

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

TECHNOLOGY DESCRIPTION:

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

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

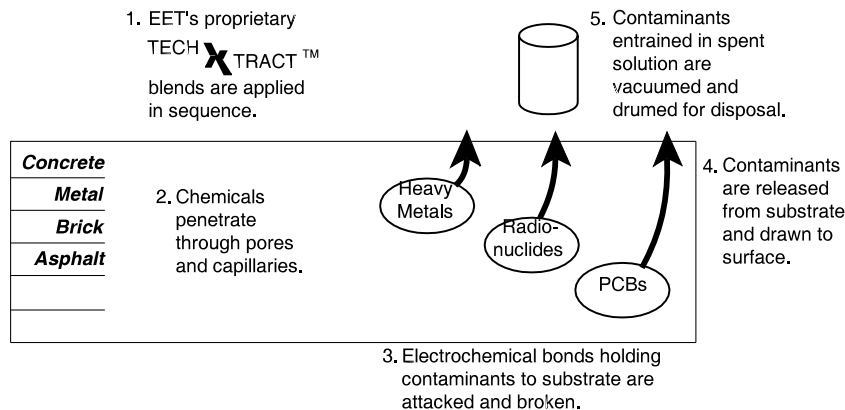
The surface preparation step uses a solution that contains buffered organic and inorganic acids, sequestering agents, wetting agents, and special hydrotrope chemicals. The extraction formula includes macro- and microemulsifiers in addition to electrolyte, flotation, wetting, and sequestering agents. The rinsing formula is pH-balanced and contains wetting and complexing agents. Emulsifiers in all the formulations help eliminate fugitive releases of volatile organic compounds or other vapors.

The chemical formulation in each stage is sprayed on the contaminated surface as a fine mist and worked into the surface with a stiff bristle brush or floor scrubber. The chemicals are allowed to penetrate into the subsurface and are then rinsed or vacuumed from the surface with a wet/dry, barrel-vacuum. No major capital equipment is required.

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

WASTE APPLICABILITY:

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



Process Flow Diagram of the TECHXTRACT® Process

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

STATUS:

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

The technology has been used in over 200 successful decontamination projects for the U.S. Department of Energy; U.S. Department of Defense; the electric, heavy manufacturing, steel, and aluminum industries; and other applications. Further research is underway to apply the technology to soil, gravel, and other loose material. AET also plans to study methods for removing or concentrating metals in the extracted liquids.

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ADVANCED REMEDIATION MIXING, INC.
(formerly Chemfix Technologies, Inc.)
(Solidification and Stabilization)

TECHNOLOGY DESCRIPTION:

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

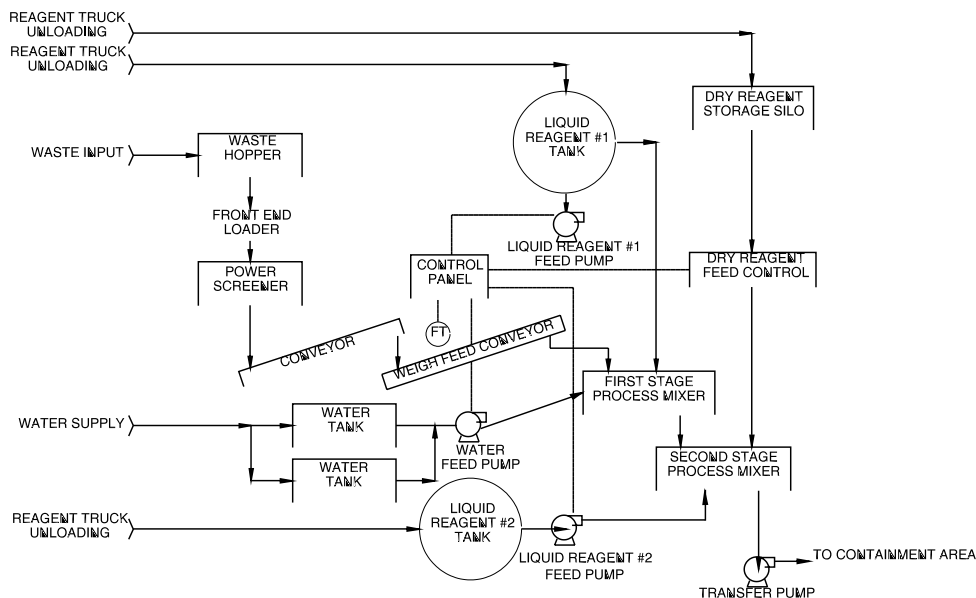
The figure below illustrates the Chemfix Technologies, Inc. (Chemfix), process. Typically, the waste is first blended in a reaction vessel with pozzolanic materials that contain calcium hydroxide. This blend is then dispersed throughout an aqueous phase. The reagents react with one another and with toxic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

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

WASTE APPLICABILITY:

STATUS:

The solidification and stabilization process was accepted into the SITE Demonstration Program in 1988. The process was demonstrated in March 1989 at the Portable Equipment Salvage Company site in Clackamas, Oregon. The Technology Evaluation



Process Flow Diagram

Report (EPA/540/5-89/011a) and the Applications Analysis Report (EPA/540/A5-89/011) are available from EPA.

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

DEMONSTRATION RESULTS:

The demonstration yielded the following results:

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

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AMEC EARTH AND ENVIRONMENTAL (formerly GeoSafe Corporation) (GeoMelt Vitrification, previously In Situ Vitrification)

TECHNOLOGY DESCRIPTION:

AMEC Earth and Environmental's GeoMelt vitrification process uses electricity to melt soil or other earthen materials at temperatures of 1,600 to 2,000°C, destroying organic pollutants by pyrolysis. Inorganic pollutants are immobilized within the vitrified glass and monolith. Water vapor and organic pyrolysis products are captured in a hood, which draws the off-gases into a treatment system that removes particulates, acid gases and other pollutants.

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

The melting process is performed under a hood through which air flow is controlled to maintain a negative pressure. Excess oxygen is supplied for combustion of any organic pyrolysis products. Off-gases are treated by quenching, pH-controlled scrubbing, dewatering (mist elimination), heating (for dew point control), particulate filtration, and either activated carbon adsorption or thermal oxidation as a final off-gas polishing step. Individual melt settings may encompass a total melt mass of up to 1,400 tons, a maximum width of 40 feet, and depths as great as 22 feet. Special settings to reach deeper contamination are also possible. Void volume and volatile material removal results in a 30 to 50 percent volume reduction for typical soils. The mobile GeoMelt system is mounted on three semi-trailers. Electric power may be provided by local utility or on-site diesel generator. Typical power consumption ranges from 600 to 800 kilowatt-hours per ton of soil. The electrical supply system has an isolated ground circuit to provide safety.

WASTE APPLICABILITY:

The GeoMelt vitrification process can destroy or remove organics and immobilize most inorganics in contaminated soils, sediments, sludges, or other earthen materials. The process has been tested on a broad range of volatile and semivolatile organic compounds, other organics including dioxins and



In Situ Vitrification Process Equipment

polychlorinated biphenyls (PCB), and on most priority pollutant metals and heavy metal radio-nuclides. The process can also treat large amounts of debris and waste materials present in soil. In addition to soils applications, the process has been used to treat mixed-transuranic (TRU) buried waste and underground tanks containing waste. Underground tank treatment employs a new method of vertically planar melting which enable sideways melting rather than top-down melting. Tanks to 4,500 gallons have been treated to date.

STATUS:

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

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

In December 1995, Geosafe completed the remediation of the Wasatch Chemical Superfund Site in Salt Lake City, Utah. This site contained about 6,000 tons of dioxin, pentachlorophenol, herbicide, pesticide, and other organic contaminants in soil containing up to 30 percent debris by weight. In 1996, Geosafe completed remediation of the Apparatus Service Shop Site in Spokane, Washington. A total of 6,500 tons of PCB-contaminated soil was treated at the site.

GeoMelt vitrification is currently being employed for the in situ treatment of mixed-TRU buried waste at the Maralinga Test Range in South Australia. Twenty-one pits containing Plutonium, Uranium, Lead, Barium, and Beryllium are being treated there. That project was to be completed in 1999.

DEMONSTRATION RESULTS:

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

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AMERICAN COMBUSTION, INC.
(PYRETRON® Thermal Destruction)

TECHNOLOGY DESCRIPTION:

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

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

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

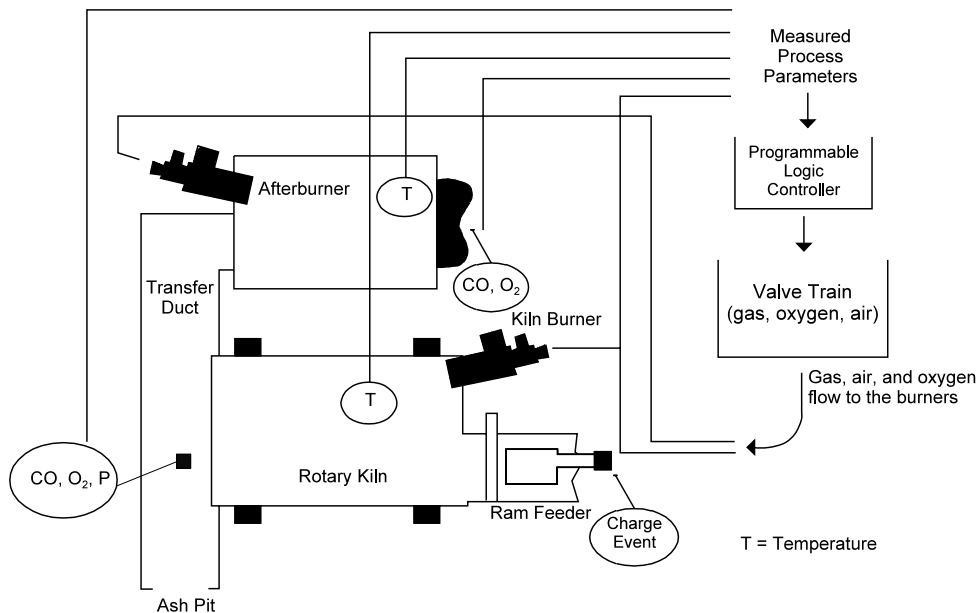
WASTE APPLICABILITY:

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

STATUS:

The PYRETRON® technology was demonstrated at EPA's Incineration Research Facility in Jefferson, Arkansas, using a mixture of 40 percent contaminated soil from the Stringfellow Acid Pit Superfund site in Glen Avon, California and 60 percent decanter tank tar sludge (K087) from coking operations. The demonstration began in November 1987 and was completed at the end of January 1988.

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



PYRETRON® Thermal Destruction System

DEMONSTRATION RESULTS:

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

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

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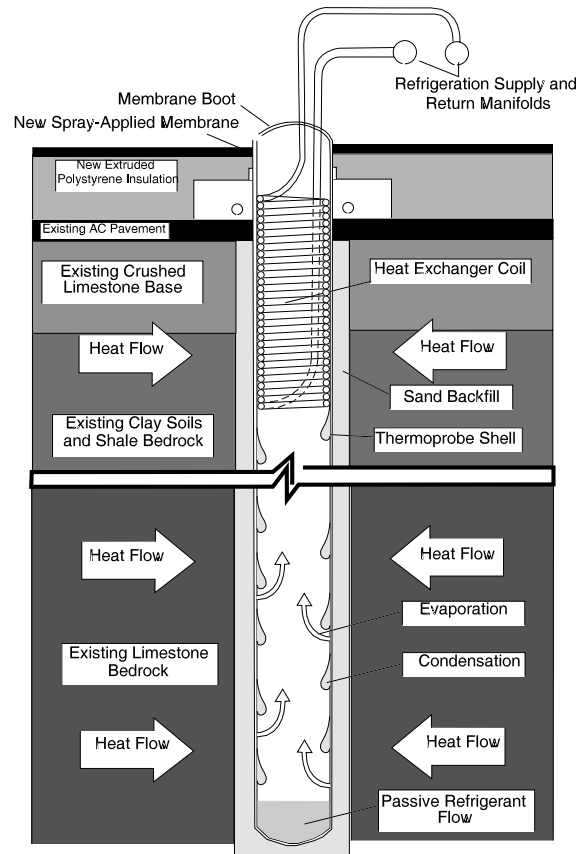
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**ARCTIC FOUNDATIONS, INC.
(Cryogenic Barrier)**

TECHNOLOGY DESCRIPTION:

Long-term containment and immobilization of hazardous wastes using ground freezing technology is a relatively new field, even though ground freezing has been used as a temporary construction aid for several years. Ground freezing is ideally suited to control waterborne pollutants, since changing water from a liquid to a solid has an obvious immobilizing effect. The challenge for conventional ground freezing technologies is to be technically and economically viable in the long-term. Arctic Foundations, Inc. (AFI), has developed a ground freezing technology that can be used as a temporary or permanent, long-term solution for containing and immobilizing hazardous wastes. Buried hazardous waste may be totally confined by surrounding it with

a frozen barrier. A frozen barrier is created by reducing the ground temperature around the waste to the appropriate freezing temperature and subsequently freezing the intervening waste. Artificial injection of water is usually unnecessary since moisture is present in sufficient quantities in most soils. The ground freezing process is naturally suited to controlling hazardous waste because in-ground moisture is transformed from serving as a potential waste mobilizing agent to serving as a protective agent. A typical containment system consists of multiple thermoprobes, an active (powered) condenser, an interconnecting piping system, a two-phase working fluid, and a control system. The thermoprobes (AFI's heat removal devices) and piping are inserted into the soil at strategic locations around and sometimes underneath the waste source depending on the



Cryogenic Barrier Insulation Plan

presence or absence of a confining layer. Two-phase working fluid circulates through the piping and reduces the temperature of the surrounding soil, creating a frozen barrier around the waste source. The thermoprobes may be installed in any position and spacing to create a frozen barrier wall of almost any required shape and size. The selection of working fluids depends on the specific waste application, site conditions, and desired soil temperatures, and may consist of freon, butane, propane, carbon dioxide, or ammonia.

WASTE APPLICABILITY:

The cryogenic barrier can provide subsurface containment for a variety of sites and wastes, including the following: underground storage tanks; nuclear waste sites; plume control; burial trenches, pits, and ponds; in situ waste treatment areas; chemically contaminated sites; and spent fuel storage ponds. The barrier is adaptable to any geometry; drilling technology presents the only constraint.

STATUS:

The AFI cryogenic barrier system was accepted into the SITE Demonstration Program in 1996. The demonstration was conducted over a 5-month period at the U.S. Department of Energy's Oak Ridge National Laboratory (ORNL) in Oak Ridge, Tennessee in 1998. The demonstration was conducted to evaluate the barrier's ability to contain radionuclides from the ORNL Waste Area Grouping 9 Homogeneous Reactor Experiment pond. The evaluation of the technology under the SITE Program was completed in July 1998. The barrier continued in operation after the demonstration to maintain containment of the contaminants.

DEMONSTRATION RESULTS:

Phloxine B dye injected in the center of the impoundment showed no movement over an initial two-week time period. A Phloxine B "hit" was then detected outside the barrier, but upgradient of the injection point. This was inconsistent with other data. After further investigation, it was determined that this anomaly was due to transport through an abandoned, subsurface inlet pipeline to the pond. A temporary, artificial reverse-gradient condition was created by "chasing" the Phloxine B dye with deionized water, pushing the dye through the pipe, which was at least partially void of soil/water during initial freezing. This was a site anomaly considered unrelated to performance of Frozen Soil Barrier technology, although it serves as a "lesson learned" for further deployments.

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ARGONNE NATIONAL LABORATORY
(Development Of Phytoremediation)**TECHNOLOGY DESCRIPTION:**

The 317/319 areas at Argonne National Laboratory-East (ANL-E) are contaminated by volatile organic compounds (VOCs) in soil and groundwater and low levels of tritium in the groundwater from past waste disposal practices. As part of a nationwide effort to find more cost-effective and environmentally friendly remediation technologies, the U.S. Department of Energy (DOE), through the Accelerated Site Technology Development (ASTD) program, funded the deployment of a phytoremediation system in the 317/319 area. The 317 and 319 areas are located on the extreme southern end of the ANL-E site, immediately adjacent to the DuPage County Waterfall Glen Forest Preserve. The main objective of this deployment, which was selected in place of the baseline approach of an asphalt cap and extraction wells, are to hydraulically contain groundwater migration and to remove the VOCs and tritium within and downgradient of the source area.

Phytoremediation is a technique using plants to take in contaminants along with water and nutrients from the soil. It is defined as the engineered use of natural processes by which woody and herbaceous plants extract pore water, and entrained chemical substances from subsurface soils degrade, sequester, and transpire them (along with water vapor) into the atmosphere. The process has several advantages over the traditional and often invasive cleanup techniques in which the soil is sometimes dug up and incinerated in a kiln to break down the compounds. Not only is phytoremediation all natural, but the plants can address a range of contaminants at one time. It is also low cost and low maintenance, because the trees do the bulk of the work.

Additional advantages of the phyto-remediation system are (1) the ability of trees to actively promote and assist in the degradation of the contaminants at the source area, which the baseline asphalt cap would not do, and (2) the optimal fit of vegetation with the planned future land use of the contaminated site and adjacent areas, as the phytoremediation plantation will contribute to increased soil fertility to host subsequent prairie species.

WASTE APPLICABILITY:

This technology is designed to treat soils and groundwater contaminated by volatile organic compounds (VOCs) and tritium.

STATUS:

Approximately 800 trees were planted in the summer of 1999. These trees are expected to provide full, year-round hydraulic control by the year 2003 and be self-sustaining for the expected life of the engineering plantation.

The use of the trees to remediate and contain contaminated groundwater has been successfully demonstrated in treating contaminated groundwater. Applied Natural Sciences, Inc. (ANS) demonstrated the use of phreatophytic trees (i.e., plants such as poplars and willows that do not rely on precipitation but seek water deep in the soils) with its TreeMediation™ and TreeWell™ systems, that use a unique and patented process to enhance the aggressive rooting ability of selected trees to clean up soil and groundwater up to 50 ft deep.

DEMONSTRATION RESULTS:

A rapid method was optimized to measure chlorinated solvents and their degradation products in plant tissues. Trichloroacetic acid (TCAA), a known intermediate of the compound of TCE and PCE, was analyzed throughout the vegetative season in addition to the parent compounds as an indicator of their degradation. Both parent compounds and TCAA were found in the plant samples (an indication that the trees are taking up contaminants), with a prevalence of TCAA in the leaf tissue and the parent compounds in the branches. TCAA showed a trend toward accumulation in the leaf tissue as the vegetative season progressed. The levels of TCAA in the leaf samples were quite constant within a single tree but varied significantly as a function of the location of the tree within the contaminated area.

Samples of the air immediately surrounding the leafed branch were compared to air at the contaminated area and from other, uncontaminated areas within Argonne. While the air at the French Drain contained higher concentrations of VOCs than other clean areas on site, the presence of the leafed branches did not induce a measurable increase in the VOC concentration in the air, suggesting that most of the VOCs detected in the air come from direct venting off the soil. Tritium levels in the leaves and transpirate of hybrid poplars planted in the hydraulic control area showed levels comparable to background, indicating that the trees have not yet reached the contaminated aquifer.

Preliminary evaluations put the cost savings over the lifetime of deployment at 50 percent of the baseline approach. A significant cost savings over the avoidance of secondary waste (pumped groundwater) and related treatment.

Because the phytoremediation system will reach its optimal growth stage and steady performance state in 2003, future plans are to evaluate the performance of the remediation system. Some of the questions raised by this objective cannot be answered by conventional, compliance-related monitoring, so a more hypothesis-driven approach will be adopted to find mechanistic evidence of the effects of the plants on the removal of the contaminants.

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ARS TECHNOLOGIES, INC.
(formerly Accutech Remedial Systems, Inc.)
(Pneumatic Fracturing ExtractionSM and Catalytic Oxidation)

TECHNOLOGY DESCRIPTION:

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

The Accutech system forces compressed gas into a geologic formation at pressures that exceed the natural in situ stresses, creating a fracture network. These fractures allow subsurface air to circulate faster and more efficiently throughout the formation, which can greatly improve contaminant mass removal rates.

PFESM also increases the effective area that can be influenced by each extraction well, while intersecting new pockets of contamination that were previously trapped in the formation. Thus, VOCs and SVOCs can be removed faster and from a larger section of the formation.

PFESM can be combined with a catalytic oxidation unit equipped with special catalysts to destroy halogenated organics (see photograph below). The heat from the catalytic oxidation unit can be recycled to the formation, significantly raising the vapor pressure of the contaminants. Thus, VOCs and SVOCs volatilize faster, making cleanup more efficient. PFESM can also be combined with hot gas injection (HGI), an in situ thermal process, to further enhance VOC and SVOC removal rates. HGI returns to the ground the energy generated during catalytic oxidation of the VOCs.



WASTE APPLICABILITY:

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

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

STATUS:

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

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

DEMONSTRATION RESULTS:

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

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AWD TECHNOLOGIES, INC (AquaDetox®/SVE System)

TECHNOLOGY DESCRIPTION:

This technology integrates two processes: (1) AquaDetox®, a moderate vacuum steam stripping tower (tower pressure no less than 50 mm Hg) that treats contaminated groundwater and (2) a soil vapor extraction (SVE) system that removes contaminated soil-gas for subsequent treatment with granular activated carbon (GAC). The two technologies are integrated into a closed-loop system, providing simultaneous remediation of contaminated groundwater and soil-gas with no air emissions. The integrated AquaDetox® is a high-efficiency, countercurrent stripping technology developed by the Dow Chemical Company. Stripping is commonly defined as a process that removes dissolved volatile compounds from water. A carrier gas, such as air or steam, is purged through the contaminated water, with the volatile components being transferred from the water into the gas phase. SVE is commonly used for the in-situ removal of VOCs from soil. A vacuum is applied to vadose zone extraction wells to induce airflow within the soil toward the wells. The air acts as a stripping medium that volatilizes the VOCs in the soil. Soil-gas from the extraction wells is typically treated in GAC beds before release to the atmosphere. Alternatively, the treated soilgas is reinjected into the soil to control the direction of airflow in the soil. The

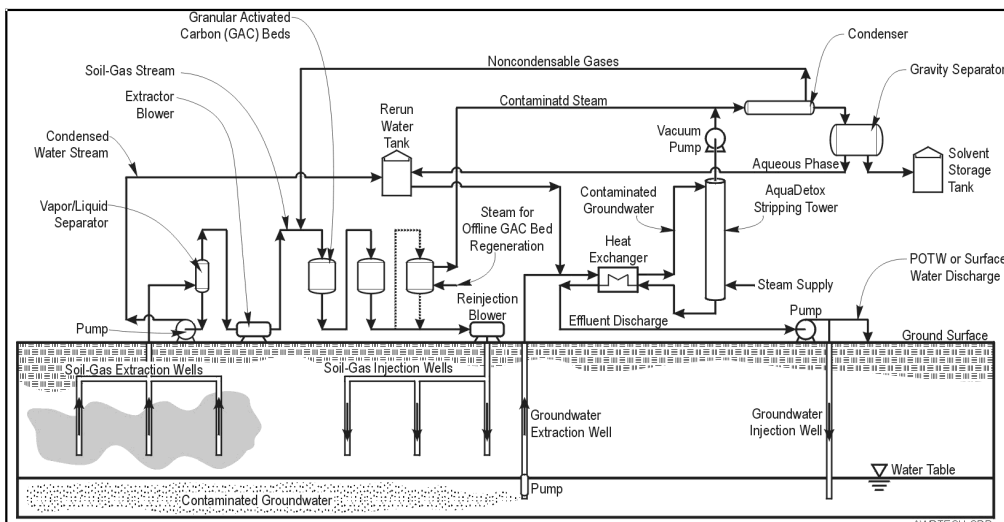
AquaDetox® and SVE systems are connected in a closed loop. Noncondensable vapors from the AquaDetox® system are combined with vapors from the SVE compressor and treated using the GAC beds.

WASTE APPLICABILITY:

AWD technology simultaneously treats groundwater and soil-gas contaminated with volatile organic compounds (VOCs), such as trichloroethylene (TCE) and tetra-chloroethylene (PCE). According to the developer, the AquaDetox® technology can be used to remove a wide variety of volatile compounds and many compounds that are normally considered "nonstrippable" (i.e., those with boiling points in excess of 200°C).

STATUS:

The SITE demonstration was conducted at the Lockheed site in Burbank, California. The treatment system at this site is a full-size unit capable of treating 1,200 gallons per minute (gpm) of groundwater and 300 standard cubic feet per minute (scDm) of soil-gas. The system began operation in September 1988. The demonstration was completed in September 1990.



Integrated AquaDetox®/SVE Schematic

DEMONSTRATION RESULTS:

During the demonstration, the system treated groundwater and soil-gas contaminated with VOCs. The primary contaminants present at the Lockheed site were trichloroethylene (TCE) and tetrachloroethylene (PCE) in soil and groundwater. The effectiveness of the technology was evaluated by analyzing the soil-gas and groundwater samples. The analytical results indicate that the technology effectively reduced the concentration of VOCs in the treated groundwater and soil-gas. Groundwater removal efficiencies of 99.92 percent or better were observed for TCE and PCE. In addition, the effluent groundwater concentrations of TCE and PCE were below the regulatory discharge limit of 5 µg/L. Soil-gas removal efficiencies ranged from 98.0 to 99.9 percent for total VOCs.

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

TECHNOLOGY DESCRIPTION:

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

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

processes create the following four output streams: (1) coarse clean fraction; (2) enriched fine fraction; (3) separated contaminated humic materials; and (4) process wash water. The coarse clean fraction particles, which measure greater than 45 μm (greater than 325 mesh) each, can be used as backfill or recycled for concrete, masonry, or asphalt sand application. The enriched fine fraction particles, measuring less than 45 μm each are prepared for subsequent treatment, immobilization, destruction, or regulated disposal. Separated contaminated humic materials (leaves, twigs, roots, grasses, wood chips) are dewatered and require subsequent treatment or disposal. Upflow classification and separation, also known as elutriation, separates light contaminated materials such as leaves, twigs, roots, or wood chips. The process wash water is treated by flocculation and sedimentation, oil-water separation, or dissolved air flotation to remove solubilized heavy metal and emulsified organic fractions. The treated process wash water is then returned to the plant for reuse.



Bergmann Soil and Sediment Washing

WASTE APPLICABILITY:

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

STATUS:

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

DEMONSTRATION RESULTS:

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

The demonstration provided the following results:

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

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

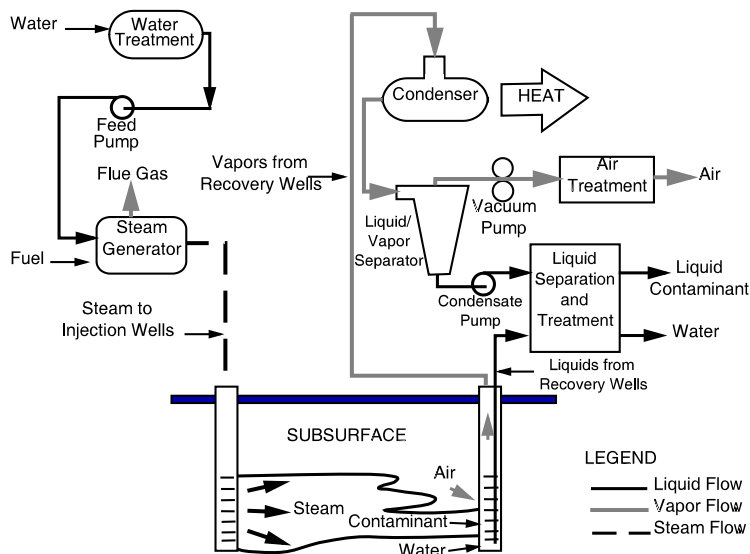
TECHNOLOGY DESCRIPTION:

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

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

WASTE APPLICABILITY:

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



In Situ Steam Enhanced Extraction Process

STATUS:

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

In December 1993, a full-scale demonstration was completed at a gasoline spill site at Lawrence Livermore National Laboratory (LLNL) in Altamont Hills, California. Gasoline was dispersed both above and below the water table due to a 25-foot rise in the water table since the spill occurred. The lateral distribution of liquid-phase gasoline was within a region 150 feet in diameter and up to 125 feet deep. Appendix A of the Hughes Environmental Systems Innovative Technology Evaluation Report (EPA/540/R-94/510) contains detailed results from the LLNL SITE demonstration. This report is available from EPA.

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

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

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

DEMONSTRATION RESULTS:

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

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

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

TECHNOLOGY DESCRIPTION:

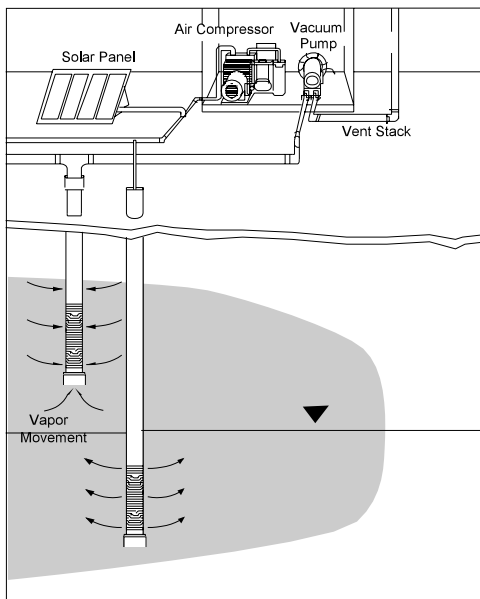
The Subsurface Volatilization and Ventilation System (SVVS®), developed by Billings and Associates, Inc. (BAI), and operated by several other firms under a licensing agreement, uses a network of injection and extraction wells (collectively called a reactor nest) to treat subsurface organic contamination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

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

This placement allows the groundwater to be used as a diffusion device.

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

To enhance vaporization, solar panels are occasionally used to heat the injected air. Additional valves for limiting or increasing air flow and pressure are placed on individual reactor nest lines (radials) or, at some sites, on individual well points. Depending on groundwater depths and fluctuations, horizontal vacuum screens, "stubbied" screens, or multiple-depth completions can be applied. Positive and negative air flow can be shifted to different locations at the site to emphasize remediation on the most contaminated areas. Negative pressure is maintained at a suitable level to prevent escape of vapors.



Subsurface Volatilization and Ventilation System (SVVS®)

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

WASTE APPLICABILITY:

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

STATUS:

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

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

DEMONSTRATION RESULTS:

Results from the SVVS® demonstration are as follows:

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

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BIOGENESIS ENTERPRISES, INC.
(BioGenesisSM Soil and Sediment Washing Process)

TECHNOLOGY DESCRIPTION:

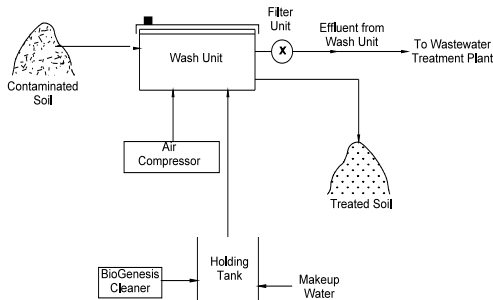
The BioGenesisSM soil and sediment washing process uses specialized, patent-pending equipment, complex surfactants, and water to clean soil, sediment, and sludge contaminated with organic and inorganic constituents. Two types of mobile equipment wash different sizes of particles. A truck-mounted batch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

The principal components of the process consist of pretreatment equipment for particle sizing, a truck-mounted soil washer for larger particles, a sediment washing unit(s) for fine particles, and water treatment and reconditioning equipment. The BioGenesisSM soil washing system for larger particles consists of a trailer-mounted gondola plumbed for air mixing, water and chemical addition, oil skimming, and liquid drainage (see figure below). Water, BioGenesisSM cleaning chemicals, and soil are loaded into the gondola. Aeration nozzles feed compressed air to

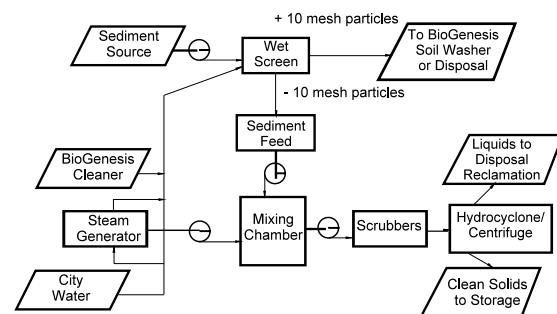
create a fluidized bed. The resulting slurry is agitated to release organic and inorganic contaminants from the soil particles. After mixing, a short settling period allows the soil particles to sink and the removed oil to rise to the water surface, where it is skimmed for reclamation or disposal. Following drainage of the wash water, the treated soil is evacuated by raising the gondola's dump mechanism. Processed soil contains a moisture level of 10 to 20 percent depending on the soil matrix.

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

In the sediment washing machine, sediment is pretreated to form a slurry. The slurry passes to a shaker screen separator that sizes particles into two streams. Material greater than 1 millimeter (mm) in diameter is diverted to the large particle soil washer. Material 1 mm and smaller continues to the sediment washer's feed hopper. From there, the slurry is injected to the sediment cleaning chamber to loosen the bonds between the pollutant and the particle.



Soil Washing Process



Sediment Washing Process

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

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

WASTE APPLICABILITY:

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

STATUS:

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

DEMONSTRATION RESULTS:

Results of the SITE demonstration are presented below:

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

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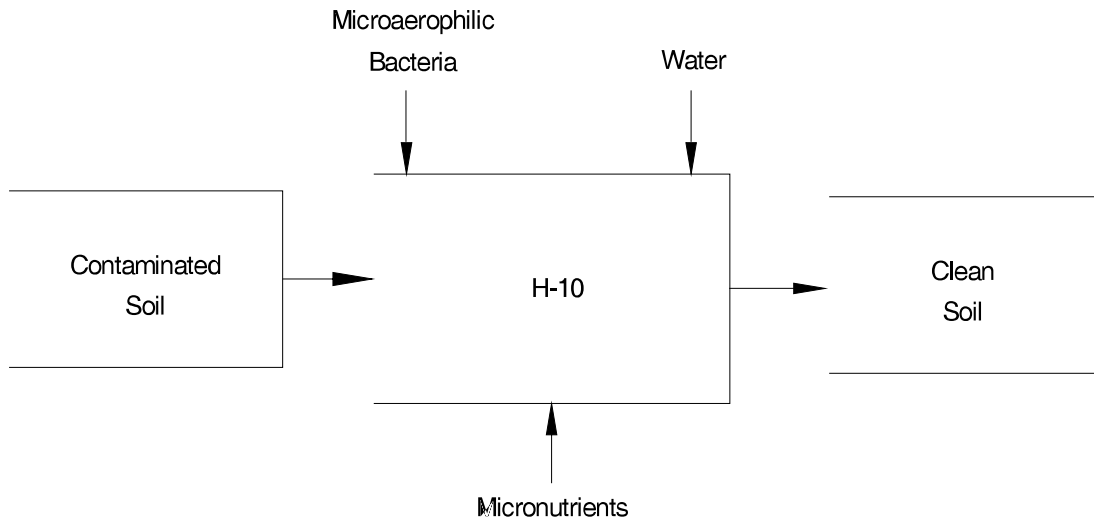
BIO-REM, INC. **(Augmented In Situ Subsurface Bioremediation Process)**

TECHNOLOGY DESCRIPTION:

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

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

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



Augmented In Situ Subsurface Bioremediation Process

STATUS:

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

DEMONSTRATION RESULTS:

Results from the Demonstration indicate that the BIO-REM process was unsuccessful in reducing target contaminants in the soil to the project clean-up levels.

Baseline sampling indicated that a majority of the soil samples were significantly higher than the cleanup levels of 130 ppb for benzene and 100 ppm for TRPH. Furthermore, soil samples analyzed one and three months after inoculation did not show significant reductions in benzene or TRPH contamination (Table 1). The lack of progress in the remediation prompted concerns regarding the effectiveness of the technology. It was jointly decided between the SITE Program and BIO-REM to collect sixteen samples (four boreholes) at six months to determine the progress of the remediation at the predicted end of the project. Results from the six month sampling event also indicated a lack of significant reduction in contaminant concentrations.

Based on these results, BIO-REM submitted a request to the Air Force to re-inoculate the site based on their assessment that sub-surface lithological conditions inhibited the remedial process. In March of 1993 BIO-REM re-inoculated the site by injecting approximately 35,000 gallons of H-10 slurry into 104 boreholes deepened to a depth of 23 feet below land surface. The inoculation to deeper depths was implemented to overcome the sub-surface lithological conditions identified by BIO-REM. In June of 1993 a confirmatory sampling event initiated by the Air Force. In conjunction with the SITE Program, indicated that significant contamination existed at the site, and that the re-inoculation was unsuccessful in reducing the target contaminants to the project specific clean-up levels. Based on these results, these site activities were concluded.

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

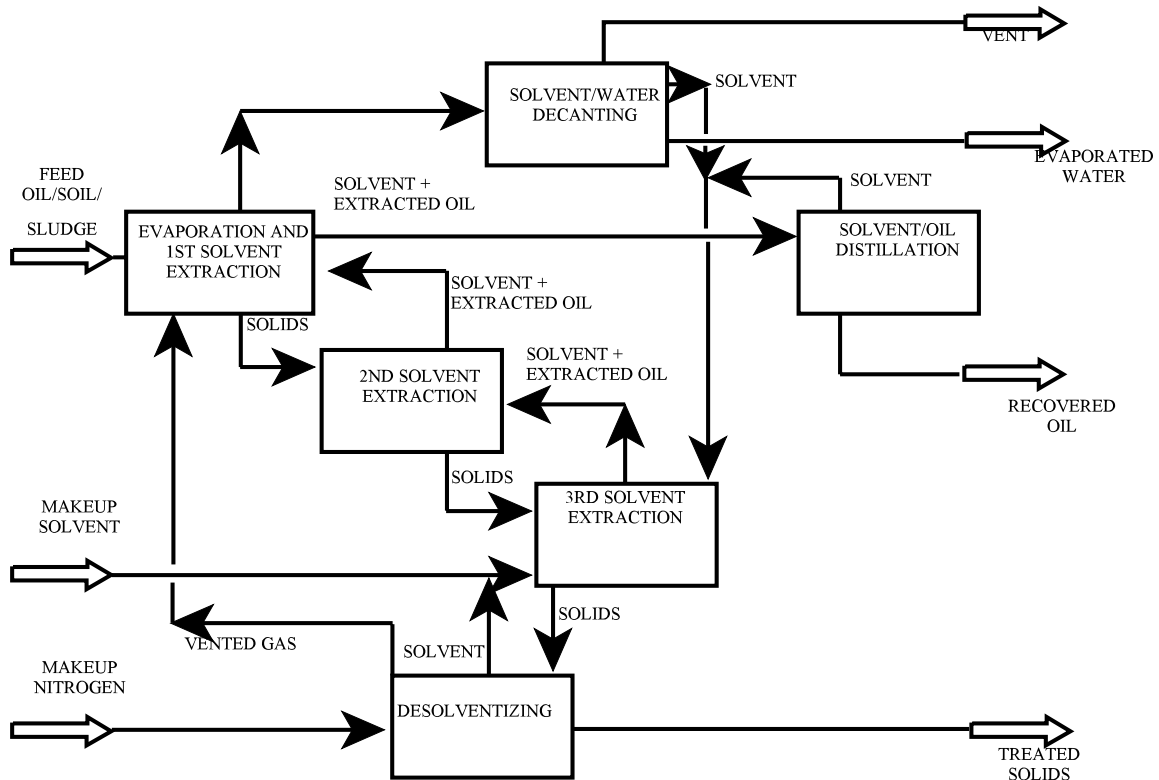
TECHNOLOGY DESCRIPTION:

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

Waste is first mixed with a low-cost hydrocarbon solvent. The resultant slurry mixture is fed to an evaporator system that vaporizes water and initiates solvent extraction of the indigenous oil extraction unit, where solids contact recycled solvent until the target amount of indigenous oil is removed. Depending on the water content of the feed, single-effect or energy-saving multi-effect evaporators may

be used. Next, the slurry of dried solids is treated in a multistage solvent. Finally, solids are centrifuged away from the solvent, followed by "desolventizing," an operation that evaporates residual solvent. The final solids product typically contains less than 2 percent water and less than 1 percent solvent. The spent solvent, which contains the extracted indigenous oil, is distilled to separate the solvent for reuse, and the oil for recovery or disposal.

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



Biotherm Process™ Schematic Diagram

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

WASTE APPLICABILITY:

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

STATUS:

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

DEMONSTRATION RESULTS:

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

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

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BIOTROL® (Biological Aqueous Treatment System)

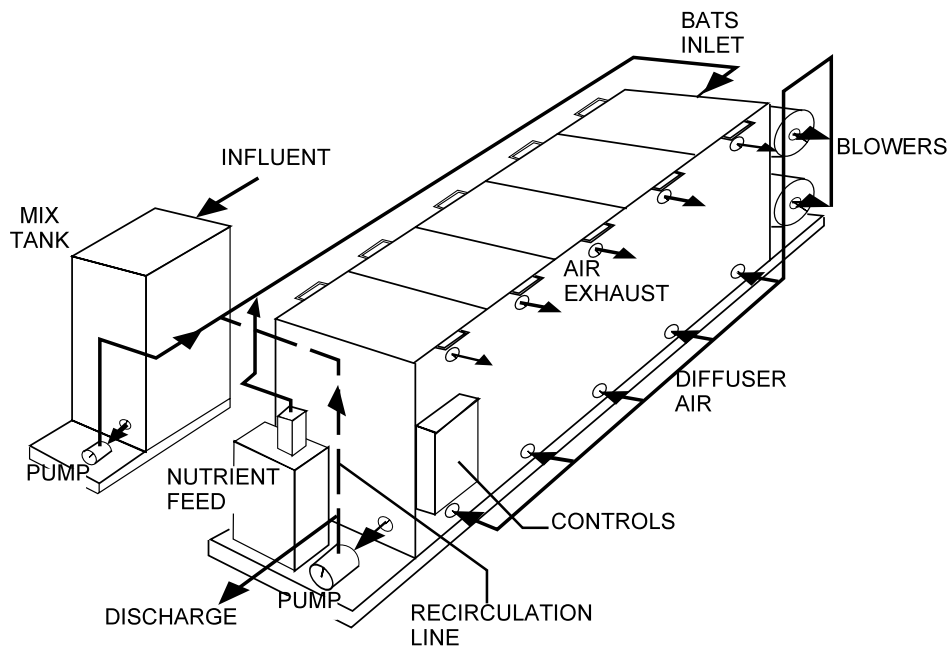
TECHNOLOGY DESCRIPTION:

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

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

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

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



BioTrol Biological Aqueous Treatment System (BATS)

WASTE APPLICABILITY:

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

STATUS:

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

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

DEMONSTRATION RESULTS:

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

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

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

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BIOTROL® (Soil Washing System)

TECHNOLOGY DESCRIPTION:

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

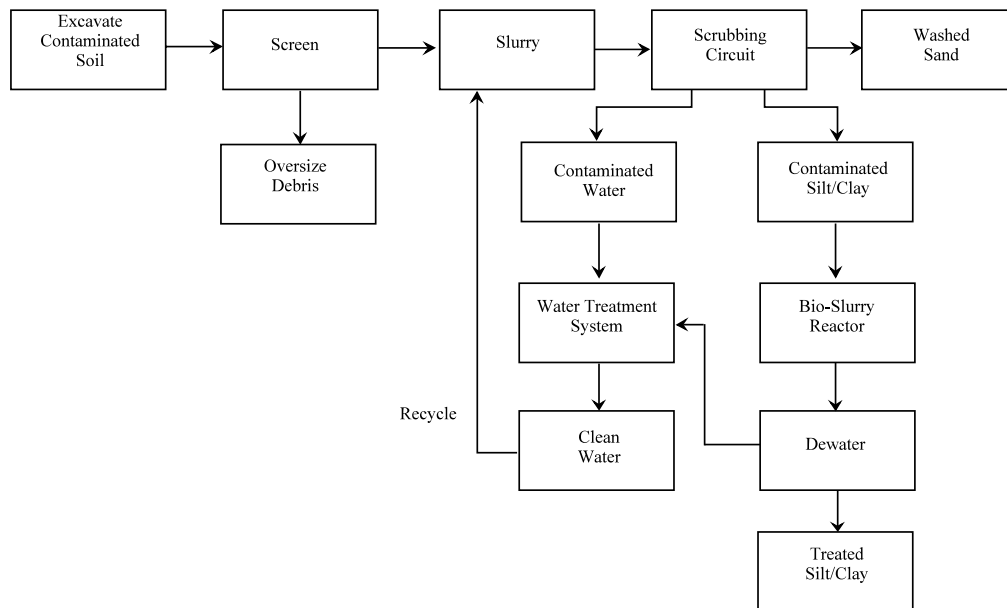
In the first part of the process, debris is removed from the soil. The soil is then mixed with water and subjected to various unit operations common to the mineral processing industry (see figure below). The equipment used in these operations can include mixing trommels, pug mills, vibrating screens,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

The core of the process is a multistage, countercurrent, intensive scrubbing circuit with interstage classification. The scrubbing action disintegrates soil aggregates, freeing contaminated

fine particles from the coarser material. In addition, surficial contamination is removed from the coarse fraction by the abrasive scouring action of the particles themselves. Contaminants may also be solubilized, as dictated by solubility characteristics or partition coefficients.

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

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



BioTrol Soil Washing System Process Diagram

STATUS:

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

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

DEMONSTRATION RESULTS:

Key findings from the BioTrol demonstration are summarized below:

- Feed soil (dry weight basis) was successfully separated into 83 percent washed soil, 10 percent woody residues, and 7 percent fines. The washed soil retained about 10 percent of the feed soil contamination; 90 percent of this contamination was contained within the woody residues, fines, and process wastes.

- The multistage scrubbing circuit removed up to 89 percent PCP and 88 percent total PAHs, based on the difference between concentration levels in the contaminated (wet) feed soil and the washed soil.
- The scrubbing circuit degraded up to 94 percent PCP in the process water during soil washing. PAH removal could not be determined because of low influent concentrations.
- The cost of a commercial-scale soil washing system, assuming use of all three technologies (soil washing, water treatment, and fines treatment), was estimated to be \$168 per ton. Incineration of woody material accounts for 76 percent of the cost.

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BRICE ENVIRONMENTAL SERVICES CORPORATION

(Soil Washing Process)

TECHNOLOGY DESCRIPTION:

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

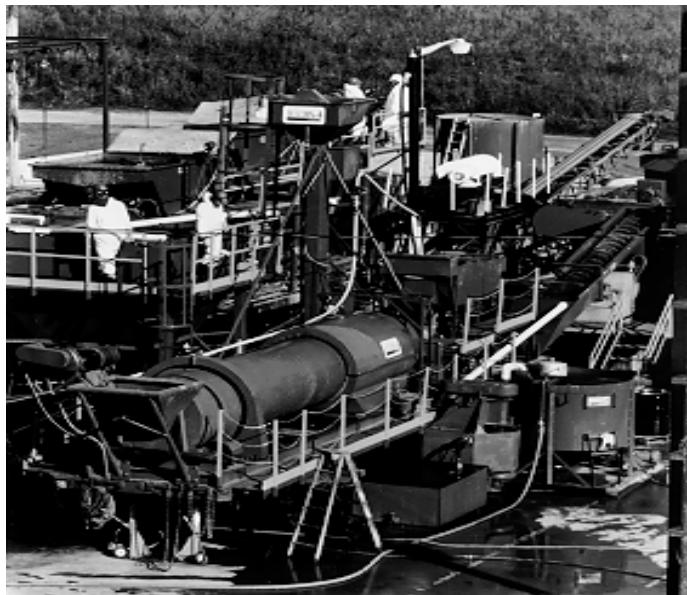
Particulate metal contaminants removed from soil, and metals recovered from the leaching system (if used), are recycled at a smelting facility. Instead of stabilizing the metals in place or placing the materials in a landfill, the Brice technology removes metal contaminants from the soil, thereby eliminating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

WASTE APPLICABILITY:

The Brice soil washing process treats soils contaminated with heavy metals. Typical materials suited for treatment with the technology include soils at small arm ranges, ammunition manufacturing and testing facilities, foundry sites, and sites used for lead-acid battery recycling.

STATUS:

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



Brice soil Washing Plant

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

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

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

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

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

DEMONSTRATION RESULTS:

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

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

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

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

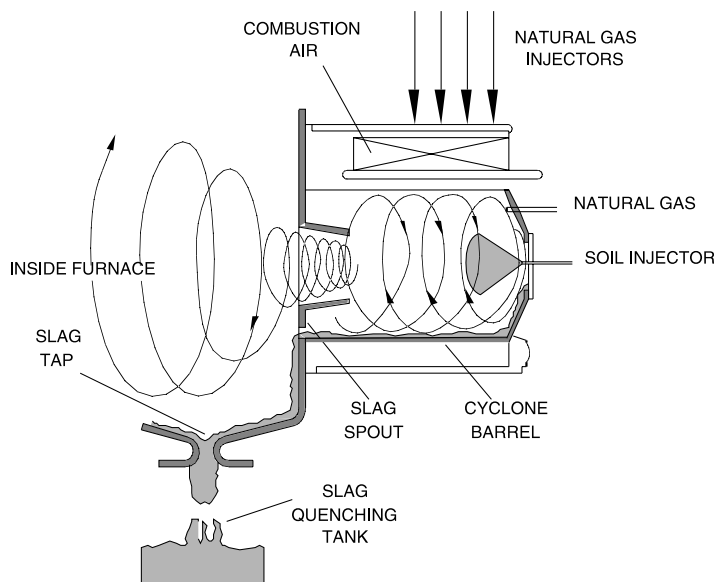
TECHNOLOGY DESCRIPTION:

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

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

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

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



Cyclone Furnace

The energy requirements for vitrification are 15,000 Btu per pound of soil treated. The cyclone furnace can be operated with gas, oil, or coal as the supplemental fuel. If the waste is high in organic content, it may also supply a significant portion of the required fuel heat input.

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

WASTE APPLICABILITY:

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

STATUS:

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

DEMONSTRATION RESULTS:

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

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

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