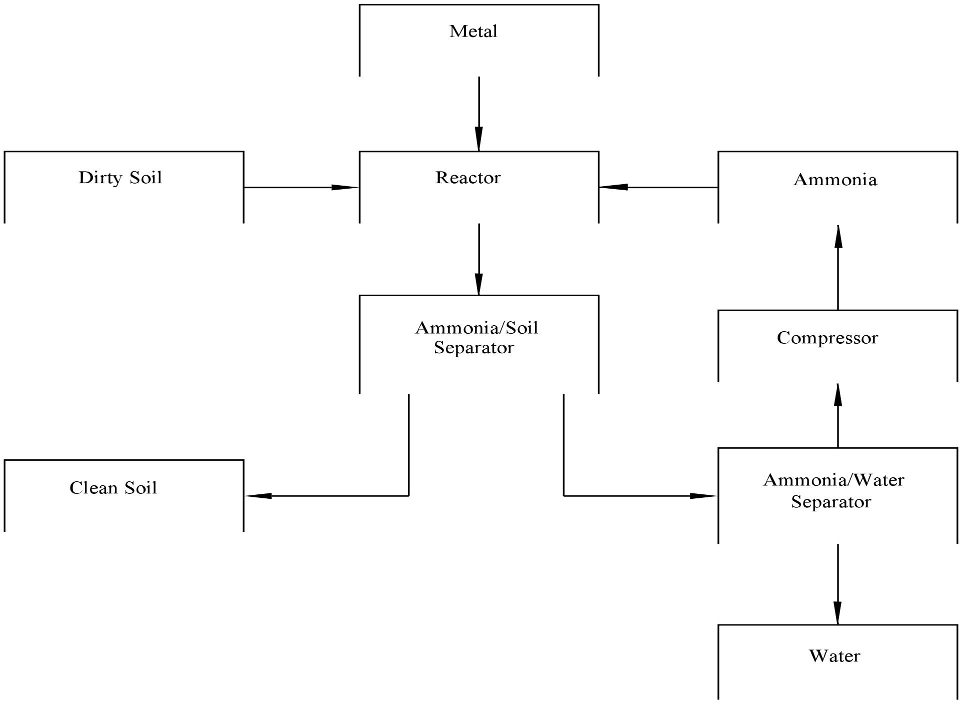
Commmodore Applied Technologies, Inc.'s (Commodore), solvated electron technology (SET™) remediation system chemically reduces toxic contaminants such as polychlorinated biphenyls (PCB), pesticides, and other halogenated compounds into benign substances. The solvating system uses a solution of ammonia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

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

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

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

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



Schematic Diagram of the Solvated Electron Remediation System

WASTE APPLICABILITY:

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

STATUS:

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

DEMONSTRATION RESULTS:

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

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

A nationwide permit for the destruction of PCBs and metals in soils was issued for the SET™ process by the EPA in March, 1997.

This permit was amended in May 1998 to include the destruction of PCBs in oil.

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CURRENT ENVIRONMENTAL SOLUTIONS
(Six-Phase Heating™ of TCE)

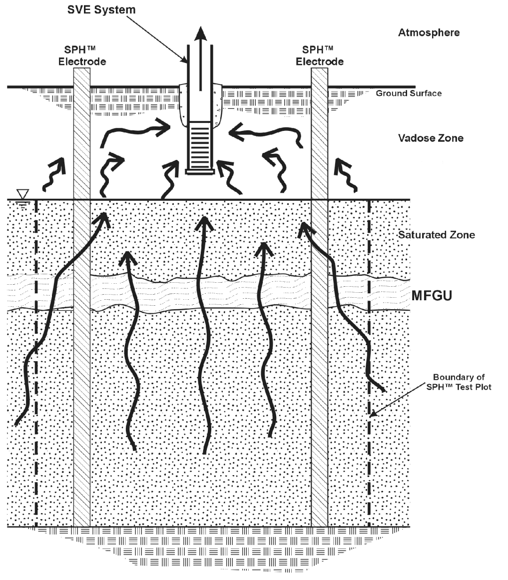
TECHNOLOGY DESCRIPTION:

Six-Phase Heating™ (SPH) is a thermally enhanced soil vapor extraction (SVE) technique that targets both contaminated soil and groundwater. The technology splits conventional three-phase electricity into six phases and delivers the electricity to the subsurface through metal electrodes. Once in the subsurface, the electrical energy resistively heats the soil and groundwater to generate steam. Direct volatilization and in situ steam stripping mobilize the contaminants present in the soil and groundwater. The volatilized contaminants are recovered by SVE, and treated before venting to the atmosphere. Contaminants are also destroyed in situ by means of hydrolysis, hydrous pyrolysis oxidation, and thermally accelerated biodegradation.

The ability of SPH to produce steam in situ in low permeability formations represents a significant advantage over other thermal technologies that are limited by hydraulic transport and conductive transfer to deliver heat to the subsurface. Instead, SPH creates steam within the soil pore structure itself, driving the contaminants towards the surface for collection and treatment.

This is important at heterogeneous sites like Cape Canaveral, where contaminants are trapped in the low-permeability clay and silt stringers in fine gain units. As these stringers are heated, internal steam formation drives contaminants into overlying permeable sands, overcoming diffusion-limited mass transfer and enabling rapid cleanup. When the required voltage was applied to the subsurface soils and groundwater, operating conditions were monitored and maintained within acceptable design limits. After startup, the system was monitored and controlled remotely. Routine visits were performed to collect data and perform system maintenance as required. Four to five weeks were required to heat the test plot to the boiling point of water. An additional seven to eight weeks were required to accomplish cleanup goals.

This technology is designed to treat DNAPL (dense nonaqueous phase liquid) contaminated soils and groundwater. At Cape Canaveral, trichloroethylene (TCE), cis-DCE, trans-DCE, and vinyl chloride in soil and groundwater were treated with SPH.



Conceptual Illustration of Resistive Heating Technology

STATUS:

Scientists and engineers at the Pacific Northwest National Laboratory (PNNL) developed and demonstrated the SPH technology in the early 1990s. In July 1997, Battelle Memorial Institute and Terra Vac Corporation formed a joint venture called Current Environmental Solutions, LLC (CES) to commercialize the SPH technology. SPH has been demonstrated on six occasions at government sites owned by the Department of Defense (DoD) and Department of Energy (DOE) during the past four years. SPH is now being commercially applied on a full-scale basis at a site impacted by chlorinated DNAPL underneath a building.

The Interagency DNAPL Consortium (IDC), recently formed by the DoD DOE and the Environmental Protection Agency (EPA), is tasked with identifying successful technologies for DNAPL remediation, in soils and groundwater, at corresponding government sites. In July of 1998, the IDC selected four in situ technologies for demonstration at an Air Force site in Cape Canaveral, Florida, that was impacted with chlorinated DNAPL. One of the selected technologies included SPH. The demonstration was completed in 2001 and the Application Analysis Report is available from the EPA.

DEMONSTRATION RESULTS:

The SPH technology, provided commercially by Current Environmental Solutions, was demonstrated at Launch Complex 34 at Cape Canaveral, Florida, as part of a multiple technology demonstration for the in situ remediation of DNAPL. The contaminant of concern was TCE, primarily residing as a separate phase along the surface of a clay aquitard at a depth of 45 ft. The demonstration was successful in that 97% of the DNAPL mass was removed, based on analysis of soil cores taken before and after the demonstration. However, the effect of SPH on dissolved-phase fractions of the contaminant could not be quantified because of large influxes of contaminated groundwater caused by tropical storms, and the nearby injection of nearly 2.7 pore volumes of an oxidant solution directly upgradient of the test area. Attempts to perform a total mass balance on the contaminants were similarly confounded.

Based on the production of elevated levels of chloride ion and other degradation by-products throughout the demonstration, decontamination took place as follows:

- 44 % was removed via the primary route, an in situ degradation pathway
- 19% was removed in the vapor phase by steam stripping
- Approximately 2% was mobilized to the surrounding aquifer during a single flooding event, caused by a tropical storm that occurred early in the demonstration
-
- The remaining 33% could not be accounted for, but is likely to have been degraded in situ
- Sampling wells and soil borings beyond the perimeter of the treatment area revealed a net decrease in contaminant levels, indicating that treatment extended beyond the boundaries of the test cell.
- The total cost of the SPH deployment was $569K, including all costs for electricity, reporting, secondary waste treatment, equipment mobilization, and significant system modifications and repairs prompted by severe weather. Based on a treatment volume of 6,250 yd^3 (4,780 m^3), this corresponds to a total unit cost of \$91/yd^3 (\$70/m^3). Of this, the net cost for SPH implementation (design, installation, operations, demobilization) was \$65/yd^3 (\$50/m^3), and the cost of electricity was \$12/yd^3 (\$9/m^3).

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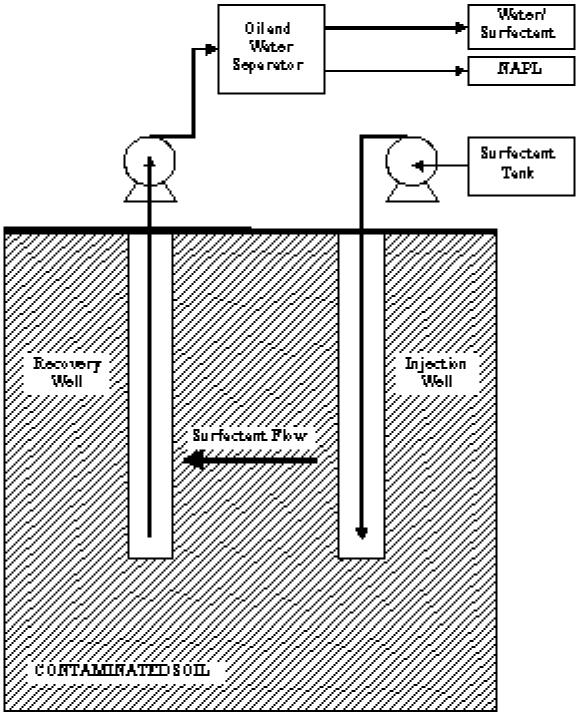
DUKE ENGINEERING AND SERVICES, INC.

(Surfactant Enhanced Aquifer Remediation of Nonaqueous Phase Liquids)

TECHNOLOGY DESCRIPTION:

Surfactant enhanced aquifer remediation (SEAR) technology greatly enhances the removal of residual nonaqueous phase liquids (NAPL) from the subsurface by increasing the solubility of the NAPL and lowering the interfacial tension between the NAPL and aqueous surfactant solution. Increasing the solubility of the NAPL with surfactants substantially enhances the removal of the NAPL mass through pumping. Lowering the interfacial tension between the NAPL and the aqueous surfactant solution reduces the capillary forces that trap the NAPL in the pore spaces of the aquifer. Under certain conditions, the interfacial tension can be lowered sufficiently to drain NAPL from the pore spaces thereby forming an oil bank in the subsurface, which is then recovered at extraction wells.

Before SEAR technology can be implemented, site specific characteristics must be determined. Normal aquifer properties such as stratigraphy, grain size distribution, mineralogy, hydraulic conductivity, vertical and horizontal gradients, depth to ground water, etc., are determined. In addition, a fundamental understanding of the NAPL composition, distribution, and quantity in the subsurface is required. Knowledge of the quantity of NAPL present prior to using SEAR prevents either under- or over-designing the surfactant flood. Laboratory experiments using soil core, contaminant, groundwater, and source water from the site are conducted to determine the optimum surfactant solution mix. A geosystem model is then developed which incorporates all the data gathered. Simulations are run to determine optimum injection and extraction well placement, percent recoveries of the compounds injected, contaminant concentration levels in the effluent, percent removal of the contaminant mass, and all other pertinent results of the surfactant flood.



SEAR Technology

Once the surfactant flood has been fully designed, the surfactant solution is injected into the contaminated zone in the subsurface through one or more wells. The surfactant is drawn through the subsurface by pumping at surrounding extraction wells. As the surfactant moves through the subsurface it solubilizes or, if the design calls for it, mobilizes the NAPL for recovery at the extraction wells. The recovered groundwater and NAPL are then typically sent to a phase separator. The recovered NAPL is either disposed of or recycled, and the groundwater and surfactant is treated. For large scale projects, recovery and reuse of the surfactant from the effluent stream is economical.

WASTE APPLICABILITY:

SEAR technology is applicable for the rapid removal of residual phase NAPL in the subsurface. Although it does not directly remediate the dissolved phase plume, removal of the source zone contamination can greatly reduce long term liability and risk. SEAR technology can be effective for the removal of a broad range of organic contaminants. This technology may not be suitable for sites with low hydraulic permeabilities (10^{-5} cm/sec or less).

DEMONSTRATION RESULTS:

A demonstration of SEAR to remove a high viscosity hydrocarbon (Navy Special Fuel Oil [NSFO]) was completed at Mullican Field, Pearl Harbor, HI. The hydrocarbon was successfully mobilized using a custom-designed surfactant and heating. The surfactant solution to 60°C.

SEAR technology has been successfully demonstrated with three separate surfactant floods at a U.S. Air Force base containing chlorinated solvent contamination in an alluvial aquifer.

STATUS:

SEAR technology was accepted into the Superfund Innovative Technology Evaluation (SITE) Demonstration program in 1997.

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DYNAPHORE, INC.
(FORAGER® Sponge)

TECHNOLOGY DESCRIPTION:

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

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

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

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

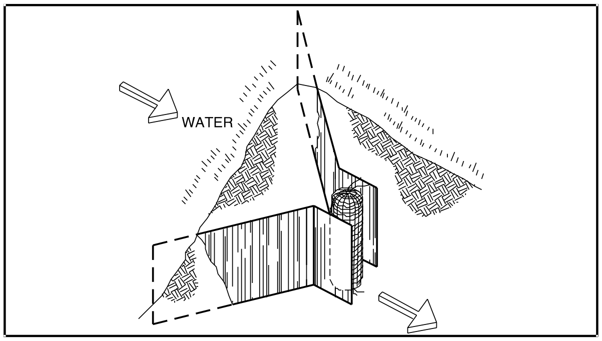
CrO_4^{-2}, AsO_4^{-3}, $Au(CN)_2^{-}$, SeO_4^{-2}, $HgCl_3^{-}$, $Ag(S_2O_3)^{-3}$, SiO_3^{-2}, UO_4^{-2}

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

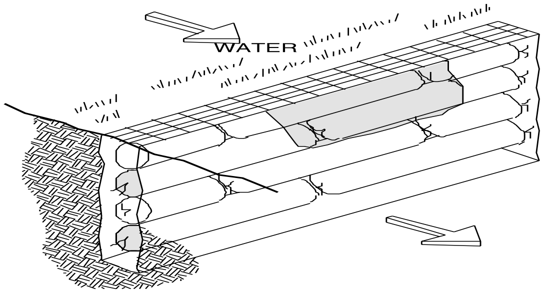
The removal efficiency for transition-group heavy metals is about 90 percent at a flow rate of 0.1 bed volume per minute. The Sponge's highly porous nature speeds diffusional effects, promoting high rates of ion absorption. The Sponge can be used in columns, fishnet-type enclosures, or rotating drums.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

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

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



Fishnet Bags Placed Vertically in a Well



Fishnet Bags Placed
Horizontally in a Trench

next page. Alternatively, the groundwater can be treated aboveground in a packed column configuration.

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

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

Analyte	Average Influence Concentration (µg/L)	Percent Removal
Cadmium	537	90
Copper	917	97
Lead	578	97
Chromium^{III}	426	32

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

DEMONSTRATION RESULTS:

Treatment performance from the SITE demonstration was as follows:

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

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

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E.I. DUPONT DE NEMOURS AND COMPANY, and OBERLIN FILTER COMPANY

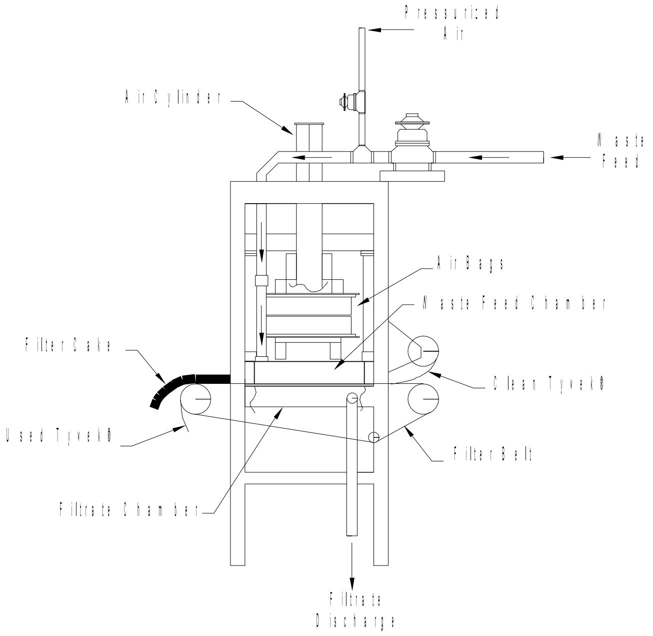
(Membrane Microfiltration)

TECHNOLOGY DESCRIPTION:

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

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

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



Membrane Microfiltration System

WASTE APPLICABILITY:

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

STATUS:

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

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

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

DEMONSTRATION RESULTS:

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

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

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E&C Williams, Inc.

(Calcium Sulfide and Calcium Polysulfide Technologies)

TECHNOLOGY DESCRIPTION:

Enthrall® (CaS) is an inorganic, nonhazardous sulfide compound developed by E&C Williams, Inc., for the treatment of metals and cyanide compounds in various media. Enthrall® is manufactured as powder, liquid, and granulated solid to provide the widest range of applications and uses.

The primary active ingredient in Enthrall® is calcium sulfide which reacts with metals to form a metal sulfide. This form of a metal is insoluble under the test conditions imposed by the Toxicity Characteristic Leaching Procedure (TCLP; which simulates the acidic conditions found in most landfills), the Multiple Extraction Procedure (MEP; which simulates approximately 1,000 years of acidic leaching), and the Synthetic Products Leaching Procedure (SPLP; more aggressive than the TCLP). Enthrall® has an inherently high reaction efficiency, requiring much less product than others.

The powder and liquid forms present enormous potential for soil remediation products for both in situ and ex situ. Enthrall® is effective over entire range of regulated metals. Its reaction time is nearly instantaneous, allowing for immediate sampling and testing. Stabilized waste is truly stable – it is not subject to leaching at a later date under acidic conditions.

Calcium polysulfide (CaS_x), while derived from different raw materials, shares many characteristics with calcium sulfide. It is effective over the entire range of regulated metals and reacts with metals to form metal sulfides as quickly as contact is achieved. Both are single-phase additives requiring no other compound to completely stabilize metals.

WASTE APPLICABILITY:

Both technologies are suitable for stabilizing metals in a wide variety of media and physical states. Upon exposure to acidic conditions, some hydrogen sulfide gas may be generated. Both sulfide technologies can be formulated to a high alkalinity range to offset the effects of gassing.

STATUS:

The calcium sulfide technology was accepted into the SITE Demonstration Program in November 2000. Enthrall® was used as the active ingredient on a SITE demonstration at treating mine tailings containing mercury. The setup consisted of treating columns of material from a site mining facility in Butte, Montana. Enthrall® was used to treat the assigned column(s) and the columns were then subjected to a twelve-week leaching procedure. The results of this study are in the process of final evaluation and will be published in 2002.

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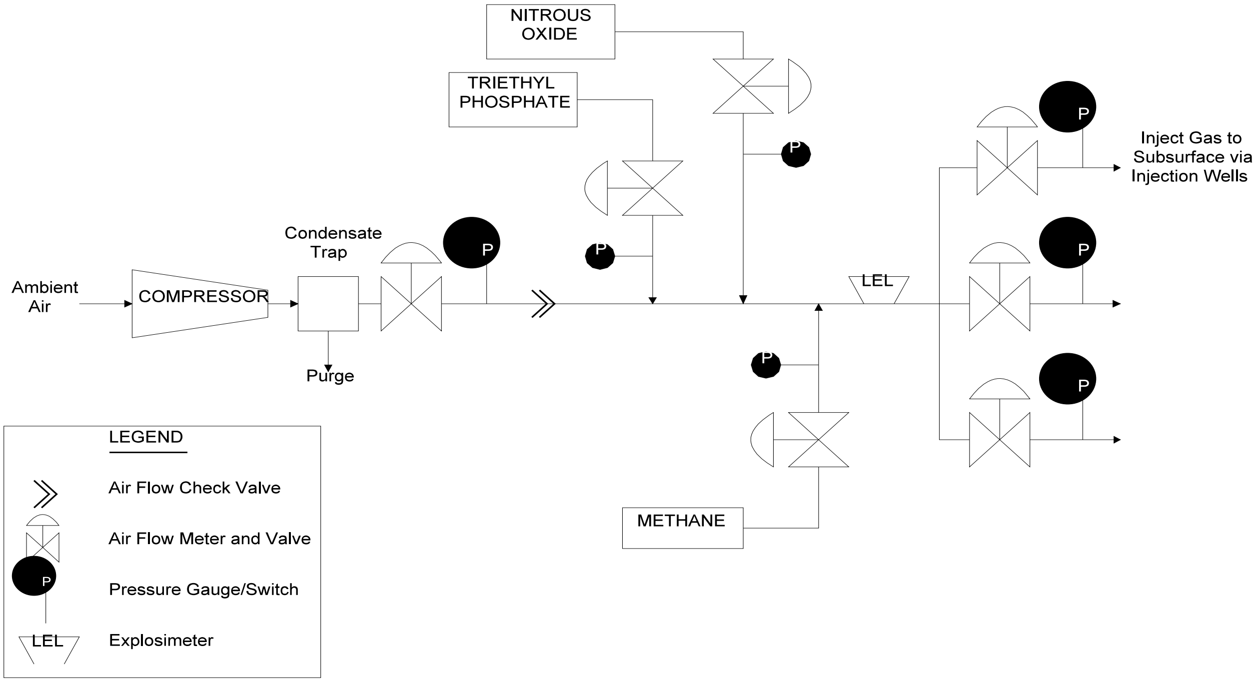
EARTH TECH/WESTINGHOUSE SAVANNAH RIVER COMPANY

(Enhanced In Situ Bioremediation of Chlorinated Compounds in Groundwater)

TECHNOLOGY DESCRIPTION:

ITT Night Vision is conducting in situ enhanced aerobic bioremediation of contaminated groundwater in fractured bedrock utilizing technologies developed at the U.S. Department of Energy Savannah River Site and licensed to Earth Tech, Inc. This project currently involves remediation of groundwater in the vicinity of one contaminant source area as a pilot-scale operation, with the possibility of applying the technology elsewhere on site. Contaminants of concern in on-site groundwater include chlorinated solvents and their daughter products, plus acetone and isopropanol. To accelerate the intrinsic (natural) biodegradation observed at the site, the selected remedy involves the subsurface injection of air, gaseous-phase nutrients (triethyl phosphate and nitrous oxide), and methane. The amendments are being added to stimulate existing microbial populations (particularly methanotrophs) so that they can more aggressively break down the contaminants of concern. Amendment delivery to the is accomplished through an injection well, and the injection zone of influence is confirmed using surrounding groundwater monitoring wells and soil vapor monitoring points.

The patented PHOSter™ process for injection of triethyl phosphate in a gaseous phase was licensed for use at this site as an integral element of the enhanced bioremediation operation. This technology maximizes the subsurface zone of influence of nutrient injection as compared to technologies injecting nutrients in liquid or slurry form. Monitoring of contaminant (and breakdown product) concentrations in groundwater and soil vapor, measurement of microbiological population density and diversity, and monitoring of nutrient concentrations and groundwater geochemical parameters provides feedback on system effectiveness. This in turn allows adjustments to be made in the sequencing and rate of delivery of air, nutrients, and methane in response to changing subsurface conditions.



WASTE APPLICABILITY:

This enhanced bioremediation technology breaks down volatile organic compounds in groundwater. Compounds which are amenable to intrinsic (natural) biodegradation can be degraded more rapidly when the subsurface microbial populations are stimulated through the injection of air, gaseous-phase nutrients, and methane. By providing an aerobic environment for contaminant degradation, harmless breakdown products are produced and toxic daughter products of anaerobic degradation of chlorinated solvents (such as vinyl chloride) can be broken down completely. This in-situ technology is especially applicable in situation where subsurface infrastructure (for example, networks of utilities) limit or preclude excavation or extraction technologies.

STATUS:

The enhanced bioremediation system, currently being used in the ongoing RCRA corrective action interim measure at the ITT Night Vision facility, was accepted into the SITE program in 1997, with system start up occurring in March of 1998. The technology had previously been approved by EPA Region 3 as an Interim Measure part of the facility's ongoing RCRA Corrective Action program.

SITE program participants collected groundwater quality and microbiological data prior to system start up (baseline monitoring), between the air and nutrient injection campaigns (interim monitoring), and after 16 months of operation (final monitoring).

DEMONSTRATION RESULTS:

Baseline monitoring established a statistical reference point for contaminants of concern in groundwater. Interim monitoring suggests that the initial injection campaigns have successfully stimulated the growth of native microbial populations based upon the results of phospholipid fatty acid assays and methanotroph most probable number plate counts. Corresponding decreases in concentrations of contaminants of concern have also been discernible.

Final monitoring indicated that the average percent reduction, based on 28 baseline and 28 final samples were as follows:

- Chloroethane - 36%
- 1,1-Dichloroethane - 80%
- *cis*-1,2-Dichloroethene - 97%
- Vinyl chloride - 96%

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EARTHSOFT

(EQuIS Software)

TECHNOLOGY DESCRIPTION:

The EQuIS software is designed as an advanced environmental data management and analysis platform for monitoring and remediation projects. The EQuIS applications provide a data warehouse where environmental data can be entered and reviewed, and then exported to a variety of industry standard tools.

The EQuIS system contains the following components:

EQuIS Chemistry:
Electronic Lab Data Checker
EQuIS CrossTab Report Writer
EQuIS Data Verification Module
CARStat

EQuIS Geology:
  LogPlot, RockWorks, GMS, EVS
  EQuIS ArcView GIS Interface
  EVS, GMS, & ESRI's 3D Analyst

A brief description of each software module is presented in the following paragraphs.

EQuIS Chemistry manages sampling information and analytical data generated in the field or by commercial laboratories. EQuIS Chemistry offers an interface and relational database to organize chemical field and lab data, as well as interfaces to numerous statistical analyses, reporting and visualization packages. Chemistry QA/QC data is also managed to support advanced remediation projects. Referential and relational integrity is enforced resulting in high quality data. Electronic Lab Data Checker (ELDC) allows users to check electronic deliverables for format accuracy using default or user-defined formats. The ELDC can trap out many errors of consistency and completeness. EQuIS CrossTab Report Writer allows users to create complex cross tab reports using data from existing EQuIS Chemistry project databases. EQuIS Data Verification Module (DVM) provides data and review and validation in accordance with EPA programs, as well as analytical program requirements from other agencies. The DVM produces extensive validation reports and provides a suggested qualifying flag that can be written back to the database. CARStat eliminates unnecessary site assessments and remediation due to misapplication of statistical methods or simple comparison of measurements to regulatory standards. Site-wide false positive and negative rates are directly computed via Monte Carlo simulations.

EQuIS Geology manages geological and geotechnical information. EQuIS Geology facilitates rapid modeling, calibration and analysis using any of several standard commercial borehole logging, groundwater modeling and solid contouring and reporting techniques. EQuIS Arc View GIS Interface encapsulates EQuIS and allows users to query and view EQuIS Chemistry and Geology data inside of ArcView GIS. Many basic and even advanced operations such as creating borehole logs, CrossTab reports, and solid models can be done in only a few keystrokes.

STATUS:

The objective of the SITE Demonstration Program is to develop reliable engineering performance and cost data innovative alternative technologies so that potential users can evaluate the applicability of each technology for a specific site. This demonstration is being performed on environmental data management software and is carried out with data from hazardous waste sites in New Jersey.

In a software evaluation, select data set(s) will be utilized to evaluate capabilities of the software. The procedures used to evaluate the software performance and to document project activities will be critical to this analysis.

In consultation with the EQuIS vendor, seven primary modules will be tested in this evaluation. These are: EQuIS Chemistry, ELDC, EQuIS CrossTab Report Writer, DVM, CARStat, EQuIS Geology, and the EQuIS ArcView GIS Interface. The EPA will publish the technology evaluation results in Summer 2002.

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EcoMat, Inc.

(Biological Denitrification Process)

TECHNOLOGY DESCRIPTION:

EcoMat has developed and patented a continuously circulating reactor that contains fixed film biocarriers that are retained within the system, thereby minimizing solids carryover. Fixed film treatment allows rapid and compact treatment of nitrate with minimal by-products. Methanol is added as a source of carbon for the metabolic processes that remove free oxygen, to encourage the bacteria to consume nitrate instead, and as a source of carbon for cell growth.

The EcoLink membrane media consists of a polyurethane-based sponge that is cut into 1-cm cubes. The media last for a long time – up to several years. The size of the interstitial spaces within the sponge is designed to permit passage of gas, as well as passage of water into these spaces. The surface area involved is sufficiently great to provide for high bacteria concentrations and high interaction efficiency.

The mechanism for anoxic biodegradation of nitrate consists of initial removal of dissolved oxygen followed by the total removal of oxygen from the nitrate. In the first step, available oxygen must be consumed to a dissolved oxygen concentration of <1 mg/L so that the bacteria are forced to substitute the nitrate as the electron acceptor. The nitrate is first reduced to nitrite and then further reduced to nitrogen gas.

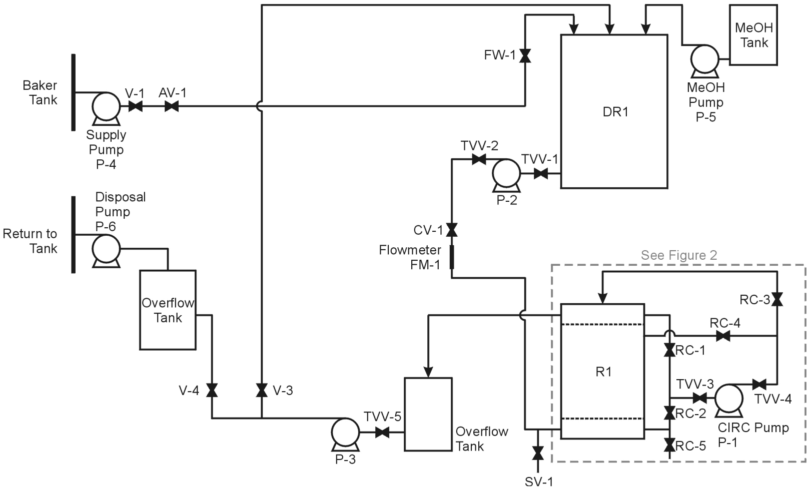
The effluent from the denitrification system will contain small amounts of bacteria and suspended solids, which must be removed by a posttreatment system. EcoMat can incorporate an oxidation component (ozonation and/or ultraviolet disinfection) into its posttreatment system to accomplish some degree of chlorinated hydrocarbon destruction as well as oxidation of any residual nitrite to nitrate, oxidation of any residual methanol, and destruction of bacterial matter. A filtration component can also be incorporated into the posttreatment system to remove suspended solids.

Design of the treatment process/system for a particular site requires the characterization of the water source that will be fed to the system in terms of contaminants present, variability in waste characteristics.

WASTE APPLICABILITY:

This technology is suitable for any water-based contaminant remediation which permits the proliferation of the lives of the various hardy bacteria which consume the oxygen and methanol.

The technology has been applied to nitrate within seawater (in commercial aquariums). It has also been applied to industrial waste. Another potential application is for remediation of sites subject to eutrophication. The system has been demonstrated to remediate perchlorate, after the dissolved oxygen and nitrate have been removed. A relatively minor modification of the reactor permits remediation of both MTBE and ethylene glycol.



EcoMat Perchlorate Removal System

STATUS:

The technology evaluation under the SITE program was conducted between May and December of 1999, and the results have been analyzed (see Technology Evaluation Report, May 2001 draft).

DEMONSTRATION RESULTS:

The demonstration site was the location of a former public water supply well in Bendena, Kansas. The well water is contaminated with high levels of nitrate, with concentrations ranging from 20 to 130 ppm of nitrate (N). The results of the testing program showed that EcoMat successfully removed the nitrate, although the posttreatment systems applied were not always successful in reducing the nitrite sufficiently or in filtering the exiting bacteria and suspended solids. This relatively straightforward work remains to be done before the system is approved for drinking water application.

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ECOVA CORPORATION

(Bioslurry Reactor)

TECHNOLOGY DESCRIPTION:

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

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

Bioslurry Reactor

WASTE APPLICABILITY:

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

STATUS:

This technology was accepted into the SITE Demonstration Program in spring 1991. From May through September 1991, EPA conducted a SITE demonstration using six bioslurry reactors at EPA's Test and Evaluation Facility in Cincinnati, Ohio.

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

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

DEMONSTRATION RESULTS:

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

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EDENSPACE, INC.
(formerly Phytotech)
(Phytoremediation Technology)

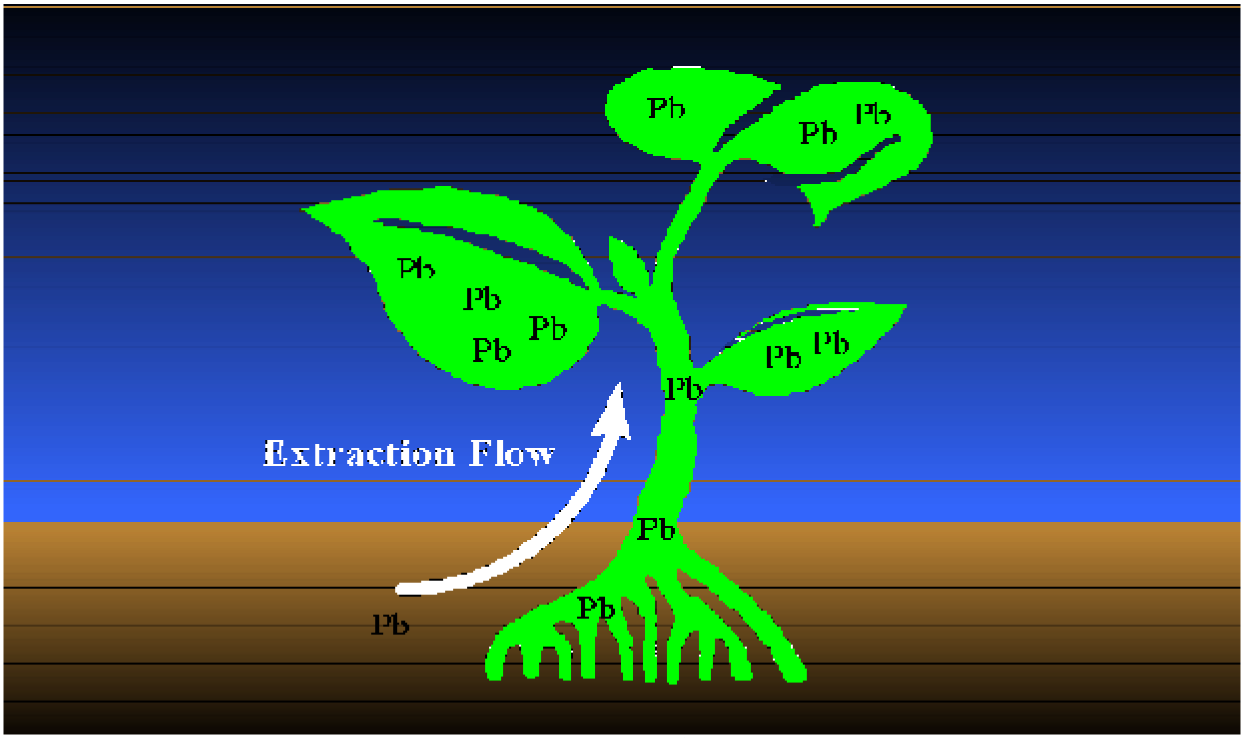
TECHNOLOGY DESCRIPTION:

Phytotech is an environmental biotechnology company that uses specially selected and engineered plants to treat soil and water contaminated with toxic metals such as lead and cadmium, as well as radionuclides. The treatment of soils or sediments with this technology is referred to as phytoextraction (see figure below).

Phytoextraction offers an efficient, cost-effective, and environmentally friendly way to clean up heavy metal contamination. Plants are grown in situ on contaminated soil and harvested after toxic metals accumulate in the plant tissues. The degree of accumulation varies with several factors, but can be as high as 2 percent of the plants' aboveground dry weight, leaving clean soil in place with metal concentrations that equal or are less than regulatory cleanup levels. After accumulation in the plant tissues, the contaminant metal must be disposed of, but the amount of disposable biomass is a small fraction of the amount of soil treated. For example, excavating and landfilling a 10-acre site contaminated with 400 parts per million (ppm) lead to a depth of 1 foot requires handling roughly 20,000 tons of lead-contaminated soil. Phytoextraction of a 10-acre site to remove 400 ppm of lead from the top 1 foot would require disposal of around 500 tons of biomass - about 1/40 of the soil cleaned. In the example cited, six to eight crops would typically be needed, with three or four crops per growing season.

Compared to traditional remedial technologies, phytoextraction offers the following benefits:

- Lower cost
- Applicability to a broad range of metals
- Potential for recycling the metal-rich biomass
- Minimal environmental disturbance
- Minimization of secondary air- and water-borne wastes



Phytoextraction

WASTE APPLICABILITY:

Phytotech's phytoextraction technology can be used to clean soil or sediments contaminated with lead, cadmium, chromium, cesium/strontium and uranium. Phytoremediation of other metals such as arsenic, zinc, copper, and thorium is in the research stage.

STATUS:

Phytotech was accepted into the SITE Demonstration Program in 1997. Under the SITE Program, Phytotech is demonstrating its phytoremediation technology at a former battery manufacturing facility in Trenton, New Jersey. where soil is contaminated with lead. The site has been prepared and characterized, two crops of Indian Mustard were grown and harvested over the Spring and Summer of 1997, and one crop of sunflowers was grown and harvested in 1998.

Phytotech has also conducted several successful field trials of its phytoextraction technology at other contaminated sites in the U.S. and abroad.

DEMONSTRATION RESULTS:

Results show that treatment increased the portion of the treatment area with lead concentrations below 400 mg/Kg from 31% to 57%. The average lead concentrations accumulated in the above-ground plant tissue samples from the two *Brassica* crops were 830 mg/Kg and 2,300 mg/Kg. Differences in lead uptake between the two *Brassica* crops are attributed to amendment optimization. Lead in the above-ground plant tissues of the sunflowers was measured at an average concentration of 400 mg/Kg. All three of these average values exceeded the minimum project objective of 200 mg/Kg (dry weight). This demonstration confirmed earlier findings that the use of Indian Mustard plants to extract metals is most applicable to intermediate levels of lead contamination (less than 1,500 mg/Kg), soil pH levels of 4.3-8.3, and moderate climates.

Phytotech has conducted several field demonstrations of its rhizofiltration technology for the removal of (1) cesium/strontium at Chernobyl, and (2) uranium from contaminated groundwater at a DOE site in Ashtabula, Ohio. At Chernobyl, sunflowers were shown to extract 95 percent of the radionuclides from a small pond within 10 days. At the Ashtabula site, Phytotech ran a 9-month pilot demonstration during which incoming water containing as much as 450 parts per billion (ppb) uranium was treated to 5 ppb or less of uranium.

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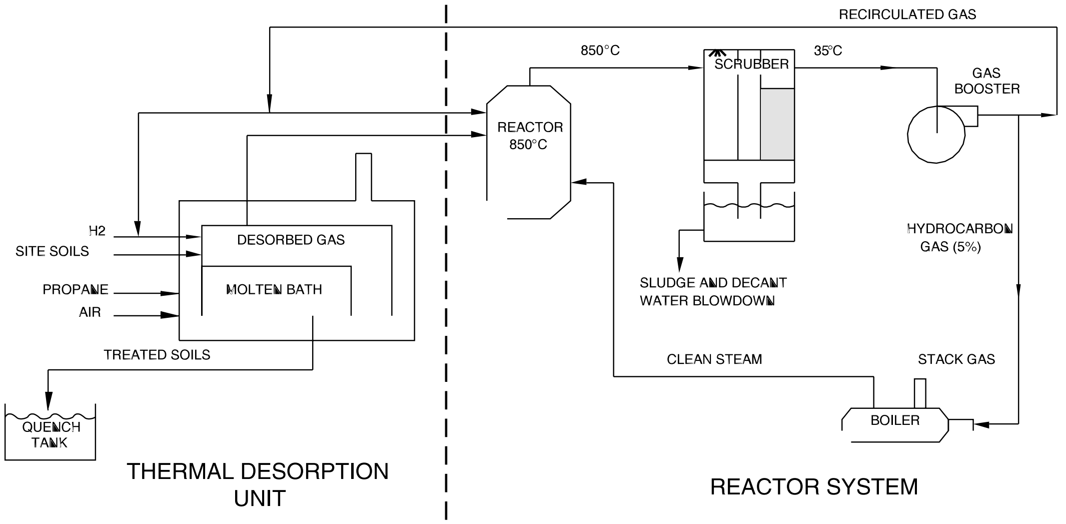
ELI ECO LOGIC, INC.

(Thermal Gas Phase Reduction Process and Thermal Desorption Unit)

TECHNOLOGY DESCRIPTION:

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

Contaminated soil is conveyed into the TDU feed hopper, where an auger feeds the soil into the TDU. A screw feeder provides a gas seal between the outside air and the hydrogen atmosphere inside the TDU. The auger's variable speed drive provides feed rate control. Soil inside the TDU floats on top of the molten tin and is heated to 600 °C, vaporizing the water and organic material. Decontaminated soil is removed from the tin bath into a water-filled quench tank. The water in the quench tank provides a gas seal between the TDU's hydrogen atmosphere and the outside air. A scraper mechanism removes decontaminated soil from the quench tank into drums. After desorption from the soil, the organic contaminants are carried from the TDU to Eco Logic's proprietary gas-phase reduction reactor. In the reactor, the organic contaminants undergo gas-phase chemical reduction reactions with hydrogen at elevated temperatures and ambient pressure. This reaction converts organic and chlorinated organic contaminants into a hydrocarbon-rich gas product. After passing through a scrubber, the gas product's primary components are hydrogen, nitrogen, methane, carbon monoxide, water vapor, and other lighter hydrocarbons. Most of this gas product recirculates into the process, while excess gas can be compressed for later analysis and reuse as supplemental fuel. For further information on the Eco Logic gas-phase chemical reduction process, see the profile in the Demonstration Program section (completed projects).



Thermal Desorption Unit

WASTE APPLICABILITY:

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

STATUS:

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

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

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

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

DEMONSTRATION RESULTS:

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

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

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EMTECH ENVIRONMENTAL SERVICES
(formerly HAZCON, INC.)
(Dechlorination and Immobilization)

TECHNOLOGY DESCRIPTION:

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

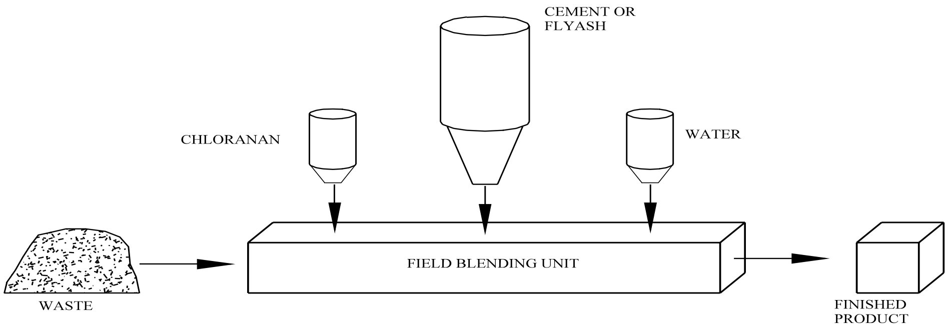
Soils, sludges, and sediments can be treated in situ or excavated and treated ex situ. Sediments can be treated under water. In the finished product, immobilized metals have a very low solubility. Ex situ treatment occurs in batches, with volumetric throughput rated at 120 tons per hour. The treatment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

WASTE APPLICABILITY:

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

STATUS:

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



Dechlorination and Immobilization Treatment Process

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

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

DEMONSTRATION RESULTS:

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

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

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ENVIROMETAL TECHNOLOGIES INC.

(In Situ and Ex Situ Metal-Enhanced Abiotic Degradation of Dissolved Halogenated Organic Compounds in Groundwater)

TECHNOLOGY DESCRIPTION:

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

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

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

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

WASTE APPLICABILITY:

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

The technology has degraded a wide variety of chlorinated alkanes and alkenes, including trichloroethene (TCE), tetrachloroethene (PCE), vinyl chloride, 1,1,1-trichloroethane, and 1,2-dichloroethene

(DCE). The technology also degrades other organic contaminants, including Freon-113, ethylene dibromide, certain nitroaromatics, and N-nitrosodimethylamine.

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

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

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

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

DEMONSTRATION RESULTS:

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

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

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ENVIROMETAL TECHNOLOGIES, INC.

(In Situ Reactive Barrier)

TECHNOLOGY DESCRIPTION:

The Reactive Barrier technology is an innovative treatment system that uses the oxidation capacity of zero-valent iron to induce reduction of oxidized metals, reductive dechlorination of chlorinated volatile organic compounds (VOCs), and immobilization of some metals such as uranium by a combination of reduction and sorbtion.

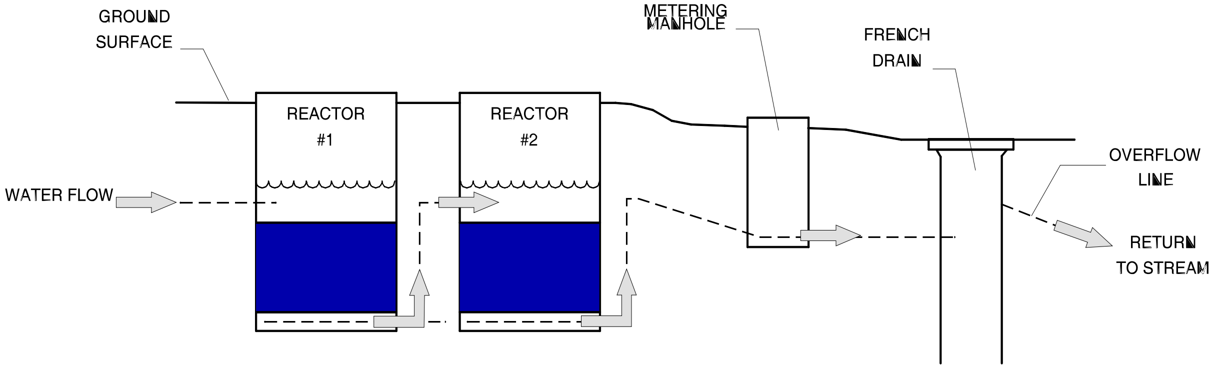
Granular zero-valent iron oxidizes within the reactor vessel or reactive wall. As groundwater containing VOCs flows through the reactor and around these granules, electrons released by oxidation of the iron create a highly reducing environment in solution.

The hydrocarbon-chloride bonds in the chlorinated contaminants become unstable and break down sequentially, forming less chlorinated compounds and releasing nontoxic chloride ions to the groundwater. The completely hydrolyzed hydrocarbon compounds are nontoxic and degrade naturally. The rate of reaction depends primarily on the surface area of the iron or its abundance in the permeable reactive media. The dechlorination reaction is typically accompanied by an increase in groundwater pH and a decrease in oxidation/reduction potential. Inorganic constituents such as calcium, magnesium, and iron combine with carbonate or hydroxide ions in the treated water to form compounds such as metal carbonates and metal hydroxides that precipitate from solution as groundwater moves through the iron. Due to the precipitation of these metallic compounds from solution, the reaction is also typically accompanied by a decrease in total dissolved solids in the groundwater.

WASTE APPLICABILITY:

The Reactive Barrier technology is applicable to subsurface or above-ground treatment of VOCs and metals in groundwater or wastewater. The technology is adaptable to a variety of sites when used in combination with funnel and gate systems. Depth of the contaminated groundwater is the only constraint on the applicability of the technology.

The technology was accepted into the SITE Demonstration Program in 1996. The demonstration of the technology was completed at the Rocky Flats Environmental Technology Site in Golden, Colorado. The technology's effectiveness was evaluated through sampling and analysis of untreated and treated groundwater that is collected by a french drain system and transferred to two subsurface reactor tanks through gravity flow. Project reports will be available in September 2001.



Schematic of the Reactive Barrier Technology
Installation of Pilot-Scale In Situ Treatment System
at an Industrial Facility in Northeast United States

DEMONSTRATION RESULTS:

Groundwater contamination in this area-known as the mound site plume-originated from a former waste drum storage area used by DOE in the 1950s. Consisting of shallow groundwater with a flowrate of 0.5 to 2.0 gallons per minute, the plume horizontally extends approximately 220 feet. Its primary contaminants are uranium and volatile organic compounds (VOCs), including carbon tetrachloride, tetrachloroethene, thrichloroethene, and vinyl chloride.

This barrier system begins with the downgrade-side collection of groundwater in subsurface hydraulic barrier (French drain) lined with high-density polyethylene. The drain is located in the unconfined aquifer at depths ranging from 8 to 15 feet below ground surface. Groundwater is diverted through the drain to piping that transfers it by gravity to the reactive media treatment system containing granular, zero-valent iron.

VOCs are dechlorinated to nonchlorinated hydrocarbons and uranium in the oxidized state (U^{6+}) is converted to uranium in the reduced state (U^{4+}) and precipitated. Following treatment, groundwater exits the barrier system directly through surface water that flows to retention ponds.

Treatment reduced carbon tetrachloride, tetrachloroethene, trichloroethane, and uranium concentrations by >95%. Vinyl chloride concentration was reduced by 70% (2.0 µg/L to 0.6 µg/L). The treated effluent was below the Colorado Water Quality Standards for each of the contaminants.

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EPOC WATER, INC.

(Precipitation, Microfiltration, and Sludge Dewatering)

TECHNOLOGY DESCRIPTION:

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

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

Metals are removed through precipitation by adjusting the pH in the EXXFLOW feed tank.

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

Constituents other than metals can be removed using seeded slurry methods in EXXFLOW. Hardness can be removed by using lime. Oil and grease can be removed by adding adsorbents. Nonvolatile organics and solvents can be removed using adsorbents, activated carbon, or powdered ion-exchange resins. The EXXFLOW demonstration unit (see photograph below) is transportable and is mounted on skids. The unit is designed to process approximately 30 pounds of solids per hour and 10 gallons of wastewater per minute.

WASTE APPLICABILITY:

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

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

STATUS:

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

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

DEMONSTRATION RESULTS:

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

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

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