

# Installation Restoration and Hazardous Waste Control Technologies

1992 Edition



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# **INSTALLATION RESTORATION AND HAZARDOUS WASTE CONTROL TECHNOLOGIES**

*1992 Edition*

## **Introduction**

Both the Department of Defense (DOD) and private industries face the increasingly difficult and costly task of disposing of hazardous wastes. Alternatives to traditional waste disposal methods, while eliminating the wastes or at least rendering them nontoxic, can be expensive. Sites contaminated in the past by the use of methods formerly considered acceptable, such as impoundments and lagoons, must now be restored properly in order to protect the public health.

The purpose of this document is to provide a reference of pertinent and current treatment technologies to public and private sector program managers dealing with installation restoration and hazardous waste control technologies. This is the third edition of this handbook. The second edition was published in 1990 (U.S. Army Corps of Engineers Toxic and Hazardous Materials Agency Report CETHA-TS-CR-90067, August 1990).

The information contained in this handbook was obtained through personal interviews with Army, Navy, Air Force, and U.S. Environmental Protection Agency personnel directly involved in research, development, and implementation of new and effective methods to accomplish the following: restoration of contaminated soil, groundwater, and structures; and minimization of the generation of hazardous waste materials.

The organizations that supplied information for this updated edition are identified in table 1. Acronyms in the table will be used throughout this report to identify the organizations from which the information was obtained. This document represents a starting point in the review of available waste treatment technologies and should not be regarded as a sole source of information. It does not represent all treatment technologies nor all technology demonstrations performed by these organizations.

## **Description of Technical Notes**

Each technical note summarizes a specific technology. The summaries include the purpose of developing the technology; in what cases the technology is applicable; a description of the technology; advantages and limitations of the technology with respect to environmental impact, costs, ease of operation, and byproducts relative to alternative technologies; capital and operating costs associated with implementing the technology; availability of equipment required; the current status of development; references including reports, journal articles, and patents; photographs and drawings if available; and points of contact for additional technical information. The technologies included in this report are organized according to the categories in table 2.

The technologies listed in table 3 are included in this handbook. Although each technology is associated with a specific category, many of the technologies have multiple applications within each category. For example, although "In Situ Biodegradation" is listed as a method of restoring groundwater, it is a method used to restore soils also.



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**TABLE 1. Organizations That Supplied Information for the 1992 Edition of *Installation Restoration and Hazardous Waste Control Technologies*.**

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AFCESA	U.S. Air Force Civil Engineering Support Agency at Tyndall Air Force Base, Panama City, FL
USAWES	U.S. Army Corps of Engineers Waterways Experiment Station in Vicksburg, MS
USATHAMA	U.S. Army Corps of Engineers Toxic and Hazardous Materials Agency at the Edgewood Area of Aberdeen Proving Ground, MD
USACERL	U.S. Army Corps of Engineers Construction Engineering Research Laboratories in Champaign, IL
NCEL	U.S. Naval Civil Engineering Laboratory in Port Hueneme, CA
NEESA	U.S. Naval Energy and Environmental Support Activity in Port Hueneme, CA
NAVSWC DET	U.S. Naval Surface Warfare Center, Carderock Division Detachment, Annapolis in Annapolis, MD
NCCOSC	U.S. Naval Command, Control, and Ocean Surveillance Center, RDT&E Division in San Diego, CA
EPA/EMSL	U.S. Environmental Protection Agency Environmental Systems Monitoring Laboratory in Las Vegas, NV
EPA/RREL	U.S. Environmental Protection Agency Risk Reduction Engineering Laboratory in Cincinnati, OH

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*TABLE 2. Organization of Technical Notes*

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Category	Sub-Category
I. Installation Restoration	a. Groundwater treatment b. Soil treatment c. Structural treatment
II. Hazardous Waste Control Technologies	a. Recovery and reuse of energetics b. Minimization or treatment of munition production and/or handling waste streams c. Minimization or treatment of metal finishing wastes d. Minimization or treatment of other liquid wastes e. Minimization or treatment of other solid wastes f. Minimization or treatment of gases g. Management Strategies h. Risk Assessment
III. Analytical Methods and Instrumentation Development	

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## **TECHNICAL NOTES**



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# 1. ABOVEGROUND BIOLOGICAL TREATMENT OF TRICHLOROETHYLENE-CONTAMINATED GROUNDWATER

**Category:** I.a. Groundwater Treatment

**Purpose:** To destroy trichloroethylene (TCE) in groundwater using aerobic biodegradation.

**Application:** The technology is applicable to the removal of short chain ( $C_1$  and  $C_2$ ) chlorinated aliphatic hydrocarbons from water. It can be used as an above-ground – pump and treat – method of treating contaminated groundwater. Other applications can include in situ decontamination or the removal of similar compounds from any water stream.

**Description:** Methane and aromatic-compound degrading bacteria co-metabolize short-chain, chlorinated aliphatic hydrocarbons. An enzyme, a non-specific oxygenase that metabolizes methane or aromatics, attacks TCE. However, the bacteria cannot use TCE as food but must have methane as a carbon source. The reaction can take place in a bioreactor or in situ. A mixture of oxygen and methane or aromatics is passed through the reactor or reaction zone to sustain the microbial population. The contaminated water is allowed to percolate down through the bed. The packing material used can be soil, but care must be taken to avoid plugging. Approximately 80% destruction of TCE has been achieved. Complete biodegradation may be achieved with lengthening of the reactor columns. No hazardous intermediate compounds are created with this process. Flow rate for contaminated water in the process is 2 to 3 L/min with a retention time of 20 to 50 minutes in the reactor, depending upon the packing material used.

**Advantages:** This method eliminates, rather than disposes of, toxic compounds. The chlorinated compounds are converted to organic chlorides, water, and carbon dioxide. Indigenous bacteria are utilized for the degradation.

**Limitations:** With the present reactors only 80% degradation is achieved; however, work by others shows promise of improved reactor performance.

**Cost:** Based on research to date, cost estimates will be reported in the final technical report (ESL-TR-90-03) to be published in late FY92. This is a developing technology, therefore all cost information will be refined with application experience.

**Availability:** A follow-on field study is being conducted with the DOE Oak Ridge National Laboratory to compare the effectiveness of the methanotrophic system to a *pseudomonas*-based system which co-metabolizes TCE in the presence of some aromatic compounds. This comparative field study began during the fall of 1991 and will continue through 1992. Commercial applications equipment is available if key technical issues can be resolved.

**Status:** Field pilot testing was conducted at Tinker AFB, OK during FY 89. WES is currently developing an aerobic bioreactor that can be used for treating TCE-contaminated groundwaters using aromatic or aliphatic compound based degradation pathways. WES is currently developing a bioslurry system for treating chlorinated solvents. This system will include a process gas recirculation system that will allow volatile co-metabolites and target contaminants to remain within the system.

**References:** Palumbo, A.V., P.A. Boerman, G.W. Strandberg, T.L. Donaldson, S.E. Herkes, and W. Eng, **Effects of Diverse Organic Contaminants on Trichloroethylene Degradation by Methanotrophic Bacteria and Methane-Wiling Consortia**, Proceedings, *In Situ* and On-Site Bioreclamation: An International Symposium, San Diego, CA, March 19-21, 1991.

Allen, B.R., K.R. Anderson, and R.A. Ashworth. **Use of Methanotrophs in an Above-Ground Reactor to Treat Groundwater Contaminated With Trichloroethylene**. Presented at the Petroleum Hydrocarbons and Organic Chemicals in Groundwater Conference, Houston, TX, Nov 9-11, 1988.

Fliermans, C.B., et al. **Mineralization of Trichloroethylene by Heterotrophic Enrichment Cultures**. *Appl. & Env. Microbiology*, 54:1709-1714, 1988

Little, C.D. **Trichloroethylene Biodegradation by a Methane-Oxidizing Bacterium**. *Appl. & Env. Microbiology*, 54:951-956, 1988.

Wilson, J.T. and B.H. Wilson. **Biotransformation of Trichloroethylene in Soil**. *Appl. & Env. Microbiology*, 49(1):242-3, 1985.

Wilson, B.H. and M.V. White. **A Fixed-Film Bioreactor to Treat Trichloroethylene-Laden Waters From Interdiction Wells**. Presented at the 6th National Symposium and Exposition on Aquifer Restoration and Ground Water Monitoring, Ohio State University, May 1986.

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## 2. PERMEABLE BARRIERS – IMPERMEABLE TO CONTAMINANTS

**Category:** I.a. Groundwater Treatment.

**Purpose:** The removal of contaminants from shallow aquifers.

**Application:** This technology is applicable to benzene, methytertiarybutylether (MTBE), gasoline spills, heavy metals (in laboratory experiments), and benzene/ toluene/xylene (BTX) spills in soils that have contaminated shallow groundwater, i.e., depths  $\leq 50$  ft.

**Description:** This technology is applicable only through excavation and fill. A trench perpendicular to the flow of water is excavated across the shallow aquifer to the lower confining bed. A barrier that is designed specifically for the particular contaminant in the groundwater is placed in the trench as fill, e.g., activated carbon, sand/clay mixture, etc. Contaminants are filtered out of the groundwater without pump and treat because the barrier is permeable to water, allowing flow, and impermeable to the contaminant. The contaminant is absorbed by the impermeable barrier concentrating the contaminant. Life of the impermeable barrier is dependent upon the concentration of the contaminant. The impermeable barrier is disposed of when it has absorbed all of the contaminant possible.

**Advantages:** This technology eliminates pump and treat technology for decontamination of an aquifer. This is a low maintenance system that is user friendly because an on site operator for the process is not needed. In situ bioremediation can be utilized in association with the filter media for destruction of contaminants.

**Limitations:** The process is intrusive, penetrating an aquifer to the lower confining bed. Since this is a intrusive process, the aquifer and contaminants may contaminate lower confining beds while excavating the trench through the aquifer.

**Cost:** Not available, site specific.

**Availability:** Not commercially available.

**Status:** Laboratory testing phase occurred at CERL from 1989 to present. Full-scale implementation occurred in Albuquerque, NM 1989 – 1992.

**References:** Not available.

**Contact:** Richard Scholze or Erica May  
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### 3. COMPATIBILITY TESTING OF SOIL BENTONITE SLURRY WALLS WITH CONTAMINATED GROUNDWATERS AND LEACHATES

**Category:** I.a. Groundwater Treatment

**Purpose:** To test the efficiency of bentonite slurry walls as a barrier to the flow and spread of contaminants in groundwater.

**Application:** Compatibility testing is desirable when chemical barrier installation is planned as a chemical-control measure to prevent contaminants from spreading through groundwater transport and/or leachate generation.

**Description:** The interactions of solutes found in leachates and contaminated groundwaters from uncontrolled landfills with components of a soil-bentonite (SB) slurry wall are capable of causing swelling or shrinking of the SB material which alters the hydraulic conductivity of the slurry wall. To determine properly the possible effects that chemical constituents may have on the hydraulic conductivity of SB materials, compatibility testing is performed on the SB materials using site groundwater samples as permeants in permeameters. Triaxial and rigid wall permeameters have been used in compatibility testing. Elevated hydraulic gradients ( $< 50$  psi) are used to complete testing within a reasonable amount of time. Typically, 1 pore volume of uncontaminated water is pumped through the permeameters before contaminated water is used as a permeant. Then at least 2 pore volumes of contaminated permeant are pumped before testing is considered complete.

**Advantages:** Proper evaluation of groundwater/barrier compatibility could ensure proper contaminant containment on site and possibly improve design of a full-scale containment wall.

**Limitations:** None known.

**Cost:** Cost will vary with test conditions and sponsor requirements.

**Status:** WES has evaluated the compatibility of contaminated groundwater with SB slurry walls and contaminants in Basin F liquid at the Rocky Mountain Arsenal (RMA), Denver, CO. WES is presently evaluating the compatibility of contaminated groundwater from the Ninth Avenue Dump Superfund Site with two SB slurry wall backfill mixtures.

**References:** Zappi, M.E., R.A. Shafer, and D.D. Adrian, *Compatibility of Ninth Avenue Superfund Site Ground Water With Two Soil-Bentonite Slurry Wall Backfill Mixtures*, WES Report No. EL-90-9, 1990.

Zappi, M.E., D.D. Adrian, and R.R. Shafer. *Compatibility of Soil-Bentonite Slurry Wall Backfill Mixtures with Contaminated Groundwater*. Proc. 1989 Superfund Conference, Washington, DC, Nov 1989.

Miller, S.P. *Geotechnical Containment Alternatives for Industrial Waste Basin F, Rocky Mountain Arsenal, Denver, Colorado: A Quantitative Evaluation*. USAE Waterways Experiment Station Technical Report GL-79-23, Sep 1979.

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## 4. SOLVENT EXTRACTION (CF SYSTEMS)

**Category:** I.a. Groundwater Treatment

**Purpose:** To extract (separate) contaminants from the media in which they are contained.

**Application:** This technology can be applied to waste containing carbon tetrachloride, chloroform, benzene, naphthalene, gasoline, vinyl acetate, furfural, butyric and higher organic acids, dichloroethane, oils and greases, xylene, toluene, methyl acetate, acetone, propanol and higher alcohols, phenol, heptane, polychlorinated biphenyls (PCB), and other complex organic compounds. This is a specific application of the general category of solvent extraction techniques described in technical note #23.

**Description:** This technology uses supercritical fluid as a solvent to extract organics from wastewater or contaminated sludges and soils. Carbon dioxide is the fluid used for aqueous solutions, while propane and/or butane are used for sediment, sludges and soils (semisolids). Contaminated solids, slurries, or wastewaters are fed into the extractor (see figure 4). Supercritical fluid (or solvent) is also fed to the extractor, making nonreactive contact with the waste. Typically, the process separates more than 99% of the organics from the waste feed. Following phase separation of the solvent, organics and treated water are removed from the extractor while the mixture of solvent and organics passes to the separator through a valve where pressure is partially reduced. In the separator, the solvent is vaporized and recycled as fresh solvent. The organics are drawn off from the separator and either reused or disposed. The extractor design is different for contaminated wastewaters and semisolids. For wastewaters, a trayed-tower contactor is used; for semisolids, a series of extractor/decanter operating counter-currently is used.

**Advantages.** Extraction efficiencies of 90 to 98% were achieved on sediments containing between 350 and 2,575 ppm PCBs. PCB concentrations were as low as 8 ppm in the treated sediment. In the laboratory, extraction efficiencies of 99.95 % have been obtained for volatile and semivolatile organics in aqueous and semisolid wastes.

**Limitations** The use of treated sediment as feed to the next pass caused cross-contamination in the system. Operating problems included solids being retained in the system hardware and foaming in receiving tanks.

**Costs:** Projected costs for PCB cleanups are estimated at approximately \$150 to \$450 per ton, including material handling and pre and post-treatment costs. These costs are highly sensitive to the utilization factor and job size, which may result in lower costs for large cleanups.

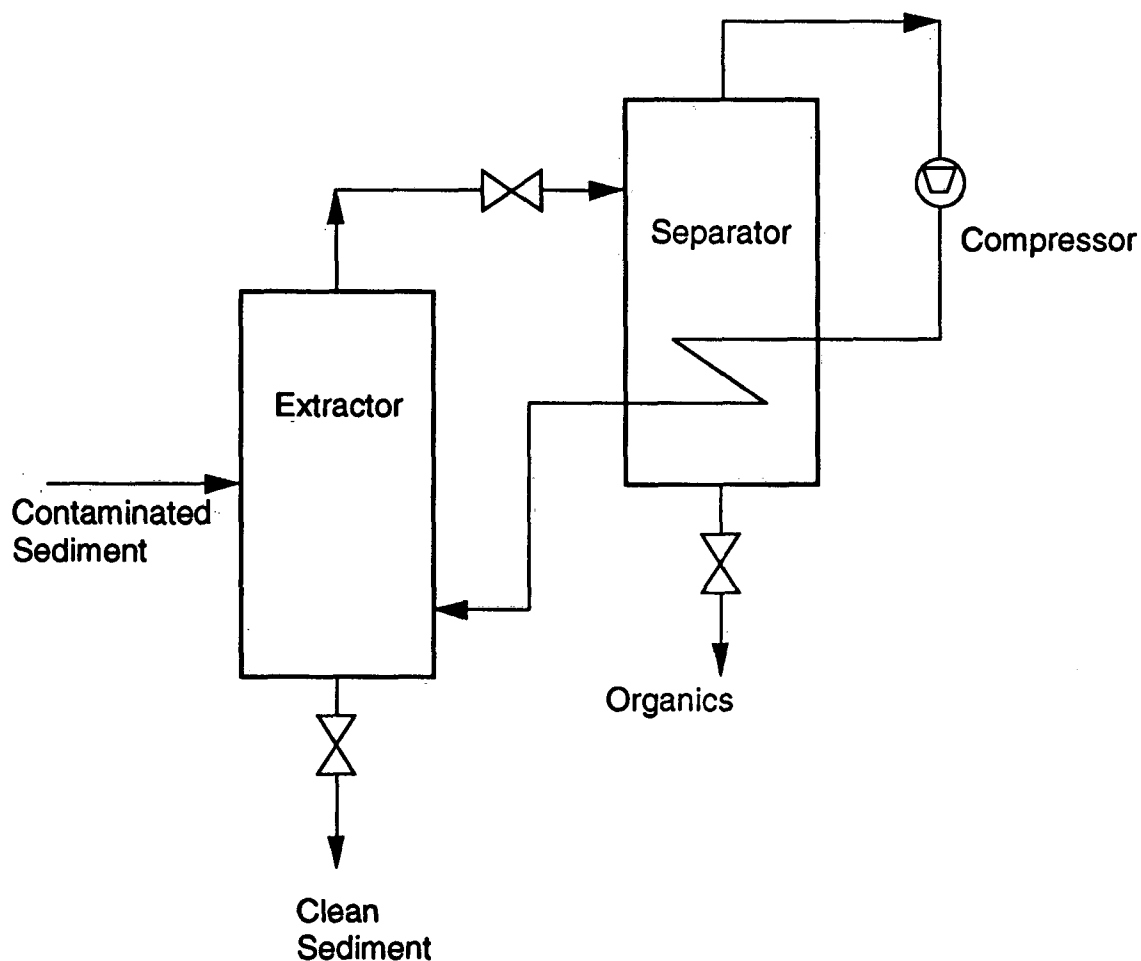
**Status:** The pilot-scale system was tested on PCB-laden sediments from the New Bedford (MA) Harbor Superfund site during September 1988. PCB concentrations in the harbor ranged from 300 to 2,500 ppm. The technology was demonstrated concurrently with dredging studies managed by the U.S. Army Corps of Engineers. Contaminated sediments were treated by the CF System Pit Cleanup Unit, using a liquefied propane and butane mixture as the extraction solvent.

**References:** The Superfund Innovative Technology Evaluation Program: Technology Profiles. U.S. Environmental Protection Agency Report EPA/540/5-89/013, Nov 1989, pp. 25-26.

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*Figure 4. Solvent extraction unit process diagram (CF Systems).*

## 5. XANTHATE TREATMENT FOR HEAVY METALS IN GROUNDWATER

**Category:** I.a. Groundwater Treatment.

**Purpose:** To reduce the concentration of metals contained in metal-contaminated groundwaters and to reduce the volume of metal-contaminated sludges that require disposal as a hazardous waste.

**Application:** Xanthate precipitation is a process that can remove metals from metal-contaminated groundwaters through precipitation, much like conventional hydroxide or sulfide precipitation processes. Xanthate precipitation offers several advantages over hydroxide precipitation as described in the advantages section below. Xanthate precipitation can be directly substituted for hydroxide precipitation if solid feeding or slurring processing equipment is available.

**Description:** Xanthate is added to the contaminated groundwaters in aboveground treatment systems in which the xanthate combines with metals to form insoluble metal complexes. The insoluble complexes settle out of the liquid, thus removing the metals. The resulting sludge can be dewatered and generally is sent to a RCRA landfill for disposal as a hazardous waste. The sludge is reported to be more easily dewatered than conventional hydroxide or sulfide sludges. Recent research indicates that a mixture of metals in solution can be complexed with xanthate. The complexed metals can then be segregated and retrieved into relatively pure metal solutions that can be recycled. This may eliminate the need to dispose of hazardous residue.

**Advantages:** Xanthate precipitation processes offer many advantages over conventional precipitation processes: (1) unlike hydroxide complexes which are amphoteric (form complexes soluble at both low and high pH) xanthates, like sulfide metal complexes, show little variation in solubility with pH; (2) xanthates work well in the presence of chelating and complexing agents such as EDTA; (3) xanthates reduce the possibility of hazardous hydrogen sulfide releases which may occur with sulfide precipitation processes; and (4) xanthate metal contaminated sludges may be recycled.

**Limitations:** Xanthates are unstable at normal temperatures and may decompose which may render the xanthates ineffective for metal removal. These problems are overcome by: (1) producing fresh xanthate material on site, (2) storing xanthate at low temperatures prior to use, and (3) cross-linking the xanthate to decrease the degree of decomposition at room temperature.

**Cost:** As with all waste treatment processes, costs vary greatly depending on the application and configuration. Xanthate precipitation processes are reported to be in the cost range of sulfide precipitation processes.

**Availability:** Starch xanthate is commercially available but currently is not utilized on a wide scale.

**Status:** Laboratory testing and bench-scale testing of the sludge recycling processes have been investigated in detail for synthetic metal wastes along with surveys of the effectiveness of currently utilized commercial applications.

**References:** Bricka, R.M., Investigation of the Performance of Solidified Cellulose and Starch Xanthate Heavy Metals Sludges, U.S. Army Corps of Engineers Technical Report, EL-88-5, Feb 1988.

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## 6. ACTIVATED CARBON ADSORPTION

- Category:** I.a. Groundwater Treatment
- Purpose:** Removal of organic and explosive contaminants from wastewater and contaminated groundwater.
- Application:** Activated carbon is suited for removal of low-to-medium concentrations of organic contaminants from waste streams. Activated carbon systems are also used as polishing units for the removal of trace organics from effluents of other treatment systems.
- Description:** Carbon adsorption is a phase-separation process that uses the electrophysical attraction of contaminants in the fluid phase to adsorption sites on the surface of the activated carbon. Carbon adsorption technology has been used for removing organic contaminants from contaminated wastewaters and air streams in a variety of configurations. Some configurations include fixed and pulse-bed columns that incorporate granular activated carbon (GAC) for removing contaminants from waste streams. Activated carbon is also used in powdered form (PAC) in activated sludge biological reactors for removing refractory compounds in the aeration tank and reducing off-gassing of volatile compounds during aeration. A schematic diagram is given in figure 6.
- Advantages:** Activated carbon treatment is capable of removing a large variety of contaminants from water and air. The waste streams can vary in terms of contaminant concentrations without affecting performance.
- Limitations:** Disposal of spent carbon is required.
- Cost:** Costs are estimated to be between \$0.10 and \$0.40 per gallon.
- Availability:** The technology is commercially available.
- Status:** WES has evaluated PAC addition to an activated sludge bioreactor for treatment of contaminated groundwater and has generated several adsorption isotherms for evaluation of the applications potential of GAC for a variety of organic compounds. Also, WES has performed pilot GAC column studies for removal of n-nitrosodimethylamine, diisopropylmethylphosphonate, chloroform, and RDX from contaminated waters.
- References:** Zappi, M.E., B.C. Fleming, and C.L. Teeter, DRAFT – **Treatability of Contaminated Groundwater from the Lang Superfund Site**, USAE Waterways Experiment Station, Vicksburg, MS, 1992.
- Zappi, M.E., C.L. Teeter, and N.R. Francingues, **Biological Treatment of Contaminated Groundwater**, 1991 HMCRI Superfund Conference, Washington, D.C., 1991.
- Zappi, M.E., C.L. Teeter, B.C. Fleming, and N.R. Francingues, **Treatability of Ninth Avenue Superfund Site Groundwater**, WES Report EL-91-8, 1991.



Faust, S.D. and O.M. Aly. **Adsorption Processes for Water Treatment.** Butterworths Publishers, 1987.

Thompson, D.W. et al. **North Boundary Contaminant Treatment System Performance Report.** Rocky Mountain Arsenal, Commerce City, CA, Dec 1985.

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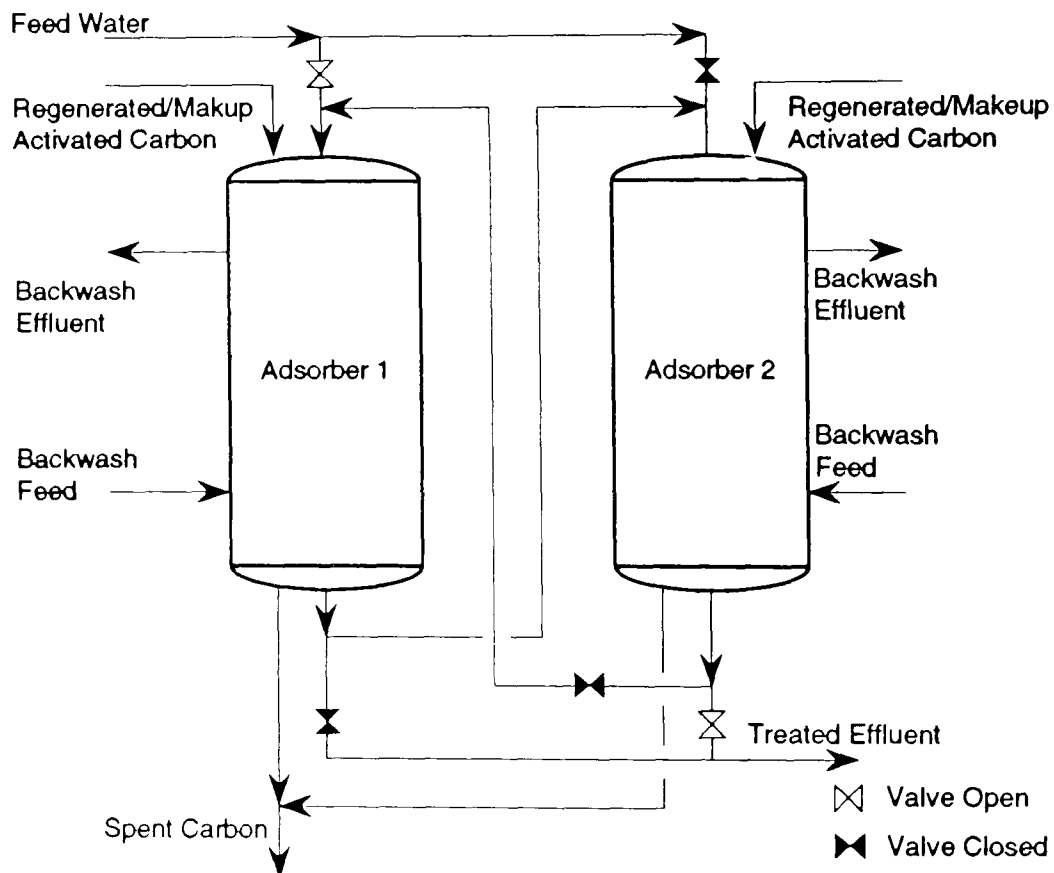


Figure 6 Schematic diagram of an activated carbon treatment system.

## 7. AIR STRIPPING, COUNTER CURRENT

**Category:** I.a. Groundwater Treatment

**Purpose:** To extract volatile contaminants from groundwater.

**Application:** Air stripping is applicable for removing volatile contaminants from contaminated wastewaters. Air purifying equipment may be required depending on air pollution criteria imposed by state and federal regulatory agencies.

**Description:** Air stripping is a phase-change technology that removes, or strips, volatile contaminants from the aqueous phase into the gas, or air, phase. Air stripping is typically configured with wastewater flowing downward and air flowing counter-currently upward through a packed column (see figure 7). Air stripping utilizes the difference in volatility of the carrier fluid and contaminants in solution to strip the contaminants into the gaseous phase. These differences are typically characterized by the relative differences in Henry's Law constants. Process design variables include column height, packing type, and air-to-water flow rate.

**Advantages:** Air stripping is a cost-effective method for removing volatile contaminants from aqueous solutions.

**Limitations:** Only volatile contaminants can be removed by air stripping. Air pollution abatement equipment may be required.

**Cost:** Capital and operating costs will depend upon the contaminant to be removed and on the volume of contaminated water to be treated.

**Availability:** The technology is commercially available.

**Status:** WES is using bench-scale air stripping units for evaluating air stripping as a treatment technology for removing volatile organic contaminants in groundwater for the Ninth Avenue Dump Superfund Site in Gary, Indiana. The Omaha District is the project sponsor in conjunction with EPA Region V. WES is also supporting the Program Manager at Rocky Mountain Arsenal (RMA) in evaluating and optimizing existing air stripping equipment currently operating at RMA.

**References:** Zappi, M.E., C.L. Teeter, B.C. Fleming, and N.R. Francingues, **Treatability of Ninth Avenue Superfund Site Groundwater**, USAE Waterways Experiment Station Report EL-91-8, 1991

Zappi, M.E., C.L. Teeter, B.C. Fleming, and N.R. Francingues, **Treatability of Ninth Avenue Superfund Site Groundwater**, USAE Waterways Experiment Station Report EL-91-8, 1991

Elliott, M.G. and E.G. Marchand. **USAF Air Stripping and Emissions Control Research**. Proc. 14th Annual Army Environmental Symposium, U.S. Army Toxic and Hazardous Materials Agency Report CETHA-TE-TR-90055, Apr 1990.

Hand, D.W. et al. **Design and Evaluation of an Air Stripping Tower for Removing VOCs from Groundwater.** *J. American Water Works Association*, Sep 1986.

Lenzo, F.C. **Air Stripping of VOCs from Groundwater: Decontaminating Polluted Water.** Presented at the 49th Annual Conference of the Indiana Water Pollution Control Association, Aug 1985.

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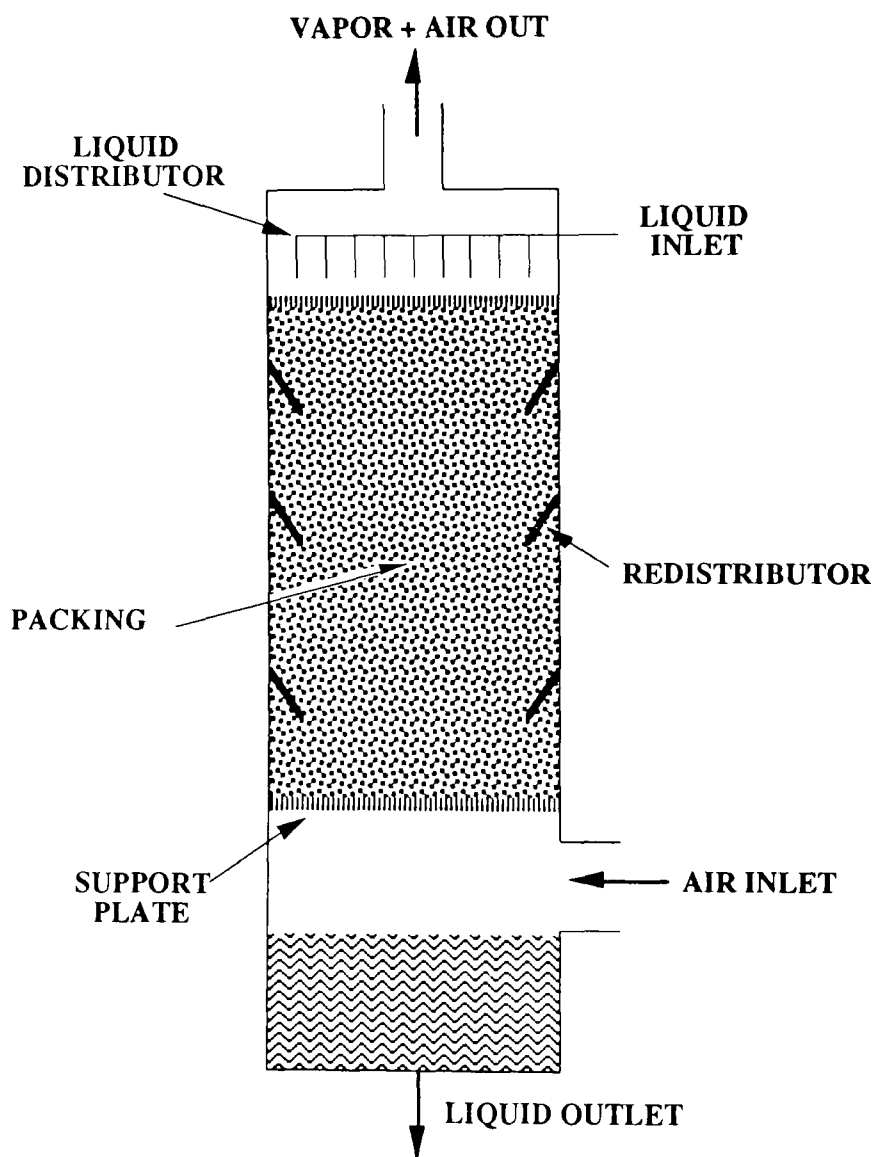


Figure 7. Schematic diagram of a typical counter-current air stripping unit.

## 8. AIR STRIPPING, ROTARY

**Category:** I.a. Groundwater Treatment

**Purpose:** The extraction of volatile contaminants from groundwater.

**Application:** Air stripping is applicable for removing volatile contaminants from water.

**Description:** A rotary air stripper is a vapor and liquid contactor which uses centrifugal force to push contaminated water through packing material while air is pushed counter current to the flow of water (see figure 8). The centrifugal force results in a high mass transfer rate of the contaminant from the water to the air. The main advantage of the rotary air stripper is the reduction in the height of the stripping equipment. Large, tall towers are inherent in conventional packed-column air stripping.

The first tests with a rotary air stripper were conducted at a contaminated site at a U.S. Coast Guard Station at Traverse City, MI. In these tests, a 100-gpm rotary air stripper showed removal of the contaminant as a function of the liquid to gas ratio and the speed (rpm) of the spinning rotor. The data showed the removal efficiency increased with an increase in the gas-to-liquid ratio up to a value of about 30 (volume/volume). Above this value, minimal increases in removal efficiencies were realized with increased gas-to-liquid ratios. A similar phenomenon was observed when assessing the effect of the rotor speed on the removal efficiency. Increasing the rotation above approximately 600 rpm produced minimal changes in the removal efficiency. In all the tests, high removal efficiencies (> 99 %) were achieved with the highly volatile contaminants (such as trichloroethylene and tetrachloroethylene), while relatively low removal efficiencies were observed for the less volatile contaminants (such as 1,2-dichloroethane). In the tests at Traverse City, only one size and type of packed rotor was used and only influent and effluent data could be taken. Because of these restrictions, a limited amount of mass transfer data could be obtained. In the field-testing of rotary air stripping at Eglin AFB, FL, three different sizes of rotors and two different types of packing materials, along with an internal sampling mechanism were used. The sizes included 9, 12, and 15-inch sponge and a wire gauze. Using the different packed rotors, data were obtained to develop and compare equations for predicting the mass transfer pressure drops and power consumption of the rotary air stripper. The equations can be used to design the size, rotating speed, air-to-water ratios, and energy necessary for a rotary air stripper to meet site specific performance requirements.

The initial expectations of the rotary air stripper were that it would be less susceptible to fouling of the packing by hardness precipitation or biological growth due to the high shear forces. This was found not to be valid during testing at Eglin AFB. Signs of plugging due to mineral deposits were observed in the rotors; however, it should be emphasized that the groundwater at Eglin AFB has a very high iron content (approximately 9 ppm) and may not provide opportunity for a fair evaluation of the device.

**Advantages:** The main advantage of the rotary air stripper is the reduction in the height of the stripping equipment enabling its placement in more confined places.

**Limitations:** Plugging due to mineral deposits was observed in the rotors; however, it should be emphasized that the groundwater at Eglin AFB has a very high iron content (approximately 9 ppm) and may not provide opportunity for a fair evaluation of the machine. Only volatile contaminants can be removed by air stripping. Air pollution abatement equipment may be required.

**Cost:** \$1.10 per gallon at a rate of 500 gallons per minute.

**Availability:** The technology is commercially available.

**Status:** Successful field tests have been conducted at Eglin AFB and at the US Coast Guard Station at Traverse City, MI.

**References:** Wilson, J.H., R.M. Counce, A.J. Lucero, H.L. Jennings, and S.P. Singh, **Air Stripping and Emissions Control Technologies: Field Testing of Counter Current Packings, Rotary Air Stripping, Catalytic Oxidation, and Adsorption Materials**, ESL TR 90-51, Nov. 1991.

Elliott, M.G. and E.G. Marchand. **USAF Air Stripping and Emissions Control Research**. Proc. 14th Annual Army Environmental Symposium, U.S. Army Toxic and Hazardous Materials Agency Report CETHA-TE-TR-90055, Apr 1990.

Singh, S.P. **Air Stripping of Volatile Organic Compounds from Groundwater: An Evaluation of a Centrifugal Vapor-Liquid Contactor**. University of Tennessee Dissertation, Knoxville, TN, Aug 1989.

Dietrich, C., D. Treichler, and J. Armstrong, **An Evaluation of Rotary Air Stripping for Removal of Volatile Organics from Groundwater**. U.S. Air Force Environmental and Service Center Report ESL-TR-86-46, Feb 1987.

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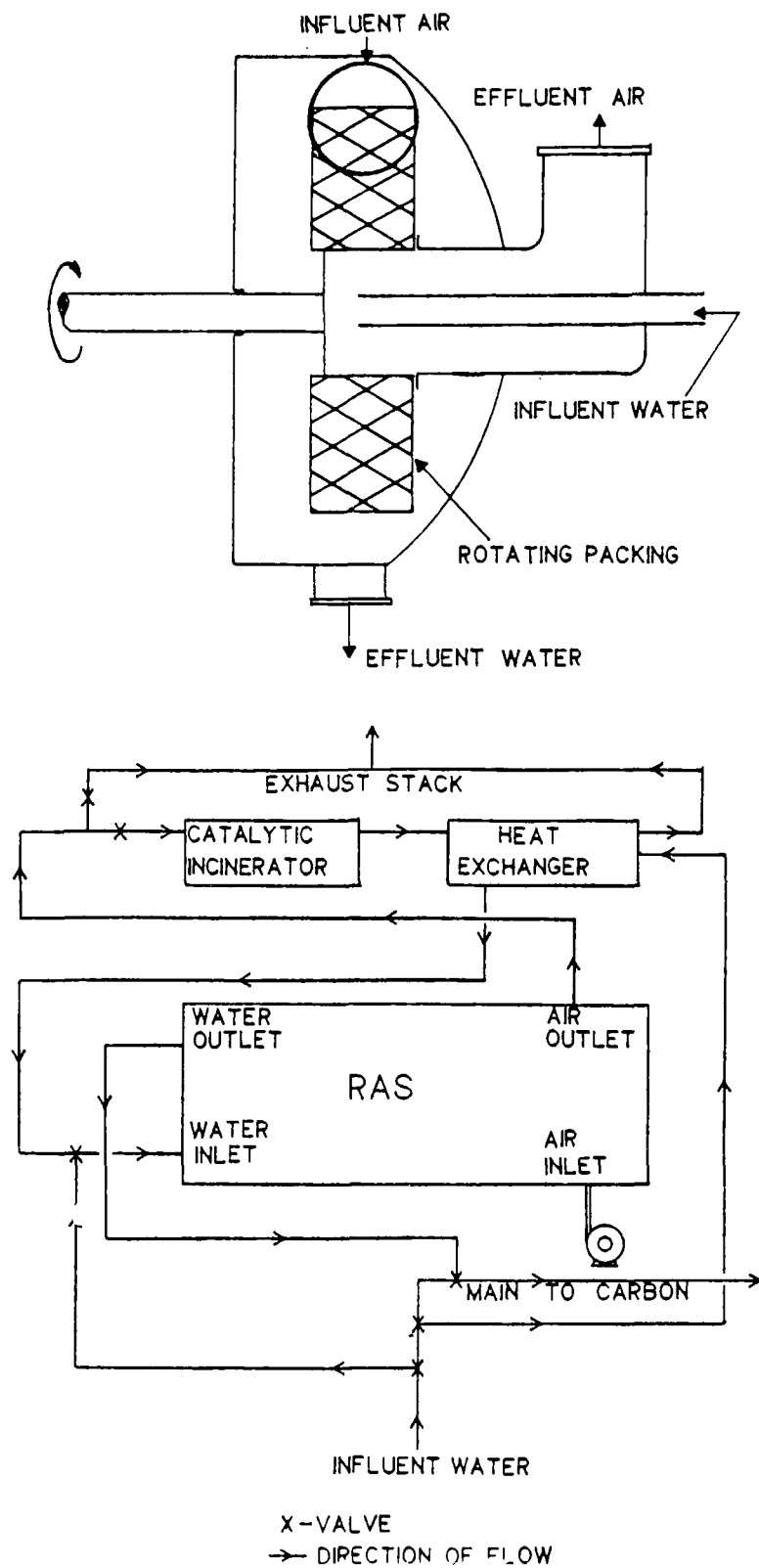


Figure 8 Schematic diagrams of the rotary air stripping unit (top) and system flow (below).

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## 9. MENU BASED PERSONAL COMPUTER DESIGN PROGRAM FOR AIR STRIPPERS

- Category:** I.a. Groundwater Treatment
- Purpose:** To facilitate the design of air stripper systems using a computer.
- Application:** This personal computer (PC) design program can be used to design air stripper units for treatment of water contaminated by volatile organic compounds (VOC).
- Description:** The computer data base contains 114 different chemicals that are known contaminants of groundwater. It also has a selection of 57 materials used as packing for air stripping columns. The computer program also contains design data for flow rates and design optimization of air stripper systems for contaminants listed in the data base. A minimum of 640 K RAM and a CGA, VGA, or EGA card are necessary to run the program on an IBM or IBM compatible PC.
- Advantages:** The program provides a fast method for designing air stripper columns for remediation of contaminated groundwater.
- Limitations:** The program is not a true expert system, i.e., it is best used by experts and not by persons unfamiliar with vapor-liquid mass transfer operations.
- Cost:** Part of the public domain.
- Availability:** For software availability, the point of contact is listed below.
- Status:** The software is completed and ready for distribution.
- References:** Dzonbak, David A., ASDC: A Microcomputer-Based Program for Air Stripper Design and Costing, AFESL Report ESL-TR 91-40, 1991.
- Contact:** Capt. Edward G. Marchand  
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## 10. BIOLOGICAL AQUEOUS TREATMENT SYSTEM

**Category:** I.a. Groundwater Treatment

**Purpose:** Decontamination of groundwater, wastewaters, lagoons, and process waters.

**Application:** This technology is applicable to a wide variety of wastewaters, including groundwater, lagoons, and process water. Contaminants amenable to treatment include pentachlorophenol, creosote components, gasoline and fuel oil components, chlorinated hydrocarbons, phenolics, and solvents. Other potential target waste streams include coal tar residues and organic pesticides.

**Description:** This patented biological treatment system is effective for treating contaminated groundwater and process water. The system uses an amended microbial mixture; i.e., a microbial population indigenous to the wastewater to which a specific microorganism has been added. This system removes the target contaminants as well as the naturally occurring background organics.

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, using a heat exchanger to minimize energy costs. The water then flows to the reactor, where the contaminants are biodegraded.

The microorganisms that perform the degradation are immobilized in a three-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 operate under anaerobic conditions.

As the water flows through the bioreactor, the contaminants are degraded to carbon dioxide, water, and chloride ion. The resulting effluent may be discharged to a Publicly Owned Treatment Works (POTW) or may be reused on site. In some cases, discharge with a National Pollutant Discharge Elimination System (NPDES) permit may be possible.

**Advantages:** Pentachlorophenol (PCP) is reduced to less than 1 ppm at all flow rates. Removal percentage was as high as 97% at the lowest flow rate.

**Limitations:** NPDES permits may be needed in some cases for discharges.

**Cost:** Not available.

**Availability:** Commercially available.

**Status:** In 1986-87, a 9-month pilot field test was successfully performed at a wood preserving facility. Since that time, several other demonstrations and commercial installations have been completed. The SITE demonstration of the technology took place from July 24 to September 1, 1989 at the MacGillis and Gibbs Superfund Site in New Brighton, MN. The system was operated continuously for 6 weeks at three different flow rates.

**References:** **Synopses of Federal Demonstrations of Innovative Site Remediation Technologies.** U.S. Environmental Protection Agency Report EPA/540/8-91/009, May 1991, pg. 12.

**The Superfund Innovative Technology Evaluation Program: Technology Profiles,** U.S. Environmental Protection Agency Report EPA/540/5-90/006, Nov 1990, pp. 24-25.

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## 11. DEWATERING/RECHARGE WELL AND TRENCH REHABILITATION AT SUPERFUND SITES

**Category:** I.a. Groundwater Treatment

**Purpose:** To rehabilitate groundwater well systems by remediating plugging due to various factors such as microbes, particulates, and precipitates.

**Application:** Well rehabilitation has been used in the petroleum industry to rejuvenate shallow wells (much of the initial research on well rejuvenation was done by the petroleum industry). Well rehabilitation can be applied to any groundwater well, whether it is a dewatering or a recharge well, in which marked reductions of system flow capacity have been observed. These processes may be used to renovate water supply wells furnishing clean water as well as those remediating contaminated water.

**Description:** Many environmental remediation scenarios used at Superfund sites involve the use of dewatering and/or injection wells. Both treated and untreated groundwaters may contain enough electron acceptors or nutrient sources to support significant microbiological populations within the well screen and packing, substantially reducing the flow capacity of the well. Significant microbiological growth also can occur in an aquifer immediately surrounding a well with significant reductions in population densities radially outward from the well. The reduction of well capacity due to excessive microbial growth is termed biofouling. Although biofouling is the most common form of well capacity reduction, other factors such as particulate clogging, cementation, metal oxide precipitation, air binding, and decreased aquifer permeability can reduce well capacity. Well rehabilitation methods exist that can return well capacity to design capacity. Common well rehabilitation methods are air and block surging. Specially designed well cleaning methods are available for addressing biofouling as well as other well clogging factors. These well rehabilitation methods use combinations of disinfecting solutions, high temperatures and pressures, and extreme surging to return fouled wells to their original capacity. Well rehabilitation can be coupled with process modifications to prevent or reduce the frequency of further well rehabilitation.

**Advantages:** Cost effective over drilling new wells.

**Limitations:** Wells never recover to 100% capacity.

**Cost:** The cost is site specific, varying from \$1,000 to \$5,000 per well.

**Availability:** The technology is commercially available.

**Status:** WES has evaluated several well rehabilitation methods for rejuvenating Corps of Engineers Districts' pressure relief wells around hydraulic structures. Research is underway to improve the recharge capacity of the North Boundary Treatment System at Rocky Mountain Arsenal (RMA) under sponsorship from the office of the Program Manager (PM).

**References:** Zappi, M.E., N.R. Francingues, and D.D. Adrian. *An Evaluation of Operational Factors Contributing to Reduced Recharge Capacity of the North Boundary*

**Treatment System, Rocky Mountain Arsenal, Commerce City, Colorado.**  
Draft Report, USAE Waterways Experiment Station, 1990.

Zappi, M.E., N.R. Francingues, and D.D. Adrian, **Reduction of Effluent Recharge Capacity at the North Boundary Treatment System, Rocky Mountain Arsenal, Commerce City Colorado**, HMCRI Hazardous Waste and materials Conference, St. Louis, MO, 1990.

Leach, R.E. and M.M. Taylor. **Proceedings of REMR Workshop on Research Priorities for Drainage System and Relief Well Problems.** USAE Waterways Experiment Station, 1989.

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## 12. FRENCH DRAIN

**Category:** I.a. Groundwater Treatment

**Purpose:** To remove floating free product from shallow groundwater.

**Application:** The method is applicable for fuels and other chlorinated or non-chlorinated hydrocarbons. The method is being used to remediate Moffett Trenches and crash crew pits at the Marine Corps Air Station (MCAS), Tustin, CA. The soils should not be highly contaminated. Rocks are not a problem except as they impact the digging of trenches. The method works best in low-permeability soils where extraction wells will not work.

**Description:** Excavation of the site is not required. Trenches are dug, generally using a back hoe; however, a chain trencher could be used as well. Slotted PVC pipe is installed in the trenches which are then backfilled with gravel and topped with clay material. The pipes drain to a central manifold for collection. Waste fuel is collected in tanks, pumped into trucks, and hauled away for recycling. To prevent contamination of the underlying high permeability aquifer at MCAS Tustin, CA, special precaution was taken so that trenches were not cut through the boundary between the upper, low-permeability clay layer and the lower, high-permeability aquifer.

**Advantages:** This method is more cost effective than excavation/treatment. Air emissions are lower than if the site were excavated. As compared with slurry wall containment, the contaminants are removed rather than immobilized. Once installed, the system is entirely below ground, and the surface can be used.

**Limitations:** A low-permeability zone below the contamination is necessary; otherwise, wells are required.

**Costs:** At Tustin, for a system of 3,500 ft of trench at a depth of 20 ft, the pre-implementation investigation required \$500,000, the engineering design required \$75,000, and total construction costs were \$1.5 million.

**Availability:** Technical details are available from NEESA.

**Status:** A system was installed at MCAS Tustin and is expected to operate for at least 30 years.

**References:** Technology transfer package in draft form should be available from NEESA in FY91.

Construction contract No. N62474-C-8658 available from NEESA.

Steve Eikenberry, Project Mgr. **Predesign Study - Moffett Trenches and Crash Crew Pits, MCAS Tustin, CA, Vol. III.** NEESA Report 17-008, December 1986.

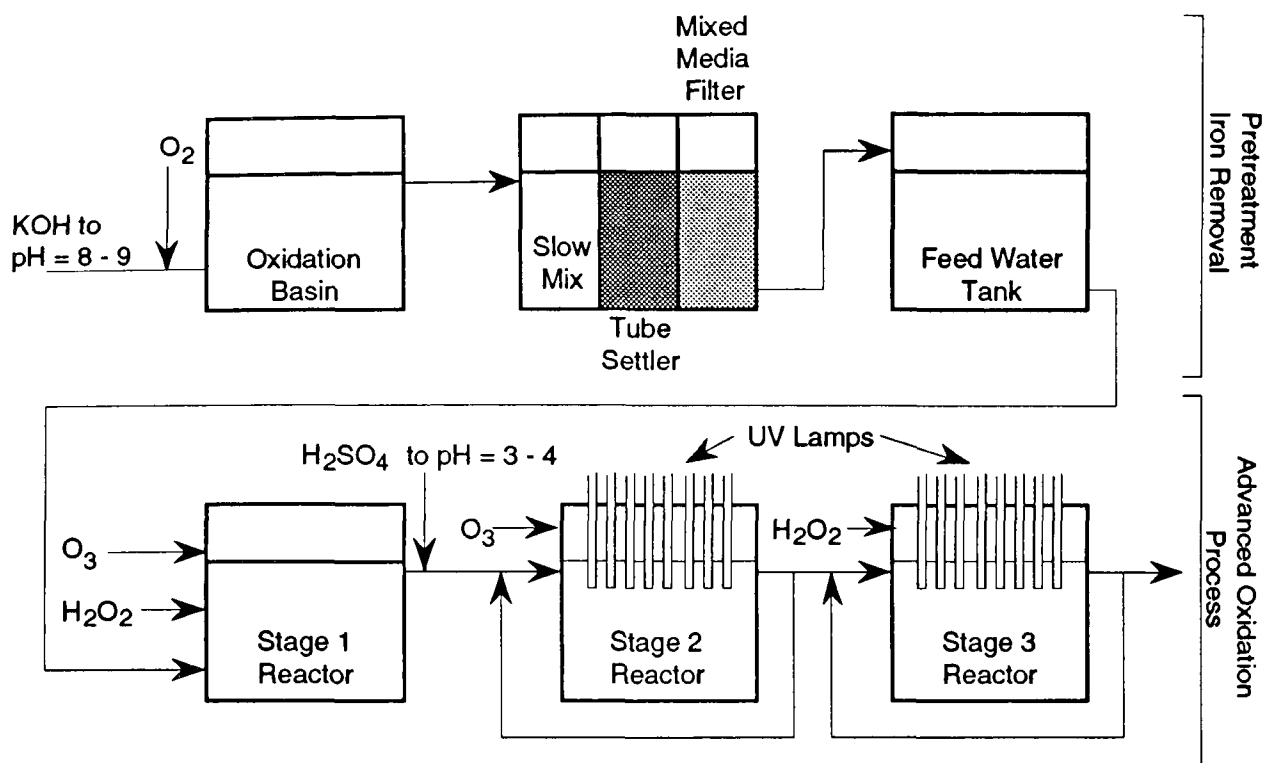
E.B. Luecker, Engineer in Charge. **Confirmation Study - Moffett Trenches and Crash Crew Pits, MCAS Tustin, CA, Vols. I and II.** NEESA Report 17-008, September 1986.

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## 13. ADVANCED OXIDATION PROCESSES

- Category:** I.a. Groundwater Treatment
- Purpose:** To remove organic contaminants from groundwater.
- Application:** The method is applicable to organic compounds, such as chlorinated hydrocarbons and other solvents and fuels, in groundwater or other water. The waste is destroyed.
- Description:** The method utilizes ultraviolet (UV) light, ozone, and hydrogen peroxide in various combinations depending on the waste. A staged approach is followed: total organic compounds (TOC), carbonyls, and organic acids are tracked by gas chromatography. The process can be optimized to reduce waste and cost. TOC levels in the laboratory are reduced from 30 to 50 ppm to below 1 ppm. In pilot-plant studies, TOCs are reduced from 30 ppm to less than 0.1 ppm. A flow schematic for the pilot plant is shown in figure 13.
- Advantages:** The method is clean, i.e., no harmful byproducts are produced other than very small quantities of iron during pretreatment.
- Limitations:** The method is not applicable for highly concentrated waste streams having TOCs greater than about 100 ppm.
- Costs:** Exact cost information is not available. The costs will depend on the waste and its concentration.
- Availability:** Equipment is commercially available.
- Status:** Laboratory testing was conducted at the University of Illinois, Champaign, in FY90. Field-pilot studies were conducted at Lakehurst NAEC in FY91.
- References:** Peyton, Gary R. and Andy Law. **Initial Feasibility Report: Investigation of Photochemical Oxidative Techniques for Treatment of Contaminated Groundwater.** NCEL Technical Memorandum TM-71-90-9, Sep 1990.
- A pilot-plant report will be available in FY92.
- Contact:** Dr. Andy Law  
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Environmental Restoration Division, Code L71  
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**Figure 13.** Flow schematic of advanced oxidation process pilot plant, Lakehurst Naval Air Engineering Center.

## 14. ULTRAVIOLET/OZONE/HYDROGEN PEROXIDE OXIDATION

- Category:** I.a. Groundwater treatment  
II.b. Minimization or Treatment of Munition Production and/or Handling Waste Streams  
II.d. Minimization or Treatment of Other Liquid Waste
- Purpose:** To remove organic contaminants from groundwater and liquid waste streams.
- Application:** Ultraviolet (UV) oxidation is suitable for a wide variety of wastewaters containing low to high concentrations of organic compounds. UV oxidation is capable of destroying many organic compounds that are traditionally very difficult to treat. In-line treatment of organic pollutants by the UV oxidation process may be used for liquid waste minimization before organics become pollutants in groundwater (see also technical notes #13 and #15).
- Description:** UV/Ozone/Hydrogen Peroxide Oxidation, also known as UV oxidation, is a destruction process that oxidizes organic constituents in wastewaters by the addition of strong oxidizers and irradiation with intense UV light. The oxidation reactions are catalyzed by UV light, while ozone ( $O_3$ ) and/or hydrogen peroxide ( $H_2O_2$ ) are commonly used together or separately as oxidizing agents. The final products of oxidation are carbon dioxide and water. The main advantage of UV oxidation is that since the process is a destruction process, no contaminants or waste streams are released during oxidation of the contaminants. UV oxidation processes can be configured in batch or continuous flow modes. Design and operational parameters include: contact or retention time, oxidizer influent dosages, pH, temperature, UV lamp intensity, and various catalysts. Destruction of contaminants using UV oxidation meets or exceeds detection limits.
- Advantages:** The UV oxidation process is a destruction technology for difficult-to-treat contaminants. This process will treat a larger variety of contaminants than some other processes.
- Limitations:** The UV oxidation process has the potential for production of hazardous intermediate compounds if the system is not properly operated. Pretreatment of contaminated material may be necessary, depending on the chemistry of the water. Off gasses may be a pollution problem when  $O_3$  is used for oxidation.
- Cost:** Costs will vary with run time and oxidizer dosage; however, costs generally run between \$0.10/1,000 gal to \$10.00/1,000 gal.
- Availability:** The technology is commercially available. The technology described in technical note #15, "Ultraviolet/Oxidation (ULTROX)," is one of the commercially available systems in the general category of UV oxidation.
- Status:** WES has performed several treatability studies using chemical oxidation, including: (a) UV/hydrogen peroxide oxidation of four contaminated waters from Rocky Mountain Arsenal; (b) photolysis of n-nitrosodimethylamine-contaminated groundwater; (c) UV/hydrogen peroxide oxidation of contaminated groundwater from the Lang Superfund Site; (d) UV/ozone oxidation of Well 118 groundwater from Rocky Mountain Arsenal; (e) UV/ozone and UV/hydrogen peroxide oxidation of RDX-

contaminated groundwater from Piccatinny Arsenal; (f) ozone/hydrogen peroxide (peroxone), UV/ozone, and UV/hydrogen peroxide oxidation of diisopropylmethylphosphonate (DIMP)-contaminated groundwater from Rocky Mountain Arsenal; (g) ozone/hydrogen peroxide (peroxone), UV/ozone, and UV/hydrogen peroxide oxidation of diisopropyl-methylphosphonate (DIMP), aromatic hydrocarbon, and chlorinated solvent-contaminated groundwater from Rocky Mountain Arsenal in support of the Feasibility Study; and (h) WES is currently performing research on chemical oxidation of TNT- and RDX- contaminated groundwaters under the Army's Environmental Quality and Technology Program.

**References:** Zappi, M.E., E.C. Fleming, and M.J. Cullinane. **Treatment of Contaminated Groundwater Using Chemical Oxidation.** 1992 ASCE Water Forum Conference, Baltimore, MD, 1992

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## 15. ULTRAVIOLET OXIDATION (ULTROX)

**Category:** I.a. Groundwater Treatment

**Purpose:** To destroy toxic organic compounds, especially chlorinated hydrocarbons, in water.

**Application:** Contaminated groundwater, industrial wastewaters, and leachates containing explosives, halogenated solvents, phenol, pentachlorophenol, pesticides, polychlorinated biphenyls (PCB), and other organic compounds are suitable for this treatment process.

**Description:** This ultraviolet (UV) radiation/oxidation process uses UV radiation, ozone ( $O_3$ ), and hydrogen peroxide ( $H_2O_2$ ) to destroy toxic organic compounds, especially chlorinated hydrocarbons, in water. The process oxidizes compounds that are toxic or refractory (resistant to biological oxidation) in concentrations of parts per million or parts per billion. The ULTROX system consists of a reactor module, an air compressor/ozone generator module, and a hydrogen peroxide feed system (see figure 15). It is skid-mounted and portable and enables on site treatment of a wide variety of liquid wastes, such as industrial wastewater, groundwater, and leachate. The reactor size is determined from the expected wastewater flow rate and the necessary hydraulic retention time to treat the contaminated water. The approximate UV intensity and  $O_3$  and  $H_2O_2$  dose are determined from pilot-scale studies. Influent to the reactor is simultaneously exposed to UV radiation,  $O_3$ , and  $H_2O_2$  to oxidize the organic compounds. Off-gas from the reactor passes through an  $O_3$  destruction (Decompozon) unit, which reduces ozone levels before air venting. The Decompozon unit also destroys gaseous volatile organic compounds (VOC) stripped off in the reactor. Effluent from the reactor is suitable for recharge of an aquifer or discharge to surface waters. Contaminated groundwater treated by the ULTROX system met regulatory standards. Removal efficiencies for total VOCs were about 90%. For some compounds, removal from the water phase was due to both chemical oxidation and stripping. The Decompozon unit reduced ozone to less than 0.1 ppm (OSHA standards), with efficiencies greater than 99.99%. VOCs present in the air within the treatment system, at approximately 0.1 to 0.5 ppm, were not detected after passing through the Decompozon unit. Very low total organic carbon (TOC) removal was found, because the organic carbon associated with VOCs was < 2% of the TOC. The TOC data was not adequate to conclude if complete oxidation of VOCs occurred in the system. The average electrical energy consumption was about 11 kW/hour of operation. This system is one of the commercially available systems in the general category of UV oxidation (see note #14).

**Advantages:** Contaminated groundwater treated by the ULTROX system met regulatory standards. Removal efficiencies for trichloroethylene were about 99%. The Decompozon unit reduced ozone to less than 0.1 ppm (OSHA standards), with efficiencies greater than 99.99% (see also advantages in note #14). Treatment residuals, such as spent carbon, sludge, etc., are not generated by this process as they are by carbon adsorption or biological treatment processes.

**Limitations:** Removal efficiencies for 1,1-DCA and 1,1,1-TCA were about 58 and 85%, respectively. Removal efficiencies for total VOCs were about 90%.

**Cost:** Costs will vary with run time and oxidizer dosage.

**Availability:** This technology is commercially available.

**Status:** A field-scale demonstration was completed in March 1989 at a hazardous waste site in San Jose, CA. The test program was designed to evaluate the performance of the ULTROX System at several combinations of five operating parameters: (1) influent pH, (2) retention time, (3) O<sub>3</sub> dose, (4) H<sub>2</sub> O<sub>2</sub> dose, and (5) UV radiation intensity. WES has evaluated this technology at several sites. Results indicate that UV/ozone is an attractive alternative to air stripping and activated carbon adsorption.

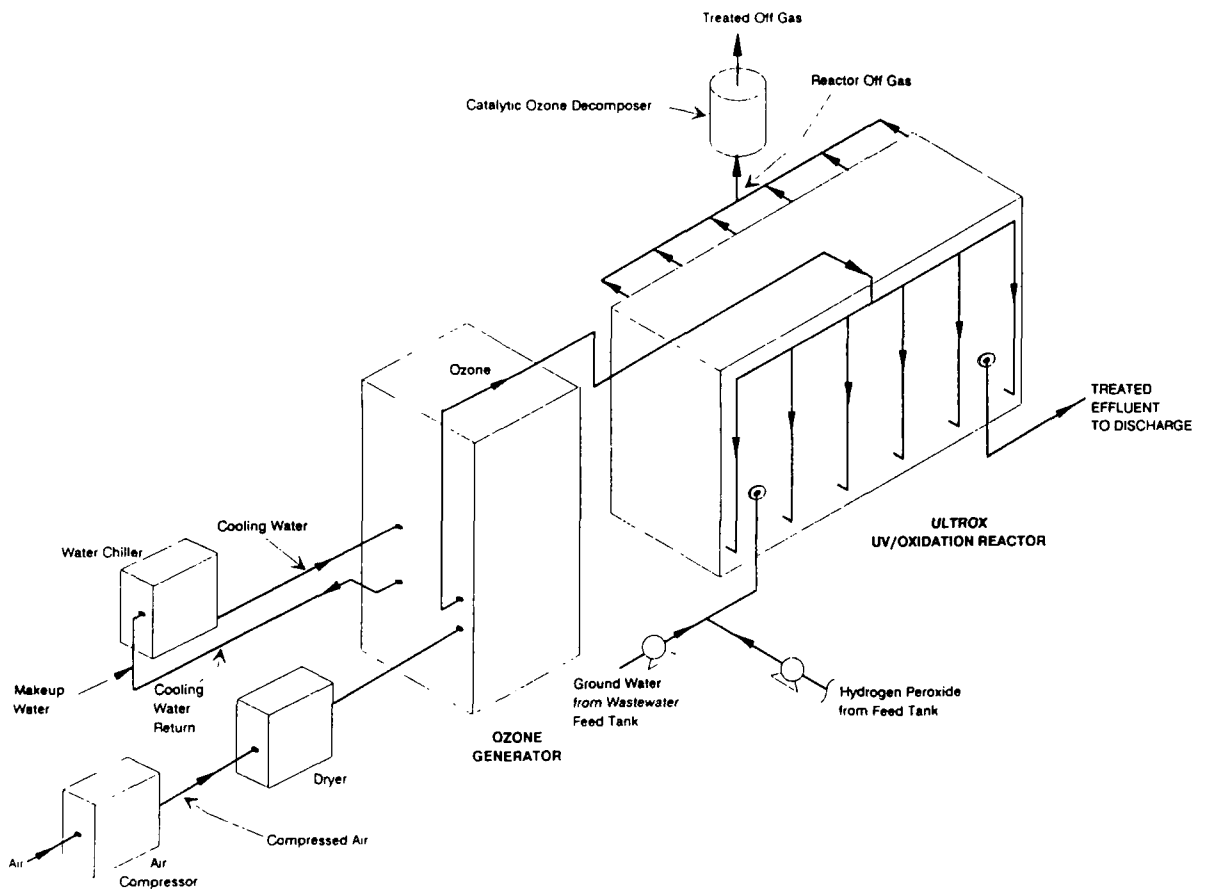
**References:** Zappi, M.E., E.C. Fleming, and M.J. Cullinane. **Treatment of Contaminated Groundwater Using Chemical Oxidation.** 1992 ASCE Water Forum Conference, Baltimore, MD, 1992

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*Figure 15. Isometric view of ULTROX system.*

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## 16. ELECTROKINETICS (EK)

**Category:** I.a. Groundwater Treatment  
I.b. Soil Treatment

**Purpose:** To treat or assist in treating organic- and inorganic-contaminated soils in situ and as a barrier system to control contaminated aquifers.

**Application:** This technology may be used as an in situ means of removing heavy metals, organic compounds and explosives from contaminated soils. Also, WES is evaluating using electrokinetics (EK) as a means of introducing additives required for establishing biologically active zones in relatively tight soils during in situ bioremediation activities.

**Description:** This technology was essentially developed during World War II by the Germans to stabilize Norwegian railroad beds. It has been used since by geotechnical engineers as a means of dewatering fine-grained soils or stabilizing banks.

The technology involves installation of an anode and cathode within the soil matrix to be treated. An electrical potential across the two electrodes is initiated. The voltage potential across the target area can cause several processes to be initiated depending on the soil matrix, including: (1) movement of water through soil systems at rates much faster than obtainable using hydraulic heads, (2) removal of contaminants through the pore water or water films at a rate much faster than the water phase, and (3) development of an acid front that moves through the treatment zone.

**Advantages:** EK can be applied in-situ, i.e., without excavation of the soils. Preliminary studies indicate that this technology can be performed in both saturated and unsaturated soils.

**Limitations:** Being an innovative technology in terms of site remediation, little performance, design, and cost information is available. Also, there is little information on how low a level of contamination can be attained using this technology.

**Cost:** At a recent DOE working group meeting, remediation costs for this technology were estimated in the \$45/yd<sup>3</sup> range. Actual cost estimates are not yet available, but pilot and bench studies should produce more accurate cost estimates.

**Availability:** EK technology is commercially available on a limited scale in the United States; the European Community apparently has more established vendors with some application experience.

**Status:** During the DOE EK Workshop, it was reported that the Russians are using this technology to move radioactive species downward into clay lenses as a means of eliminating mobility. To date they reportedly have remediated several thousand square kilometers using EK. There are three commercial vendors of the technology within the U.S with limited field experience. EK has been used on the pilot scale successfully to remediate heavy metals-contaminated soils and to form hydraulic barriers. WES is currently investigating the potential uses of EK for site remediation.



**References:** Loo, W.W, **Electrochemical Treatment of Metals and Organic Compounds in Soil, Sludges, and Groundwater.** 1991 HMCRI Hazardous Materials Control/Superfund Conference, Washington, DC, 1991.

Acar, Y.B., Hamed, J., and Gale, R.J., **Electrokinetic Soil Processing: An emerging Technology in Waste Remediation.** Proc. from the Hazmat 90 Conference, June 5-7, 1990.

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## 17. MICROBIAL CONSORTIA DEVELOPMENT AND APPLICATION

**Category:** I.a. Groundwater Treatment  
I.b. Soil Treatment

**Purpose:** Existing biotreatment procedures for removal of hazardous organic contaminants from soils and groundwater rely on native populations which take time to grow in response to treatment conditions or on addition of exotic microorganisms that have poor to nonexistent survival in foreign soils and waters. A technology to rapidly isolate, characterize, and add effective native microorganisms in large numbers to the soil or water to be treated is needed.

**Application:** This procedure is applicable to all hazardous organic contaminants for which effective microorganisms can be isolated.

**Description:** Organisms are isolated from the soil or water to be treated using elective culture methods specific for the compound(s) to be degraded.

The organisms are characterized as to physiological properties and their ability to form desirable (not toxic) intermediate and final products and by-products. The organisms are then grown in large quantities and added to bench-scale systems to determine their effectiveness before using at the pilot and/or demonstration scale.

This procedure is applicable to restoration methods that involve either in situ biotreatment or excavation, biotreatment, and disposal technologies. WES or other outside agencies/contractors will often be required to obtain microbial isolates effective in removing the contaminant. Once this has been achieved, the actual treatment may often be performed by site personnel. Alternatively, outside contractors may be utilized. The specific soil type, presence of drums or other objects, and the time required are all site-specific and must be addressed on a case-by-case basis. If the correct microorganisms are obtained, the contaminant will ultimately be converted to carbon dioxide or methane and water, plus nitrate or nitrogen gas, if nitrogen containing compounds are present.

This procedure can be applied to waste treatment. However, the amount of waste reduction, the level of contaminants in the waste, and the final disposition of the waste are all dependent on the biotreatment system in which the microorganisms are utilized. Any instrumentation involved is associated with the specific biotreatment system in which the microbial isolates are utilized. Specific risk assessment strategies applied are dependent on the biotreatment system in which the microbial isolates are utilized.

**Advantages:** Biotreatment systems using microbial isolates specific for the contaminant and the soil/water being treated will be more effective than other biotreatment systems. This should result in a significant increase in treatment effectiveness, shorter retention times, and reduced costs. The exact amount of such cost reductions are not available at present.

**Limitations:** The method will not work for soils and waters that have received levels of waste that have been so concentrated as to kill off all native microbial populations.

**Cost:** Cost will be site specific.

**Availability:** Personnel will have to be trained in implementation of the procedures, once routine practices have been developed.

**Status:** Conceptual phase at the USAE Waterways Experiment Station Vicksburg, MS.

**References:** Journal articles and symposia proceedings will be produced over the next 2 years.

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## 18. ON SITE BIOREMEDIATION OF UNLEADED GASOLINE SPILLS

**Category:** I.a. Groundwater Treatment  
I.b. Soil Treatment

**Purpose:** To remediate unleaded gasoline spills

**Application:** The process is applicable to aromatic fuel components in groundwater and soil.

**Description:** The process entails aerobic and anaerobic bioremediation. The demonstration at Naval Weapons Station Seal Beach, CA, utilized four pilot-scale reactors at the site and indigenous microbial species: one aerobic and three anaerobic (methanogenic, nitrate reducing, and sulfate reducing). Nutrients, including nitrogen, phosphorus, and hydrogen peroxide in the aerobic case, are added. The reactors, loaded with a volume of about 84 L of contaminated zone soil, are made of stainless steel having a diameter of 12 inches and are operated in an upward flow mode (see figure 18).

**Advantages:** The method is inexpensive and not labor intensive. Excavation is not required. Aromatic components in the aerobic reactor effluent were reduced to 10% of influent concentrations.

**Limitations:** Only aromatics were degraded. The concentration is limited, i.e., no free product can be introduced to the reactor.

**Cost:** Process costs have not been determined.

**Availability:** Technical information is available from the Naval Civil Engineering Laboratory.

**Status:** Pilot-scale testing is in progress at Naval Weapons Station Seal Beach, CA.

**References:** Huxley, M.P. et al. **Anaerobic and Aerobic Degradation of Aromatic Hydrocarbons Using In-Situ Bioreactors at an Unleaded Gasoline Spill Site.** Proc. 18th Environmental Symposium and Exhibition, Feb 1992.

**Contact:** Mary Pat Huxley and Carmen Lebron  
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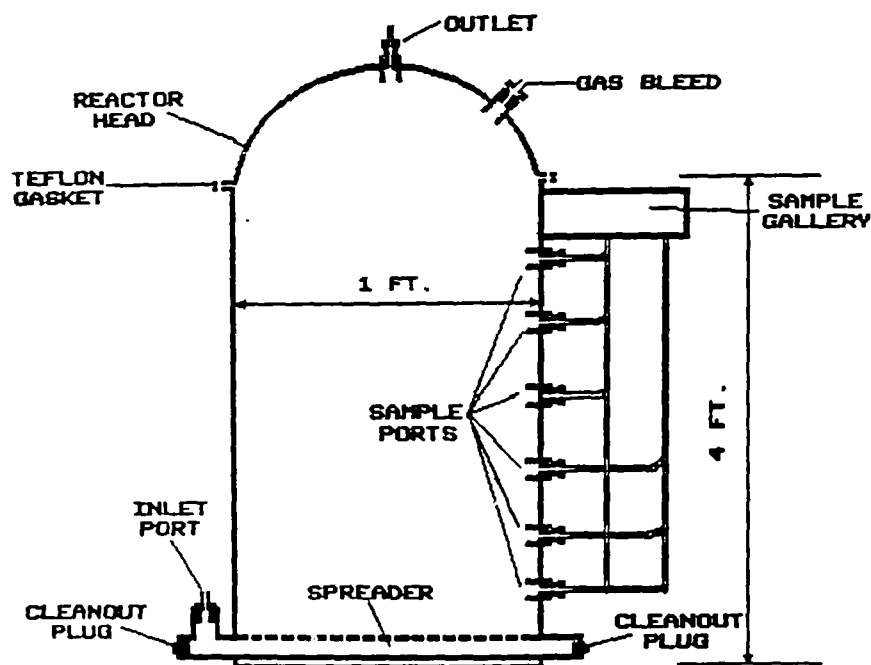


Figure 18a. Schematic diagram of bioreactor.

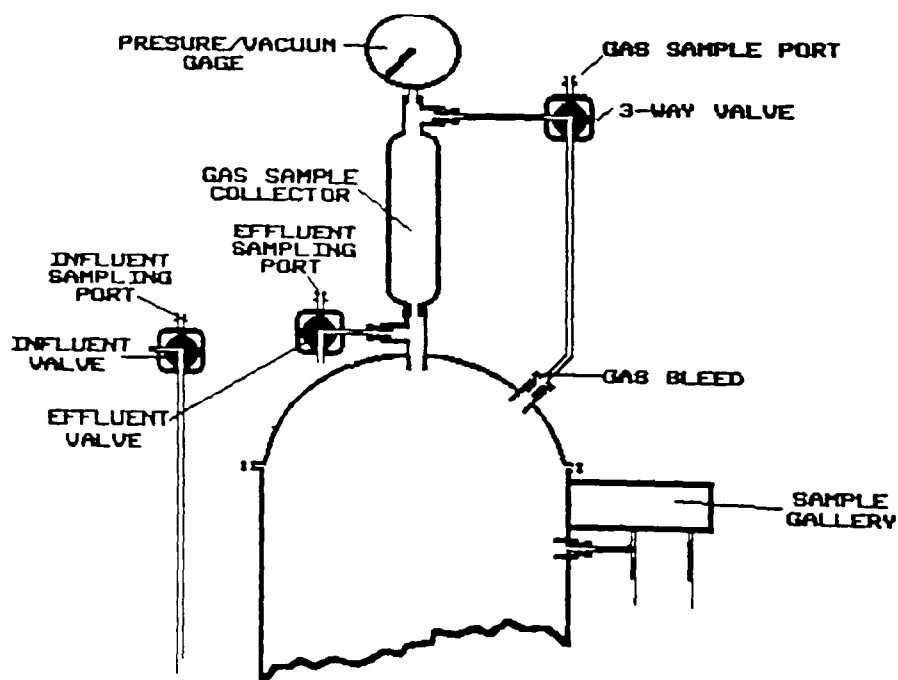


Figure 18b. Modifications made to bioreactor design.

## 19. BIOLOGICAL TREATMENT FOR GROUNDWATER REMEDIATION

- Category:** I.a. Groundwater treatment  
I.b. Soils treatment
- Purpose:** To remove organic contaminants from groundwater, surface water, and soils.
- Application:** Biological treatment is suitable for moderately to highly contaminated organic wastewater. Biological treatment has been used in small research capacities for heavy metals removal and reclamation. Biological treatment can be a very cost-effective process which offers a high degree of flexibility.
- Description:** Biological treatment technologies incorporate acclimated bacteria that use contaminant in wastewater as their food source. Biological treatment can be implemented in a variety of flow configurations and microbiological systems. Biotreatment can be operated in anaerobic and aerobic conditions, depending on microbial type and treatment requirements. Aerobic treatment is usually more successful in degrading complex organic compounds. Activated sludge is the most common form of aerobic biological treatment in which large microbial populations are kept in suspension in an aeration tank by means of diffused air bubbling through the tank (see figure 19). The success of any biological treatment technology is dependent on the ability of the microbial populations to use the contaminants of concern in the wastewater as a food source. The feasibility of biotreatment, along with bacteria acclimation rates, nutrient addition rates, and process design biological kinetic constants are typically determined in bench-scale treatability tests. Biological treatment ultimately results in destruction of organic contaminants. Contaminants are destroyed at or below detection limits. Time necessary for complete destruction of organic contaminants is site specific. Contaminated media may be excavated, pumped, or dredged for remediation in a bioreactor that is designed for site-specific contaminant conditions. Personnel will need training similar to that provided for those working at municipal sewage disposal plants.
- Advantages:** This is a destruction process that is cost effective and flexible, since contaminants serve as food for microbes.
- Limitations:** Some contaminants are not biodegradable. Some contaminants are incompletely degraded, forming intermediate compounds that may pose environmental problems. Some contaminants may need to be biodegraded in several stages by different microbes.
- Cost:** Capital costs are estimated to be \$6.3 million for a 1,000-gal/d unit. Operation and maintenance costs are estimated to be \$0.0165/gal.
- Availability:** Process is commercially available.
- Status:** Bench-scale pilot testing has been conducted at WES. WES also has performed field studies concerning intermittent loading of bioreactors. Treatability studies have been performed using biological processes for treatment of contaminated groundwater from numerous military and Superfund sites. WES is currently developing a zero-head bioreactor for treatment of volatile organic compounds.

**References:** Zappi, M.E., B.C. Fleming, and C.L. Teeter, **Treatability of Contaminated Groundwater From The Lang Superfund Site**, Draft Report, USAE Waterways Experiment Station, Vicksburg, MS, 1992.

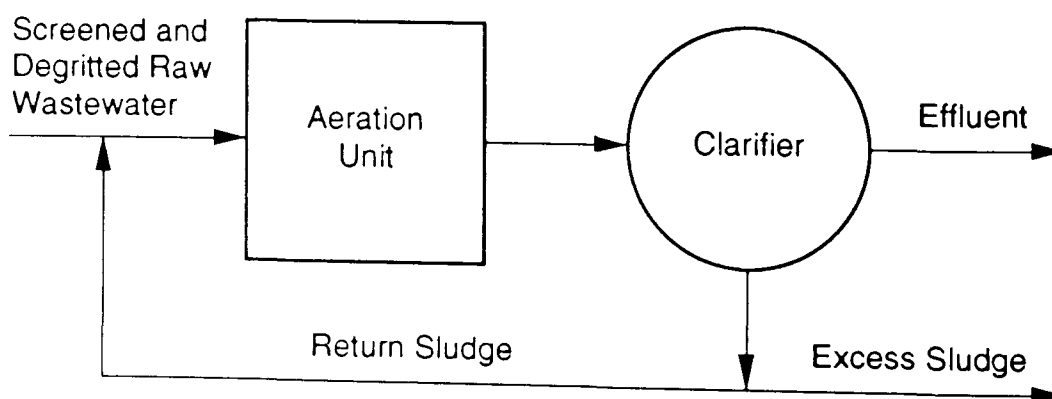
Zappi, M.E., C.L. Teeter, B.C. Flemming, and N.R. Francingues. **Treatability of Ninth Avenue Superfund Site Groundwater**. WES Report No. EL-91-8, USAE Waterways Experiment Station, 1991.

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*Figure 19. Schematic diagram of an activated sludge treatment system.*

## 20. IN SITU BIOTREATMENT OF PETROLEUM, OILS, AND LUBRICANTS

**Category:** I.a. Groundwater Treatment  
I.b. Soil Treatment

**Purpose:** To remove petroleum, oils, and lubricants (POL) from contaminated soil and groundwater.

**Application:** This process is best for treating fuels with high aromatic content, such as gasoline and other soluble organic components of POL. It is not recommended for in situ treatment of hydrophobic fuel components having soil concentrations greater than 0.05 % or highly viscous hydrocarbons.

**Description:** **Aerobic Treatment** – At locations where fuel contamination levels are low (less than 0.01% for JP-5), contaminants are water soluble. As a follow-up to soil venting, nutrients and an oxygen source can be injected with water into the zone of contamination (see figure 20). Groundwater pumped down-gradient from the injection wells can serve as the water source, thus providing a controlled, closed loop for groundwater flow. The groundwater is usually treated and clarified prior to reinjection into the subsurface at locations up gradient of the recovery wells. Reinjection methods include use of surface spray irrigation, shallow infiltration galleries with large exposed surface area, or large-diameter injection wells. Permit requirements for injection frequently include meeting drinking water quality standards. Oxygen sources for aerobic in situ biodegradation include phosphate-stabilized hydrogen peroxide ( $H_2O_2$ ) and air or pure oxygen sparging of groundwater. Air sparging saturates water with only about 10 ppm of oxygen compared with up to 5 and 50 times this concentration when pure oxygen and  $H_2O_2$  are used, respectively.  $H_2O_2$  is toxic at less than 100 ppm to some microorganisms, and stabilized hydrogen peroxide seems to be susceptible to rapid microbial breakdown. Point-source addition of  $H_2O_2$  also may cause precipitation of iron oxides or slimy bacterial growth that can plug injection zones. Surfactant compounds produced by microorganisms can help to emulsify and remove poorly soluble contaminants from the contaminated soil profile. The addition of synthetic surfactants to the soil should increase availability of contaminants to the soil microorganisms, but some can be toxic while others provide a preferential food source, inhibiting biodegradation of the contaminant. More research is needed on both synthetic and natural surfactant use in bioremediation. In situ aerobic bioremediation of fuels and chlorinated VOCs is also being investigated through bioventing (see note #37). Similar to soil venting but controlled at much slower rates of air injection and vacuum, it stimulates biodegradation in both vadose and saturated zones.

**Anaerobic Processes** – Research is being conducted concerning the mechanisms by which anaerobic microbes can be coaxed into performing more rapid degradation of fuels. Recent data have shown that most fuel components are biodegradable under anaerobic conditions, when nitrate, carbon dioxide, or other oxidized substrates are used as oxygen sources for microbial respiration instead of molecular oxygen. These compounds provide a stable source of oxygen and nitrogen to the subsurface. Nitrate is considerably more stable than hydrogen peroxide in groundwater, and its horizontal flow with the groundwater could serve as a means to supply nitrogen and



oxygen to the areas of subsurface contamination. This process will be field tested by the Navy shortly.

**Mixed or Sequential Processes** – Many highly chlorinated toxic contaminants, such as perchloroethylene (PCE) and higher chlorinated polychlorinated biphenyls (PCB), appear to be degraded only under anaerobic conditions. The limiting step in the biodegradation, removal of chlorine atoms, is performed through reductive dechlorination. The lower chlorinated molecules that result are only slowly dechlorinated and degraded further. Anaerobic degradation of trichloroethylene (TCE) often promotes the accumulation of vinyl chloride, a carcinogen. Vinyl chloride and other organic compounds containing low percentages of chlorination tend to be degraded most rapidly under aerobic conditions, through oxidative enzyme processes. Therefore, highly chlorinated toxic organics may be biodegraded at accelerated rates by using serial or batch treatment techniques. The first step may be an anaerobic process, followed by aerobic conditions that support the degrading microbial population.

**Advantages:** Aerobic – soluble contaminants can be flushed through unsaturated soil and biodegraded in situ; groundwater can be treated simultaneously. Anaerobic – labor-intensive oxygen injection is avoided; nutrients and oxygen source can be added in situ simultaneously. Mixed processes – highly chlorinated organic compounds in water or extracted vapor may be biodegraded at rapid rates through aerobic-anaerobic processes.

**Limitations:** Inability to supply sufficient oxygen to groundwater for aerobic biodegradation.  $H_2$   $O_2$  breaks down rapidly in soils. High concentrations of hydrocarbons prevent contact between microbes and contaminants and water does not penetrate water-immiscible hydrocarbons effectively. Aerobic processes require highly permeable (sandy) soils or reworking of the soils to increase permeability.

**Cost:** Costs will depend upon local conditions and specific applications.

**Availability:** Technical information regarding implementation is available from WES or NCEL.

**Status:** Bench-scale pilot testing has been conducted by Battelle – large soil columns 1 ft. x 3 ft. comparing hydrogen peroxide treatment with soil venting. The anaerobic system was field-tested at DFSP Charleston, SC, and NWS Seal Beach, CA, in FY90 and FY91. WES is currently evaluating the feasibility of treating hydrocarbons at an Army installation using in situ biotreatment.

**References:** Zappi, M.E. et al. **An Assessment of the Applications Potential of In Situ Biotreatment for Remediation of Saturated Aquifers.** 15th Annual Army Environmental R&D Symposium, Williamsburg, VA, 1991.

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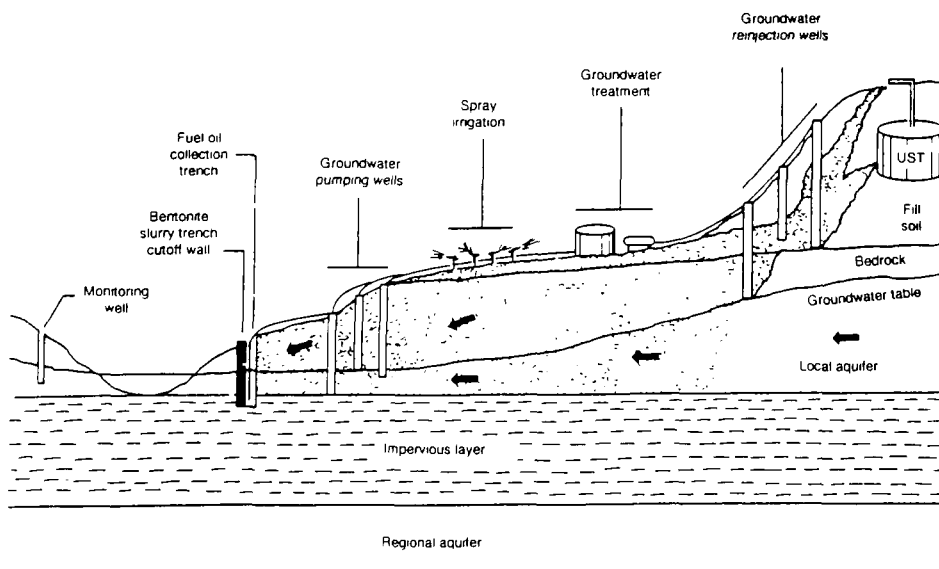


Figure 20. *In situ bioreclamation of fuel oil contaminated soil and groundwater (Hoeppel, 1989).*

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## 21. IN-SITU BIOTREATMENT OF ORGANICS AND EXPLOSIVES

**Category:** I.a. Groundwater Treatment  
I.b. Soil Treatment

**Purpose:** To reclaim in situ soil and groundwater contaminated with fuel, fuel oil, or other organic compounds.

**Application:** In situ biodegradation (ISB) is applicable to treatment of soils or sediments contaminated with organic compounds known to be susceptible to biodegradation. In some cases, it may be desirable to use laboratory testing procedures to establish the potential for ISB of organic compounds that are more refractory (recalcitrant) in nature. Applications could include fuel spills, leaky storage tanks, and fire training pits. The method probably is not applicable to waste disposal pits.

**Description:** ISB involves enhancement of environmental conditions that facilitate biodegradation of organic contaminants by native or exotic soil or sediment microorganisms. Aerobic degradation is normally the most efficient means by which microorganisms break down organic contaminants. Direct exposure to the atmosphere is one means to provide aerobic conditions for ISB, and this can be attained by procedures that improve exposure to the atmosphere and improve drainage. For flooded or poorly drained soils or subsurface soils, it may not always be possible to provide direct exposure to atmospheric oxygen. In such situations, ISB can be enhanced by providing alternate electron acceptors, such as nitrate or hydrogen peroxide, to the system (see figure 21). The efficiency of ISB enhancement procedures can be tested in laboratory reactors before scale-up for field application is carried out.

Nutrients (especially nitrogen and phosphorus), soil-conditioning chemicals, and hydrogen peroxide can be introduced through infiltration wells, ditches, or soil surface irrigation. Another source of oxygen for aerobic biodegradation may be fresh air introduced during the process of soil venting for remediation of volatile organic compounds (VOCs) from the soil. Pumping wells remove excess fluids or contaminated groundwater. Contaminated water can be treated on the surface or reinjected for treatment in the soil. Monitoring wells must be placed within and surrounding the site. Increased fluid throughput might be accomplished by surface spray irrigation techniques. Although every pound of hydrocarbon contaminant requires about 10 pounds of molecular oxygen for complete degradation, in practice, more oxygen will be required to satisfy other demands, such as oxidation of iron.

**Advantages:** In practice, ISB is an enhancement of the natural biodegradation process. Excavation is not required. The resulting products are not toxic. Contaminant concentrations are reported to have been reduced by bacteria to less than 1 ppm (see references). Theoretically, treatment of soil contaminants in situ can be accomplished faster than the long-term flushing required for surface-based water treatment. Therefore, ISB is a cost-effective technology.

**Limitations:** Some site conditions may inhibit application of ISB technology. Excessive time may be required for biodegradation. High calcium, magnesium, or iron concentrations in the soils, and plugging and loss of soil permeability limit the effectiveness of the method. Currently, the method is limited primarily to sandy soils having a hydraulic

conductivity of at least 0.0001 cm/s. Some mobilization of heavy metals, especially antimony, can occur. Metal sulfides might be released due to sulfide oxidation.

The applicability is site-specific. Laboratory tests on the target soil and contaminants should be conducted prior to using the method in the field. A pilot test, consisting of at least one injection and one production well, conducted before implementation is recommended. The method requires considerable oxygen. Daily maintenance might be necessary if hydrogen peroxide is in the lines and pumps and if special materials are not used.

**Cost:** The cost varies depending on site-specific conditions.

**Availability:** The method is still under development, but with some commercial availability.

**Status:** The Waterways Experiment Station (WES) currently is assisting the US Navy in evaluation of anaerobic ISB for cleanup of a gasoline spill from an underground tank located in a wetland area. Demonstration units of both the controlled oxidation-reduction potential-pH and percolation column reactors will be running at WES during May and June 1990. The method was implemented at Eglin AFB, FL, starting in November 1986. Full-scale implementation began in early summer of 1987. The site contained about 20,000 to 30,000 gallons of fuel. After 15 months of operation at this site, it was concluded that using hydrogen peroxide as an oxygen source for biodegradation has limitations which could restrict its successful application to relatively few Air Force sites. Many vendors report success stories from other reclamation projects. A large-scale pilot field test was conducted at Kelly Air Force Base, Texas, from May 1985 to February 1986. The test area was 2,800 ft<sup>2</sup> of a backfilled waste-disposal pit. The site was contaminated with petroleum hydrocarbons, chlorinated solvents, and heavy metals. To stimulate aerobic biodegradation, hydrogen peroxide was injected. Ammonium chloride and potassium phosphate were injected to condition the groundwater and provide nutrients to the indigenous bacteria. Trichloroethylene and perchloroethylene were degraded to dichloroethylene. Degradation of petroleum hydrocarbons was indicated. Biodegradation of these compounds by indigenous bacteria had been demonstrated in laboratory-scale microcosms under anaerobic and aerobic conditions, respectively; however, the site was not ideal for this method. Injection wells became clogged from precipitation of calcium phosphate, which reduced their injection capacity by 90%. This test showed that design of hydraulic delivery systems and compatibility of injection chemicals with soil minerals are as important to successful treatment as is enhancement of bacteria.

WES, under the Army's Environmental Quality and Technology, is investigating innovative methods of applying additives required to stimulate *in situ* biotreatment into potential treatment zones. WES is also developing bench-scale evaluation protocol that can be used to assess the feasibility of *in situ* biotreatment. WES is providing the USEPA and the USAE Omaha District with some technical review support during the remediation of a Superfund Site. Finally, WES is evaluating the feasibility of *in situ* biotreatment for remediation of a BTEX (benzene, toluene, ethylbenzene, and xylene) spill at an Army installation.

The U.S. Air Force is sponsoring research in nitrate enhancement for the *in situ* biodegradation of fuel compounds. This research is being conducted at the U.S. EPA Robert S. Kerr Environmental Research Laboratory. Column studies will be completed in January 1992 to quantify the effect of nitrate enhancement on BTEX

biodegradation. This will be followed by a pilot-scale field study at an Air Force JP-4 fuel contamination site in mid 1992.

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the National Water Well Association) and the American Petroleum Institute, Houston, Texas, Nov 1987.

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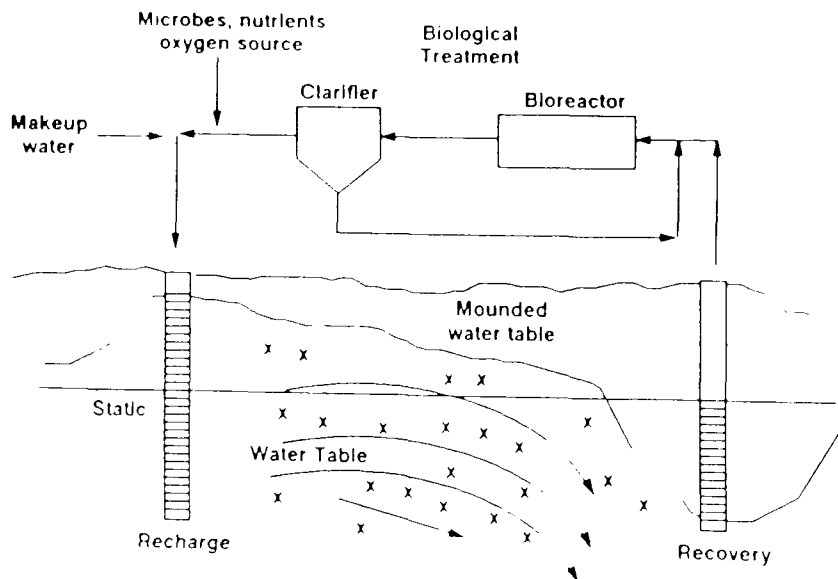


Figure 21. Schematic diagram of an in situ bioreclamation process (Ecova Corporation).

## 22. CATALYTIC OXIDATION UNIT

- Category:** I.a. Groundwater Treatment  
I.b. Soil treatment
- Purpose:** Oxidation of volatile organic compounds (VOC) or other organic groundwater and/or soil contaminants by incineration using a catalyst bed.
- Application:** This technology can be utilized for oxidation of VOCs, soil vapor extraction, or groundwater cleanup.

**Description:** Contaminated groundwater is pumped to the surface and contacted counter-currently with air in two packed columns (see notes #7 and #8) to transfer the VOCs from the water to the air. Following contact with the water, the air exiting from the first packed column contains most of the volatile compounds that were in the groundwater. This contaminated air stream is treated by a catalytic oxidation unit, also known as a catalytic incinerator, to destroy the VOCs and is then released to the atmosphere. Water samples normally ranging from ~400 to 600 µg/L corresponds to ~7 to 11 µg/L in the air exiting from the first packed column.

The catalytic oxidation unit destroys the VOCs in the air stream by contact with a fluidized bed of catalyst granules at a controlled temperature. Prior to contacting the bed of catalyst, the air stream is preheated to the bed temperature with an auxiliary natural gas flame. The oxidation unit is normally operated at a bed temperature of 370° C and treats 0.57 m<sup>3</sup> air/second (1,200 std ft<sup>3</sup>/min).

The catalyst granules in the fluidized-bed incinerator are composed of an aluminum oxide support impregnated with chromium. Because the granules constantly grate against each other, they are normally attrited, and the catalyst bed must be periodically replenished. The pressure drop across the catalyst bed was 124 Pa (0.5 in. H<sub>2</sub>O) after 4 months of operating time. According to the manufacturer, a pressure drop of 1-in. H<sub>2</sub>O corresponds to a 1-in. depth of catalyst in the bed.

**Advantages:** A catalytic oxidation unit is preferred over a thermal incinerator because it operates at a lower temperature than the thermal incinerator to obtain high destruction efficiencies and is more economical to operate. Contaminants are destroyed on site rather than being transferred to another media as occurs with air stripping and carbon sorption of contaminants. Catalyst life may be as long as 2 years as continuous abrasion occurs when in use.

**Limitations:** High concentrations of organics will melt the catalyst. Products of incomplete combustion (PICs) have been found in preheater effluent and/or the stack effluent that were not combustion products and were not in the feed stream. PICs may be present as a result of: (1) compounds originally present in the feed stream to the incinerator but not previously identified through analysis, (2) compounds introduced through the auxiliary natural gas used to preheat the feed stream to the temperature of the catalyst bed, and (3) compounds that are actual combustion byproducts of the organic compounds in the incinerator feed stream. Compounds identified as PICs included benzene, toluene, 2-butanone, 1,1,1-trichloroethane, ethylbenzene, methylene chloride, and chloroform. Benzene and toluene are the most common PIC



compounds found in the preheater effluent and stack effluent in the highest concentrations.

**Cost:** Cost varies for unit size. A 1,200 ft<sup>3</sup> /min unit will cost about \$110,000 installed. Operating cost will be \$0.40/1000 gallons of H<sub>2</sub> O treated at a rate of 185 gal/min.

**Availability:** Commercially available.

**Status:** Currently in use at Wurtsmith Air Force Base, MI at a trichloroethylene (TCE) spill site. Full-scale implementation was October 1989 to present.

**References:** Hylton, T.C., **Evaluation of the TCE Catalytic Oxidation Unit at Wurtsmith Air Force Base**, for Air Force Engineering and Services Center Report ESL TR 91-43, 1991.

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## 23. SOLVENT EXTRACTION

**Category:** I.a. Groundwater treatment  
I.b. Soil Treatment

**Purpose:** Solvent extraction is potentially effective in treating oily sludges and soils contaminated with polychlorinated biphenyls (PCB), polycyclic aromatic hydrocarbons (PAH), and pesticides by separating the sludges into three fractions: oil, water, and solids. As the fractions separate, contaminants are partitioned into specific phases.

**Application:** This process can be used to remove most hydrocarbons or oily contaminants in sludges or soils, including PCBs, PAHs and pesticides (table 23). Performance can be influenced by the presence of detergents and emulsifiers, low pH materials, and reactivity of the organics with the solvent. Solvent extraction (SE) is suitable for treating wastes containing high levels of organics. SE may offer a lower cost alternative than traditional thermal destruction technologies (see also note #4).

*Table 23. Specific Wastes Capable of Treatment by Solvent Extraction*

RCRA Listed Hazardous Wastes	<ul style="list-style-type: none"> <li>• Creosote-Saturated Sludge</li> <li>• Dissolved Air Flotation (DAF) Float</li> <li>• Slop Oil Emulsion Solids</li> <li>• Heat Exchanger Bundle Cleaning Sludge</li> <li>• API Separator Sludge</li> <li>• Leaded Tank Bottoms</li> </ul>
Non-Listed Hazardous Wastes	<ul style="list-style-type: none"> <li>• Primary Oil/Solids/Water Separation Sludges</li> <li>• Secondary Oil/Solids/Water Separation Sludges</li> <li>• Bio-Sludges</li> <li>• Cooling Tower Sludges</li> <li>• HF Alkylation Sludges</li> <li>• Waste FCC Catalyst</li> <li>• Spent Catalyst</li> <li>• Stratford Unit Solution</li> <li>• Tank Bottoms</li> <li>• Treated Clays</li> </ul>

**Description:** Secondary or tertiary amines [usually triethylamine (TEA)] are used to separate organics from soil and sludges. The technology is based on the fact that TEA is completely soluble in water at temperatures below 20°C. Because TEA is flammable in the presence of oxygen, the treatment system must be sealed from the atmosphere and operated under a nitrogen blanket. Prior to treatment, it is necessary to raise the pH of the waste material above 10, creating an environment in which TEA will be conserved effectively for recycling through the process. Pretreatment also includes screening the contaminated feed solids to remove cobbles and debris to effect smooth flow through the process.

The process begins by mixing and agitating the cold solvent and waste in a washer/dryer. The washer/dryer is a horizontal steam-jacketed vessel with rotating

paddles. Hydrocarbons and water in the waste simultaneously dissolve in cold TEA, creating a homogeneous mixture. As the solvent breaks the oil-water-solid emulsions in the waste, the solids are released and allowed to settle by gravity. The solvent mixture is decanted, and fine particles are released and allowed to settle by gravity. The solvent mixture is decanted and fine particles are removed by centrifuging. The resulting dry solids have been cleansed of hydrocarbons but contain most of the original waste's heavy metals; thus, further treatment may be required prior to disposal.

The solvent mixture from the washer/dryer unit (containing the organics and water extracted from the waste) is heated. As the temperature of the solvent increases, the water separates from the organics and solvent. The organics-solvent fraction is decanted and sent to a stripping column, where the solvent is recovered for recycle, and the organics are discharged for recycling or disposal. The water phase is passed to a second stripping column, where residual solvent is recovered for recycling.

**Advantages:** The recovery of oils and organics from the contaminated material, if saleable, will help defer the cost of remediation. The technology is modular, allowing for on site treatment. Based on the results of many bench-scale treatability tests, the process significantly reduces the hydrocarbon concentration in the solids. Other advantages of the technology include the production of dry solids, the recovery and reuse of soil, and waste volume reduction. By removing contaminants, the process reduces the overall toxicity of the solids and water streams. It also concentrates the contaminants into a smaller volume, allowing efficient final treatment and disposal.

**Limitations:** TEA is flammable. Large pieces of contaminated solids (rocks or soils that have been consolidated or cemented by contaminants) must be reduced in size.

**Cost:** Cost will vary depending on the contaminant and the media. If sold, this material can help defer the cost of remediation.

**Availability:** Commercially available.

**Status:** WES is assisting the EPA evaluate SE technology as a best demonstrated available technology (BAT). A demonstration unit was operated at WES Vicksburg during May 1989. Wastes evaluated included listed wastes K049 and K051.

A pilot-scale system was tested by EPA on PCB-laden sediments from the New Bedford (MA) Harbor Superfund site during September 1988. PCB concentrations in the harbor ranged from 300 ppm to 2,500 ppm.

**References:** **The Superfund Innovative Technology Evaluation Program: Technology Profiles**, United States Environmental Protection Agency, EPA/540/5-90/006, Nov 1990, pp. 78-79.

Sandrin, J.A., D.W. Hall, and R.E. McBride. **Case Study of the Bench-Scale Solvent Extraction Feasibility Testing of Contaminated Soils and Sludges from the Arrowhead Refining Superfund Site, Minnesota**. Proc. Superfund '89, Washington, DC, Nov 1989.

Sudell, Gerard W., **Evaluation of the BEST Solvent Extraction Sludge Treatment Technology Twenty-Four Hour Test**, Site Technology Profile, USEPA Report No. EPA/600/z-88/051, USEPA RREL, Cincinnati, OH, 1988.

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## 24. GROUNDWATER AND SOIL VAPOR RECOVERY SYSTEM

**Category:** I.a. Groundwater Treatment  
I.b. Soil Treatment

**Purpose:** To remove fuel contamination from saturated and unsaturated groundwater zones.

**Application:** The method is applicable for remediation of gasoline and other fuel leak sites.

**Description:** This technology is a combination of groundwater treatment and soil vapor extraction technologies. The commercial unit is designed to handle groundwater flow rates of up to 10 gal/min. The equipment is called spray aeration vacuum extraction (SAVE) system and it consists of the following three components: (1) treatment of groundwater by vacuum and temperature enhanced spray aeration, (2) extraction of soil vapors from vadose zone, and (3) an internal combustion engine that drives a vacuum pump for vapor extraction and a water pump that recirculates water in the spray chamber through nozzles. The hydrocarbons removed from groundwater and soil are used as fuel for the internal combustion engine and are oxidized during combustion. The engine can also drive a small air compressor to provide air for a low-capacity groundwater pump. The groundwater is treated in a spray aeration chamber that is operated under a vacuum of about 10 inches of Hg and at about 80° to 90° F. The combined action of low pressure and slightly higher temperature enhances the volatilization and hence removal of contaminants from groundwater. A portion of the engine coolant is recirculated through a heat exchanger to heat the groundwater to the operating temperature. During the demonstration project at a gasoline-contaminated site, the removal efficiencies in terms of benzene, toluene, ethyl benzene, xylene (BTEX) and total petroleum hydrocarbons (TPH) as gasoline, ranged from 80% to 90% at 2 to 8 gal/min flow rates. The lower efficiencies were observed at higher flow rates. The treated groundwater generally requires final polishing by carbon adsorption (see note #1) to meet local discharge limitation. The inlet of the vacuum pump is connected to the vapor extraction well and to the spray chamber. The negative pressure at the well draws subsurface contamination through the vacuum pump to the engine and is utilized as fuel. The radius of influence for vapor extraction depends on the permeability of the subsurface. At this site, due to high permeability of the silty sand, the radius was in excess of 80 ft. The exhaust gases from the engine pass through a dual catalytic converter before discharge to meet local air regulations. Depending on the concentration of hydrocarbons in the extracted vapors, supplemental fuel, such as propane or natural gas, may be necessary to operate the engine. No supplemental fuel was required during the demonstration study as the recovered vapors had high enough hydrocarbon concentrations to sustain the engine. The vapor extraction technique requires wells that are screened in the vadose zone or vapor extraction trenches with slotted pipes. The efficiency of the vapor extraction system depends on the site-specific conditions, and detailed site characterization is needed prior to installation.

**Advantages:** The unit provides both groundwater and soil vapor extraction and treatment. This mobile unit is relatively easy to install at the site provided the monitoring wells are already in place. External power may not be needed if the vapors have high hydrocarbon concentrations. The operators need special training.

**Limitations:** This commercial unit can handle relatively low flow rates and is suitable for relatively small sites. Generally, the treated water will require additional polishing to meet discharge requirements. Depending on the groundwater characteristics, a pretreatment system to remove free product or suspended solids may be needed. The unit may require permits from local air pollution control districts. The contamination must be amenable to destruction in an internal combustion engine.

**Costs:** Capital costs are about \$70,000 excluding wells and pretreatment.

**Availability:** The unit is commercially available.

**Status:** Full-scale implementation was demonstrated at CBC, Port Hueneme, CA, in FY91.

**References:** A technical report providing details about the performance of this system at a gasoline leak site is under preparation.

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## 25. INTEGRATED VAPOR EXTRACTION AND STEAM VACUUM STRIPPING

**Category:** I.a. Groundwater Treatment  
I.b. Soil Treatment

**Purpose:** To remove volatile organic compounds (VOC) and chlorinated hydrocarbons from groundwater and soil.

**Application:** This technology removes VOCs, including chlorinated hydrocarbons, in groundwater and soil. Sites with contaminated groundwater and soils containing trichloroethylene (TCE), perchloroethylene (PCE), and other VOCs are suitable for this on site treatment process. It is capable of effectively removing over 90 of the 110 volatile compounds listed in 40 CFR Part 261, Appendix VIII.

**Description:** The integrated system simultaneously treats groundwater and soil contaminated with VOCs. The integrated system consists of two basic processes: a moderate vacuum stripping tower that uses low-pressure steam to treat contaminated groundwater; and a soil gas vapor extraction/reinjection (SVE) process to treat contaminated soil. The two processes form a closed-loop system that provides simultaneous in situ remediation of contaminated groundwater and soil with no air emission.

It is a high efficiency, counter-current stripping technology. A single-stage unit will typically reduce up to 99.99% of VOCs from water. The SVE system uses a vacuum to treat a VOC-contaminated soil mass, inducing a flow of air through the soil and removing vapor phase VOCs with the extracted soil gas. The soil gas is then treated by carbon beds to remove additional VOCs and reinjected into the ground. The integrated systems share a granulated activated carbon (GAC) unit (figure 25). Non-condensable vapor from the system is combined with the vapor from the SVE compressor and decontaminated by the GAC unit. Byproducts of the system are a free-phase recyclable product and treated water. Mineral-regenerable carbon will require disposal after approximately 3 years.

A key component of the closed-loop system is a vent header unit designed to collect the non condensable gases extracted from the ground water or air that may leak into the portion of the process operating below atmospheric pressure. Further, the steam used to regenerate the carbon beds is condensed and treated in the system.

**Advantages:** The integrated system is capable of treating VOCs from soil vapor extraction and contaminated groundwater simultaneously. Contaminated steam used in the process is condensed and processed by the integrated system. VOCs and chlorinated hydrocarbons in groundwater and soil are processed in this system.

**Limitations:** Twenty of the volatile compounds listed in 40 CFR Part 261, Appendix VIII are not removed from the pollution stream. Leaking into the portion of the process operating below atmospheric pressure can occur.

**Cost:** Not available.

**Availability:** Commercially available.



**Status:** The integrated system is currently being used at the Lockheed Aeronautical Systems Company in Burbank, CA. At this site, the system is treating groundwater contaminated with as much as 2,200 ppb of TCE and 11,000 ppb PCE and soil gas with a total VOC concentration of 6,000 ppm. Contaminated groundwater is being treated at a rate of up to 1,200 gpm, while soil gas is removed and treated at a rate of 300 ft<sup>3</sup>/min. The system occupies approximately 4,000 ft<sup>2</sup>.

A SITE demonstration project was evaluated as part of the ongoing remediation effort at the San Fernando Valley Ground-Water Basin Superfund site in Burbank, CA, in September 1990.

**References:** **The Superfund Innovative Technology Evaluation Program: Technology Profiles**, United States Environmental Protection Agency, EPA/540/5-90/006, Nov 1990, pp. 22-23.

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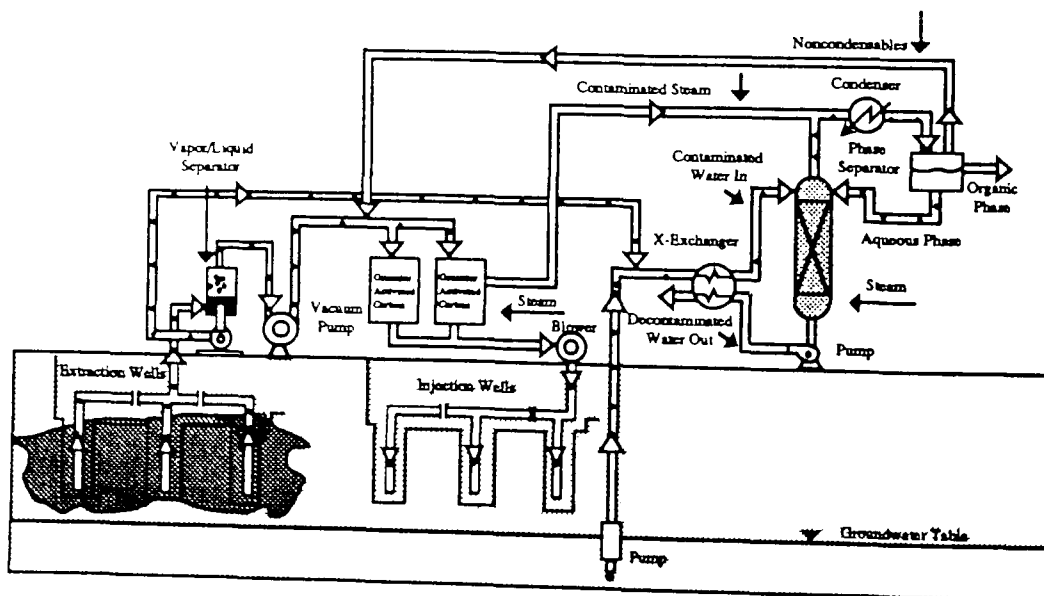


Figure 25. Zero air emissions integrated AquaDetox/SVE system.

## 26. WHITE ROT FUNGUS

**Category:** I.b. Soil Treatment

**Purpose:** To bioremediate soil contaminated with ordnance compounds, specifically TNT and RDX

**Application:** The method is applicable for decontaminating ordnance-contaminated soil.

**Description:** Two different treatment systems, both of which will utilize white rot fungus, will be tested on site: (a) in situ, and (b) bioreactor. The in situ system will consist of a 10-meter square plot on site, mixed with soil nutrient, fungus, and any amendments required. The bioreactor study will consist of three 10 ft<sup>3</sup> reactors filled with soil from the site and mixed with nutrients, fungus, and any amendments required. Excavation is not required for the in situ method. The restoration process will require approximately 2.5 months. The ultimate fate of the contaminants is CO<sub>2</sub>. Restoration can be conducted by site personnel and contractors.

**Advantages:** The method is low in cost and environmentally friendly.

**Limitations:** Limitations are not known.

**Costs:** The costs are estimated at \$75/yd<sup>3</sup>.

**Availability:** The technology is not available off the shelf, but it is not difficult to implement.

**Status:** Bench-scale studies have been conducted at Utah State University from June 1990 to the present. A field-pilot test is planned for Site D, SUBASE Bangor, ME, starting in FY92.

**References:** Lebron, C.A. *Ordnance Bioremediation - Initial Feasibility Report*, Naval Civil Engineering Laboratory, Jun 1990.

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## 27. BIODEGRADATION OF LUBE OIL CONTAMINATED SOILS

**Category:** I.b. Soil Treatment

**Purpose:** To remove used motor oil from contaminated soil by enhancing natural biodegradation.

**Application:** The method is applicable for oil spills at maintenance facilities, air strips, along roadways and streets, and parking lots. Although research on the method has been directed to degradation of used lubrication oil, it should be applicable to almost any nonfunctionalized aliphatic hydrocarbon.

**Description:** The soil to be treated must be disked. The inoculant and nutrients are applied during disking, and the site is covered with plastic sheeting. The nutrients in the pilot studies have consisted of sodium acetate, minerals (potassium, magnesium, ammonium, phosphate, and sulfate ions), and Tween 80, a surfactant. The plastic sheet must have holes to allow transport of air.

**Advantages:** The method is simple and can be carried out by facilities personnel. It is a destructive technique. Indigenous microorganisms enhanced by laboratory selection are used for the degradation. Microorganisms that have been naturally exposed and that metabolize the hydrocarbons are collected. Those microorganisms that exhibit the highest level of survival and metabolism in the presence of the waste oil are returned to the contaminated site. The enhanced microbe population degrades the waste oil faster than the natural population, but since these organisms are located at the site originally, nothing unnatural is introduced to the environment.

**Limitations:** Not much is known about the products of the biodegradation. The effects of heavy metals, often present in used lube oils, are not known. Aerobic biodegradation can remove about 60 % of the waste oil. More work will be required to determine if anaerobic degradation can be used for the remaining 40 %. Weather is important – extremes in temperature, either hot or cold, can limit the growth and metabolism of the microorganisms. The proper soil moisture content is important as well. Because of these restrictions of weather and moisture, the site being restored must be covered. As described, the method is limited to the depth at which the microbes are applied through disking the soil.

**Costs:** Costs are estimated at between \$50 and \$150/yd<sup>3</sup>.

**Availability:** Commercial systems are available.

**Status:** Small-scale pilot testing (1 to 10 drums) has been conducted at U.S. Army Construction Engineering Research Laboratories. Noticeable reduction in contaminant concentrations are evident after 4 to 6 weeks. Pilot plots consist of plastic tubs containing 8 kg of contaminated soil placed outside and covered with plastic. Flask tests were conducted initially to identify optimum conditions.

WES has completed a bench-scale evaluation of mechanisms responsible for degradation of heavy petroleum hydrocarbons in a landfarming biotreatment system. WES has also performed both bench- and pilot-scale bioslurry studies for treating petroleum hydrocarbon-contaminated soils.

**References:** Gunnison, D., **Evaluation of the Potential use of Microorganisms in the Cleanup of Petroleum Hydrocarbon Spills in Soils**, WES Technical Report, EL-91-13, 1991.

Zappi, M.E., D. Gunnison, C.L. Teeter, and N.R. Francingues. **Development of a Laboratory Method for Evaluation of Bioslurry Treatment Systems**. Presented at the 1991 Superfund Conference, Washington, DC, 1991.

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Brown, L.R. **Oil-Degrading Microorganisms**. *Chemical Engineering Progress*, 83(10):35-40, Oct 1987.

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## 28. COMPOSTING OF EXPLOSIVES CONTAMINATED SOILS

- Category:** I.b. Soil Treatment
- Purpose:** To decontaminate soils and sediments contaminated with TNT, HMX, and RDX, through the biodegradation process of composting.
- Application:** The composting process may be applied to soils and lagoon sediments contaminated with explosives and propellants.
- Description:** Composting is a controlled biological process by which biodegradable hazardous materials are converted by microorganisms to innocuous, stabilized byproducts. In most cases, this is achieved by the use of indigenous microorganisms. Research and development efforts have demonstrated that aerobic, thermophilic composting is able to reduce the concentration of explosives (TNT, RDX, and HMX) and associated toxicity to acceptable levels. Explosives-contaminated soils are excavated and mixed with bulking agents and organic amendments such as animal and vegetative wastes. Maximum degradation efficiency is controlled by maintaining moisture content, pH, oxygenation, temperature, and the carbon-to-nitrogen ratio. There are three process designs used in composting: aerated static piles, windrowing (see figure 28), and mechanically agitated in-vessel composting.
- Advantages:** The process is a low-cost alternative technique for the remediation of explosives-contaminated soils. The process is more publicly acceptable than incineration, and the product is agriculturally enriched.
- Limitations:** Substantial space is required for composting; excavation of contaminated soil is required; composting results in a volumetric increase in material due to amendment material; and heavy metals are not treated by this method.
- Cost:** Costs will vary with the amount of soil to be treated, availability of amendments, and the type of process design employed.
- Availability:** All materials and equipment used for composting are commercially available, and a treatability protocol is being developed.
- Status:** The first full-scale remediation using composting to remediate explosives-contaminated soils is being proposed for the remediation of Umatilla Depot Activity's washout lagoons, a current national priority list site. A field pilot scale demonstration was conducted at the Louisiana Army Ammunition Plant from December 1987 to July 1988. A composting optimization field study to compare two systems has been completed at the Umatilla Army Depot Activity (UMDA), Hermiston, OR. The study confirmed the conclusions from previous pilot-scale field demonstrations that composting is an effective remediation technology for decontaminating explosives-contaminated soils. Since the results indicated that mixing and amendment selection are important process parameters in achieving more rapid and thorough explosives destruction, a pilot-scale field demonstration to obtain windrow process design information is scheduled.
- WES is currently developing a bench protocol to evaluate compost treatment of explosives-contaminated soils.

**References:** Williams, R.T. and P.J. Marks. **Optimization of Composting for Explosives Contaminated Soils.** USATHAMA Report CETHA-TS-CR-91053, Nov 1991.

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Montemagno, C.D. and R.L. Irvine. **Feasibility of Biodegrading TNT Contaminated Soils.** Proc. 14th Annual Army Environmental Symposium, U.S. Army Toxic and Hazardous Materials Agency Report CETHA-TE-TR-90055, Apr 1990.

Williams, R.T., P.S. Ziegenfuss, and P.J. Marks. **Field Demonstration - Composting of Propellants Contaminated Sediments at the Badger Army Ammunition Plant (BAAP).** USATHAMA Report CETHA-TE-CR-89061, Mar 1989.

**Procedure for the Workshop on Composting of Explosives Contaminated Soils,** USATHAMA Report CETHA-TS-CR-89276, Oct 1989.

Williams, R.T., P.S. Ziegenfuss, and P.J. Marks. **Field Demonstration - Composting of Explosives - Contaminated Sediments at the Louisiana Army Ammunition Plant.** USATHAMA. Report AMXTH-IR-TE-88242, Sep 1988.

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*Figure 28 Photograph of windrow composting conducted at Umatilla Army Depot Activity, Hermiston, OR.*



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## 29. COMPOSTING OF PROPELLANTS

- Category:** I.b. Soil Treatment  
II.b. Minimization or Treatment of Munition Production and/or Handling Waste Streams
- Purpose:** To develop composting as an environmentally acceptable method to dispose of waste nitrocellulose (NC) fines and to remediate soils contaminated with NC-based propellants.
- Applications** The method is applicable for treatment of NC from wastewater streams resulting from the manufacture of NC and soils contaminated with NC by previous manufacturing operations.
- Description:** Composting is initiated by mixing biodegradable organic contaminants (NC in this case) with organic carbon sources and bulking agents, which are added to enhance the porosity of the mixture to be decomposed. In static pile composting, an aeration system (a network of a perforated pipe underlying the compost pile) is utilized to increase process control (see note #28). Test facilities were constructed of a concrete pads with runoff collection systems and sumps, covered by a roof to protect the piles from weather. Bulking agents and carbon sources consisted of horse manure, alfalfa, straw, and horse feed. Baled straw was used to contain the piles. After mixing the compost was transported to the composting pads. Blowers were used to pull air through the piles to promote aeration and remove excess heat. As an example of the decomposition efficiency, the initial concentration in the piles was about 3,600 mg NC/kg compost; after 152 days, the concentration in the pile maintained at 55° C was 54 mg/kg.
- Advantages:** The process is a low-cost alternative technique for the remediation of explosives-contaminated soils. The process is more publicly acceptable than incineration and the product is agriculturally enriched.
- Limitations:** Substantial space is required for composting; excavation of contaminated soil is required; composting results in a volumetric increase in material due to amendment material; and heavy metals are not treated by this method.
- Costs:** Exact cost information is not available. Costs will be site-specific.
- Availability:** All materials and equipment used for composting are commercially available, and a treatability protocol is being developed.
- Status:** The field-scale demonstration was conducted at Badger Army Ammunition Plant (BAAP) in Sauk County, WI, in 1988 and 1989.
- References:** **Final Technical Report, Engineering/Cost Evaluation of Options for Removal/Disposal of NC Fines.** U.S. Army Report DAAK11-85-D-0008, 1987.
- Final Technical Report, Field Demonstration – Composting of Propellants Contaminated Sediments at the Badger Army Ammunition Plant (BAAP).** USATHAMA Report CETHA-TE-CR-89061.

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## 30. PHYSICAL SEPARATION OF ORGANIC CONTAMINATED SOIL

**Category:** I.b. Soil Treatment

**Purpose:** To separate organic-contaminated soil (usually fines) from less coarse material.

**Application:** This technology may be used on organic-contaminated soil as a pretreatment prior to application of disposal technology (incineration, biodegradation, solvent extraction, low temperature treatment, etc.).

**Description:** Organic chemicals are known to associate with the small particle-size fraction of contaminated soils. Existing mining equipment can be adapted to separate the relatively cleaner coarse-size fraction of the soil from the highly contaminated fine fraction of the soil. Thus, the use of such equipment can reduce the volume of materials requiring additional processing and thus reduce treatment cost.

**Advantages:** Off the shelf equipment is available that can treat high volumes of soil at relatively low costs. If the technology is applicable to the waste, it can greatly reduce treatment costs. The non-contaminated fraction of soil, free of contaminants, thus may offer the potential for backfilling on site.

**Limitations:** The contaminants must partition into some fraction of the soil, usually the fines. Wet-soil processing can generate a wastewater that will require treatment. This process is only a pretreatment method and must be used in conjunction with other soil treatment methods.

**Cost:** Costs depend upon specific applications, but are estimated to range between \$30 and \$200 per ton.

**Availability:** While the technology has been used extensively for the processing and mining of minerals, it is relatively unproven for contaminated soils. Treatability testing is required prior to its application.

**Status:** Physical separation has been demonstrated in a variety of pilot studies, but generally applied to soils contaminated with radionuclides and metals. Bench-scale feasibility studies for explosive-contaminated materials have been initiated at the USAE Waterways Experiment Station.

**References:** None available.

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## 31. PHYSICAL SEPARATION FOR EXPLOSIVES CONTAMINATED SOILS

**Category:** I.b. Soil Treatment

**Purpose:** To provide a pretreatment method that reduces the volume of soil that will require additional treatment such as biological remediation or incineration. This technique simply removes the contaminated fraction of soil from the non-contaminated fraction.

**Application:** Physical separation is a process that is applicable to the treatment of explosives-contaminated wet or dry soils, sludges, sediments, and other solid wastes. It can be applied to discrete contaminant particles or adsorbed onto soil particles. To be useful, the contaminant must preferentially associate with some fraction of the soil, e.g., smaller particles. This selective partitioning of contaminants commonly occurs with both organics and metals.

**Description:** Organic chemicals are known to associate with the small particle-size fraction of contaminated soils. Existing mining equipment can be adapted to separate the relatively cleaner coarse size fraction of the soil from the highly contaminated fine fraction of the soil. Thus, the use of such equipment can reduce the volume of materials requiring additional processing and thus reduce treatment cost.

**Advantages:** Off the shelf equipment is available which can treat high volumes of soil at relatively low costs. If the technology is applicable to the waste, it can greatly reduce treatment costs. The non-contaminated fraction of soil, free of contaminants, thus may offer the potential for backfilling on site.

**Limitations:** The contaminants must partition into some fraction of the soil, usually the fines. Wet-soil processing can generate a wastewater that will require treatment. This process is only a pretreatment method and must be used in conjunction with other soil treatment methods.

**Cost:** Costs depend upon specific applications, but are estimated to range between \$30 and \$200 per ton.

**Availability:** While the technology has been used extensively for the processing and mining of minerals, it is relatively unproven for contaminated soils. Treatability testing is required prior to its application.

**Status:** Physical separation has been demonstrated in a variety of pilot studies, but generally applied to soils contaminated with radionuclides and metals. Bench-scale feasibility studies for explosive-contaminated materials have been initiated at the USAE Waterways Experiment Station.

**References:** Plans of study for the physical separation of soils contaminated with explosives, as well as arsenic and mercury, have been prepared and initiated at the USAE Waterways Experiment Station (see point of contact below).

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## 32. PHYSICAL SEPARATION FOR HEAVY METAL CONTAMINATED SOILS

**Category:** I.b. Soil Treatment

**Purpose:** To provide a pretreatment method to reduce the volume of soil requiring additional treatment such as solidification or extraction technologies. This technique simply removes the metal-contaminated fraction of soil from the non-contaminated (clean) fraction.

**Application:** Physical separation is a process that is applicable to the treatment of metal-contaminated wet or dry soils, sludges, sediments, and other solid wastes. It can be applied to discrete contaminant particles or contaminants adsorbed onto soil particles. To be useful, the contaminant must preferentially associate with some fraction of the soil, e.g., the smaller particles. This selective partitioning of contaminants commonly occurs with both organics and metals.

**Description:** Heavy metal contaminants typically associate with the small particle-size fraction of contaminated soils. Existing mining equipment can be adapted to separate the relatively cleaner coarse size fraction of the soil from the highly contaminated fine fraction of the soil. Thus, the use of such equipment can reduce the volume of materials requiring additional processing and thus reduce treatment cost.

**Advantages:** Off the shelf equipment is available which can treat high volumes of soil at relatively low costs. If the technology is applicable to the waste, it can greatly reduce treatment costs. The non-contaminated fraction of soil, free of contaminants, thus may offer the potential for backfilling on site.

**Limitations:** The contaminants must partition into some fraction of the soil, usually the fines. Wet-soil processing can generate a wastewater which will require treatment. This process is only a pretreatment method and must be used in conjunction with other soil treatment methods.

**Cost:** Costs depend upon specific applications, but are estimated to range between \$30 -- \$200 per ton.

**Availability:** While the technology has been used extensively for the processing and mining of minerals, it is relatively unproven for contaminated soils. Treatability testing is required prior to its application.

**Status:** Physical separation has been demonstrated in a variety of pilot studies, but generally applied to soils contaminated with radionuclides and metals. Bench-scale feasibility studies for explosive-contaminated material have been initiated at the USAE Waterways Experiment Station.

**References:** Plans of study for the physical separation of soils contaminated with arsenic, mercury, and explosives have been prepared and initiated at the USAE Waterways Experiment Station.



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### 33. EXTRACTION OF METALS FROM CONTAMINATED SOILS

**Category:** I.b. Soil Treatment.

**Purpose:** Metal extraction technologies can be utilized to remove the metals from contaminated soils so that the treated soil may be backfilled. This will avoid long term problems associated with immobilization technologies such as solidification/stabilization where the metals are not removed from the waste and thus may pose environmental threats. In addition, many metals remediation activities involve dig-and-haul disposal techniques, which simply transfer the contamination problem from one area to another and in many cases require RCRA landfill disposal. Metal extraction technologies will avoid such problems.

**Application:** This technology may be applicable to any metal-contaminated soil.

**Description:** Many factors such as pH, oxidation/reduction potential, metal species, ionic strength, etc., are known to effect the solubility of metals. By changing such parameters, metals may be extracted from the soils. The most frequently utilized technique is acid soil washing. With this technique the metals are removed from the soil into an acid solution that requires additional treatment.

**Advantages:** This technology will remove the metal contamination from the soil. This may reduce the requirement of RCRA land disposal and will reduce the long-term possibility of contaminant migration.

**Limitations:** This technology has not been utilized in the field on a wide scale.

**Cost:** On the order of \$100/yd<sup>3</sup>.

**Availability:** The technology is currently commercially available.

**Status:** Laboratory and bench-scale testing are currently being conducted to determine the effectiveness of the process for lead-, mercury-, and arsenic-contaminated soils. Field evaluation of this technique is currently being conducted at the Rocky Mountain Arsenal.

**References:** Plan of Study for Extraction of Arsenic and Mercury From Rocky Mountain Arsenal Soil by USAE Waterways Experiment Station.

Nunno, T.J., et al, **Assessment of International Technologies for Superfund Applications**, U.S. Environmental Protection Agency Report EPA/540/2-88/003, Sep 1988.

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## 34. CHEMICAL EXTRACTION OF EXPLOSIVES COMPOUNDS

- Category:** I.b. Soil Treatment
- Purpose:** To treat or facilitate treatment of explosives-contaminated soils.
- Application:** This technology can be used in conjunction with soil washing or bioslurry treatment systems.
- Description:** Chemical extraction involves extraction of explosives compounds from soils using some type of extraction fluid (see notes #4 and #23). Candidate extraction fluids include solvents, surfactants, acids and bases, and water. The success of an extraction system is judged based on the fluid's ability to increase desorption rate and total mass of explosive compound extracted from the soil.
- Advantages:** Chemical extraction can reduce treatment times in a bioslurry reactor (see note #43) by increasing the availability of the compound to the microbial populations. Chemical extraction may also represent an economic means of remediating mid- to low-level explosive-contaminated soils.
- Limitations:** The addition of an extraction fluid such as a surfactant will increase treatment costs. Also, in terms of usage with a bioslurry reactor, the extraction fluid must be compatible with the microbial populations.
- Cost:** Will vary with extraction fluid type and required dosages.
- Availability:** Several candidate extraction fluids are commercially available; however, using these fluids as a means of extracting explosive compounds has been done on a very limited scale.
- Status:** WES has evaluated extraction of TNT from soils using aqueous solutions of acetone and various commercial surfactants. Currently, WES is evaluating the addition of an extraction fluid in a bioslurry reactor to increase TNT degradation rate. A treatment system for TNT-laden acetone/water solution is under development at WES.
- References:** Pennington, J.C. and W. H. Patrick, Jr., **Adsorption and Desorption of 2,4,6-Trinitrotoluene by Soil**. *J. Environmental Quality*, 19(3):559-567, 1990.
- Sikka, H.C., S. Banerjee, E.J. Pack, and H.T. Appleton, **Environmental Fate of RDX and TNT**. U.S. Army Medical Research and Development Command Report TR-81538, 1980.
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## 35. SOIL WASHING SYSTEM

**Category:** I.b. Soil Treatment

**Purpose:** Decontamination of soils contaminated with hazardous chemicals, hazardous substances, or hazardous materials.

**Application:** This technology was initially developed to clean soils contaminated with wood preserving wastes such as polyaromatic hydrocarbons (PAH) and pentachlorophenol (PCP). The technology is also applicable to soils contaminated with petroleum hydrocarbons, pesticides, polychlorinated biphenyls (PCB), various industrial chemicals, and metals.

**Description:** This soil washing system (BIOTROL) is a patented, water-based, volume reduction process for treating excavated soil. Soil washing systems are offered by other vendors. Soil washing is applicable to contaminants concentrated in the fine-size fraction of soil (silt, clay, and soil organic matter) and contaminants associated with the coarse soil fraction (sand and gravel), primarily surficial. The objective of the process is to concentrate the contaminants in a smaller volume of material separate from a washed-soil product. The goal is that the soil product will meet appropriate cleanup standards. After debris is removed, soil is mixed with water and subjected to various unit operations common to the mineral processing industry. Process steps can include mixing trommels, pug mills, vibrating screens, froth flotation cells, attrition scrubbing machines, hydrocyclones, screw classifiers, and various dewatering operations. The core of the process is a multi-stage, counter-current, intensive scrubbing circuit with interstage classification. The scrubbing action disintegrates soil aggregates, freeing contaminant fine particles from the coarser sand and gravel. 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. In many cases water alone is sufficient to achieve the desired level of contaminant removal while minimizing cost. The efficiency of soil washing can be improved using surfactants, detergents, chelating agents, pH adjustment, or heat. The volume of material requiring additional treatment or disposal is reduced significantly by separating the washed, coarser soil components from the process water and contaminated fine particles (figure 35). The contaminated residual products can be treated by other methods. Process water is normally recycled after biological or physical treatment. Options for the contaminated fines can include off-site disposal, incineration, stabilization, or biological treatment.

**Advantages:** In the BIOTROL SITE demonstration, PCP and PAH levels in the washed soil were reduced by about 90%.

**Limitations:** Additional treatment and/or disposal off-site is required.

**Cost:** Not available.

**Availability:** Commercially available.

**Status:** The SITE demonstration of the BIOTROL soil washing technology took place from September 25 to October 27, 1989 at the MacGillis & Gibbs Superfund site in New

Brighton, MN. A pilot-scale unit with a treatment capacity of 500 pounds per hour was operated 24 hours per day during the demonstration. Feed for the first phase of the demonstration (2 days) consisted of soil contaminated with 170 ppm PCP and 240 ppm total PAHs. During the second phase (7 days), soil containing 980 ppm PCP and 340 ppm total PAHs was fed to the system.

Contaminated process water from soil washing was treated biologically in a fixed film reactor and recycled. A portion of the contaminated fines generated during soil washing was treated biologically in a three-stage, pilot-scale reactor system.

**References:** **Engineering Bulletin Soil Washing Treatment.** U.S. Environmental Protection Agency Report EPA/540/2-90/017, Sep 1990.

**The Superfund Innovative Technology Evaluation Program: Technology Profiles.** U.S. Environmental Protection Agency Report EPA/540/5-90/006, Nov. 1990, pp. 26-27.

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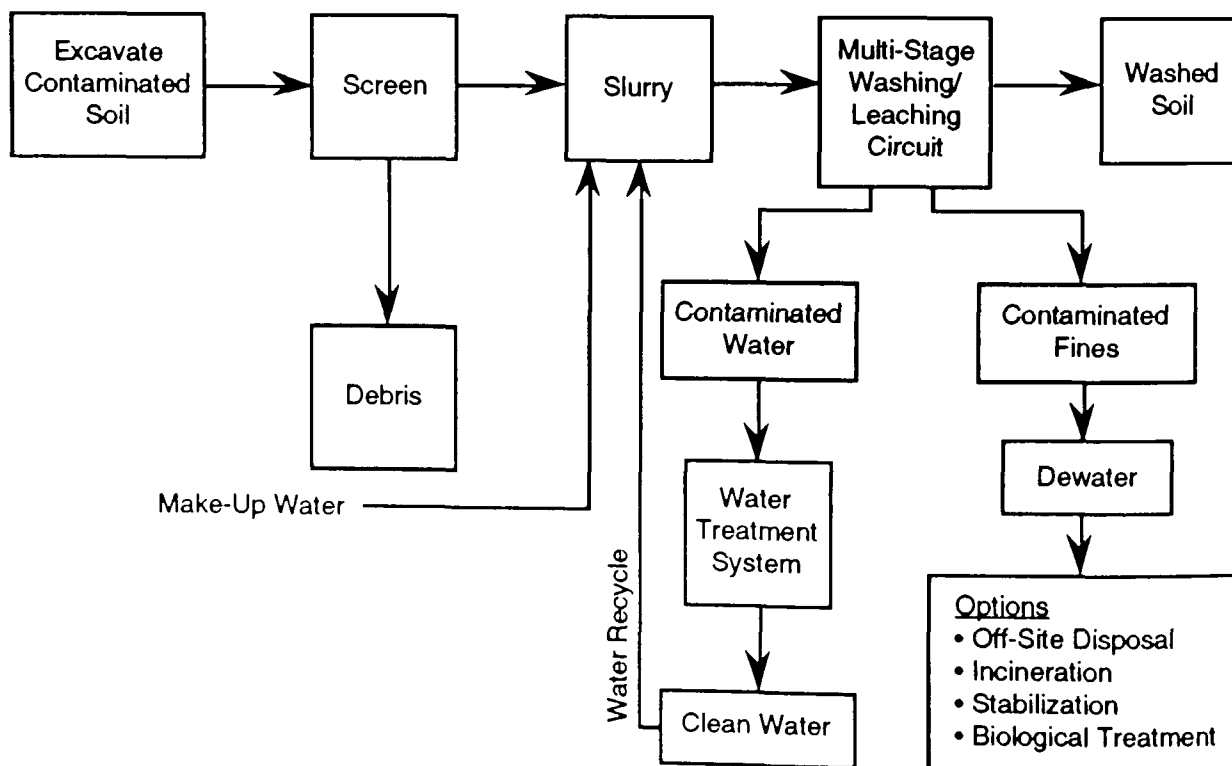


Figure 35 Biotrol Soil Washing System Process Flowsheet

## 36. DEBRIS WASHING SYSTEM

**Category:** I.b. Soil Treatment

**Purpose:** Decontamination of debris (metallic, masonry, or other solid debris) by a portable washing process.

**Application:** The Debris Washing System (DWS) can be applied on site to various types of debris (metallic, masonry, or other solid debris) that is contaminated with hazardous chemicals such as pesticides, polychlorinated biphenyls, lead, and other metals.

**Description:** This technology was developed to decontaminate debris currently found at Superfund sites throughout the country. The DWS was demonstrated under the innovative program and will be commercialized. The DWS consists of 300-gallon spray and wash tanks, surfactant and rinse water holding tanks, and an oil/water separator. The decontamination solution treatment system includes a diatomaceous earth filter, an activated carbon column, and an ion exchange column. Other required equipment includes pumps, stirrer motor, tank heater, metal debris basket, and particulate filters (figure 36). The DWS unit is transported on a 49-foot semitrailer. At the treatment site, the DWS unit is assembled on a 25 by 24 foot concrete pad and enclosed in a temporary shelter. A basket of debris is placed in the spray tank with a forklift, where it is sprayed with an aqueous detergent solution. An array of high pressure water jets blast contaminants and dirt from the debris. Detergent solution is continually recycled through a filter system that cleans the liquid. The wash and rinse tanks are supplied with water at 140° F and 60 psig. The contaminated wash solution is collected and treated prior to discharge. An integral part of the technology is treatment of the process detergent solution and rinse water to reduce the contaminant concentration to allowable discharge levels. Process water treatment consists of particulate filtration, activated carbon adsorption and ion exchange. Approximately 1,000 gallons of liquid are used during the decontamination process.

**Advantages:** The equipment for application of this technology is portable. Debris washed by this process can be declassified and sold by the EPA. Detergents used in cleaning debris are recycled.

**Limitations:** Contaminants washed from debris must be disposed of after cleaning the detergents.

**Cost:** Not available.

**Availability:** Commercially available.

**Status:** The first pilot-scale testing was performed at the Region V Carter Industrial Superfund site in Detroit, MI. Polychlorinated biphenyl (PCB) reduction averaged 58 % in batch 1 and 81% in batch 2. Design changes were made and tested on the unit prior to additional field testing.

Field testing occurred using the upgraded pilot-scale DWS unit at a Region IV PCB-contaminated Superfund site in Hopkinsville, KY, during December 1989. The results were promising. PCB levels on the surfaces of metallic transformer casings were reduced to less than or equal to 10 micrograms PCB/100 cm<sup>2</sup>. All 75



contaminated transformer casings on site were decontaminated to U.S. EPA acceptable cleanup criteria, and sold by Region 4 to a scrap metal dealer.

The unit was also field tested at another Superfund site in Region IV, the Shaver's Farm site in Walker County, GA. The contaminants of concern were Dicamba and benzonitrile. Fifty-five gallon drums cut into sections were placed in the DWS and carried through the decontamination process.

**References:** **The Superfund Innovative Technology Evaluation Program: Technology Profiles**, United States Environmental Protection Agency, pp. 76-77, 80-81, EPA/540/5-90/006, Nov 1990.

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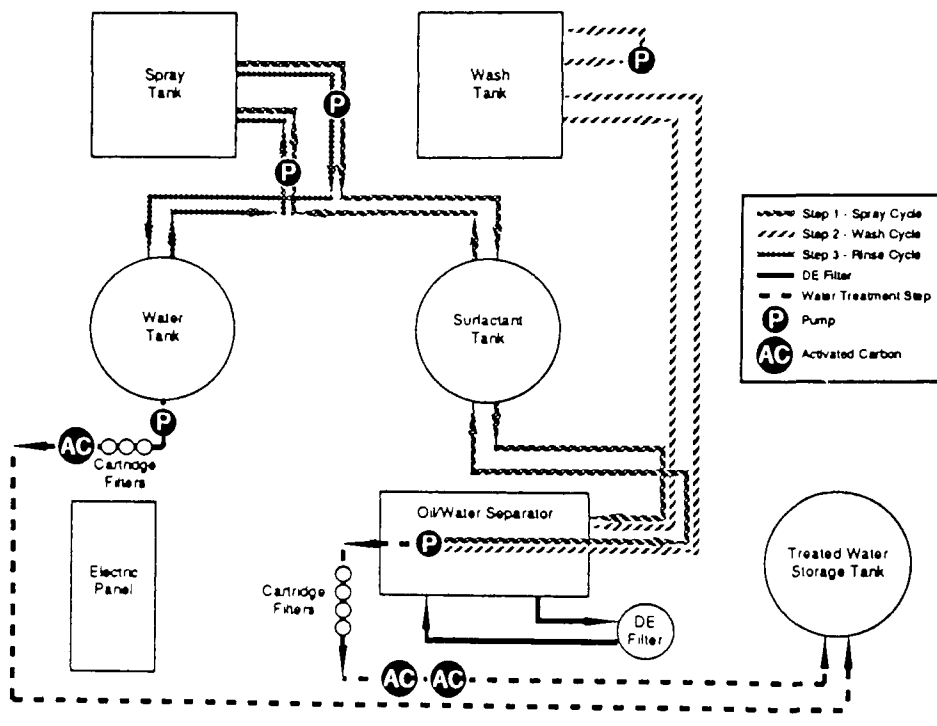


Figure 36. Schematic of the pilot-scale Debris Washing System.

## 37. IN SITU BIOVENTING

**Category:** I.b. Soil Treatment

**Purpose:** To destroy fuel contamination in soil.

**Application:** The process may be applied to fuels and biodegradable organics (see also notes #56 and #57).

**Description:** This technology can be applied to the cleanup of unsaturated soils contaminated with petroleum hydrocarbons. Soil venting is effective for the physical removal of volatile hydrocarbons from unsaturated soils. This technology also provides oxygen for the biological degradation of hydrocarbons in contaminated soil. Common strains of soil bacteria are capable of biodegrading hydrocarbon contaminants. Treatment of the off gas from a soil venting system can contribute up to 50 % of the overall cost of the remediation system. Through the optimization of the venting air flow rates, the proportion of hydrocarbon removal attributed to in situ biodegradation can be greatly increased. This approach may eliminate the need for off gas treatment, thereby reducing overall site remediation costs.

**Advantages:** Reduction of volatile emissions to the air during soil venting. Therefore, air pollution controls are not necessary. No soil excavation is required.

**Limitations:** Low-permeability, tight soils limit the use of bioventing.

**Cost:** Costs for this technology range from \$12-\$15/yd<sup>3</sup> of soil assuming off gas treatment will not be required.

**Availability:** Soil venting technology is commercially available. Nutrient and moisture controls are site specific.

**Status:** Bench-scale and field pilot-scale testing has been successfully conducted at Tyndall AFB, FL. A pilot-scale feasibility test of bioventing began in August 1991 to determine the applicability of this technology in a sub-arctic environment. The U.S. EPA is co-funding this effort to allow the Air Force to investigate soil warming techniques to enhance biodegradation rates. In addition to this study, a full-scale bioventing demonstration will begin in early 1992 at an Air Force base in the northern U.S. Technical issues that will be studied during this demonstration include well placement optimization, air sparging wells for air injection, and soil warming.

In addition to these research projects, the Air Force has implemented a 50-site bioventing initiative. The goal of this effort is to screen 50 Air Force JP-4 jet fuel contamination sites to determine if bioventing offers a feasible treatment alternative. If the screening tests yield positive results, a bioventing system will be installed and long term monitoring will be initiated.

**References:** Dupont, R.R., W.J. Doucette, and R.E. Hinchee, **Assessment of *In Situ* Bioremediation Potential and the Application of Bioventing at a Fuel-Contaminated Site**, Proceedings, *In Situ* and On-Site Bioreclamation: An International Symposium, San Diego, CA, March 19-21, 1991.

Miller, R.N., R.E. Hinchee, and C.M. Vogel, **A Field Scale Investigation of Petroleum Hydrocarbon Biodegradation in the Vadose Zone Enhanced by Soil Venting at Tyndall AFB, FL**, Proceedings: *In Situ* and On Site Bioreclamation, An International Symposium, San Diego, CA, March 19-21, 1991.

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## 38. UNSATURATED ZONE IN SITU BIORECLAMATION

**Category:** I.b. Soil Treatment

**Purpose:** To remove hydrocarbon from the unsaturated, or vadose, zone.

**Application:** The process may be applied to biodegradable fuels, volatile organic compounds (VOC), chlorinated solvents such as trichloroethylene, etc.

**Description:** The process may be described briefly as a combination process of soil venting and biodegradation or bioventing (see figures 38a and 38b). A vacuum is induced at the surface on extraction wells. Extracted gases may be vented to the atmosphere provided they meet EPA emission standards. Gases that do not meet emission standards may be disposed of by catalytic combustion or in an internal combustion engine if the concentration is great enough. Those gases that do not meet emission standards may also be disposed of through biodegradation in small-scale bioreactors or by reinjecting effluent vapors into uncontaminated soils above the contaminated zone. Bioreactors used in this process may contain soil, activated carbon, specially treated diatomite, or other suitable matrices as microbial fixed bed growth support media. Fixed-film or fluidized-bed bioreactor designs show promise for vapor phase biodegradation.

**Advantages:** The method enables both the rapid movement of air (oxygen gas) through the subsurface and fuel vapor removal. A greater surface area for contact of hydrocarbons and microbes is provided in the subsurface through vapor-phase fuel depletion and in the bioreactor or uncontaminated soil in situ because of the small size of the vapor molecules and even distribution.

**Limitations:** Little is known about how to introduce nutrients and to vent simultaneously or if low-volatility fuels, such as JP-5, can be biodegraded rapidly in situ during or after bioventing.

**Cost:** Costs for soil venting and enhanced in situ bioreclamation are each around \$50/yd<sup>3</sup>. Bioventing cost should be comparable, but detailed cost estimates are not available.

**Availability:** Technical information is available from NCEL.

**Status:** Bench-scale and field-pilot testing has been conducted by Battelle for bioventing of JP-4, but not for JP-5. Field-pilot testing is planned for NAS Patuxent River and/or NAS Fallon on JP 5.

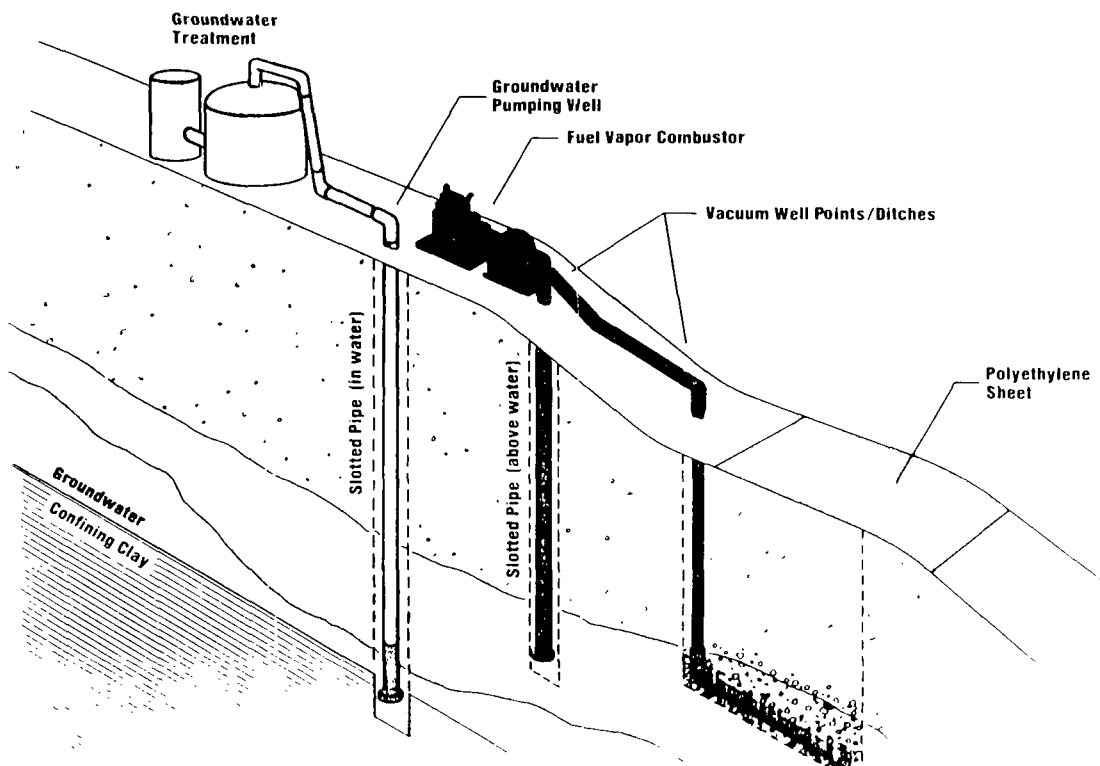
**References:** Hoeppe, R. **Ongoing and Planned Studies at Naval Civil Engineering Laboratory Pertinent to Advancement in Biotechnology.** NCEL Biotechnology Work Group Meeting, Monterey, CA. Feb. 21-23, 1989.

Watts, R.J., P.N. McGuire, W. Lee, R.E. Hoeppe. **Effect of Concentration on the Biological Degradation of Petroleum Hydrocarbons Associated with In Situ Soil-Water Treatment.** National Conference on Environmental Engineering. Austin, TX. July 10-12 1989.

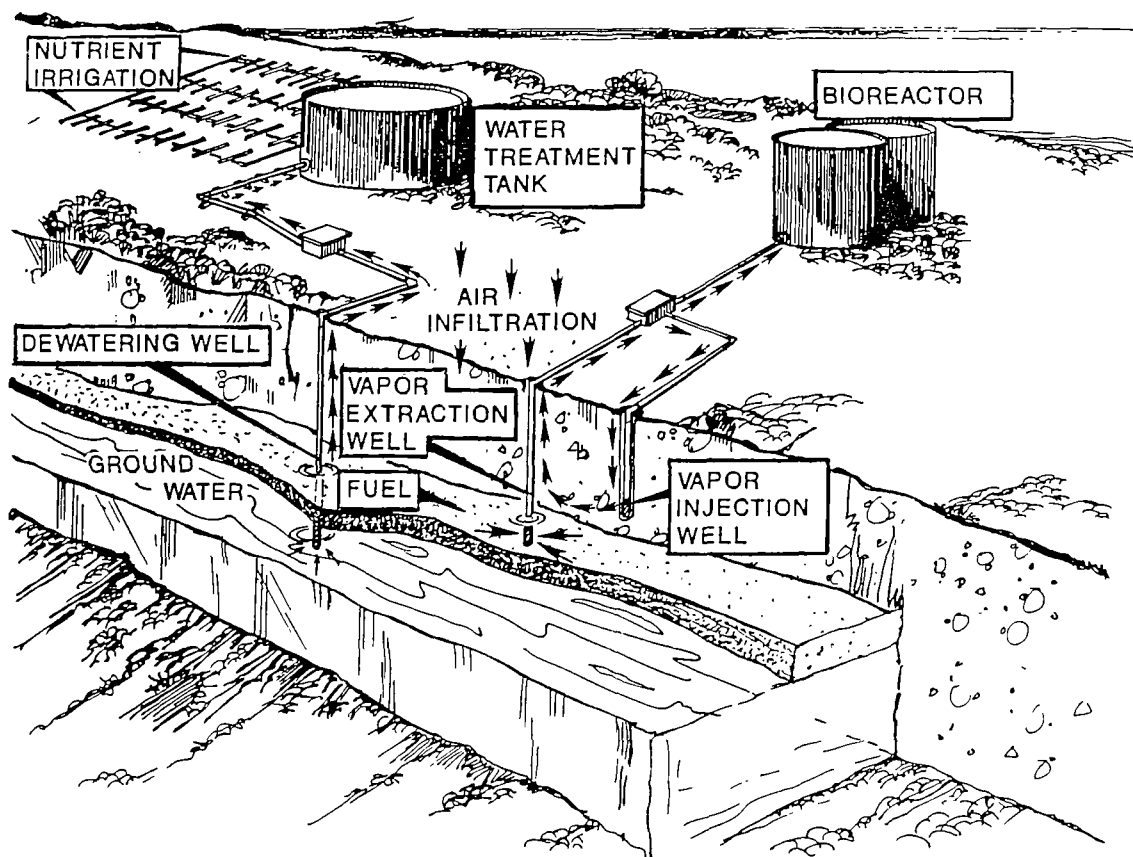
Hoeppel, R.E. **Combined In Situ Technologies for Reclamation of Jet Fuel Contamination at a Maryland Fuel Farm.** Soc. Envir. Toxic. & Chem., Tenth Annual Meeting, Toronto, Canada. Oct. 28 – Nov. 2, 1989.

Arthur, M.F., T.C. Zwick, G.K. O'Brien, R.E. Hoeppel. **Laboratory Studies to Support Microbially Mediated In Situ Soil Remediation.** 4th Annual DOE Model Conference. Oak Ridge, TN . Oct. 3-7, 1988.

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*Figure 38a. Soil venting of volatile organics in unsaturated subsoil.*



*Figure 38b. Bioventing*

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## 39. RADIO FREQUENCY (RF) THERMAL SOIL DECONTAMINATION

**Category:** I.b. Soil Treatment

**Purpose:** To remove volatile contaminants from soils.

**Application:** The method is applicable for removing volatile organic compounds (VOC) such as solvents and fuels from soil at sites such as fire training pits, spills, and sludge pits containing solvents. Some soil moisture can aid the process because of steam stripping. The method is most economical when less than 1 acre of ground must be treated.

**Description:** The system is made up of four components: (1) radio frequency (RF) energy deposition electrode array; (2) RF power generation, transmission, monitoring, and control system; (3) vapor barrier and containment system; and (4) gas and liquid condensate handling and treatment system (see figure 39). Full-scale treatment would be accomplished in 50-ft x 100-ft grids. Three or more rows of vertical or horizontal electrodes are inserted in boreholes. A vapor barrier shroud is placed over the plot. The RF power supplied to the electrodes heats the soil block above 150° C vaporizing contaminants and moisture. The vapor barrier directs the off gases to an appropriate treatment system.

The efficiency of the RF decontamination process was determined by a careful comparison of pretest and post-test samples. Samples were analyzed to determine changes in moisture, volatile aliphatics, volatile aromatics, and semivolatile aliphatics and aromatics. The average removal rates from the heated volume were impressive with 97% removal of semivolatile hydrocarbons and 99% removal of volatile aromatics and aliphatics. Closer examination of the samples showed that contaminant removal at the 2-m depth, the fringe of the heated zone, exceeded 95 %.

**Advantages:** Demonstrations have shown higher than 90% reduction of jet fuel components from soils. The contaminants are recovered in a relatively concentrated form without dilution from large volumes of air or combustion gases. This is an in situ method, and the soil does not have to be excavated. All equipment is portable.

**Limitations:** High moisture or presence of groundwater in the treatment zone will result in excessive power requirements to heat the soil. The method cannot be used if large buried metal objects are in the treatment zone.

**Cost:** It is estimated that the treatment of a 3-acre site to a depth of 8 ft containing 12% moisture raised to a temperature of 170° C would cost \$80/ton (see references). The treatment of such a site would require about 1 year. The initial equipment investment for full-scale projects is estimated to be about \$2.5 million. Power requirements for the pilot-scale field demonstration totaled approximately 800 kW-hr/m<sup>3</sup>. Use of a state-of-the-art RF generator for full-scale application could reduce the power input to less than 650 kW-hr/cm<sup>3</sup>.

**Availability:** The RF heating method is proprietary. The laboratory and pilot studies are being conducted by IIT Research Institute, the process developer.



**Status:** A bench-scale pilot test (volume < 20 drums) has been conducted at IIT Research Institute facilities. A larger field-pilot was completed at an Air Force site in November 1987. A full-scale field demonstration was completed at Volk Field ANGB, WI during October 1989. Full-scale implementation will begin during the fall of 1990 at Kelly AFB, San Antonio, Texas.

**References:** Dev, H., G. Sresty, and P. Carpenter. **In Situ Soil Decontamination by Radio Frequency Heating.** Proc. 18th Environmental Symposium and Exhibition, Feb. 1992.

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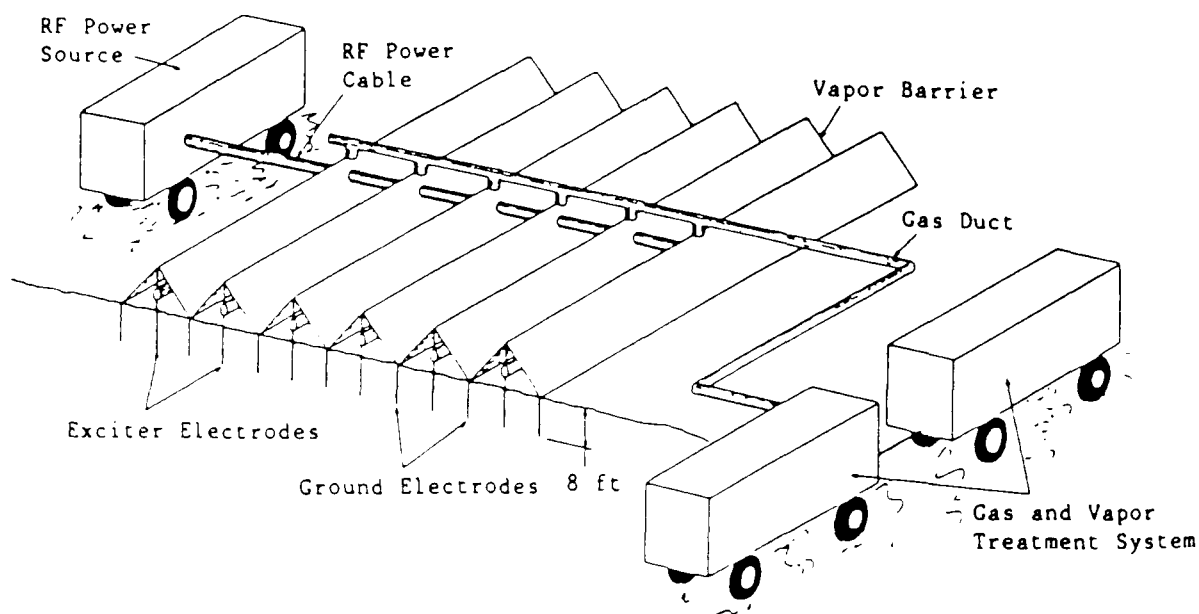


Figure 39. Equipment layout diagram for RF soil decontamination.

## 40. BASE CATALYZED DECOMPOSITION PROCESS (BCDP)

**Category** Ib. Soil Treatment

**Purpose:** To detoxify soils contaminated with chlorinated aromatic compounds.

**Application:** This method is a treatment process for halogenated aromatic contaminants such as polychlorinated biphenyls (PCB), insecticides, herbicides, pentachloro-phenol (PCP), lindane, and chlorinated dibenzodioxins and furans. The matrix can be soils, sludges, sediments, or oils.

**Description:** Contaminated soil is screened, processed with a crusher and pug mill, and stockpiled. In a rotary reactor (see figure 40), the stockpiled soil is mixed with 10% by weight sodium bicarbonate ( $\text{NaHCO}_3$ ) and heated to 644° F for 1 hour. The PCBs are decomposed and partially volatilized in the reactor. Off gases from the reactor are filtered and scrubbed with the clean gas vented to the atmosphere. The PCBs in the vapor condensate, residual dust, spent carbon, and filter cake are decomposed after 2 hours at 622° F in a stirred-tank slurry reactor (STR) utilizing a high boiling point hydrocarbon oil, catalyst, and sodium hydroxide ( $\text{NaOH}$ ). Nitrogen is injected into the STR to prevent fires. Oily residuals left in the STR, containing dust, sludge, and activated carbon, are combustible and can be burned in an oil-fired power plant or treated and reclaimed by waste oil recyclers. Clean soil from the reactor can be returned to the site from which it was excavated. Treated soil and sludge must be analyzed to ensure compliance with environmental regulations. It is possible to treat PCBs in concentrations as high as 10 wt % in dielectric fluid, 40 wt % in PCB-soaked wood and paper, and 6,000 to 7,000 ppm in soil. Treatability tests should be conducted to identify parameters such as water, alkaline metals, and humus content in the soils; presence of multiple phases; and total organic halides that could affect processing time and cost.

**Advantages:** The contaminated soil is rendered non-hazardous. The contaminant is destroyed rather than being transferred to another media. Whereas alkaline polyethylene glycol (APEG) residuals (see note #17 in the 1990 Edition of this handbook) contain chlorine and hydroxyl groups, which make them water soluble and slightly toxic, the base catalyzed decomposition process (BCDP) produces only biphenyl and low-boiling point olefins, which are not water-soluble and are much less toxic, and sodium chloride. The BCDP is easily transportable and safely operated. The process requires much less time, space, and capital investment to mobilize, set up, and demobilize than incineration.

**Limitations:** If a waste site has contaminants other than halogenated aromatic compounds, especially heavy metals, alternative treatment methods should be considered. Excavation of contaminated soil for on site treatment and refill of soil to the excavation site requires concise project planning and execution.

**Costs:** The cost for full-scale operation is estimated to be \$245/ton and does not include excavation, refilling, residue disposal, or analytical costs. Factors such as high clay or moisture content may raise treatment cost slightly.

**Availability:** The process uses off-the-shelf equipment. Technical details can be obtained NCEL or NEESA.

**Status:** NCEL and EPA have been jointly developing the BCDP since 1990. Pilot studies of the process have proven successful, and it has received approval from the EPA's Office of Toxic Substances under the Toxic Substances Control Act for PCB treatment. Complete design information is available from NCEL and NEESA. Pre-deployment testing was completed at Naval Communications Station (NCS) Stockton in November 1991. The research, development, testing, and evaluation stage is planned for Guam during the first 2 quarters of FY93.

**References:** **Chemical Dehalogenation Treatment: Base-Catalyzed Decomposition Process (BCDP).** Tech Data Sheet – Naval Energy and Environmental Support Activity and Naval Civil Engineering Laboratory, Jul 1992.

**Chemical Dehalogenation Treatment: Base-Catalyzed Decomposition Process (BCDP).** Tech Data Sheet – Naval Energy and Environmental Support Activity and Naval Civil Engineering Laboratory, Aug 1991.

**BCD: An EPA-Patented Process for Detoxifying Chlorinated Wastes.** U.S. EPA Office of Research and Development, 1991.

Rogers, C., A. Kornel, and H. Sparks. U.S. Patent Numbers 5,019,175 (May 28, 1991), 5,039,350 (August 13, 1991), and 5,064,526 (Nov. 12, 1991): Method for the Destruction of Halogenated Organic Compounds in a Contaminated Medium.

**Engineering Evaluation/Cost Analysis for the Removal and Treatment of PCB-Contaminated Soils at Building 3000 Site PWC Guam.** Naval Civil Engineering Laboratory, July 1990.

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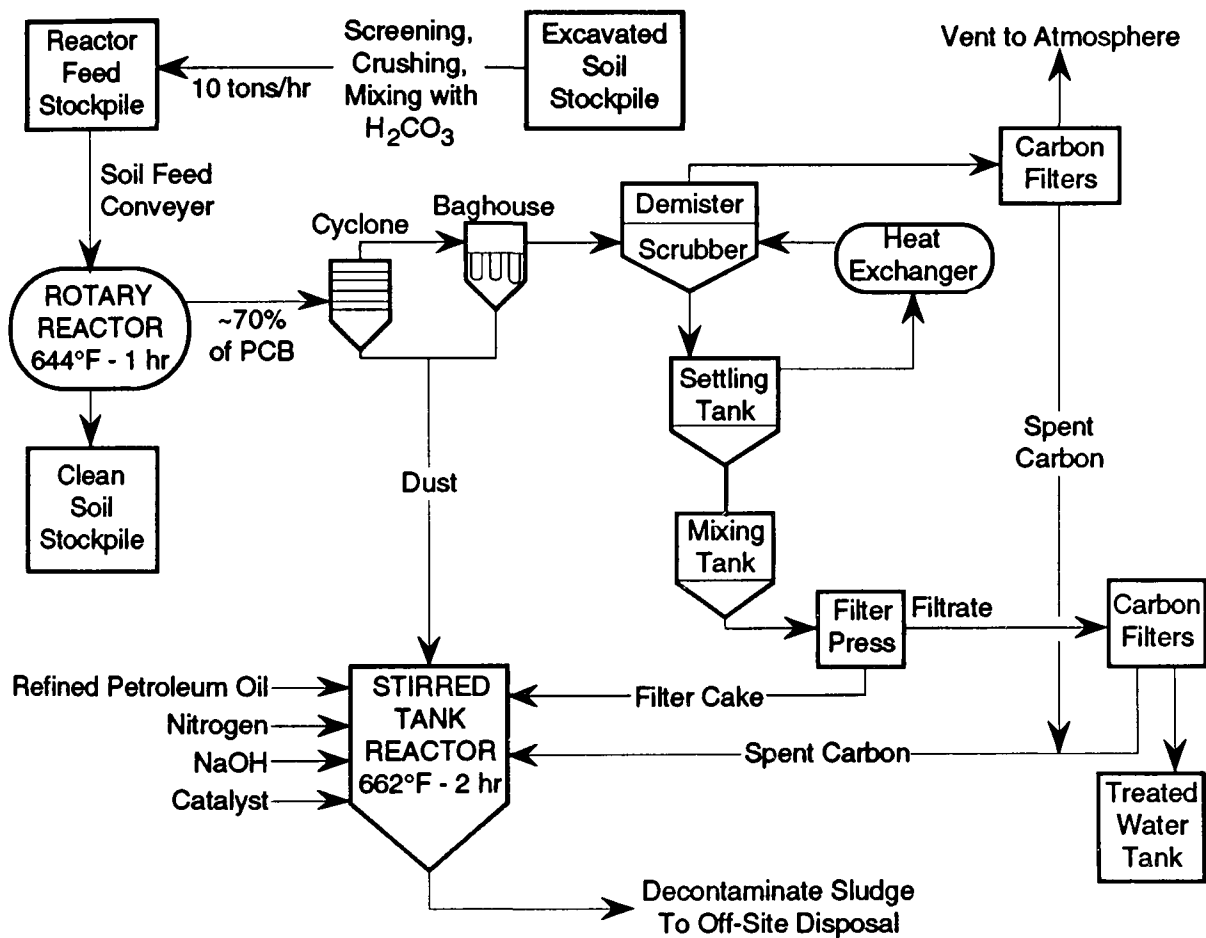


Figure 40. Flow diagram for Base Catalyzed Decomposition Process.

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## 41. SLURRY BIOREACTOR FOR EXPLOSIVES CONTAMINATED SOILS

**Category:** I.b. Soil Treatment

**Purpose:** To biologically remediate soils contaminated with explosives.

**Application:** This treatment may be applied to soils contaminated with TNT, RDX, HMX, and other biodegradable, hazardous wastes. Applicable for installations at which soil composition precludes composting.

**Description:** Contaminated soils are excavated, screened to remove large rocks, and mixed with water to create a slurry. The soil-water slurry is biologically treated in a sequencing batch reactor (SBR). Contaminant degradation is controlled by mixing rate, oxygen, and nutrient additions. Processed slurry is dewatered with the process water recycled to the reactor (see figure 41).

**Advantages:** Advantages include: more efficient biodegradation process control, contaminant destruction rather than media transfer, and residual material can be readily revegetated as part of the site restoration effort.

**Limitations:** Requires explosive safety-approved reactors not currently commercially available.

**Costs:** Estimated costs are between \$50 and \$200/yd<sup>3</sup> depending on biodegradation kinetics and required additive amounts (from WES).

**Availability:** The method is in the pilot-scale demonstration phase; however, the equipment is available for full-scale applications.

**Status:** A pilot-scale demonstration of soil-slurry SBR technology to treat explosives-contaminated soils biologically is being initiated at Joliet Army Ammunition Plant, Joliet, IL.

WES has performed a bench-scale evaluation of bioslurry treatment of TNT-contaminated soil from the Hastings East Industrial Park.

**References:** Zappi, M.E., D. Gunnison, C.L. Teeter, and N.R. Francingues. **Development of a Laboratory Method for Evaluation of Bioslurry Treatment Systems.** Presented at the 1991 Superfund Conference, Washington, DC, 1991.

Montamagno, C.D. **Feasibility of Biodegrading TNT Contaminated Soils in a Slurry Reactor - Final Technical Report.** U.S. Army Toxic and Hazardous Materials Agency Report CETHA-TE-CR-90062, June 1990

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## 42. BIOSLURRY REACTORS FOR TREATMENT OF CONTAMINATED SOILS

**Category:** I.b. Soil Treatment

**Purpose:** To develop expeditious methods of bioremediation of contaminated soils.

**Application:** This approach is applicable for petroleum wastes such as jet and diesel fuels.

**Description:** Contaminated soil is excavated and treated, and decontaminated soil is replaced. The bioremediation reactor method to be used at each site will be modified for site specific conditions. A continuous flow bioremediation process will be ideal.

Bioslurry treatment involves the slurring of contaminated soils with water in an above-ground reactor capable of keeping the slurry solids in suspension. Slurry solids concentration typically varies from 20 to 50 % by weight. Soils are excavated, passed through a prescreening stage to pass a Number 4 US Standard Sieve, slurried, then added to the reactor(s) for treatment. After treatment, the solids are separated for disposal, and the water is recycled for use in another slurry. Some reactor systems are configured with several reactors plumbed in series. A reactor system in series is needed for large slurry volumes, to improve reaction performance and to eliminate short circuiting microbes with continuous feed of contaminated slurry. Process design variables include nutrient additive amounts, soil residence time, air requirements (if anaerobic), and soil characteristics.

**Advantages:** The excavation approach will be faster than in situ bioremediation, enable more control over the process, require less energy than incineration, and enable total degradation. The process may be the only workable approach to contaminated clay soils.

**Limitations:** This technology requires excavation and that the contaminants be biodegradable.

**Cost:** Reported costs range from \$50 to \$200/yd<sup>3</sup> of soil.

**Availability:** Under development.

**Status:** Laboratory testing is being conducted at NCCOSC RDT&E Division. Scaled up field-pilot testing is planned for FY 92 - 3.

WES has several bench-scale 5-liter bioslurry reactors that have been used to evaluate technology feasibility and determine optimum treatment conditions. The WES also has six 60-liter pilot units manufactured by Eimco, Inc., Salt Lake City, UT. WES has a gas recirculation system capable of keeping volatile contaminants within the system, thereby allowing for complete degradation of all contaminants.

WES has successfully completed bench and pilot studies for a benzene, toluene, ethyl benzene, and xylene (BTEX) contaminated soil and a soil contaminated with wood-preserving wastes. These studies were funded by the Office of Solids Waste, USEPA, in support of their Best Demonstrated Available Technology (BDAT) Program. WES is also evaluating the feasibility of the technology for treatment of explosives-contaminated soils from the Hastings East Industrial Park Superfund Site for the



USAE District, Kansas City, MO. Finally, WES has evaluated bench-scale systems for biotreatment of gasoline-contaminated soil. A pilot study will be performed using gas recirculation in October 1992.

**References:** Zappi, M.E., D. Gunnison, C.L. Teeter, and N.R. Francingues. **Development of a Laboratory Method for Evaluation of Bioslurry Treatment Systems.** Presented at the 1991 Superfund Conference, Washington, DC, 1991.

Kenis, P. **Degradation of Hazardous Organic Wastes by Microorganisms.** Naval Ocean Systems Center Technical Document 1253, May 1988.

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## 43. PLASMA ARC TECHNOLOGY FOR THERMAL DESTRUCTION OF HAZARDOUS WASTE

**Category:** I.b. Soil Treatment  
I.c. Structural Treatment  
II.c. Minimization or Treatment of Metal Finishing Waste  
II.f. Minimization or Treatment of Gases

**Purpose:** Destruction of hazardous material with an intense heat source.

**Application:** This technology can be used for destruction of heavy metals, organic contaminated soils, demilitarization of storage batteries, metal finishing sludges, pyrotechnic sludges, asbestos, submarine silencing tiles, hazardous medical waste, and used tires.

**Description:** A plasma is a gas that has been ionized by the electric arc of a plasma torch and can therefore respond to electrical and magnetic fields. The resistance of the plasma converts electricity into heat energy. The plasma arc torch is essentially a steel cylinder several inches in diameter and several feet in length; the specific dimensions are related to the torch power levels. Plasma torches operate in the 100 kilowatt to 10 megawatt power range. They can routinely create controlled furnace temperatures that range from 3,000°C to more than 7,000°C. Plasma torches can operate at much higher temperatures and at greatly increased efficiencies than fossil fuel burners. Only 1% of the air necessary for fossil fuel burners is required for operation of plasma torches. Therefore, the volume of effluent gases are greatly reduced and furnace systems can be built much more compactly than traditional furnaces at correspondingly reduced capital costs. A diagram of the plasma reactor process is shown in figure 43.

There are basically two types of plasma arc torches: (1) Transferred Arc Torch – the rear electrode is the positive attachment point and the negative attachment point is the work-piece or the melt; for example, if metal scrap is being melted, the negative attachment is the metallic scrap; and (2) Non-Transferred Arc Torch – both attachment points are within the torch itself and only the generated plasma flame egresses from the torch. The plasma arc torch is only one component of the plasma heating system. The other components are: (1) a power supply can be alternating current or direct current; (2) a control panel to control the initiation and sustainment of the plasma arc column; (3) a closed-loop water system to provide cooling to the electrodes and shroud; (4) a gas system to provide the small quantity of gas required for the plasma gas; and (5) a starting system to start the torch.

**Advantages:** This treatment process eliminates waste and liquid or gas side streams. Remains of the process are vitrified solid residue, carbon dioxide and water vapor. The end product complies with toxic characteristics leaching procedure (TCLP) and can be declassified. The process has a high energy transfer efficiency and no demand for air compared to fossil-fuel incinerators, and high temperature accelerates the reaction time.

**High Temperatures:** The plasma torch can create temperatures that are not achievable with fossil fuel burners. In the plasma arc torch it is possible to routinely achieve controlled temperatures greater than 7000°C. This extreme heat is produced

instantly, and can be readily automated. Controlled, high temperatures increase feed material throughput and reduce costs.

**Controlled Atmosphere:** Because the plasma arc torch is compatible with almost any gas (e.g., reducing, oxidizing, neutral, inert gases, etc.), the furnace atmosphere can be controlled to meet unique requirements.

**Massless Heat:** Plasma arc torches use 1% of the air needed by fossil fuel heaters. Releasing heat energy with almost no mass is a simpler process than conventional heating, and it offers greater control and efficiency. It also reduces off gas handling and other capital costs.

**High Thermal Efficiency:** The efficiency of plasma arc torches consistently reaches between 85% and 93%. Therefore, the faster and more complete reaction kinetics of plasma energy sharply reduces processing time and operating costs.

**Limitations:** Operation of the process requires three-phase 100 to 1,000 kW-DC electrical power source. The process has not been used for destruction of explosive compounds or pyrotechnical compounds. Cost of operation of the process limits applications.

**Cost:** Not available.

**Availability:** Commercially available.

**Status:** The field-pilot phase for asbestos destruction occurred in Raleigh, NC, November 1990. In 1992 limited trial implementation of this technology will be at Atlanta, GA, and USACERL Champaign, IL. The technology has been used for commercial destruction of medical waste in California.

**References:** Circeo, Louis J., Ph.D., **Destruction and Vitrification of Asbestos Using Plasma Arc Technology**, Georgia Institute of Technology for U.S. Army Construction Engineering Research Laboratories (USACERL) Champaign, IL, Oct 1991.

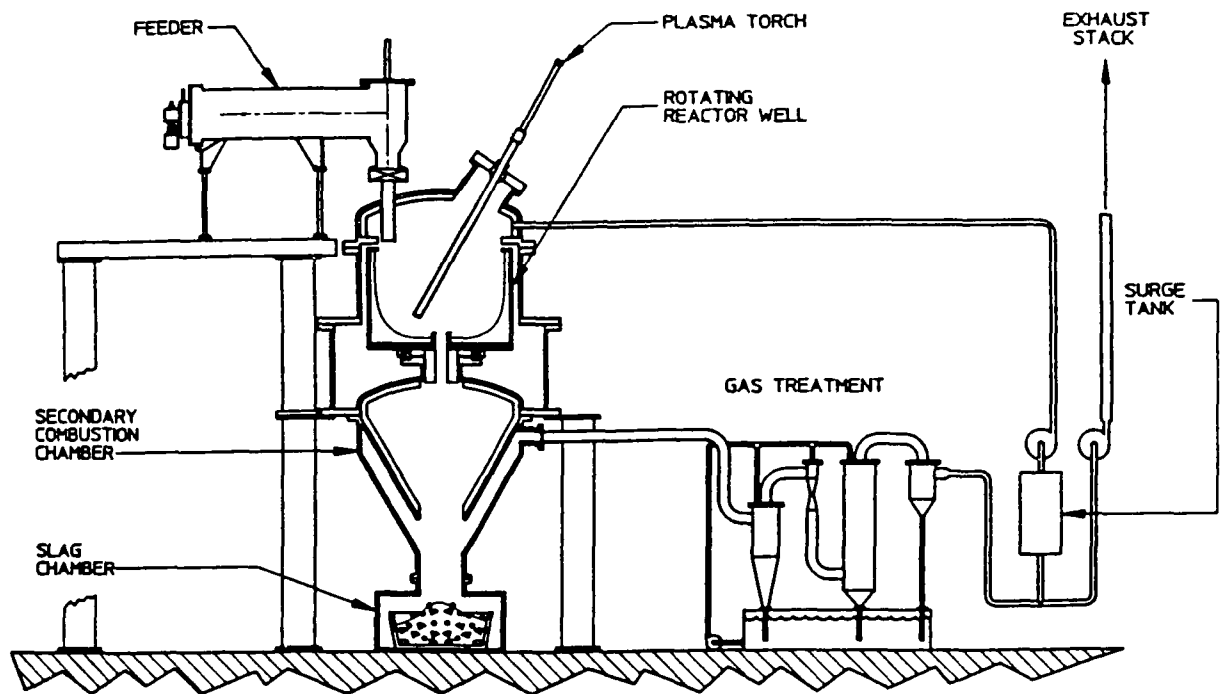
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**The Superfund Innovative Technology Evaluation Program: Technology Profiles**, United States Environmental Protection Agency, EPA/540/5-90/006, Nov 1990, pp. 74-75.

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*Figure 43. Plasma reactor process diagram.*

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## 44. LOW-TEMPERATURE THERMAL DESORPTION

**Category:** I.b. Soil Treatment

**Purpose:** To separate physically semi-volatile and volatile organic compounds (VOC), including fuels, from soils, sediments, sludges, and filter cakes.

**Application:** Thermal desorption is generally applicable to organic contaminants. It may also find applications in conjunction with other technologies or be appropriate to specific operable units at a site.

**Description:** Thermal desorption is any of a number of processes that use either indirect or direct heat exchange to vaporize organic contaminants from soil or sludge (figure 44). Air, combustion gas, or inert gas is used as the transfer medium for the vaporized components. Thermal desorption systems are physical separation processes and are not designed to provide organic destruction although the higher temperatures of some systems will result in localized oxidation and/or pyrolysis. Thermal desorption is not incineration, since the destruction of organic contaminants is not the desired result. The bed temperatures achieved and residence times designed into thermal desorption systems will volatilize selected contaminants, but typically not oxidize or destroy them. System performance is typically measured by comparison of untreated soil/sludge contaminant levels with those of the processed soil/sludge.

The waste is closely contacted with a heat transfer surface, and highly volatile components, including water, are driven off. An inert gas, such as nitrogen, may be injected in a counter-current sweep stream to prevent contaminant combustion and to vaporize and remove the contaminants. Other systems simply direct the hot gas stream from the desorption unit.

Soil/sludge is typically heated to 200° to 1,000° F, based on the thermal desorption system selected. The actual bed temperatures and residence times are the primary factors affecting performance in thermal desorption. These parameters are controlled in the desorption unit by using a series of increasing temperature zones, multiple passes of the medium through the desorber where the operating temperature is sequentially increased, separate compartments where the heat transfer fluid temperature is higher, or sequential processing into higher temperature zones. Heat transfer fluids used to date include hot combustion gas, hot oil, steam, and molten salts.

Typically, off gas from desorption is initially processed to remove particulates. Volatiles in the off gas may then be burned in an afterburner, collected on activated carbon, or recovered in condensation equipment. The selection of the off gas treatment system will depend on the concentration of the contaminants, cleanup standards, and regulatory requirements, and on the economics of the off gas-treatment system(s) employed.

Waste-material handling requires excavation of the contaminated soil/sludge or delivery of filter cake to the system. Typically, large objects are screened from the media and rejected. The medium is then delivered by gravity to the desorber inlet or conveyed by augers to a feed hopper.

Significant system variations exist in the desorption step. The dryer can be an indirectly fired rotary asphalt kiln, a single internally heated screw auger(s), or a series of externally heated distillation chambers. The later process uses annular augers to move the medium from one volatilization zone to the next. Additionally, testing and demonstration data exist for a fluidized-bed desorption system.

**Advantages:** Low temperature desorption systems can be tailored to treat contaminant types by controlling temperatures and retention times. Commercial systems are readily available and easy to implement. Many systems can be set up on site and treatment can be completed with a minimum of hauling excavated material. Treated material can be used as backfill material for the site of excavation. Treatment efficiencies up to 99% and better can be obtained, and treatment costs are very competitive with other treatment methods, especially on larger projects.

**Limitations:** A number of variables, such as specific mix and distribution of contaminants, affect system performance. A thorough characterization of the site and a well conducted treatability study are highly recommended to document the applicability and performance of a thermal-desorption system. Lower explosive limits and oxygen levels must be considered when treating soils contaminated with flammable solvents. Nitrogen may be used to reduce oxygen levels and avoid the explosion potential.

Excessively wet media may require dewatering prior to treatment due to material handling difficulties and extra heat requirements within the system. Material handling of soils that are tightly aggregated or largely clay, or that contain rock fragments and particles greater than a specific size, may result in poor processing performance due to caking and/or require screening. A high fraction of silt or clay results in the generation of fugitive dusts and a greater load on downstream pollution equipment.

Thermal desorption is generally not used for treating metals, high-boiling-point compounds, and other inorganics; however, thermal desorption has been considered for treating mercury containing waste and at least one treatability test has been performed. Material containing these contaminants may need to be further treated using other technologies or consigned to a hazardous waste landfill after treatment.

**Costs:** Several vendors have documented treatment costs in a range of \$80 to \$350 per ton processed. Unit treatment costs of contaminated media are dependent on site-specific conditions and are highly variable due to the quantity of waste to be processed, term of remediation contract, moisture content, organic constituency of the contaminated medium, and cleanup standards to be achieved.

**Availability:** The Low Temperature Thermal Stripping (LTTS) process was developed and demonstrated by USATHAMA. This system uses twin screw augers to convey contaminated media through the heat processor. This process has been patented and is available commercially from Weston.

Other commercial-scale units exist and are in operation. Thermal desorption has been selected at approximately 14 Superfund sites, and three Superfund Innovative Technology Evaluation (SITE) demonstrations are planned for 1993.

In cooperation with USATHAMA, WES established a bench-scale twin-screw thermal desorber unit to perform treatability tests of contaminated soil. These tests are available to all Federal agencies and will be performed on a cost-reimbursement basis. Results are published in a formal report and will determine the feasibility and

optimum operating parameters for using the auger feed type desorption unit at selected waste sites.

The U.S. EPA Risk Reduction Engineering Laboratory in Cincinnati, OH, has a muffle furnace treatability testing unit available for use to government agencies. This test is more basic and is generally used as a screening mechanism to determine thermal desorption feasibility.

Many commercial vendors of low temperature thermal desorption units are capable of performing either lab- or pilot-scale treatability tests to determine site feasibility.

**Status:** Significant theoretical research and direct demonstration of thermal desorption through both treatability testing and full-scale cleanups are ongoing.

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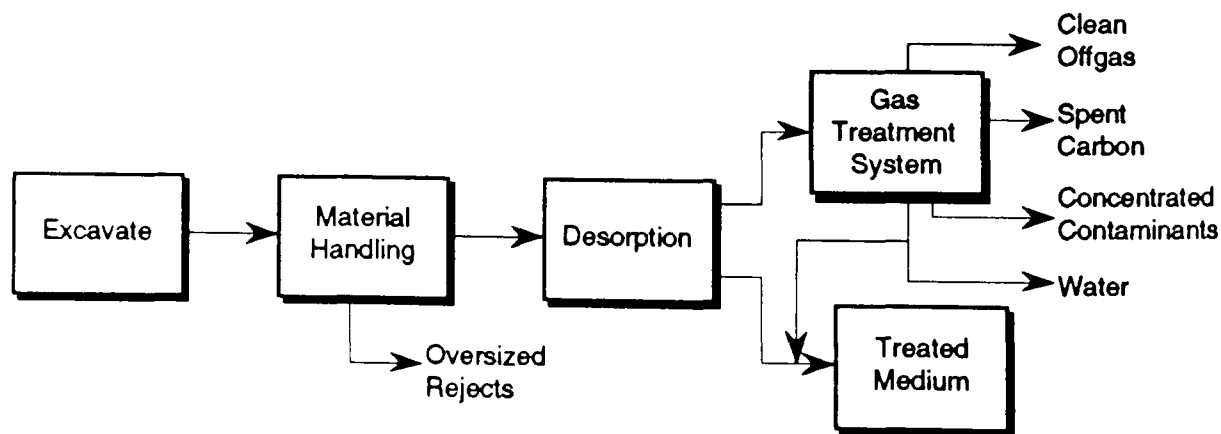


Figure 44. Schematic diagram of thermal desorption (EPA/540/2-91/008).

## 45. PROTOCOL FOR EVALUATION OF SOLIDIFICATION/STABILIZATION PROCESSES

- Category:** I.b. Soil Treatment
- Purpose:** To provide standard methods for the evaluation of the effectiveness of various solidification/stabilization (S/S) processes.
- Application:** This protocol can be utilized for any S/S process (see notes #46 – #50).
- Description:** Currently the only regulatory test for the evaluation of S/S is EPA's Toxicity Characteristics Leaching Procedure (TCLP) test. This test is used to characterize a waste as hazardous as a result of the leaching of hazardous compounds under specified conditions. Due to the nature of the test, it is inappropriate to apply this test to determine and compare the effectiveness of different S/S processes or different formulations. The Waterways Experiment Station (WES) has developed various tests and protocols for this purpose. Depending on the ultimate disposal scenario for the S/S residue, various protocols are applied and an assessment of the treatment effectiveness of the S/S process over the raw material can be made.
- Advantages:** Currently no published protocol exists for S/S waste.
- Limitations:** Long-term verification of the protocol is not available.
- Cost:** Not available.
- Availability:** The protocol is currently available at the USAE Waterways Experiment Station but is unpublished to date.
- Status:** The protocol is in preparation.
- References:** Not available.
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## 46. STABILIZATION/SOLIDIFICATION

- Category:** I.b. Soil Treatment  
II.e. Minimization or Treatment of Other Solid Wastes
- Purpose:** To immobilize metal, organic, and inorganic contaminants in wet or dry soils and sludges using chemicals, reagents, and cement-like binding materials. To determine the effectiveness of solidification/stabilization (S/S) for incinerator ash residuals.
- Application:** Stabilization and solidification is a process that is applicable to the treatment of hazardous wastes and contaminated wet or dry soils, sludges, sediments, incinerator ash, and other solid wastes. It may be used for base, neutral, or acid extractable organics of high molecular weight, such as refinery wastes, creosote, and wood treating wastes, heavy metals, oil and grease, polychlorinated biphenyls, pentachlorophenol, and chlorinated and nitrated hydrocarbons.
- Description:** S/S is a process that involves the mixing of a hazardous waste with binder material to enhance the physical properties of the waste, chemically immobilize contaminants, and/or chemically bind any free liquid. Typical binders include Portland cements, pozzolans, or thermoplastics. Proprietary additives may also be added. In most cases, the S/S process is changed to accommodate specific wastes. Since it is not possible to discuss completely all possible modifications to a S/S process, most discussions of S/S processes have to be related directly to generic process types. The performance observed for a specific S/S system may vary widely from its generic type, but the general characteristics of a process and its products are usually similar. Examples of S/S processes are given in notes #47 through #50.
- Advantages:** The hazardous material is rendered either less toxic or less mobile. The handling and transportation properties are greatly enhanced, thus reducing the potential for hazardous waste spills. Free liquids can be eliminated.
- Ash residuals offer unique problems due to the fact that contaminants are concentrated in the ashes, and there is little water to hydrate the binder.
- Limitations:** Careful chemical characterization is required to select the S/S method most applicable. Some chemicals interfere with the setting properties of the waste binding agent. This method is not optimal for materials containing high concentrations of organics. S/S is not a destruction technology; rather, it is only a means of containment.
- Costs:** Costs depend upon specific applications, but range between \$30 and \$200 per ton.
- Availability:** This process is commercially available. The next four technical notes (#48 – #51) describe commercially available S/S processes.
- Status:** S/S has been demonstrated as an effective treatment technology for immobilization of most metals. Research is underway in many areas to evaluate the ability of S/S to immobilize organic contaminants. S/S is used in conjunction with other technologies to provide additional treatment of residual solids. S/S has been applied successfully to contaminated soils.

**References:** **The Superfund Innovative Technology Evaluation Program: Technology Profiles**, United States Environmental Protection Agency, pp. 100-101, EPA/540/5-90/006, Nov 1990.

Bricka, R.M. et al. **An Evaluation of Stabilization/Solidification of Fluidized Bed Incinerator Ash (K048 and K051)**. USAE Waterways Experiment Station Technical Report EL-88-24, 1988.

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Myers, T.E. **A Simple Procedure for Acceptance Testing of Freshly Prepared Solidified Waste**, *Hazardous and Industrial Solid Waste Testing: Fourth Symposium*, ASTM Special Technical Testing Publication 886, J.K. Petros et al. eds., American Society for Testing Materials, 1986, pp. 263-72.

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## 47. STABILIZATION/SOLIDIFICATION (CHEMFIX)

**Category:** I.b. Soil Treatment

**Purpose:** To immobilize metal, organic, and inorganic hazardous wastes in wet or dry soils and sludges using chemicals, reagents, and cement-like binding materials.

**Application:** The treatment of hazardous wastes and contaminated wet or dry soils, sludges, sediments, and other solid wastes. This method is directed primarily toward metal contaminants. Based upon the vendor's claims, it may be used also for base, neutral, or acid extractable organics of high molecular weight, such as refinery wastes, creosote, and wood treating wastes, oil and grease, polychlorinated biphenyls (PCB), penta-chlorophenol, and chlorinated and nitrated hydrocarbons.

**Description:** This solidification/stabilization (S/S) process is an inorganic system in which soluble silicates and silicate setting agents react with polyvalent metal ions and certain other waste components to produce a chemically and physically stable solid material. The treated waste matrix displays good stability, a high melting point, and a friable texture. The matrix may be similar to soil or rigid depending upon the water content of the feed waste. The feed waste is first blended in the reaction vessel (see figure 47) with certain reagents, which are dispersed and dissolved throughout the aqueous phase. The reagents react with polyvalent ions in the waste. Inorganic polymer chains (insoluble metal silicates) form throughout the aqueous phase and physically entrap the organic colloids within the microstructure of the product matrix. The water-soluble silicates then react with complex ions in the presence of a siliceous setting agent, producing amorphous, colloidal silicates (gels) and silicon dioxide, which acts as a precipitating agent. Most of the heavy metals in the waste become part of the silicate. Some of the heavy metals precipitate with the structure of the complex molecules. A very small percentage (estimated to be less than 1%) of the heavy metals precipitates between the silicates and is not chemically immobilized. Since some organics may be contained in particles larger than the colloids, all of the waste is pumped through processing equipment, creating sufficient shear to emulsify the organic constituents. Emulsified organics are then solidified and discharged to a prepared area, where the gel continues to set. The resulting solids, though friable, encase any organic substances that may have escaped. The system can be operated at 5 to 80% solids in the waste feed; water is added for dryer wastes. Portions of the water contained in the wastes are involved in three reactions after treatment: (1) hydration, similar to that of cement reactions; (2) hydrolysis reactions; and (3) equilibration through evaporation. There are no side streams or discharges from this process. The process is applicable to electroplating wastes, electric arc furnace dust, and municipal sewage sludge containing heavy metals such as aluminum, antimony, arsenic, barium, beryllium, cadmium, chromium, iron, lead, manganese, mercury, nickel, selenium, silver, thallium, and zinc.

**Advantages:** The CHEMFIX technology was effective in reducing the concentrations of lead and copper in the extracts from the toxicity characteristics leaching procedure (TCLP). The concentrations in the extracts from the treated wastes were 94 to 99% less than those from the untreated wastes. Total lead concentrations in the raw waste approached 14%. The results of the tests for durability were very good. The unconfined compressive strength (UCS) of the wastes varied between 27 and 307 psi after 28 days. Permeability decreased more than one order of magnitude. The air

monitoring data suggest that significant volatilization of PCBs did not occur during the treatment process.

**Limitations:** In the CHEMFIx process, the volume increase in the excavated waste material as a result of treatment varied from 20 to 50%.

**Costs:** Not available.

**Availability:** The process is commercially available. This is one system in the general category of stabilization and solidification.

**Status:** The CHEMFIx technology was demonstrated in March 1989 at the Portable Equipment Salvage Co. site in Clackamas, OR.

**References:** **The Superfund Innovative Technology Evaluation Program: Technology Profiles**, United States Environmental Protection Agency Report EPA/540/5-90/006, pp. 32-33, Nov 1990.

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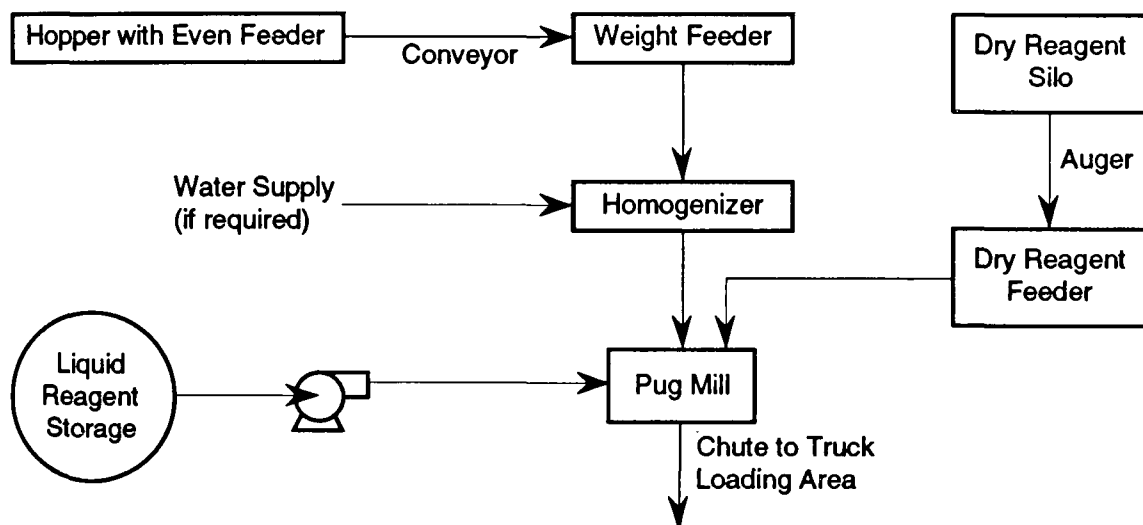
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*Figure 47. High solids-handling system block process flow diagram.*



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## 48. STABILIZATION/SOLIDIFICATION (DEEP SOIL MIXING)

**Category:** I.b. Soil Treatment

**Purpose:** To immobilize metal, organic, and inorganic hazardous wastes in wet or dry soils and sludges using chemicals, reagents, and cement-like binding materials.

**Application:** This method is applicable for the treatment of hazardous wastes and contaminated wet or dry soils, sludges, sediments, and other solid wastes. It may be used for base, neutral, or acid extractable organics of high molecular weight, such as refinery wastes, creosote, and wood-treating wastes, heavy metals, oil and grease, polychlorinated biphenyls (PCBs), pentachlorophenol, and chlorinated and nitrated hydrocarbons.

**Description:** This in situ solidification/stabilization (S/S) technology immobilizes organic and inorganic compounds in wet or dry soils, using reagents (additives) to produce a cement-like mass. The basic components of this technology are (1) Geo-Con's deep soil mixing system (DSM), a system to deliver and mix the chemicals with the International Waste Technologies' (IWT) proprietary treatment chemicals (see figure 48). The proprietary additives generate a complex crystalline connective network of inorganic polymers. The structural bonding in the polymers is mainly covalent. The process involves a two-phased reaction in which the contaminants are first complexed in a fast-acting reaction, and then in a slow-acting reaction, where the building of macromolecules continues over a long period of time. For each type of waste, the amount of additives used varies and must be determined. The DSM system involves mechanical mixing and injection. The system consists of one set of cutting blades and two sets of mixing blades attached to a vertical drive auger, which rotates at approximately 15 rpm. Two conduits in the auger are used to inject the additive slurry and supplemental water. Additive injection occurs on the downstroke; further mixing takes place upon auger withdrawal. The treated soil columns are 36 inches in diameter and are positioned in an overlapping pattern of alternating primary and secondary soil columns. Based on toxicity characteristics leaching procedure (TCLP) leachate analysis, the process appears to immobilize PCBs; however, because PCBs do not leach from most untreated soil samples, the immobilization of PCBs in the treated soil could not be confirmed. Sufficient data were not available to evaluate the performance of the system with regard to metals or other organic compounds. The bulk density of the soil increased 21% after treatment. This increased the volume of treated soil by 8.5% and caused a small ground rise of 1 inch per treated foot of soil. The unconfined compressive strength (UCS) of the treated soil was satisfactory, with values from 300 to 500 psi. The permeability of the treated soil was satisfactory, decreasing four orders of magnitude compared to the untreated soil, or  $10^{-6}$  and  $10^{-7}$  compared to  $10^{-2}$  cm/sec. The wet/dry weathering test on treated soil was satisfactory. The freeze/dry weathering test of treated soil was unsatisfactory. The microstructural analysis, scanning electron microscopy (SEM), optical microscopy, and x-ray diffraction (XRD), showed that the treated material was dense, non-porous, and homogeneously mixed. The Geo-Con DSM equipment operated reliably.

**Advantages:** In the IWT/DSM process, microstructural analyses of the treated soils indicated a potential for long-term durability. High, unconfined compressive strengths and low permeabilities were recorded. The permeability of the treated soil was satisfactory. The wet/dry weathering test on treated soil was satisfactory. The Geo-Con DSM

equipment operated reliably. The bulk density of the soil increased 21% after treatment.

**Limitations:** For the IWT/DSM process, there are insufficient data to confirm the immobilization of volatile and semivolatile organics. The treated soil volume increased by 8.5%. The freeze/dry weathering test of treated soil was unsatisfactory. Performance data are limited outside of site demonstrations. The developer modifies the binding agent for different wastes. Treatability studies should be performed for specific wastes. Based on TCLP leachate analysis, the process appears to immobilize PCBs. However, because PCBs did not leach from most of the untreated soil samples, the immobilization of PCBs in the treated soil could not be confirmed.

**Costs:** IWT/DSM process – \$194 per ton for the one-auger machine used in the demonstration; \$110 per ton for a commercial four-auger operation.

**Availability:** This process is commercially available. This is one system in the general category of stabilization and solidification.

**Status:** The SITE demonstration was conducted at a PCB-contaminated site in Hialeah, FL, in April 1988. Two 10 x 20-ft test sectors of the site were treated – one to a depth of 18 ft, and the other to a depth of 14 ft. Ten months after the demonstration, long-term monitoring tests were performed on the treated sectors.

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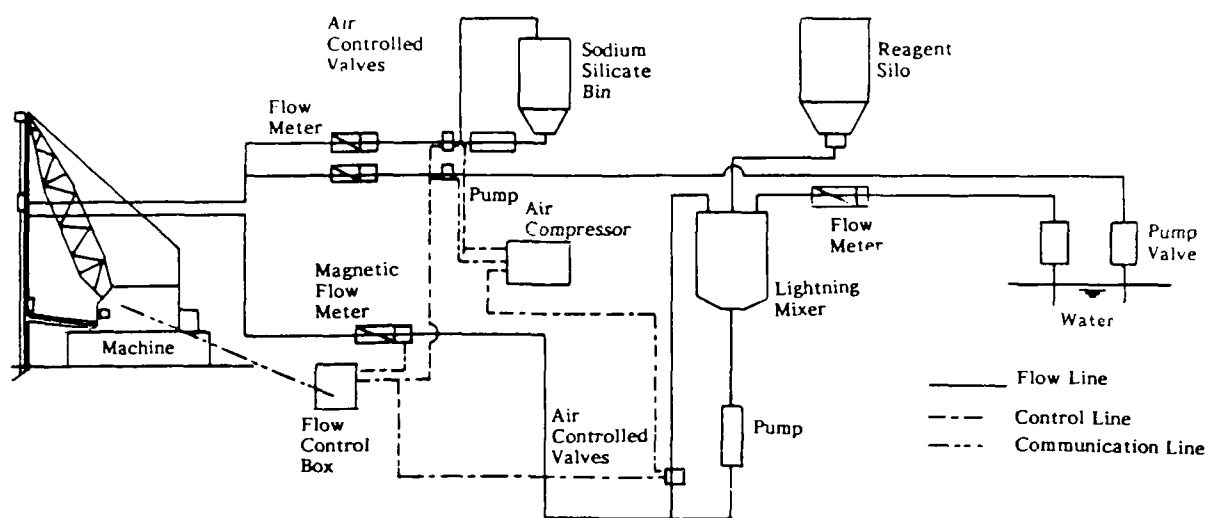
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*Figure 48. In situ stabilization batch mixing-plant process diagram.*

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## 49. STABILIZATION/SOLIDIFICATION (IM-TECH)

- Category:** I.b. Soil Treatment
- Purpose:** To immobilize metal, organic, and inorganic hazardous wastes in wet or dry soils and sludges using chemicals, reagents, and cement-like binding materials.
- Application:** This method is applicable for the treatment of hazardous wastes and contaminated wet or dry soils, sludges, sediments, and other solid wastes. It may be used for base, neutral, or acid extractable organics of high molecular weight, such as refinery wastes, creosote, and wood treating wastes, heavy metals, oil and grease, polychlorinated biphenyls (PCB), pentachlorophenol, chlorinated and nitrated hydrocarbons.
- Description:** The IM-TECH solidification/stabilization (S/S) treatment technology immobilizes contaminants in soils by binding them into a concrete-like, leach-resistant mass. The technology mixes hazardous wastes, cement, water, and an additive called chloranan that encapsulates organic molecules. Contaminated soil is excavated, screened for oversized material, and fed to a mobile field blending unit. The unit consists of soil and cement holding bins, a chloranan (a proprietary chemical) feed tank, and a blending auger to mix the waste and pozzolanic materials (Portland cement, fly ash, or kiln dust). Water is added as necessary, and the resultant slurry is allowed to harden before disposal. The treated output is a hardened, concrete-like mass that immobilizes the contaminants. For large volumes of waste, larger blending systems are available. The comparison of the soil 7-day, 28-day, 9-month, and 22-month sample test results are generally favorable. The physical test results were very good, with unconfined compressive strength between 220 to 1,570 psi. Very low permeabilities were recorded, and the porosity of the treated wastes was moderate. Durability test results showed no change in physical strength after the wet/dry and freeze/thaw cycles. The waste volume increased by about 120%. By using less stabilizer, it is possible to reduce volume increases, but lower strengths will result. There is an inverse relationship between physical strength and the waste organic concentration. The results of the leaching tests were mixed.
- Advantages:** The process may solidify contaminated material with higher concentrations (up to 25%) of organics. Heavy metals may be immobilized. In many instances, leachate reductions were greater than 100 ppb. The physical properties of the treated waste exhibit high unconfined compressive strengths, low permeabilities, and good weathering properties.
- Limitations:** In the process the treated soils undergo a volumetric increase of approximately 120%. Organic contaminants, including volatiles and base/neutral extractables were not immobilized to any significant extent. Oil and grease concentrations were greater in the treated waste toxicity characteristics leaching procedures (TCLP) than in the untreated waste, from less than 2 up to 4 ppm.
- Costs:** Costs for the process are expected to range between approximately \$90 and \$120 per ton.
- Availability:** This process is commercially available. This is one system in the general category of stabilization and solidification.

**Status:** The technology was demonstrated in October 1987 at a former oil reprocessing plant in Douglassville, PA. The site contained high levels of oil and grease (25%) and heavy metals (2.2% lead, and low levels of volatile organic compounds (VOC) (100 ppm) and PCBs (75 ppm). Since the demonstration, the technology has been used to remediate a sludge with 85% oil from a refinery lagoon in Alaska, several organic sludges for refineries on the Gulf Coast, and a California Superfund site contaminated with very high levels of heavy metals.

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**The Superfund Innovative Technology Evaluation Program: Technology Profiles.** U.S. Environmental Protection Agency Report EPA/540/5-89/013, Nov 1989, pp. 27-28, 47-48, 51-52, & 74-75.

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## 50. STABILIZATION/SOLIDIFICATION (SOLIDITECH)

**Category:** I.b. Soil Treatment

**Purpose:** To immobilize metal, organic, and inorganic hazardous wastes in wet or dry soils and sludges using chemicals, reagents, and cement-like binding materials.

**Application:** This method is applicable for the treatment of hazardous wastes and contaminated wet or dry soils, sludges, sediments, and other solid wastes. It may be used for base, neutral, or acid extractable organics of high molecular weight, such as refinery wastes, creosote, and wood treating wastes, heavy metals, oil and grease, polychlorinated biphenyls (PCB), pentachlorophenol, and chlorinated and nitrated hydrocarbons.

**Description:** The SOLIDITECH solidification/stabilization (S/S) process immobilizes contaminants in soils and sludges by binding them in a concrete-like, leach-resistant matrix. Contaminated waste materials are collected, screened to remove oversized material, and introduced to the batch mixer (figure 50). The waste material is then mixed with: (1) water; (2) urrichem, a proprietary chemical reagent; (3) proprietary additives; and (4) pozzolanic material (flash), kiln dust, or cement (cement was used for the demonstration). Once thoroughly mixed, the treated waste is discharged from the mixer. The treated waste is a solidified mass with significant unconfined compressive strength, high stability, and a rigid texture similar to that of concrete. Chemical analyses of extracts and leachates showed that heavy metals present in the untreated waste were immobilized. The process solidified both solid and liquid wastes with high organic content (up to 17%) as well as oil and grease. Volatile organic compounds in the original waste were not detected in the treated waste. Physical test results of the solidified waste samples showed: (1) unconfined compressive strengths ranged from 390 to 860 psi; (2) very little weight loss after 12 cycles of wet/dry and freeze/thaw durability tests; (3) low permeability of the treated waste; and (4) increased density after treatment. The solidified waste increased in volume by an average of 22%. The bulk density of the waste material increased by approximately 35% due to solidification. Semivolatile organic compounds (phenols) were detected in the treated waste and the toxicity characteristics leaching procedure (TCLP) extracts from the treated waste, but not in the untreated waste or its TCLP extracts. The presence of these compounds is believed to result from chemical reactions in the waste treatment mixture. Oil and grease content of the untreated waste ranged from 2.8 to 17.3% (28,000 to 173,000 ppm). The pH of the solidified waste ranged from 11.7 to 12.0. The pH of the untreated waste ranged from 3.4 to 7.9. PCBs were not detected in any extracts or leachates of the treated waste. Visual observation of solidified waste showed dark inclusions approximately 1 mm in diameter.

**Advantages:** In the SOLIDITECH process heavy metals present in the untreated waste appear to be immobilized. Both solid and liquid wastes with high organic content as well as oil and grease were solidified. Volatile organic compounds in the original waste were not detected in the treated waste. Physical test results of the solidified waste samples were satisfactory. PCBs were not detected in any extracts or leachates of the treated wastes.



**Limitations:** In the SOLIDITECH process, the solidified waste increased in volume by an average of 22%. Semivolatile organic compounds (phenols) were detected in the treated waste and the TCLP extracts from the treated waste, but not in the untreated waste or its TCLP extracts. The pH of the solidified waste ranged from 11.7 to 12.0. The pH of the untreated waste ranged from 3.4 to 7.9.

**Costs:** Not available.

**Availability:** This process is commercially available. This is one system in the general category of stabilization and solidification.

**Status:** The SOLIDITECH process was demonstrated in December 1988 at the Imperial Oil Company/Champion Chemical Company Superfund site in Morganville, NJ. This location formerly contained both chemical processing and oil reclamation facilities. Wastes treated during the demonstration were soils, a waste pile, and wastes from an old storage tank. These wastes were contaminated with petroleum hydrocarbons, PCBs, other organic chemicals, and heavy metals.

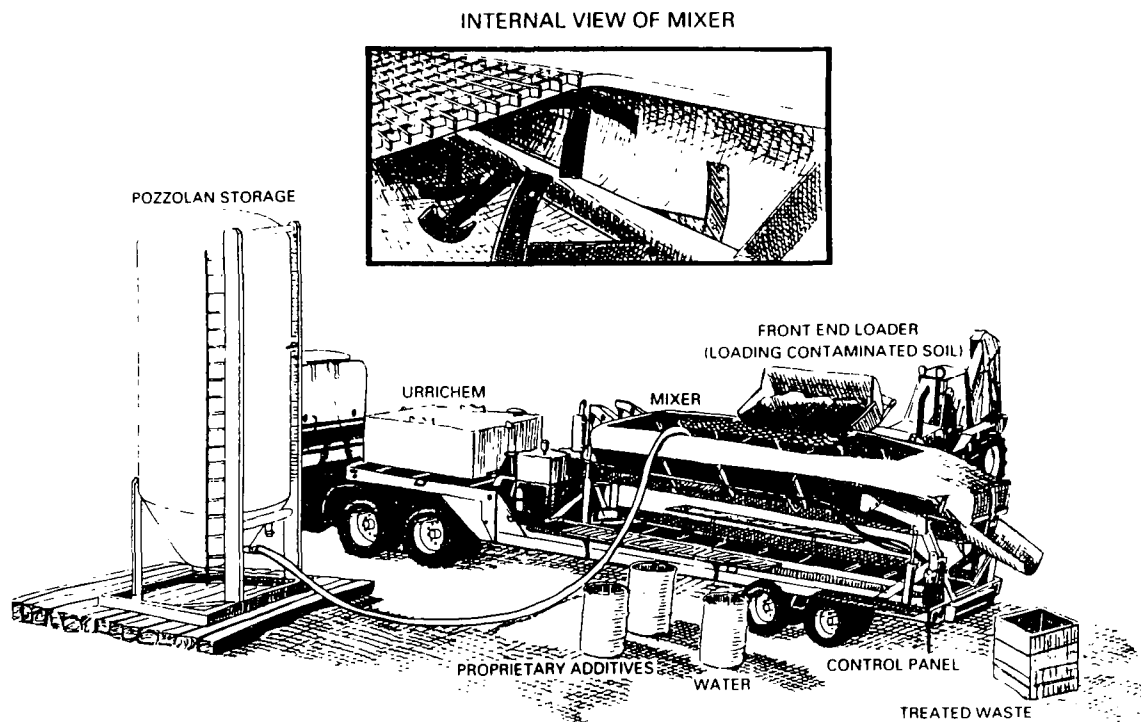
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*Figure 50. Soliditech processing equipment.*

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## 51. BIODECONTAMINATION OF FUEL OIL SPILLS

- Category:** I.b. Soil Treatment
- Purpose:** To decontaminate difficult to reach soils containing fuel oil from leaking tanks and piping.
- Application:** Special bacteria are introduced where spills of fuel oil and other biodegradable hydrocarbons have been severe and indigenous bacteria have been destroyed.
- Description:** Biodegradation is accomplished by applying special oil-degrading bacteria to a bioreactor while filling the reactor with leachate water. As the reactor overflows, bacteria are carried to a spray field pump sump and then to injection wells and the spray field. Surface sprayers apply the treated leachate water on the spray field while the injection wells apply the treated leachate water to soil under buildings. As more water is added to the system and the ground under the buildings and throughout the contaminated area becomes saturated, run-off water along with leachate water is collected in a trench down-slope from the contaminated area. The collected water is pumped back to the aerated reactor where bacterial growth on the high surface area matrix, on which some of the bacteria are immobilized, occurs. Clean nutrient-, detergent-, and oxygen-enriched water with bacteria is recirculated to the spray field and injection wells. For this implementation, the contaminated area had a considerable slope, and the contaminated soil was a thin layer over a relatively impermeable rock substrate.
- Advantages:** Excavation is not required. Buildings over a contaminated site would not have to be destroyed by excavation.
- Limitations:** The microorganisms function best at temperatures between 20° and 35° C. Biological growth in injection wells and in piping might restrict flow.
- Costs:** The site was cleaned to a satisfactory level for about \$37,000, not including shipping the equipment to the site, installation labor supplied by facilities personnel, and analytical costs. The treatment area was 800 m<sup>2</sup>. Costs generally run between \$50 and \$150/yd<sup>3</sup>.
- Availability:** The technology and equipment are commercially available. The particular system used for this implementation is proprietary and was supplied by Polybac Corp., Allentown, PA.
- Status:** The method was implemented to clean up a fuel oil spill resulting from leaking pipes at a Naval Communication Station at Thurso, Scotland. In this case, oil was entrapped in the soil matrix beneath boiler and power buildings. The project lasted from February to October 1985.

WES is currently developing a method of extracting those native microbial populations that show capability of degrading spilled product from the freshly contaminated soil. Once these consortia are identified they will be removed and incubated and a seed medium developed. The inoculum made up of the native microbes will then be added back into the soil for remediation of the spilled product. It is anticipated that the inocula consisting of the native populations should stand a

better chance of successful cleanup as opposed to inoculum made up of exotic microbes that are not native to the soil. WES has completed a bench-scale evaluation of mechanisms responsible for degradation of heavy petroleum hydrocarbons in a landfarming biotreatment system. WES has also performed both bench- and pilot-scale bioslurry studies for treating petroleum hydrocarbon-contaminated soils.

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## 52. BIOREMEDIATION IN COLD REGIONS

**Category:** I.b. Soil Treatment

**Purpose:** To biodegrade fuels and other organics in cold regions.

**Application:** This technology can be applied to jet fuels and weathered jet fuel products in soil.

**Description:** This technology is a form of landfarming of contaminated soil. A lined infiltration basin is utilized for this process. A sprinkler system is used for distribution of water for moisturizing contaminated soil and distribution of mixed fertilizer as nutrients on the soil for biodegradation. Excess water that filters through the soil is recirculated for conservation of this resource. Biodegradation is complete to below detection levels. Contaminated soil is biodegraded to carbon dioxide, water, and clean soil. Upon completion of the process, soil is returned to its original location as it is declassified.

**Advantages:** Contaminated soil is not deposited into a hazardous waste landfill, it is not left in place to cause further contamination, it is not incinerated, but rendered through biodegradation to carbon dioxide, water, and clean soil. There is no outward evidence or appearance of the application of a decontamination process on contaminated soil (e.g. no stacks or trucks carrying waste). Decontaminated soil can be declassified and returned to its original location as the process is completed.

**Limitations:** This biodegradation process is temperature-dependent. Therefore, the process does not operate in freezing temperatures during winter months.

**Cost:** Not available.

**Availability:** Commercially available.

**Status:** Full-scale implementation occurred at the Fairbanks, AK Airport during 1991-92.

**References:** None available.

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## 53. SURFACE PILE BIOREMEDIATION OF FUEL IN SOILS

**Category:** I.b. Soil Treatment

**Purpose:** To decontaminate soils that have been contaminated with fuels.

**Application:** The process may be applied to soils contaminated with diesel, JP-5, or other fuels that have leaked from underground storage tanks.

**Description:** Contaminated soil is removed from the contaminated site and stockpiled for treatment. The stockpiled soil is processed through a screen to eliminate rocks greater than 4 inches in diameter. The screened soil is transported to a site that is protected by a 40-mil liner with 8 in. of sand sub-base. Three feet of contaminated soil is spread along the base of the pile, and then a series of vacuum extraction pipes are trenched in the soil and connected to the vacuum extraction system (VES) blower. The VES blower provides movement of oxygen through the pile. The remaining soil is piled into a trapezoid shape about 15 ft high, 200 ft long, and 60 ft wide. Fertilizer is added, and an irrigation system is installed (see figure 53).

Computer-controlled sensors are placed within the pile to monitor temperature, pressure, and soil moisture. A sampling plan was designed to measure the rate of biodegradation and the effects of system design on biodegradation; i.e. compaction, distance from VES piping, and depth. Analytical procedures included total petroleum hydrocarbon (TPH) measured by EPA Method 418.1 and total recoverable petroleum hydrocarbon (TRPH) as diesel using the California Department of Health Services (DOHS) Method. Microbiological activity was measured using standard plate counts and hydrocarbon-degraded plate counts. Standard methods were used to determine water content, ammonia, nitrate, nitrite, phosphate, and pH.

The final analysis of the third set of samples taken after approximately 2 months of operation indicates that the average TPH is 120 ppm. A report has been prepared for the regional water quality board, and the site has been declared clean. A research report will be prepared when the data are finalized.

**Advantages:** Fuels that have contaminated soil are completely destroyed with no hazardous byproducts. Upon approval from the EPA, soil may be delisted and returned to the excavation site. The method is not limited by the concentration of fuel in the soil.

**Limitations:** The process is not proven or approved for concentrations > 500 ppm.

**Costs:** Approximately \$80/ton at the Bridgeport pilot project (report not published).

**Availability:** The technology is commercially available.

**Status:** Field pilot testing has been conducted at Bridgeport, CA in FY89. Full-scale implementation at 29 Palms, CA, MC Air Ground Combat Center is in progress.

**References:** Not available.



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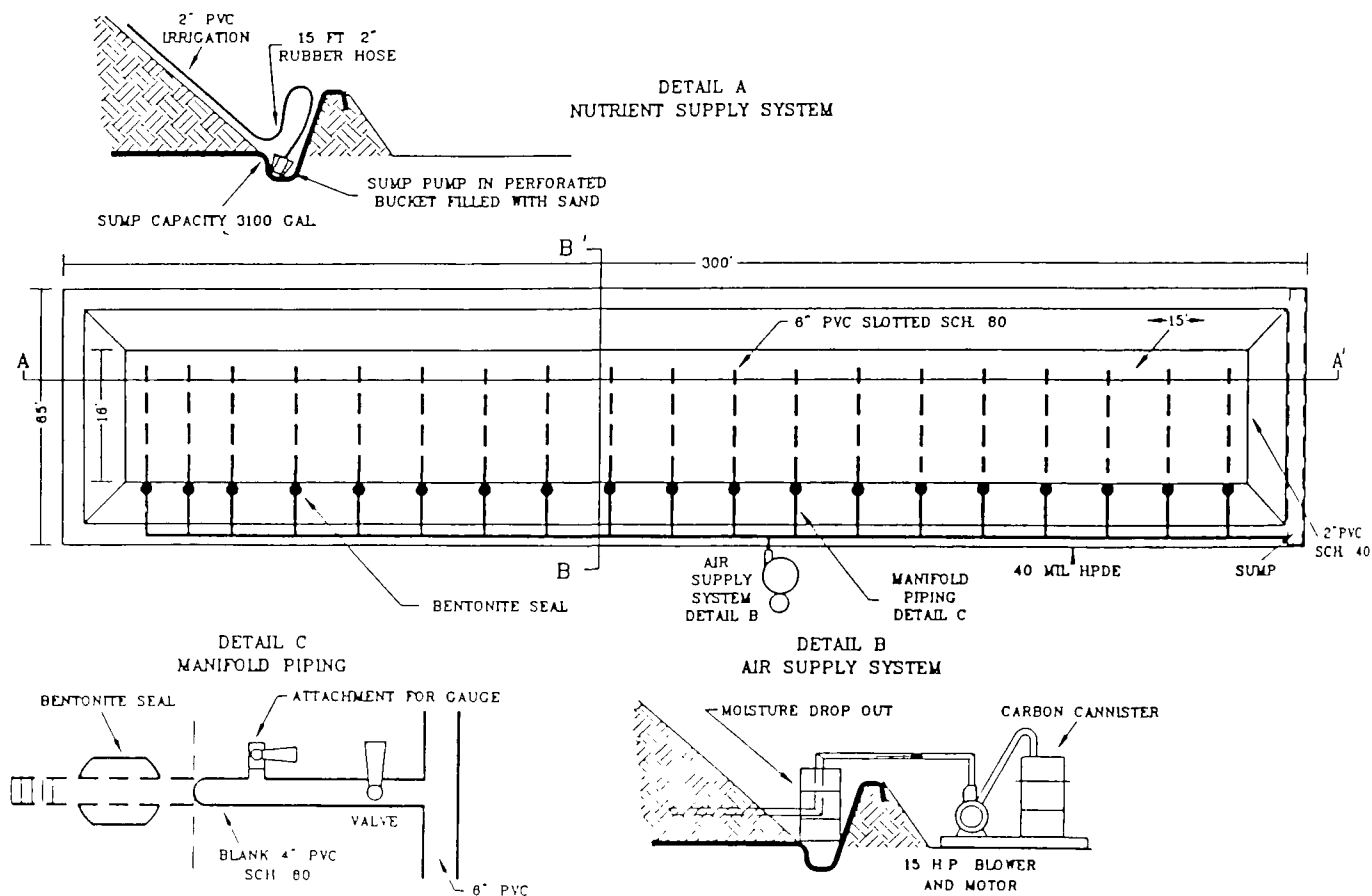


Figure 53. Nutrient supply system for the surface pile biodegradation system.

## 54. EXTRACTION OF OILY WASTES

**Category:** I.b. Soil Treatment

**Purpose:** Decontamination of soils.

**Application:** This process can be used to treat sludges, soils, and other water-bearing wastes containing oil-soluble hazardous compounds, including polychlorinated biphenyls (PCB), polynuclear aromatic (PNA) compounds, and dioxins. The process has been commercially applied to municipal wastewater sludge, paper mill sludge, rendering waste, pharmaceutical plant sludge, and many other wastes.

**Description:** This process is designed to separate materials into their constituent solid, oil (including oil-soluble substances), and water phases. It is primarily intended for soils and sludges contaminated with oil-soluble hazardous compounds. The technology uses food-grade carrier oil to extract the oil-soluble contaminants (figure 54). Pretreatment is necessary to achieve particle sizes less than 3/8-inch.

The carrier oil, with a boiling point of 400°F, typically is mixed with waste sludge or soil and the mixture is placed in the evaporation system to remove any water. The oil serves to fluidize the mix and maintain a low slurry viscosity to ensure efficient heat transfer, allowing virtually all of the water to evaporate.

Oil-soluble contaminants are extracted from the waste by the carrier oil. Volatile compounds present in the waste are also stripped in this step and condensed with the carrier oil or water. After the water is evaporated from the mixture, the resulting dried slurry is sent to a centrifuging section that removes most of the carrier oil from the solids.

After centrifuging, residual carrier oil is removed by a process known as hydroextraction. The carrier oil is recovered by evaporation and steam stripping. The hazardous constituents are removed from the carrier oil by distillation. This stream can be incinerated or reclaimed. In some cases, heavy metals in the solids will be complexed with hydrocarbons and will also be extracted by the carrier.

**Advantages:** This technology will extract oil, PCBs, PNAs, and dioxins from high water content (72%) sludges.

**Limitations:** Additional treatment is necessary to destroy the contaminants after extraction.

**Cost:** Not available.

**Availability:** Commercially available.

**Status:** The process has been successfully tested in a pilot plant on refinery slop oil, consisting of 72% water, as well as on a mixed refinery waste consisting of dissolved air flotation sludge, API separator bottoms, tank bottoms, and biological sludge.

**References:** The Superfund Innovative Technology Evaluation Program: Technology Profiles, U.S. Environmental Protection Agency, EPA/540/5-90/006, Nov 1990, pp. 36-7.

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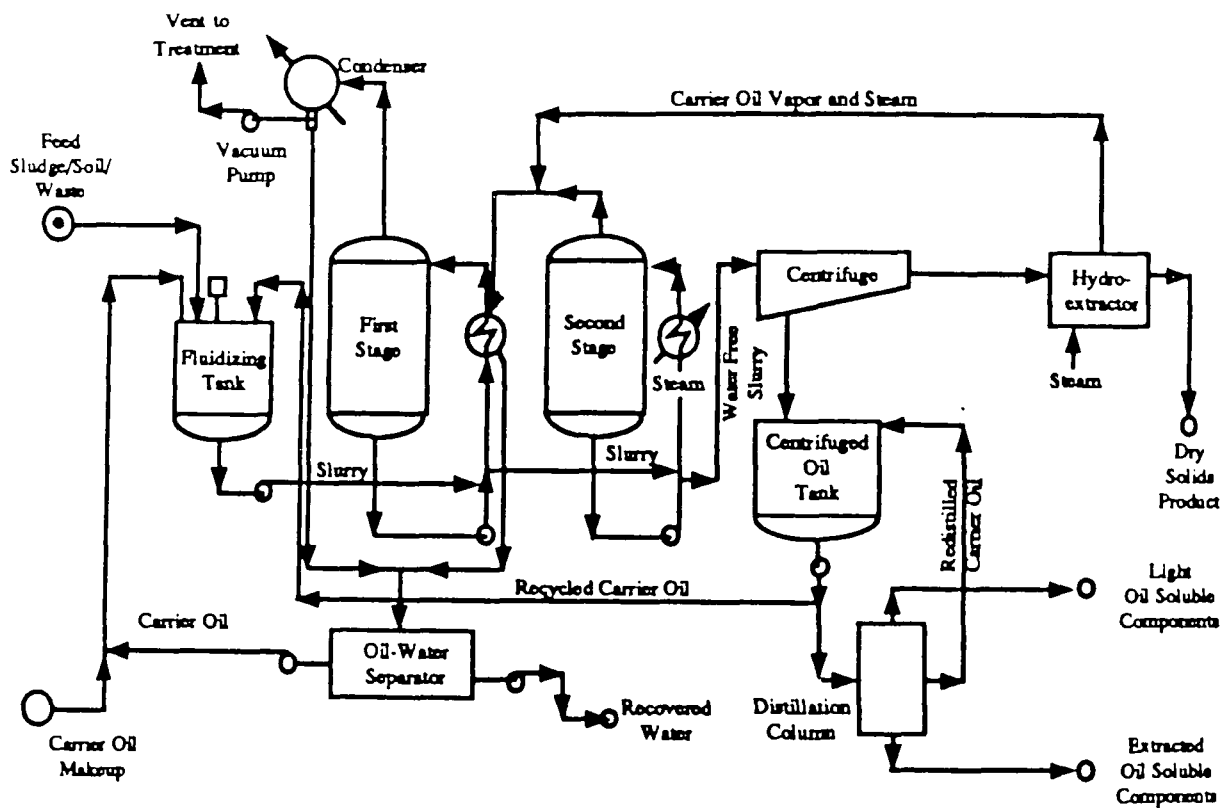


Figure 54. Simplified Carver Greenfield process flow diagram

## 55. IN SITU SOIL VENTING GUIDANCE MANUAL

- Category:** I.b. Soil Treatment
- Purpose:** Design and operation of soil vapor extraction systems.
- Application:** This method is applicable to soils contaminated with volatile organic compounds (VOC).
- Description:** The manual is for design, operation, and cost estimation of in situ soil venting systems for the removal of VOC-contaminated soils. Spread sheets are included for cost estimates for design, installation, and operation of the systems. These designs are for VOC spills of 50,000 gallons to 100,000 gallons.
- Advantages:** All data needed to design a soil vapor extraction system are in one manual.
- Limitations:** Design larger than 100,000 gallons are not covered in this manual.
- Cost:** No cost.
- Availability:** Published in December 1991.
- Status:** Manual is published.
- References:** DePaoli, D.E., et al. **Guidance Manual for the Application of In Situ Soil Venting for the Remediation of Soils Contaminated with Volatile Organic Compounds.** AFESC Report ESL-TR 90-21, Volume II, 1991.
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## 56. IN SITU SOIL VENTING

**Category:** I.b. Soil Treatment

**Purpose:** To remove volatile contaminants from unsaturated soils.

**Application:** This method is applicable for removal of volatile components such as fuels and trichloroethylene in soil. It is applicable to such sites as fire training pits, spills, and the unsaturated zone beneath leach pits. The method is most applicable for contamination at depths greater than 40 ft in fairly permeable soils (see notes #37 and #57).

**Description:** Venting wells are placed in the unsaturated zone and connected to a manifold and blower. A vacuum is applied to the manifold, and gases are extracted from the soil and fed to the treatment system. Depending upon the individual site and the depth of the contaminated zone, it might be necessary to seal the surface to the throughput of air. Analysis of soil gas for oxygen and carbon dioxide content during a field test at Hill AFB, UT, (figure 56) suggests that soil gas venting may provide oxygen for biodegradation. Further research is needed to prove conclusively that soil venting enhances biodegradation of organic contamination.

**Advantages:** This method is inexpensive, especially if the emissions require no treatment. The equipment is easily emplaced. It is less expensive than excavation at depths greater than 40 ft, and the costs are similar for depths between 10 and 40 ft. Operation is simple, excavation of contaminated soil is not required, and the site is not destroyed.

**Limitations:** This is a transfer-of-media method; the waste is not destroyed. At depths of less than 10 ft, excavation could be less expensive, depending upon the type of waste treatment required. The contamination must be located in the unsaturated zone above the nearest aquifer. Prior bench-scale testing is important in determining the effectiveness of the method to a specific site. To date, few field data exist on the level of clean-up. If the contamination includes toxic volatile organic compounds, then treatment of the vented gases may be required. The level of treatment normally is based upon local requirements.

**Costs:** The costs range from \$15/ton of contaminated soil, excluding emission treatment up to approximately \$85/ton using activated carbon emission treatment. Catalytic incineration was used at Hill AFB fuel spill at a cost of \$10/yd<sup>3</sup>. Based upon pilot studies at Twin Cities Army Ammunition Plant (TCAAP), MN, the cost to treat a site contaminated to a depth of 20 to 50 ft was between \$15 and \$20/yd<sup>3</sup>, excluding air treatment.

**Availability:** All equipment is commercially available. Treatment equipment must be selected on a case-by-case basis. Documentation by vendors is incomplete concerning the extent of cleanup by use of this method.

**Status:** A full-scale in situ field test was completed in October 1989 at Hill AFB. Based on data from the extracted gases, 80% of the 100,000-liter fuel spill was removed in 9 months of operation. Soil analysis following the test indicated an average fuel residual of less than 100 ppm in the soils. This method has been implemented by various organizations, including a full-scale remediation by the Army at TCAAP.

**References:** Kroopnick, P. **Modeling the In Situ Venting of Hydrocarbon Contaminated Soil.** Proc. 18th Environmental Symposium and Exhibition, Feb 1992.

DePaoli, D.W., S.E. Herbes, and M.G. Elliott. **Performance of In Situ Soil Venting System at a Jet Fuel Spill Site.** U. S. EPA Soil Vapor Extraction Workshop, Jun 1989.

Downey, D.C. and M.G. Elliott. **Performance of Selected In Situ Soil Decontamination Technologies: An Air Force Perspective.** American Institute of Chemical Engineers 1989 Summer National Meeting, Philadelphia, PA, Aug 1989.

Elliott, M.G. and D.W. DePaoli. **In Situ Venting of Jet Fuel-Contaminated Soil.** 44th Purdue Industrial Waste Conference, May 1989.

Metzer, N., et al., **In Situ Volatilization (ISV) Remedial System Cost Analysis Technical Report.** USATHAMA Report AMXTH-TE-CR-87123, Aug 1989.

Marks, P., et al., **Task Order 4. Laboratory Study of In Situ Volatilization (ISV) Technology Applied to Fort Campbell Soils Contaminated with JP-4, Final Report.** USATHAMA, May 1987.

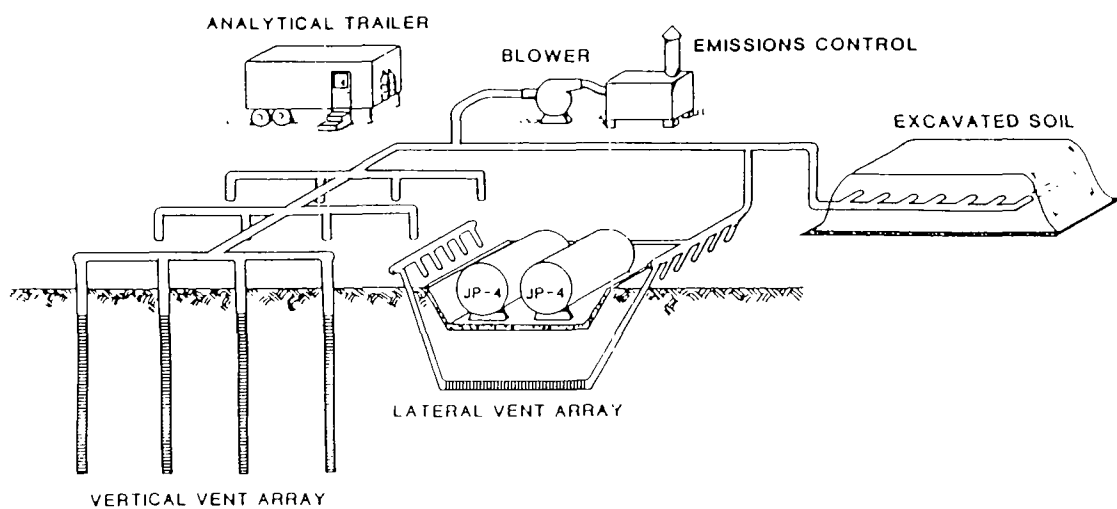
Bennedsen, M.B., J.P. Scott, and J.D. Hartley. **Use of Vapor Extraction Systems for In Situ Removal of Volatile Organic Compounds and Hazardous Materials.** Washington, D. C., Mar 1987, pp. 92-95.

Anasotos, G.J. et al. **Task 11. In Situ Stripping of Soils Pilot Study, Final Report.** USATHAMA Report AMXTH-TE-TR-85026, Oct 1985.

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*Figure 56. Conceptual drawing of in situ soil venting demonstration system, Hill AFB.*



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## 57. IN SITU SOIL VAPOR EXTRACTION

**Category:** I.b. Soil treatment

**Purpose:** To remove volatile organic compounds (VOC) from the vadose or unsaturated zone of soils (see also notes #37 and #56).

**Application:** This technology is applicable to organic compounds that are volatile or semivolatile at ambient temperatures in soils and groundwater. Contaminants should have a Henry's constant of 0.001 or higher for effective removal. The discussion here is related to Terra Vac, only one of the vendors who offer soil vapor extraction (SVE) technologies.

**Description:** In situ SVE is a process for removing VOCs from the vadose or unsaturated zone of soils. Often, these compounds can be removed from the vadose zone before they contaminate ground water. In this technology, a well is used to extract subsurface organic contaminants. The extracted contaminant stream passes through a vapor/liquid separator, and the resulting off gases undergo treatment, such as activated carbon, or thermal or catalytic destruction, before being released into the atmosphere. The technology uses readily available equipment, such as extraction and monitoring wells, manifold piping, a vapor/liquid separator, a vacuum pump, and an emission-control device, such as an activated carbon canister. Once a contaminated area is completely defined, an extraction well is installed and connected by piping to a vapor/liquid separator device (see figure 57). A vacuum pump draws subsurface contaminants through the well to the separator device and through an activated carbon canister before the air stream is discharged to the atmosphere. Subsurface vacuum and soil vapor concentrations are monitored using vadose zone monitoring wells. The technology does not require highly trained operators or soil excavation and is not limited by depth. The technology works best at sites that are contaminated by liquids with high vapor pressures. The success of the system depends on site conditions, soil properties, and the chemical properties of the contaminants. The process works in soils of low permeability (clays) if the soil has sufficient air-filtered porosity. Depending on the soil type and the depth to groundwater, the radius of influence of a single extraction well can range from tens to hundreds of feet. Typical contaminant recovery rates range between 20 and 2,500 pounds per day and are a function of volatility of the organic compound recovered and site characteristics. Therefore, the more volatile the organic compound, the faster the process works. The process is more cost-effective at sites where contaminated soils are predominantly above the water table, although some vendors offer systems designed for both vapor and groundwater recovery. The SVE demonstration at Groveland Wells Superfund site used four extraction wells to pump contaminants to the process system. Four monitoring wells were used to measure the impact of treatment on site contamination. During the SITE demonstration, 1,300 pounds of volatile organics, mainly trichloroethylene (TCE), were extracted during a 56-day operational period. The volatiles were removed from both highly permeable strata and low-permeability clays. The process represents a viable technology to fully remediate a site contaminated with VOCs. The major considerations in applying this technology are: volatility of the contaminants (Henry's constant), site soil porosity, and the required cleanup level. The process performed well in removing VOCs from soil with measured hydraulic conductivity of  $10^{-4}$  to  $10^{-8}$  cm/sec. Pilot

demonstrations are necessary when treating soils of low permeability and high moisture content.

**Advantages:** The process will remediate VOC contaminated soils with a measured air permeability of  $10^{-7}$  cm/sec. Contaminants should have a Henry's constant of 0.001 or higher for effective removal. Also, biodegradation of some organic compounds takes place during the SVE operation.

**Limitations:** The process may not remediate VOC-contaminated soils with a measured air permeability of less than  $10^{-8}$  cm/sec. Contaminants having a Henry's constant less than 0.001 may not be removed effectively.

**Cost:** Based on available data, treatment costs are typically near \$50/ton. Costs for small sites may range as high as \$150/ ton.

**Availability:** SVE technology is commercially available from several vendors.

**Status:** The Terra Vac process was first applied at a Superfund site in Puerto Rico, where carbon tetrachloride had leaked from an underground storage tank. In situ SVE processes are now used at more than 200 waste sites across the United States, such as the Verona Wells Superfund Site in Battle Creek, MI, which contains TCE and contaminants from gasoline station spills. A field demonstration of the process was performed as part of the SITE Program at the Groveland Wells Superfund site in Groveland, MA, which is contaminated by TCE.

**References:** Chatwin, T.D. et al. **Report of Results of the Vapor Vacuum Extraction Test at the Radioactive Waste Management Complex (RWMC) on the Idaho National Engineering Laboratory (INEL) in the State of Idaho.** Proc. 18th Environmental Symposium and Exhibition, Feb 1992.

**The Superfund Innovative Technology Evaluation Program: Technology Profiles.** U.S. Environmental Protection Agency Report EPA/540/5-91/008, Nov 1991, pp. 148-9.

**Soil Vapor Extraction Technology Reference Handbook.** U.S. Environmental Protection Agency Report EPA/540/2-91/003, Feb 1991.

**Engineering Bulletin - In Situ Soil Vapor Extraction Treatment.** U.S. Environmental Protection Agency Report EPA/540/2-91/006, May 1991.

**Handbook on In Situ Treatment of Hazardous Waste Contaminated Soils.** U.S. Environmental Protection Agency Report EPA/540/2-90/002, Jan 1990.

**The Superfund Innovative Technology Evaluation Program: Technology Profiles,** U.S. Environmental Protection Agency Report EPA/540/5-90/006, Nov 1990, pp. 92-3.

**The Superfund Innovative Technology Evaluation Program: Technology Profiles,** U.S. Environmental Protection Agency Report EPA/540/5-89/013, Nov 1989, pp. 77-8.

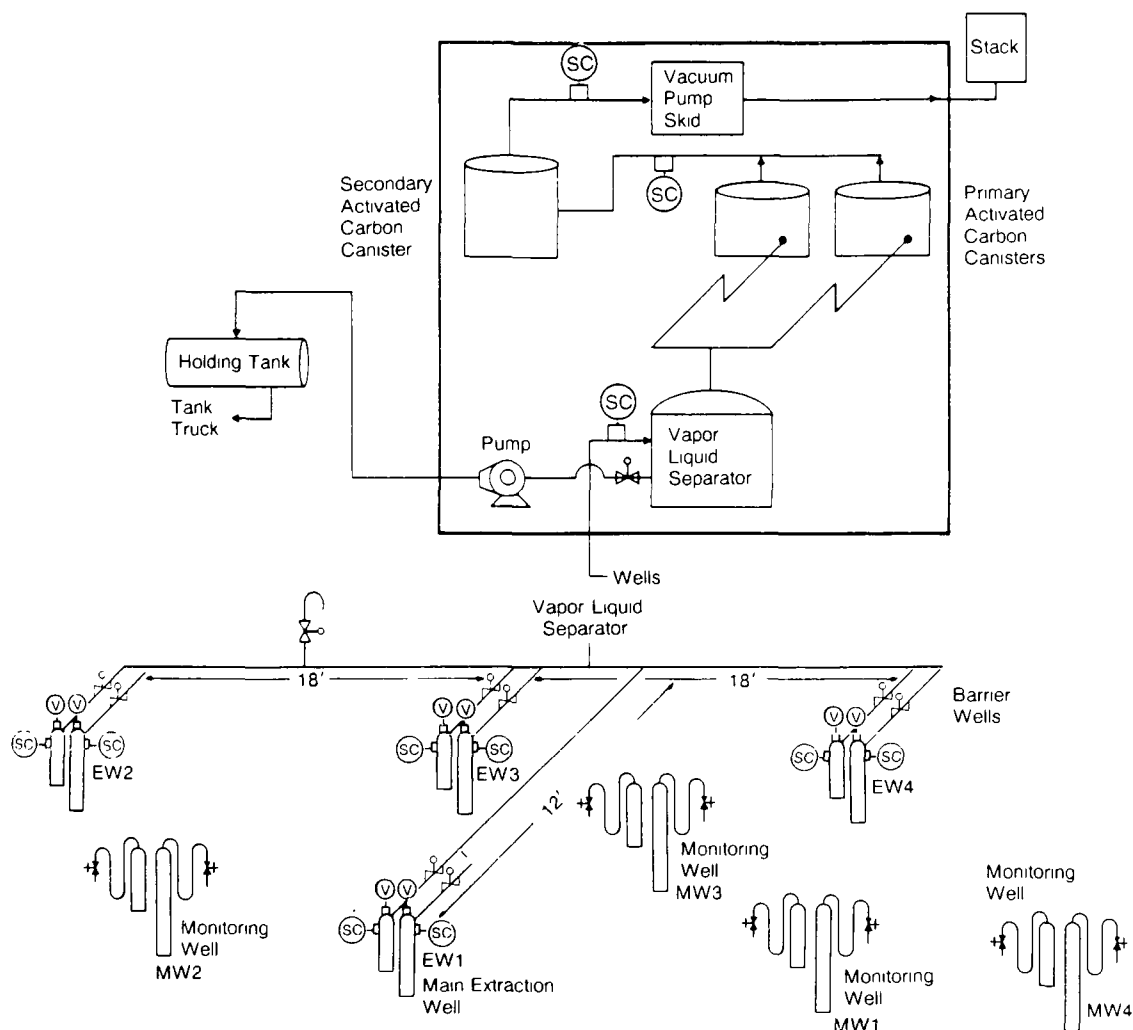
**Terra Vac In Situ Vacuum Extraction System: Applications Analysis Report.** U.S. Environmental Protection Agency, EPA/540/A5-89/003, Jul 1989

**Technology Demonstration Summary: Terra Vac In Situ Vacuum Extraction System, Groveland, Massachusetts. U.S. Environmental Protection Agency, EPA/540/S5-89/003, May 1989**

**Technology Evaluation Report: SITE Program Demonstration Test Terra Vac In Situ Vacuum Extraction System Groveland, Massachusetts, Volume 1, U.S. Environmental Protection Agency, EPA 540/5-89/003a, Apr 1989.**

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*Figure 57. Process diagram for in situ soil vapor extraction (Terra Vac).*

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## 58. IN SITU STEAM/AIR STRIPPING

- Category:** I.b. Soil Treatment
- Purpose:** To decontaminate soil contaminated with volatile organic compounds (VOC) and semi-VOCs (SVOC).
- Application:** This technology is applicable to organic contaminants, such as hydrocarbons and solvents with sufficient vapor pressure, in the soil. The technology is not limited by soil particle size, initial porosity, chemical concentration, or viscosity.
- Description:** In this technology, a transportable detoxifier treatment unit is used for in situ steam and air stripping of volatile organics from contaminated soil.

The two main components of the on site treatment equipment are the process tower and process train (figure 58). The process tower contains two counter-rotating hollow stem drills, each with a modified cutting bit 5 ft in diameter, capable of operating to a 27-ft depth. Each drill contains two concentric pipes. The inner pipe is used to convey steam to the rotating cutting blades. The steam is supplied by an oil-fired boiler at 450° F and 450 psig. The outer pipe conveys air at approximately 300° F and 250 psig to the rotating blades.

Steam is piped to the top of the drills and injected through the cutting blades. The steam heats the ground being remediated, increasing the vapor pressure of the volatile contaminants and thereby increasing the rate at which they can be stripped. Both the air and steam serve as carriers to convey these contaminants to the surface. A metal box called a shroud seals the process area above the rotating cutter blades from the outside environments, collects the volatile contaminants, and ducts them to the process train.

In the process train, the volatile contaminants and the water vapor are removed from the off gas stream by condensation. The condensed water is separated from the contaminants by distillation, then filtered through activated carbon beds, and subsequently used as make-up water for a wet cooling tower. Steam is also used to regenerate the activated carbon beds and as the heat source for distilling the volatile contaminants from the condensed liquid stream. The recovery-concentrated organic liquid can be recycled or used as a fuel in an incinerator.

- Advantages:** Soil contaminated by VOCs and SVOCs can be treated without excavation.
- Limitations:** There is a depth limitation of 27 ft for application of the process. The pollution in the aquifer is transferred to another media, carbon beds, needing further treatment and disposal.
- Cost:** Not available.
- Availability:** Commercially available.
- Status:** A SITE demonstration was performed the week of September 18, 1989 at the Annex Terminal, San Pedro, CA. Twelve soil blocks were treated for VOCs and SVOCs. Various liquid samples were collected from the process during operation, and the

process operating procedures were closely monitored and recorded. Post-treatment soil samples were collected and analyzed by EPA 8240 and 8270. In January 1990, 6 blocks which had been previously treated in the saturated zone were analyzed for EPA 8240 and 8270 chemicals.

**References:** The Superfund Innovative Technology Evaluation Program: Technology Profiles, United States Environmental Protection Agency, EPA/540/5-90/006, Nov 1990, pp. 96-97, 80-81.

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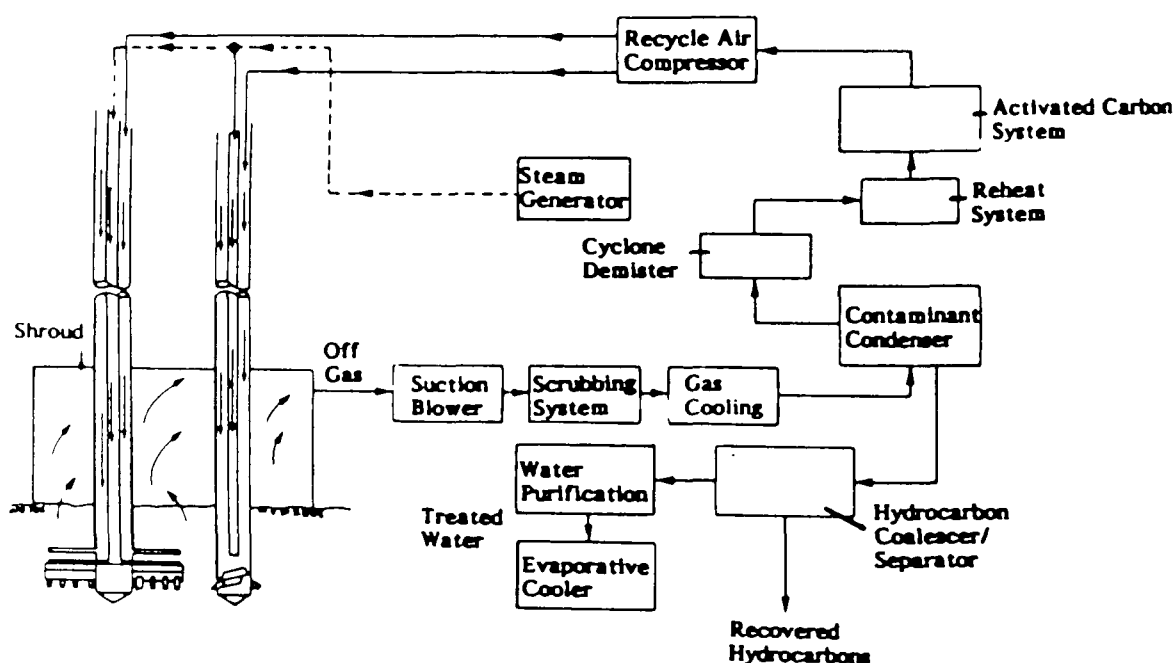


Figure 58. Typical detoxifier system process flow diagram.

## 59. IN SITU VITRIFICATION

**Category:** I.b. Soil Treatment

**Purpose:** To decontaminate soils through an electrical process that generates temperatures of 1,600° C to 2,000° C that will solidify the contaminated soil.

**Application:** This process can be used to destroy or remove organics and/or immobilize inorganics in contaminated soils or sludges. The initial application of the electric current must reduce the moisture content before the vitrification process can begin. This increases energy consumption and associated costs. Also, sludges must contain a sufficient amount of glass-forming material (non-volatile, non-destructible solids) to produce a molten mass that will destroy or remove organic pollutants and immobilize inorganic pollutants.

**Description:** In situ vitrification (ISV) uses an electrical network to melt soil or sludge at temperatures of 1,600 to 2,000° C, thus destroying organic pollutants by pyrolysis. Inorganic pollutants are incorporated within the vitrified mass, which has properties of glass. Both the organic and inorganic airborne pyrolysis byproducts are captured in a hood that draws the contaminants into an off gas treatment system that removes particulates and other pollutants of concern.

The vitrification process begins by inserting large electrodes into contaminated zones containing sufficient soil to support the formation of a melt (figure 59). An array (usually square) of four electrodes is placed at the desired treatment depth in the volume to be treated. Because soil typically has low conductivity, flaked graphite and glass frit are placed on the soil surface between the electrodes to provide a starter path for electric current. The electric current passes through the electrodes and begins to melt soil at the surface. As power is applied, the melt continues to grow downward, at a rate of 1 to 2 in./hr. Individual settings or emplacements each encompass a total melt mass of 1,000 tons and a maximum width of 30 ft. Single setting depths as great as 30 ft are considered possible. Depths of 17 ft have been achieved to date with the existing large-scale ISV equipment. Adjacent settings can be positioned to fuse to each other and to completely process the desired volume at a site. Stacked settings to reach a deep contamination are also possible.

The large-scale ISV system melts soil at a rate of 4 to 6 ton/hr. Since the void volume present in particulate materials (20-40% for typical soils) is removed during processing, a corresponding volume reduction occurs. Volume is further reduced as some materials present in the soil, such as humus and organic contaminants, are removed as gases and vapors during processing. After cooling, a vitrified monolith results, with a silicate glass and microcrystalline structure. This monolith possesses excellent structural and environmental properties.

The ISV system is mounted on three semi-trailers for transport to a site. Electric power is usually taken from a utility distribution system at transmission voltage of 125 or 138 kV; power may also be generated on site by a diesel generator. The electrical supply system has an isolated ground circuit to provide appropriate operational safety.



Air flow through the hood is controlled to maintain a negative pressure. An ample supply of air provides excess oxygen for combustion of any pyrolysis products and organic vapors from the treatment volume. The off gases, combustion products, and air are drawn from the hood by induced draft blower into the off-gas treatment system, where they are treated by: (1) quenching (2) pH controlled scrubbing; (3) dewatering (mist elimination); (4) heating (for dew point control); (5) particulate filtration; and (6) activated carbon adsorption.

**Advantages:** The process is usually conducted on site without excavation of contaminated soil. The final product is a monolith of silicate glass with a microcrystalline structure.

**Limitations:** The process is limited by : (1) individual void volumes in excess of 150 ft<sup>3</sup> ; (2) rubble in excess of 10 wt%; and (3) combustible organics in the soil or sludge in excess of 5 to 10 wt%, depending upon the heat value.

**Cost:** Not available.

**Availability:** Commercially available.

**Status:** Six full-scale demonstrations of the ISV process have been conducted on radioactive waste at the Department of Energy's Hanford Nuclear Reservation. More than 90 tests at various scales have been performed on polychlorinated biphenyl wastes, industrial lime sludge, dioxins, metal plating wastes, and other solid combustibles and liquid chemicals.

**References:** **The Superfund Innovative Technology Evaluation Program: Technology Profiles**, United States Environmental Protection Agency Report EPA/540/5-90/006, Nov 1990, pp. 52-53.

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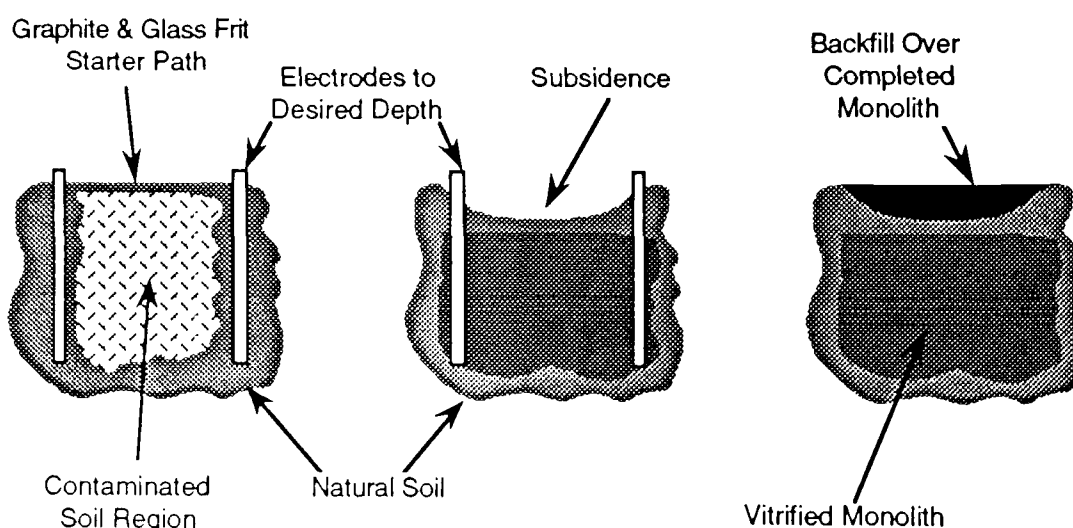


Figure 59. In situ vitrification process.

## 60. IN SITU CARBON REGENERATION

- Category:** I.b. Soil Treatment  
II.f. Minimization or Treatment of Gases
- Purpose:** To regenerate contaminated granular activated carbon on site; thereby, reducing regeneration and overall treatment costs.
- Application:** The method is applicable for the regeneration of granular activated carbon (GAC) contaminated by organic compounds and volatile organic compound (VOC) emissions from remediation systems using vapor phase treatment of off gases (see notes #1 and #74).
- Description:** A typical process involves passing a stream of contaminated air through one or more adsorbers that contain granular activated carbon. VOCs are adsorbed onto the carbon. After a period of time, the ability of the carbon to adsorb additional contaminants is reduced, and the air stream is switched to a parallel adsorber path. Regeneration gas is passed through the contaminated carbon adsorber to desorb the contaminants. The contaminants are passed into an oxidizer where they are decomposed. A schematic of a typical process is shown in figure 60. Normally, the process is automatic. The stream is switched between the alternate adsorber streams after a preset time or upon breakthrough. Another method of GAC regeneration that may be feasible is the use of acclimated microbial populations for degrading adsorbed contaminants.
- Advantages:** Waste compounds are decomposed. Costs for off site carbon regeneration are reduced. Potentially operator-free system would allow unsupervised operations.
- Limitations:** Not determined yet.
- Costs:** Not available.
- Availability:** Carbon regeneration systems are commercially available.
- Status:** Pilot test conducted at Letterkenny Army Depot, PA. WES is currently developing on site regeneration systems based on biological, chemical, and physical techniques.
- References:** Dobreviski, I., and L. Zvezdova. **Biological Regenerated Activated Carbon.** *Water Science and Technology*, 21(1):144, 1989.
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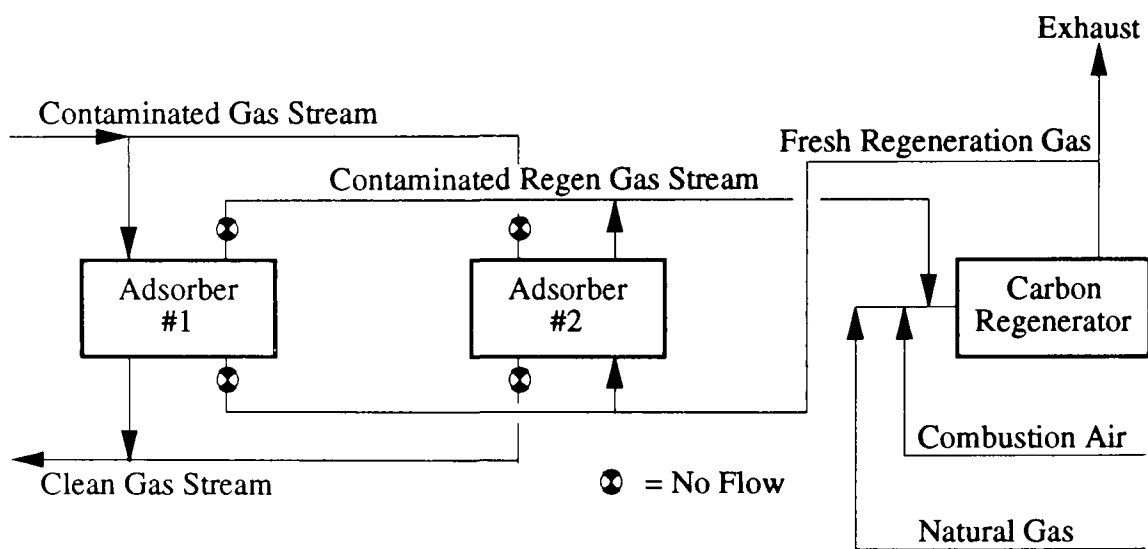


Figure 60. Schematic diagram of a typical carbon regeneration system. As shown, contaminated gas is being decontaminated in Adsorber #1 while the carbon in Adsorber #2 is being regenerated.

## 61. INCINERATION OF EXPLOSIVES CONTAMINATED SOIL

**Category:** I.b. Soil Treatment

**Purpose:** To decontaminate soils contaminated with explosives.

**Application:** This method is applicable for the decontamination of soils from lagoons used in the past for the disposal of wastewaters, known as pink water or red water, from the manufacture of explosives; from munitions load, assemble and pack (LAP) operations; and from demilitarization and wash-out operations.

**Description:** The incinerator is a rotary kiln operated at about 1,200° to 1,600° F. Other equipment includes the feed system, the bag house or scrubber system for off gases, and the ash-removal system (see figure 61). Fuel is required for the kiln, and water is required for cooling the ash and for the scrubber. The quantity of material that can be decontaminated per hour is proportional to the size of the incinerator.

**Advantages:** This is a destructive, rather than a media-transfer technique. The equipment is transportable and can be moved from one site to another and be operational within 4 to 8 weeks. Destructive efficiencies of greater than 99% have been demonstrated without any explosives detectable in the stack gases. The resulting ash is not hazardous.

**Limitations:** The method is relatively expensive. Excavation of the entire contaminated site is necessary for treatment. As with any operation dealing with explosive materials, safety is a primary concern. A rigorous explosives safety review must be conducted with particular attention to materials-handling operations.

**Costs:** Based on an economic evaluation of alternative incineration options, the total project costs for on site incineration with a transportable system range from \$200 to \$400 per cubic yard. These costs include operating and capital costs for excavation, transportation, and processing (see references).

**Availability:** The equipment is commercially available.

**Status:** The technology has been implemented at the Cornhusker Army Ammunition Plant, Grand Island, NB, and the Louisiana Army Ammunition Plant, Shreveport, LA. Incineration of explosives-contaminated soils is currently underway at Savanna Army Depot, Savanna, IL

**References:** Noland, J.W., J.R. Marks, and P.J. Marks, **Task 2. Incineration Test of Explosives Contaminated Soils At Savanna Army Depot Activity, Final Report, Savanna, Illinois, USATHAMA Report DRXTH-TE-CR-84277, Apr 1984.**

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## 62. INFRARED THERMAL DESTRUCTION (SHIRCO)

**Category:** I.b. Soil Treatment

**Purpose:** To destroy organic contaminants in the soil by combustion.

**Application:** This technology is suitable for soils or sediments with organic contaminants. Liquid organic wastes can be treated after mixing with sand or soil.

**Description:** The electric infrared incineration technology (originally developed by Shirco Infrared Systems, Inc. of Dallas, TX) is a mobile thermal-processing system that uses electrically powered silicon carbide rods to heat organic waste to combustion temperatures. Any remaining combustibles are incinerated in an afterburner. One configuration of this mobile system (see figure 62) is comprised of four components: an electric-powered infrared primary chamber, a gas-fired secondary combustion chamber, an emissions-control system, and a control center. Waste is fed into the primary chamber on a wire-mesh conveyor belt and exposed to infrared radiant heat (up to 1,850° F) provided by the horizontal rows of electrically powered silicon carbide rods above the belt. A blower delivers air to selected locations along the belt and can be used to control the oxidation rate of the waste feed. The ash material that drops off the belt in the primary chamber is quenched using scrubber water effluent. The ash is then conveyed to the ash hopper, where it is removed to a holding area and analyzed for polychlorinated biphenyl (PCB) content. Volatile gases from the primary chamber flow into the secondary chamber, which uses higher temperatures, greater residence time, turbulence, and supplemental energy (if required) to destroy these gases. Gases from the secondary chamber are ducted through the emissions-control system. In the emissions-control system, the particulates are removed in a venturi scrubber. Acid vapor is neutralized in a packed tower scrubber. An induced draft blower draws the cleaned gases from the scrubber into the free-standing exhaust stack. An emergency stack is installed prior to the venturi scrubber system so that if the temperature control system and its interlocks fail, the emissions control system will not be melted by the hot gases. The scrubber liquid effluent flows into a clarifier, where scrubber sludge settles out for disposal, and through an activated carbon filter for reuse or to a publicly owned treatment works (POTW) for disposal. In both tests, at standard operating conditions, PCBs were reduced to less than 1 ppm in the ash, with a destruction or removal efficiency (DRE) for air emissions greater than 99.99% (based on detection limits. In the pilot-scale demonstration, the standard for particulate emission (180 mg/dscf) was achieved. In the full-scale demonstration, however, this standard was not met in all runs due to scrubber inefficiencies. Lead was not immobilized; however, it remained in the ash and significant amounts were not transferred to the scrubber water or emitted to the atmosphere. The pilot testing demonstrated satisfactory performance with high feed rate and reduced power consumption when fuel oil was added to the waste feed and the primary chamber temperature was reduced.

**Advantages:** The process is capable of meeting both RCRA and TSCA DRE requirements for air emissions. Operations on waste feed contaminated with PCBs have consistently met the TSCA guidance level of 2 ppm in ash. Improvements in the scrubber system resulted in compliance with RCRA and TSCA particulate emission standards. Based on recent commercial operations, projected utilization factors range from 50 to 75%.

**Limitations:** In the full-scale demonstration the standard for particulate emission was not met in all runs due to scrubber inefficiencies. Lead was not immobilized. In some cases, restrictions in chloride levels in the waste and/or feed rate may be necessary to meet particulate emissions standards.

**Costs:** Economic analysis and observation suggest a cost range from \$180/ton to \$240/ton of waste feed, excluding waste excavation, feed preparation, profit, and ash disposal costs. Overall costs may be as high as \$800/ton.

**Availability:** Commercially available.

**Status:** EPA conducted two evaluations of the infrared system. An evaluation of a full-scale unit was conducted from August 1 to 4, 1987, during a removal action by Region IV at the Peak Oil site, an abandoned oil refinery in Tampa, FL. During the cleanup, a nominal 100 ton/day system treated nearly 7,000 cu yd of waste oil sludge containing PCBs and lead. A second demonstration of the system, at pilot-scale, took place at the Rose Township Demode Road Site, an NPL site in Michigan, from November 2 to 11, 1987. Organics, PCBs, and metals in soil were the target waste compounds to be destroyed or immobilized. The pilot-scale operation allowed the evaluation of performance under varied operating conditions. In addition to Peak Oil, infrared incineration was used to remediate PCB-contaminated materials at the Florida Steel Corporation Superfund site, and is being used on PCB-contaminated soil at the LaSalle Electric NPL site in Illinois.

**References:** **The Superfund Innovative Technology Evaluation Program: Technology Profiles**, United States Environmental Protection Agency Report EPA/540/5-90/006, Nov 1990, pp. 84-85.

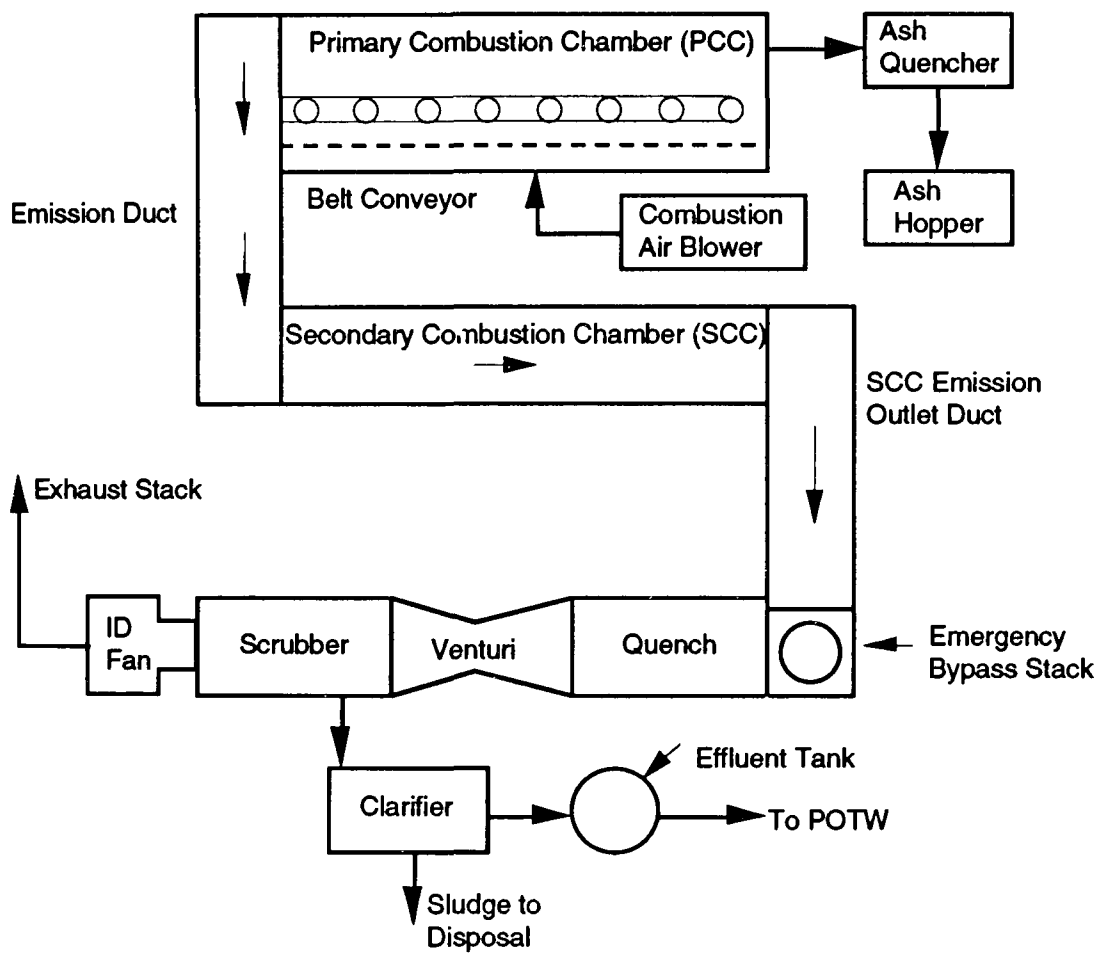
**The Superfund Innovative Technology Evaluation Program: Technology Profiles**, U.S. Environmental Protection Agency Report EPA/540/5-89/013, Nov 1989, pp. 69 & 70.

**Technology Demonstration Summary: Shirco Pilot-Scale Infrared Incineration System at the Rose Township Demode Road Superfund Site**, U.S. Environmental Protection Agency Report EPA/540/S5-89/007, Apr 1989.

**Technology Evaluation Report: SITE Program Demonstration Test Shirco Pilot-Scale infrared Incineration System at the Rose Township Demode Road Superfund Site, Vol. 1**, U.S. Environmental Protection Agency Report EPA/540/5-89/007a, Apr 1989.

**Technology Evaluation Report SITE Program Demonstration Test, Shirco Infrared Incineration System Peak Oil, Brandon, Florida, Vol. 1**, U.S. Environmental Protection Agency Report EPA/540/5-88/002a, Sep 1988.

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*Figure 62. Shirco incineration unit process diagram.*



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## 63. THERMAL DESTRUCTION (PYRETRON)

**Category:** I.b. Soil Treatment

**Purpose:** To destroy hazardous waste.

**Application:** Solid wastes contaminated with hazardous organics are suitable for the Pyretron technology. In general, the technology is applicable to any waste that can be incinerated.

**Description:** The Pyretron technology involves an oxygen-air-fuel burner and uses advanced fuel injection and mixing concepts to burn wastes. Pure oxygen, in combination with air and natural gas, is burned in the Pyretron burner to destroy solid hazardous waste. The burner operation is computer controlled to automatically adjust the amount of oxygen to sudden changes in the heating value of the waste. The burner can be fitted onto any conventional combustion unit for burning liquids, solids, and sludges. Solids and sludges can be co-incinerated when the burner is used in conjunction with a rotary kiln or similar equipment. Six polynuclear aromatic hydrocarbon compounds were selected as the principal organic hazardous constituents (POHC) for the test program – naphthalene, acenaphthylene, fluorine, phenanthrene, anthracene, and fluoranthene.

**Advantages:** The Pyretron technology achieved greater than 99.99% destruction and removal efficiencies (DRE) of all POHCs measured in all test runs performed. The technology with oxygen enhancement achieved double the waste throughput possible with conventional incineration. All particulate emission levels in the scrubber system discharge were significantly below the hazardous waste incinerator performance standard of 180 mg/dscm at 7% oxygen. Solid residues were contaminant free. There were no significant differences in transient carbon monoxide levels emissions between air-only incineration and Pyretron oxygen-enhanced operation. Cost savings can be achieved in many situations. The system is capable of doubling the capacity of a conventional rotary kiln incinerator. This increase is more significant for wastes with low heating values. In situations where particulate carryover causes operational problems, the Pyretron system may increase reliability.

**Limitations:** The technology is not suitable for processing aqueous wastes, RCRA heavy metal wastes, or inorganic wastes.

**Cost:** The costs associated with using the Pyretron in place of an air-only burner depend upon the relative costs of oxygen and fuel and to some extent the capital costs of the burners themselves. For this demonstration, operating the Pyretron with oxygen enhancement used oxygen worth between \$3,250 and \$3,870 (it was provided free of charge) and roughly \$2,672 worth of propane. Operation without oxygen enhancement consumed \$4,000 worth of propane. The Pyretron burners used in this demonstration had an estimated cost of \$150,000 and involved \$50,000 of design and development effort.

**Availability:** The technology is commercially available.

**Status:** A demonstration project was conducted at EPA's Combustion Research Facility in Jefferson, AR, using a mixture of 40% contaminated soil from the Stringfellow Acid

Pit Superfund site in California and 60% decanter tank tar sludge from coking operations (RCRA listed waste K087). The demonstration began in November 1987, and was completed at the end of January 1988.

**References:** **The Superfund Innovative Technology Evaluation Program: Technology Profiles**, U.S. Environmental Protection Agency Report EPA/540/5-90/006, Nov 1990, pp. 20-21.

**The Superfund Innovative Technology Evaluation Program: Technology Profiles**, U.S. Environmental Protection Agency Report EPA/540/5089/013, Nov 1989, pp. 15-16.

**Technology Demonstration Summary, The American Combustion Pyretron Thermal Destruction System at the U. S. EPA's Combustion Research Facility**, U.S. Environmental Protection Agency Report EPA/540/S5-89/008, May 1989.

**American Combustion Pyretron Destruction System, Applications Analysis Report**, Research and Development (MD-235) Report EPA/540/A5-89/008, Jun 1989.

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## 64. CIRCULATING BED COMBUSTOR

**Category:** I.b. Soil Treatment

**Purpose:** Decontamination of soils, slurries, and sludges.

**Application:** The circulating bed combustor (CBC) technology may be applied to soils, slurries, and sludges contaminated with halogenated and nonhalogenated hydrocarbons. The CBC technology was recently applied at two site-remediation projects for treating soils contaminated with polychlorinated biphenyls (PCB) and fuel oil.

**Description:** The CBC uses high-velocity air to entrain circulating solids and create a highly turbulent combustion zone for the efficient destruction of toxic hydrocarbons. The commercial-size combustion chamber (36 inches in diameter) can treat up to 100 tons of contaminated soil daily, depending on the heating value of the feed material.

The CBC technology operates at relatively low temperatures (approximately 1,600°F), thus reducing operation costs. The high turbulence produces a uniform temperature around the combustion chamber, hot cyclone, and return leg. It also promotes the complete mixing of the waste material during combustion. The effective mixing and relatively low combustion temperature also reduce emission of carbon monoxide and nitrogen.

As shown in Figure 64, waste material and limestone are fed into the combustion chamber along with the recirculating bed material from the hot cyclone. The limestone neutralizes acid gases. The treated ash is transported out of the system by an ash conveyor for proper disposal.

Hot gases produced during combustion pass through a convective gas cooler and baghouse before being released to the atmosphere. Ogden states that the CBC technology can attain a destruction and removal efficiency (DRE) of 99.99% for hazardous waste and 99.9999% for PCB waste.

**Advantages:** CBC technology can attain a DRE of 99.99% for hazardous waste and 99.9999% for PCB waste.

**Limitations:** The treated ash must be disposed of upon decontamination of the soil.

**Cost:** Not available.

**Availability:** Commercially available.

**Status:** The CBC technology is one of seven nationwide incinerators permitted to burn PCBs. A test burn/treatability study of waste from the McColl Superfund site was conducted in March 1989. A demonstration of the feasibility of the CBC to treat red water from TNT production is planned.

**References:** The Superfund Innovative Technology Evaluation Program: Technology Profiles, U.S. Environmental Protection Agency Report EPA/540/5-90/006, Nov 1990, pp. 64-65, 80-81.

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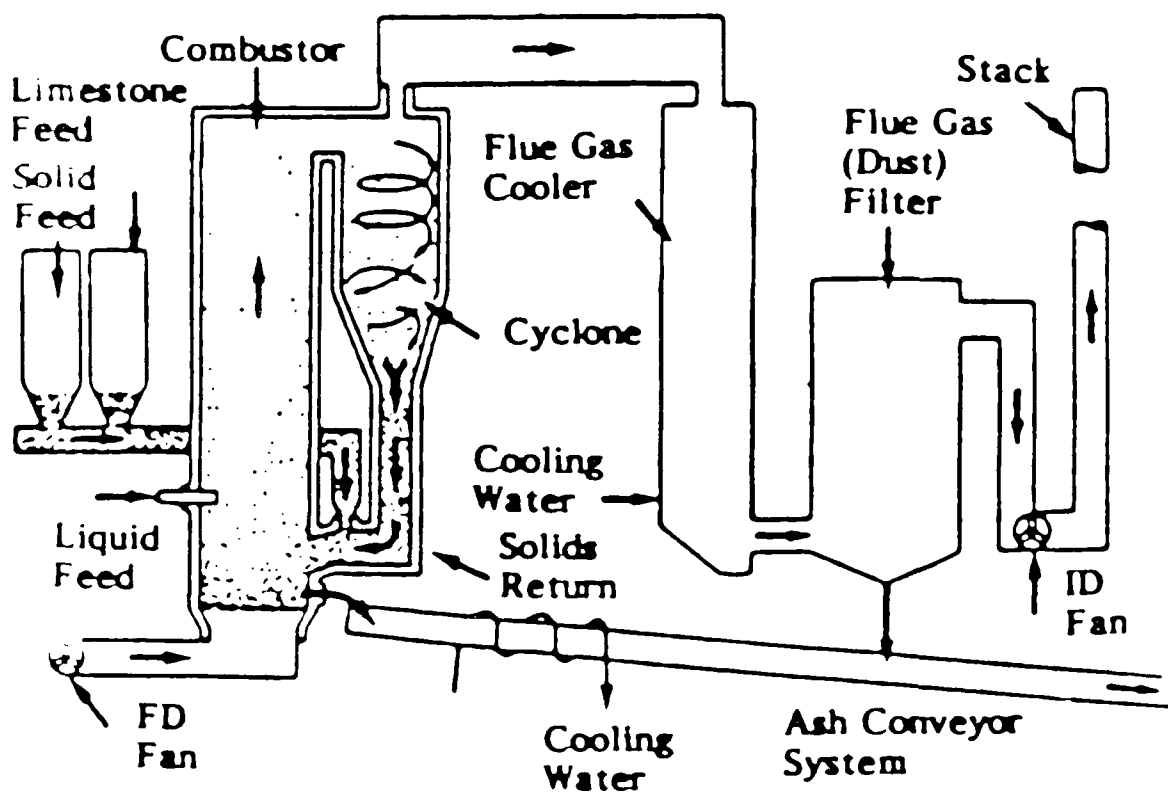


Figure 64. Circulating bed combustor process diagram.

## 65. BIOTECHNICAL SLOPE PROTECTION

- Category:** I.c. Structural Treatment  
II.g. Management Strategies
- Purpose:** To prevent migration of contaminants offsite, either through runoff or groundwater infiltration.
- Application:** This method is applicable for slope stabilization and erosion control at Defense Environmental Restoration Account (DERA) sites. The method can help to manage a site before, during, and after cleanup by keeping contaminants, especially those associated with the particulate phase, on site.
- Description:** Vegetation native to the contaminated area is established to reduce runoff and percolation. The method is to be used in conjunction with permanent cleanup technologies. The revegetation may be used to restore the site to natural conditions after cleanup is completed. Low to moderate soil TNT concentrations (up to 50 ppm) can support a healthy biomass using soil amendments, such as straw and chicken or horse manure. Higher concentrations (1,000 ppm) cannot support a viable plant community.
- Advantages:** This method reduces physical transport of contaminants, may be more cost-effective than physical barriers, and makes the area more aesthetically pleasing.
- Limitations:** The method is not well suited to industrial areas surrounded by concrete or buildings. The method may not be applicable to areas of extreme toxicity.
- Costs:** Not available.
- Availability:** Technical details are available from NCEL.
- Status:** This technology was demonstrated first at nonhazardous waste sites. The first demonstration was at Meridian Naval Air Station (NAS) where typical rill erosion was occurring along the border road. By using vegetation native to the area, the cut slope was stabilized and erosion controlled. At a second site, the method was demonstrated successfully under more adverse conditions: high precipitation, steep slopes, and highly erodable soils. Laboratory studies have been conducted at WES to determine phytotoxicity for TNT and RDX and to conduct rainfall lysimeter tests. Significant amounts of particulate and dissolved TNT were found in runoff.
- References:** None available.
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## 66. HOT GAS DECONTAMINATION OF EXPLOSIVES-CONTAMINATED STRUCTURES

- Category:** I.c. Structural Treatment
- Purpose:** To develop an innovative, nondestructive technology to decontaminate Army facilities contaminated by explosives and to prepare them for reuse or excessing.
- Application:** The method can be used for buildings or structures associated with ammunition plants, arsenals, and depots involved in the manufacture, processing, loading, and storage of pyrotechnics, explosives, and propellants.
- Description:** The method involves sealing and insulating the structures, heating with hot gas stream to 500° F for a prescribed period of time, volatilizing the explosive contaminants, and destroying them in an afterburner. Operating conditions are site-specific. Contaminants are completely destroyed. The operation can be conducted by government or contractor personnel.
- Advantages:** The advantages of this method over open burning, which is not allowed in many states, is the potential for less strict regulation. The process can be controlled and some structures may be reused.
- Limitations:** The method is more costly than open burning.
- Costs:** The cost of the decontamination will vary with the application depending upon the size and geometry of the structure to be decontaminated and the temperature and holding time required for the decontamination. No specific cost analyses have been completed.
- Availability:** All equipment is commercially available.
- Status:** Large-scale pilot testing of an explosives contaminated building was conducted at the Cornhusker Army Ammunition Plant, Grand Island, NE, in 1987.
- References:** McNeill, W., et al. **Pilot Plant Testing of Hot Gas Building Decontamination Process - Final Report.** USATHAMA Report AMXTH-TE-CR-87130, Oct 1987.
- Woodland, L.R. et al., **Pilot Testing of Caustic Spray/Hot Gas Building Decontamination Process.** USATHAMA Report AMXTH-TE-CR-87112, Aug 1987.
- Design Support for a Hot Gas Decontamination System for Explosives-Contaminated Buildings.** Maumee Research and Engineering, Apr 1986.
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## 67. HOT GAS DECONTAMINATION OF EXPLOSIVES-CONTAMINATED EQUIPMENT

- Category:** I.c. Structural Treatment
- Purpose:** To develop a technology that will allow cost effective decontamination of internal and external surfaces of process equipment contaminated with explosives.
- Application:** The method is applicable for process equipment requiring decontamination for reuse. It is also applicable for explosive items, such as mines and shells, being demilitarized or scrap material contaminated with explosives.
- Description:** The process involves raising the temperature of the contaminated equipment or material to 500° F for a specified period of time. The gas effluent from the material is treated in an afterburner system to destroy all volatilized contaminants. The method eliminates a waste that currently is stockpiled and requires disposal as a hazardous material. This method will permit reuse or disposal as non-hazardous scrap material.
- Advantages:** Compared with the alternative of open burning, which is not allowed in some states, the hot gas decontamination process is less strictly regulated. This process can be controlled. Material is completely decontaminated and may be reused in some cases.
- Limitations:** The costs of this method are higher than open burning, some capital investment is required, and the rate at which equipment or material can be decontaminated might be slower than that for open burning.
- Cost:** The cost of the decontamination will vary with the application depending upon the size and geometry of the equipment or material to be decontaminated and the temperature and holding time required for the decontamination. No specific cost analysis has been completed.
- Availability:** Equipment required is commercially available.
- Status:** Field-pilot demonstration was conducted at Hawthorne Army Ammunition Plant, NV, in 1990. Limited trial implementation of the method is planned.
- References:** Pilot Test of Hot Gas Decontamination of Explosives-Contaminated Equipment at Hawthorne Army Ammunition Plant (HWAAP), Hawthorne, NV, Final Technical Report. USATHAMA Report CETHA-TE-CR-90036, Jul 1990.
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## 68. HOT GAS DECONTAMINATION OF EXPLOSIVES-CONTAMINATED UNDERGROUND PIPING

- Category:** I.c. Structural Treatment
- Purpose:** To develop an alternative method of decontaminating underground piping contaminated with explosives.
- Application:** The method is applicable for explosives-contaminated underground piping associated with explosives production and load, assemble, and pack operations.
- Description:** To date, this technology has involved the excavation of piping, placing the piping in a flashing chamber, heating to 500° F with hot gases, and destroying the explosives volatilized by the hot gas in an afterburner. Consideration is being given to applying the hot gases in situ. The piping most likely will not be returned to service, but disposed as non-hazardous scrap. Removing the piping will eliminate a source of contamination; contaminants are completely destroyed. Throughput using this method is site-dependent. Equipment required includes a burner to generate the hot gas, a chamber in which to heat the pipe, an afterburner to destroy volatilized contaminants, and appropriate ducting. The work can be performed by government or contractor personnel.
- Advantages:** The current method of decontamination is very labor-intensive and involves excavating the piping and flushing out the contaminants with flame, one pipe at a time. The hot gas method has a higher throughput, a lower risk to personnel, a lower cost, and control of air emissions.
- Limitations:** A higher initial capital investment is required to procure the system, but it can be used to decontaminate other explosives-contaminated material in addition to piping.
- Cost:** The cost of the decontamination will vary with the application depending upon the size and geometry of the piping to be decontaminated and the temperature and holding time required for the decontamination. No specific cost analyses have been completed.
- Availability:** Equipment required is commercially available.
- Status:** Field-pilot demonstration was conducted at Hawthorne Army Ammunition Plant, NV, in 1990. Limited trial implementation of the method is planned.
- References:** Pilot Test of Hot Gas Decontamination of Explosives-Contaminated Equipment at Hawthorne Army Ammunition Plant (HWAAP), Hawthorne, NV, Final Technical Report. USATHAMA Report CETHA-TE-CR-90036, Jul 1990.
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## 69. HOT GAS DECONTAMINATION OF CHEMICAL-AGENT-CONTAMINATED FACILITIES

**Category:** I.c. Structural Treatment

**Purpose:** To identify and develop an innovative, nondestructive technology to decontaminate Army facilities and equipment contaminated by chemical agents to prepare them for reuse or excessing.

**Application:** This hot gas technology is applicable to structures that are contaminated with chemical agents. The process enables safe, effective, and environmentally acceptable decontamination of facilities for potential reuse or disposal.

**Description:** This technology uses the exhaust from an oil or gas burner to heat a building to a prescribed temperature, hold the building at temperature for a prescribed time, and then cool the building. Times and temperatures are agent-dependent and range from 6 to 24 hours and 400° F to 600° F, respectively. Exhaust gas from the building is drawn through an afterburner operated at 2,000° F with a 2-second residence time to destroy the volatilized chemical agents. From the afterburner, the exhaust gas passes through a spray quench system or some other heat reducing device to lower its temperature to 250° F to 400° F prior to passing through two carbon beds. The gas passes through an induced draft (ID) fan and then to the atmosphere. The ID fan maintains negative pressure through out the system. Chemical agent monitors are used throughout the process to detect the presence of agents.

**Advantages:** Currently, the only approved method of decontaminating structures is that of reducing the building to rubble and processing the rubble through an incinerator. The hot gas technology offers a safe and effective process to enable decontamination in place. The negative pressure of the system prevents any escape of chemical agents.

**Limitations:** Combustible materials will be destroyed during this process and may require removal prior to initiation of the process.

**Cost:** Costs would be directly proportional to the size of the facility and the length of time required to heat the entire structure to the operating temperature.

**Availability:** The technology has been tested in the laboratory and in a controlled chamber pilot-test. A field demonstration is planned for FY93.

**Status:** Field-pilot testing is planned for Rocky Mountain Arsenal, CO, for FY93.

**References:** **Demonstration of the Hot Gas Decontamination System for Chemical Agents – Task 3 Final Report.** USATHAMA Report CETHA-TE-CR-89168, Aug 1989.

**Pilot Plant Testing of Hot Gas Building Decontamination Process – Final Report.** USATHAMA Report AMXTH-TE-CR-87130, Oct 1987.

**Development of Novel Decontamination Techniques for Chemical Agents (GB, VX, HD) Contaminated Facilities, Phase II – Laboratory Evaluation of**

**Novel Agent Decontamination Concepts - Final Technical Report.**  
USATHAMA Report AMXTH-TE-TR-85012, Jun 1985.

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## 70. DREDGING AND DREDGED MATERIAL MANAGEMENT

**Category:** I.c. Structural Treatment

**Purpose:** To remove and safely dispose of contaminated underwater sediments.

**Application:** The method is applicable for contaminated sediments in harbors, waterways, lakes, reservoirs, or any water impoundment. The contamination can include organic and metallic compounds.

**Description:** Primarily, three dredging methods, although others exist, are used in this application: mud cat, cutter head, and match box (see figure 70). Once the sediment has been removed from the water environment, it must be dewatered. The dewatering generally includes gravity settling, precipitation, or active site management practices such as trenching. Settling can be enhanced through the use of polyelectrolytes and commercial floc agents. Once dewatered, the contaminated sediment can be stored in a disposal area, treated to detoxify or destroy contaminants, or subjected to stabilization (see the section on stabilization and solidification of hazardous wastes, notes 45 – 50), depending upon the type and toxicity of the contamination.

**Advantages:** In many cases, dredging is the only means of removing contaminated materials from waterways. The water column does not have to be removed. Major alteration to the existing hydraulic regime is not necessary. One alternative to dredging might be to lay an impermeable cap onto the contaminated sediments, but in shallow waterways sufficient space would not exist to prevent interference with the use of the waterway.

**Limitations:** Care must be taken during dredging operations to prevent disturbance of the sediment and stimulation of contaminant release and spreading. The depth of the water must be enough, usually at least 18 inches, to enable access by the dredge. Rocks and debris in the sediment must be small enough, usually smaller than a few inches in diameter depending upon the size of the dredge, not to interfere with the dredge operation. A clam shell dredge causes considerable mixing, resuspension of sediment, and does not allow controlled cuts. Water entrained by the hydraulic dredge might become contaminated and require treatment.

**Costs:** The cost of dredging, not including the subsequent treatment, can range widely between \$200,000 to \$3.5 million to remove  $10^4$  to  $10^6$  yd<sup>3</sup>. The costs for a specific operation depend upon the location of the contamination in the waterway, the difficulty in removal, and the disruption to the normal use of the waterway. Details of costs can be found in the references listed below.

**Availability:** All of the dredging equipment is commercially available from various vendors.

**Status:** A large scale pilot was conducted at Calumet Harbor, IL in 1985. The technology was demonstrated with a low rate of sediment resuspension. The method is widely used in Japan and the Netherlands. A pilot-scale dredging demonstration project was conducted in New Bedford Harbor, MA, a Superfund site contaminated with polychlorinated biphenyls. The project was completed in January 1989.



**References:** **New Bedford Harbor Superfund Pilot Study: Evaluation of Dredging and Dredged Material Disposal**, U.S. Army Corps of Engineers New England Division, Waltham, MA, 1990.

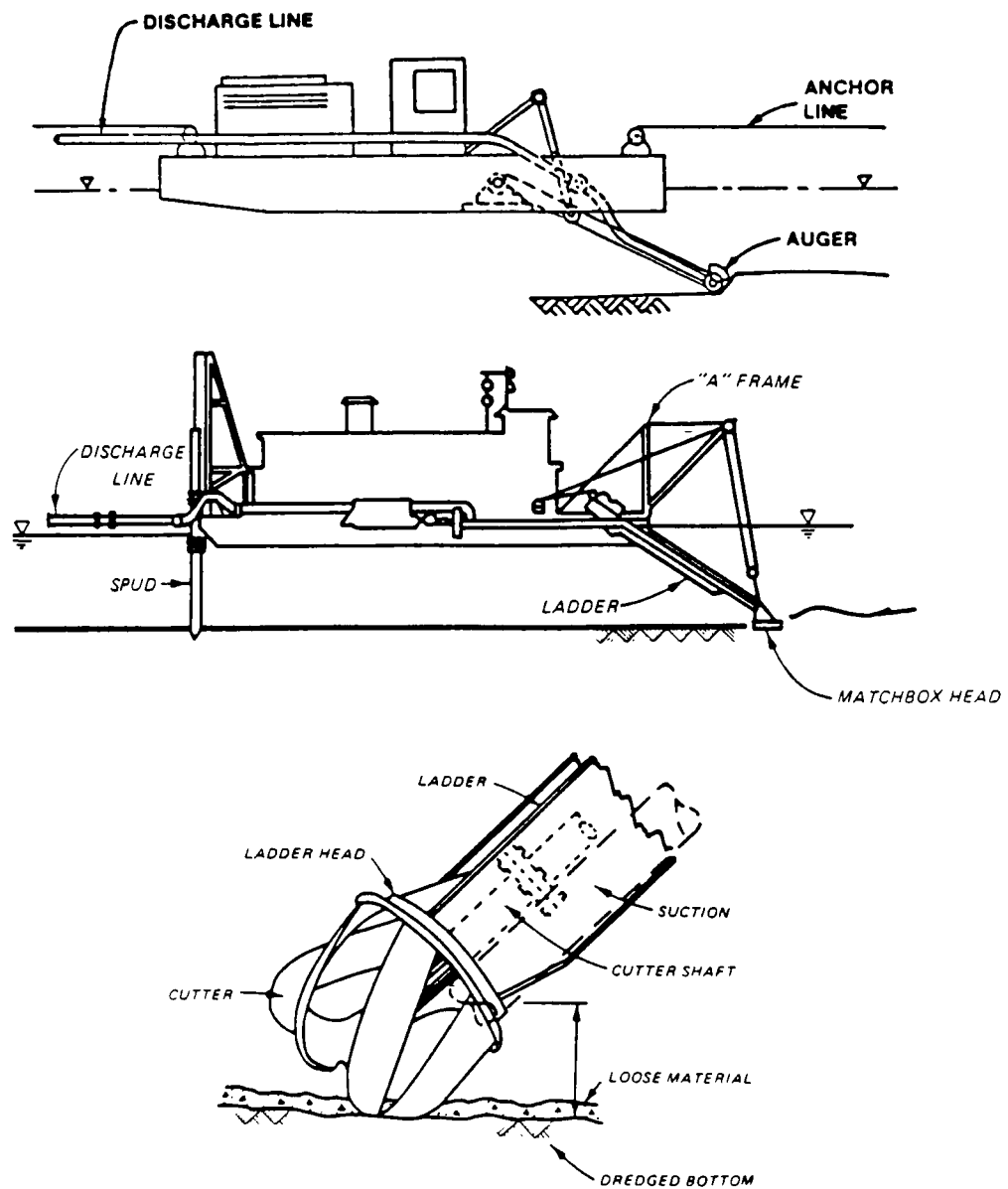
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Cullinane, M.J. et al., **Guidelines for Selecting Control and Treatment Options for Contaminated Dredged Material Requiring Restrictions**, Final Report, USAE Waterways Experiment Station, Sep 1986.

Francingues, Jr., N.R. et al., **Management Strategy for Disposal of Dredged Material: Contaminant Testing and Controls**, Final Report, USAE Waterways Experiment Station Miscellaneous Paper D-85-1, Aug 1985.

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**Figure 70.** Three types of dredge systems: mud cat (top), match box suction head (middle), and cross-section view of a typical cutterhead and suction dredge.

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## 71. USE OF WASTE EXPLOSIVES AND PROPELLANTS AS SUPPLEMENTAL FUEL IN INDUSTRIAL BOILERS

**Category:** II.a. Recovery and Reuse of Energetics

**Purpose:** To provide an alternative disposal technology for waste energetic materials which safely and effectively utilizes the energy content to fuel existing industrial boilers at DOD facilities.

**Application:** Currently, the method is applicable to the reutilization of waste TNT. The application to RDX, Composition B, nitrocellulose (NC), nitroguanidine (NG), and AA2 Double Base Propellant is being investigated.

**Description:** Waste explosives such as TNT, RDX, and Composition B are dissolved in toluene and the resultant mixture is co-fired into a standard industrial boiler. The process design has been developed to use existing industrial boilers with minimal retrofitting. Acetone is used to flush the system. A flow diagram for the process is presented in figure 71. In the case of propellants, which are less soluble in solvents and fuel oil, a 10% by weight propellant-fuel oil slurry is proposed based on the viscosity requirements (20 centistokes) of standard oil burners.

**Advantages:** Through this technology, the energy from waste explosives is reutilized to fuel industrial combustors rather than destroying these wastes by conventional incineration or open burning/detonation.

**Limitations:** Safety is a primary concern. Considerable testing has been conducted to determine parameters under which this technology can be conducted safely. Continued scrutiny of safety matters will continue. A permit may be required under the new RCRA regulations for industrial boilers.

**Costs:** Although actual costs are not available, several economic analysis studies indicate this technique is a potentially cost-effective alternative for the disposal of waste energetic materials.

**Availability:** The method is currently in the pilot-scale field demonstration phase.

**Status:** A pilot-scale demonstration on the use of explosives as a fuel supplement has been completed at Hawthorne Army Ammunition Plant, Hawthorne, NV. Initial tests have demonstrated that dilute solutions of TNT can be co-fired efficiently and safely. These tests identified the need for additional equipment and process changes. Tests are scheduled in FY92 to increase the quantity of TNT and initiate RDX co-firing tests. The Tennessee Valley Authority completed a study on the technical and economic feasibility of using propellant-fuel oil slurries. Pilot-scale demonstration of the propellant-fuel oil-slurry technology is planned for FY94.

**References:** Norwood, V.M., D.J. Craft. **Zero Gap Propagation Testing Of Propellant - No. 2 Fuel Oil Slurries.** U.S. Army Toxic and Hazardous Materials Agency Report CETHA-TS-CR-92005, Jan 1992.

Norwood, V.M., D.J. Craft, and K.E. McGill. **Technical And Economic Analyses To Assess The Feasibility Of Using Propellant - No. 2 Fuel Oil Slurries As**

**Supplemental Fuels.** U.S. Army Toxic and Hazardous Materials Agency Report CETHA-TS-CR-91046, Sep 1991.

**Cosmos, M. and P. Marks. Pilot Test to Determine the Feasibility of Using Explosives as Supplemental Fuel at Hawthorne Army Ammunition Plant (HWAAP), Hawthorne, Nevada.** U.S. Army Toxic and Hazardous Materials Agency Report CETHA-TS-CR-91006, Apr 1991.

**Myler, C.A., W.M. Bradshaw, and M.G. Cosmos. Use of Energetic Materials as a Fuel Supplement in Utility Boilers.** *J. Hazardous Materials*, **26** (1991), pp. 333-42.

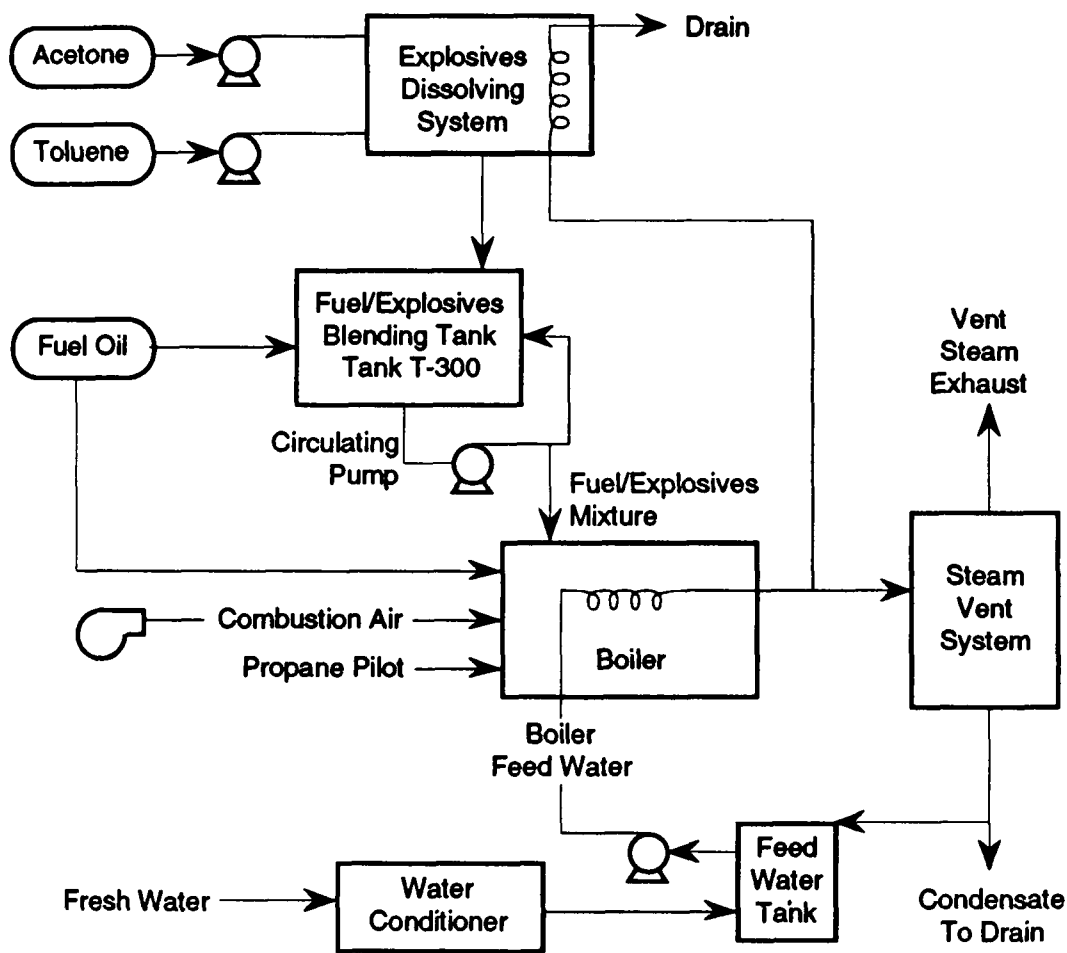
**Myler, C.A., W.M. Bradshaw and M.G. Cosmos. Use of Waste Energetic Materials as a Fuel Supplement in Utility Boilers.** Presented at AIChE National Meeting, Philadelphia, Aug 1989.

**Bradshaw, W.M. Pilot-Scale Testing of a Fuel Oil-Explosives Cofiring Process for Recovering Energy from Waste Explosives.** USATHAMA Report AMXTH-TE-CR-88272, May 1988.

**Mahannah, J.L., E.C. Fox, and M.E. Lackey. Utilization of Waste Energetic Material as Supplementary Boiler Fuel,** Proc. for the 15th Environmental Symposium "Waste Minimization and Environmental Programs Within DOD," American Defense Preparedness Association, Long Beach, CA, Apr 1987, pp. 200-5.

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*Figure 71. Process flow diagram for explosives used as supplemental fuel.*

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## 72. PROPELLANT RECOVERY AND REUSE

- Category:** II.a. Recovery and Reuse of Energetics
- Purpose:** To demonstrate the feasibility of resolution of obsolete solvent-based propellants
- Application:** The method is applicable for waste or off-specification single, double, and triple-base propellants.
- Description:** Single-base propellants, those that contain nitrocellulose (NC), are resolvated using an ether/ethanol system. Double- and triple-base propellants, those that contain NC nitroglycerin (NG), and nitroguanidine, respectively, are resolvated using an acetone/ethanol system (see figure 72).
- Advantages:** Current alternatives for disposal of waste propellants are incineration, which is costly, or open burning/open detonation, which may have negative environmental impact. Reuse/recovery offers economic and environmental advantages.
- Limitations:** For the method to be useful, the reclaimed product must meet specifications.
- Costs:** A plant with a design capacity of 3 million pounds per year of obsolete propellant would have a total installed equipment cost of \$5.8 million. The payback periods on invested capital range from a high of 1.9 years for M1 propellant to a low of 0.8 year for M31A1.
- Availability:** Technical details are available from USATHAMA.
- Status:** Bench-scale pilot testing completed at Radford Army Ammunition Plant, VA. A field pilot at Radford AAP is planned for FY92 – 93.
- References:** Smith, L.L. et al. **Propellant Reuse/Recovery Technology**. USATHAMA Report AMXTH-TE-CR-88026, Aug 1988.
- Balasco, A.A. et al. **Economic Evaluation of Propellant Reuse/Recovery Technology**. USATHAMA Report, Dec 1988.
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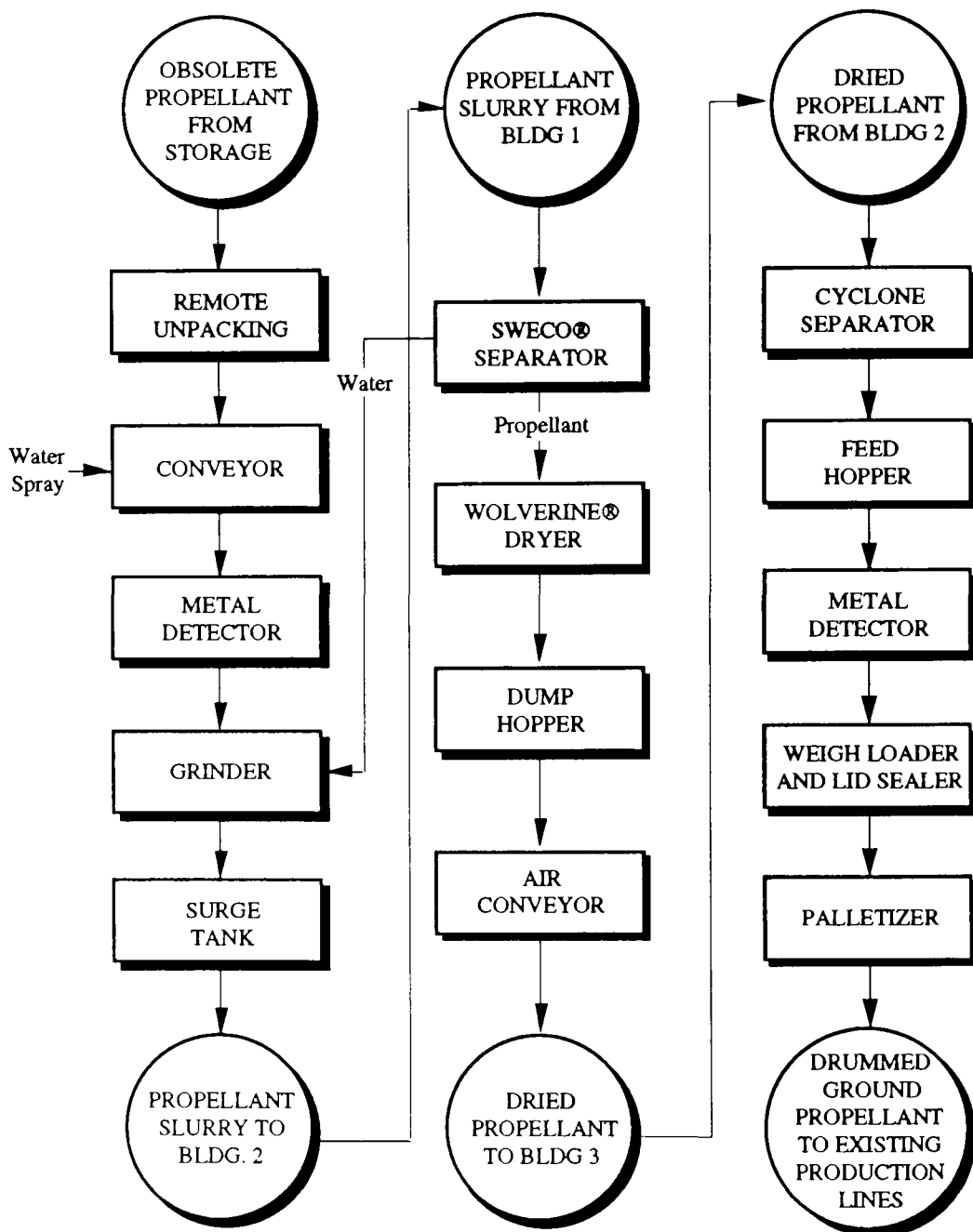


Figure 72. Schematic flow diagram of equipment necessary for the grinding operations (Balasco, 1988)

## 73. TREATMENT OF BALL POWDER PRODUCTION WASTEWATER

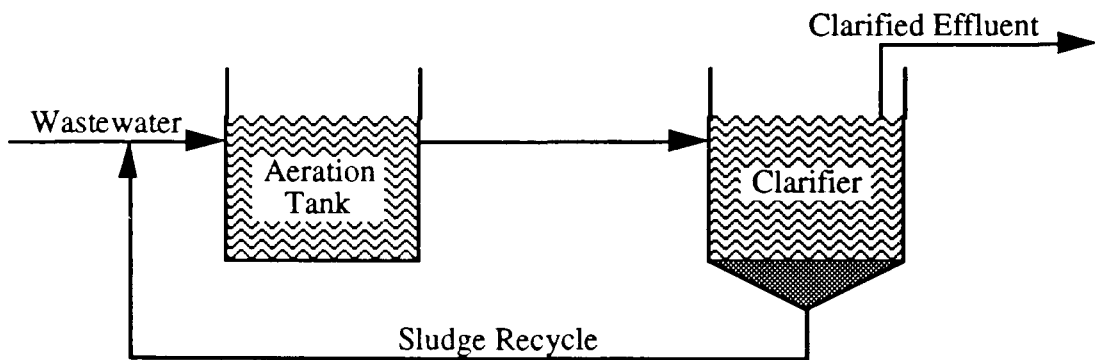
- Category:** II.b. Minimization or Treatment of Munition Production and/or Handling Waste Streams
- Purpose:** To develop a method to treat wastewater from Ball Powder® (Ball Powder propellant is a registered trademark of Olin Corporation) manufacture at Badger Army Ammunition Plant (BAAP) in Wisconsin to meet NPDES requirements.
- Application:** The method is applicable to potential wastewater from Badger AAP (currently, Badger AAP is not producing Ball Powder). Parameters expected to be limited include biochemical oxygen demand (BOD, 45 mg/L), total suspended solids (TSS, 30 mg/L monthly average and 50 mg/L daily), N-nitrosodiphenylamine (NDPA, 1.9 µg/L), and dibutylphthalate (DBP, 2.5 µg/L).
- Description:** Two methods were developed and evaluated: extended aeration and sequencing batch reactor (SBR). The extended aeration process (figure 73a) consists of an aerated biological reactor, or aeration tank, in which activated sludge interacts with incoming wastewater. The effluent from this tank is fed to a clarifier in which the suspended activated sludge solids are separated from the treated wastewater. A portion of the activated sludge solids are recycled to the aeration tank; the remainder of the solids comprise a waste stream. The SBR (figure 73b) makes use of a single tank in which all processing takes place including filling, reaction settling, and liquid/solid separation. In the absence of nitroglycerin (NG), both methods worked well; however, when NG was added during the second phase of the first demonstration, the microbes were killed. Since the literature claims that NG can be biodegraded, a second demonstration was conducted. A selection process to determine the best reaction system settled on SBR. The SBR reaction sequence was optimized so that up to 1,600 mg/L of NG in the feed to the reactor can be tolerated. The actual concentration of NG in the reactor never exceeds 160 mg/L.
- Advantages:** This system is commercially available. The main advantage of the SBR is its flexibility. It can be computer controlled so that very little human effort is needed.
- Limitations:** Nitroglycerin at a concentration above 200 mg/L causes a toxic effect on the biomass.
- Costs:** Not available.
- Availability:** These types of systems are available commercially.
- Status:** The final report of the second demonstration is available. Olin Corporation is expected to implement the system at BAAP.
- References:** Grasso, D. et al. **Ball Powder Production Wastewater Biological Treatability Studies**. USATHAMA Report CETHA-TS-CR-92047, Jun 1992.
- Lewandowski, G.A. et al. **Engineering Study of a Sequencing Batch Reactor for Denitrification of Munition Wastes**. Proc. 14th Annual Army Environmental Symposium, U.S. Army Toxic and Hazardous Materials Agency Report CETHA-TE-TR-90055, Apr 1990.

Balasco, A.A. et al. **Ball Powder Production Wastewater Pilot-Scale Biodegradation Support Studies.** USATHAMA Report CETHA-TE-CR-88344, Feb 1989.

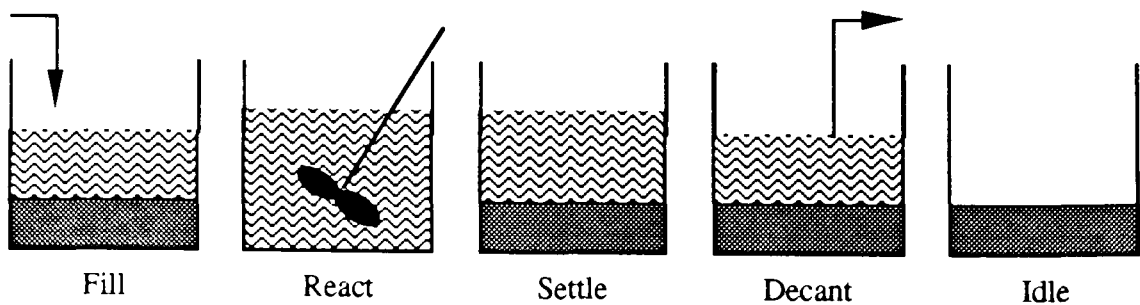
Balasco, A.A. et al. **Ball Powder Production Wastewater Pilot-Scale Biodegradation Support Studies - With Nitroglycerin, Final Report.** USATHAMA Report CETHA-TE-CR-88344, Feb 1989.

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*Figure 73a. Extended aeration process schematic*



*Figure 73b. Sequencing batch reactor schematic*

## 74. UPFLOW ANAEROBIC GRANULAR ACTIVATED CARBON (GAC) BIOREACTORS

- Category:** II.b. Minimization or Treatment of Munition Production and/or Handling Waste Streams
- Purpose:** To degrade undesirable organics and provide storage capacity for concentration variations.
- Application:** This technology is used for organics, both absorbable and slowly biodegradable dinitrotoluene (DNT) in the presence of ethanol (see also notes #6 and #60).
- Description:** The reactor is an upflow expanded bed reactor containing granular activated carbon (GAC) and anaerobic bacteria acclimated to contaminant compound. Removal of 100% of DNT from waste stream with no production of nitrotoluene.
- Advantages:** Storage capacity on activated carbon allows this unit to treat high concentration variation in contaminants. Bacteria degradation avoids requirement for carbon replacement.
- Limitations:** If other materials dissolved that are toxic to the bacteria exceed carbon capacity, carbon in the reactor must be regenerated.
- Cost:** Not available.
- Availability:** Can be built with off the shelf equipment and used in waste water plants with nitrated toluene.
- Status:** Laboratory testing phase during 1991/92 and bench-scale pilot phase during 1992 at the University of Cincinnati.
- References:** Fox, Perer, Markram T. Suidan, John T. Pfeffer, and John T. Bandy, Hybrid Expanded-Bed BAC Reactor for Treating Inhibitory Wastewaters, *J. Environmental Engineering*, 116(3), May/Jun 1990.
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## 75. WET AIR OXIDATION OF TNT RED WATER

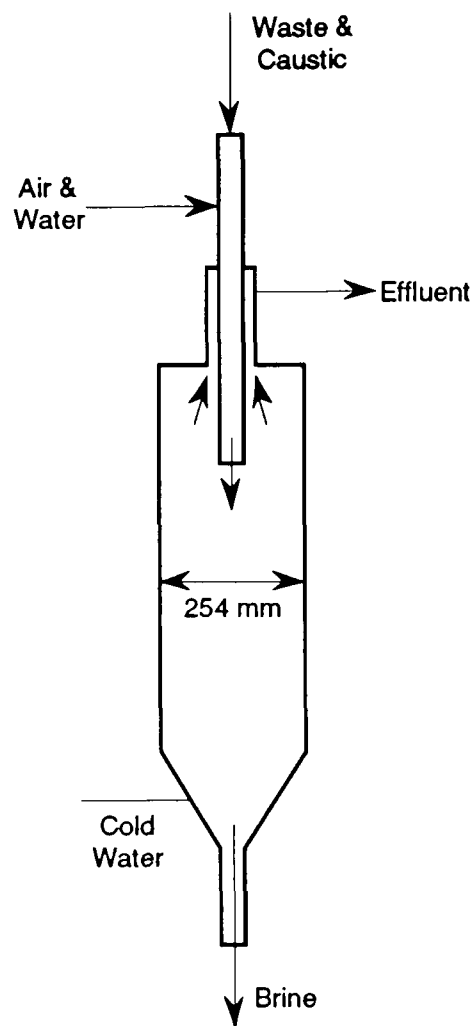
- Category:** II.b. Minimization or Treatment of Munition Production and/or Handling Waste Streams
- Purpose:** To oxidize all organics to by-products that are environmentally acceptable, e.g. carbon dioxide ( $\text{CO}_2$ ), water ( $\text{H}_2\text{O}$ ), nitrate ( $\text{NO}_3^-$ ), sulfate ( $\text{SO}_4^{2-}$ ), etc.
- Application:** This method is applicable for minimization of high strength TNT production waste waters (red water).
- Description:** Wastewater is introduced into a batch reactor pressure vessel and heated to  $325^\circ\text{C}$ , with or without pure oxygen at 2,000 psi. A flow-through reactor will be tested in 1992.
- Advantages:** In excess of 99% of dinitrotoluene sulfonate introduced into the batch reactor is rendered into less hazardous chemical compounds such as  $\text{CO}_2$ ,  $\text{H}_2\text{O}$ ,  $\text{NO}_3^-$ ,  $\text{SO}_4^{2-}$ . The process is capable of treating a large number of contaminants at the same time. It has a wide range of applications to lower toxicity of waste. Destruction of waste is handled in a one-unit process.
- Limitations:** The process is designed for high energy, high pressure reactions and should not be used for low strength waste.
- Cost:** Not currently available.
- Availability:** Commercially available.
- Status:** Laboratory testing phase during 1991/1992 by USACERL and by the University of Maryland from 1990-91. Bench-scale pilot phase will be conducted in Rothchild, WI during 1992. A field demonstration is being planned.
- References:** Hao, Oliver J., **TNT Red Water Treatment By Wet Air Oxidation**. Feasibility Study Report Contract No. DACA88-90-M-1418, Feb 1991.
- Wentz, J.A. et al. **Technology Evaluation for Treatment/Disposal of TNT Red Water**. USATHAMA Report CETHA-TE-CR-90048, 1990.
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## 76. SUPER CRITICAL WATER OXIDATION

- Category:** II.b. Minimization or Treatment of Munition Production and/or Handling Waste Streams
- Purpose:** Render inert propellants with no emissions until the process is complete.
- Application:** This technology is applicable for destruction of rocket propellants and other organic compounds. It is also used for treatment of dilute aqueous streams containing hazardous organic substances.
- Description:** Unused rocket motors with propellant are placed in a reactor cell for removal of the propellant. The process for hazardous waste destruction operates at nominal conditions of 1,112° F (600° C) and 3,300 psi (23 MPa). The process for destruction of rocket propellant operates at 392°F to 572°F (200°C to 300°C) and 200 atmospheres (19 MPa) pressure. Under these conditions, organic compounds are completely miscible with supercritical water, oxygen, and nitrogen, and can be rapidly oxidized to carbon dioxide and water. Inorganic salts to a large extent precipitate at reaction conditions. In this process hazardous wastes are oxidized and inorganic salts are separated in a single reaction vessel. The configuration of the pilot-scale reactor is shown in figure 76. In excess of 99.99% destruction efficiency of hazardous organic waste constituents is achieved in a single step. The formation of nitrogen oxides and sulfur dioxide is precluded by in-situ acid gas neutralization. Propellants and organic waste streams are rendered inert or destroyed in a clean, safe reaction.
- Advantages:** The waste stream or propellant is rendered inert with no waste plumes that are visible in a community.
- Limitations:** Some byproducts may need bioremediation.
- Costs:** Estimate of millions of dollars to rocket propellant and rocket manufactures when full-scale design is completed.
- Availability:** Bench-scale only at the present time.
- Status:** Bench-scale 1989 to present (1992) at Los Alamos National Laboratory, NM and 1992 bench-scale at SRI International, Menlo Park, CA.
- References:** Barner, H.E., et al. **Supercritical Water Oxidation: An Emerging Technology**, Presented atACHEMA '91 – International Meeting on Chemical Engineering and Biotechnology, June 9, 1991.
- Buelow, S.J., et al. **Destruction of Propellant Components in Supercritical Water**, Proceedings: Workshop on Alternatives for OB/OD of Propellants and Explosives, 1990.
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*Figure 76. Configuration of pilot-scale reactor for super-critical water oxidation.*

## 77. PINK WATER TREATMENT

- Category:** II.b. Minimization or Treatment of Munition Production and/or Handling Waste Streams
- Purpose:** Remove contaminants in wash water from load, assemble, and pack (LAP) facilities (pink water).
- Application:** The method can be used to remove explosive contaminants in water arising from washing equipment and surfaces contacted during LAP operations (see notes #1 and #60).
- Description:** The waste stream flows through a settling chamber, a diatomaceous earth filter, and an activated carbon filter (see figure 77). A survey of carbon treatment methods at Army Ammunition Plants indicates that the methods are dependent on the characteristics of the pink water, carbon used, and specific requirements of the installation. At some sites, carbon is regenerated, while at others the carbon is burned as supplemental fuel in cement kilns. No current need exists for the Army to install carbon regeneration systems.
- Advantages:** The operations are simple; unique equipment is not required.
- Limitations:** The method is not suitable for red water from trinitrotoluene production. Currently, some open burning is used to dispose of the contaminated activated carbon resulting from this method, but that practice might be subject to local regulations. Regeneration of the carbon, a feasible technology, might be necessary.
- Costs:** The costs depend upon the size of the operation and are detailed in the referenced report.
- Availability:** All equipment is commercially available from several vendors. Contractors supply and install the equipment, which can be operated by facilities personnel.
- Status:** The method has been implemented at several facilities including Iowa Army Ammunition Plant (AAP), IA; Louisiana AAP, LA; Joliet AAP, IL; Volunteer AAP, TN; Radford AAP, VA; and Holston AAP, TN.
- References:** Mahannah, J. **Survey of Generation and Management of Explosive-Laden Spent Carbon.** USATHAMA Report CETHA-TS-CR-92024, Sep 1992.
- Wentz, J.A. et al. **Technology Evaluation for Treatment/Abatement of TNT Red Water.** Proc. 14th Annual Army Environmental Symposium, U.S. Army Toxic and Hazardous Materials Agency Report CETHA-TE-TR-90055, Apr 1990.
- Chaiko, D.J. et al. **Development of a Process for Treating Red Water by Organic/Inorganic Separation and Biodegradation.** Proc. 14th Annual Army Environmental Symposium, U.S. Army Toxic and Hazardous Materials Agency Report CETHA-TE-TR-90055, Apr 1990.
- Lowe, W.L. et al. **Use of Activated Carbon for Treatment of Explosives Contaminated Groundwater.** Proc. 14th Annual Army Environmental

Symposium, U.S. Army Toxic and Hazardous Materials Agency Report CETHA-TE-TR-90055, Apr 1990.

Carltech Associates, **Granular Activated Carbon Performance Capability and Availability**, DRXTH-TE-CR-88323, Jun 1983.

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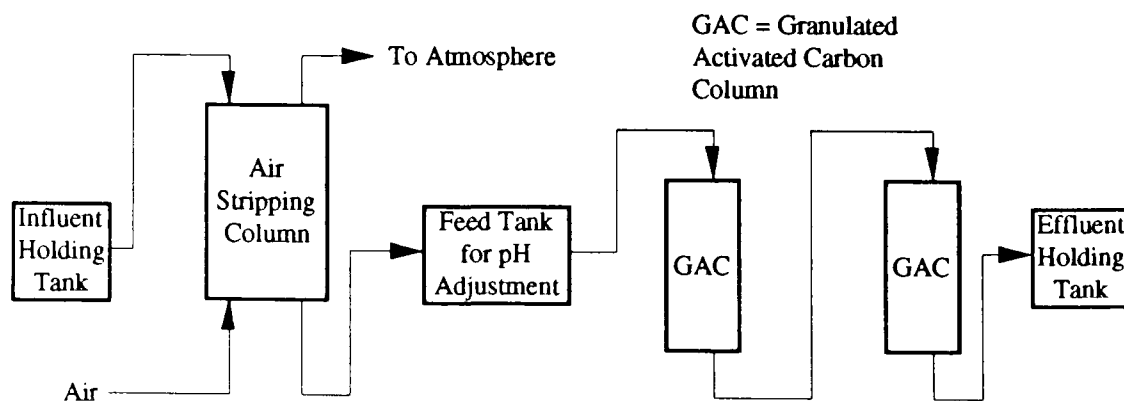


Figure 77. *Schematic diagram of pilot-scale granular activated carbon method to treat explosives contaminated groundwater (after Lowe, 1990).*

## 78. NON-CYANIDE ELECTROPLATING

- Category:** II.c. Minimization or Treatment of Metal Finishing Wastes
- Purpose:** To eliminate cyanide (CN) wastes from electroplating operations without sacrificing plating quality.
- Applications:** The method is applicable to plating operations in which CN is used. The method development has been directed toward cadmium (Cd) plating, but eventually will be applicable to other metals.
- Description:** Direct current and pulse-current plating are employed in a slightly acidic bath (pH = 5.8 to 6.1) at a moderate temperature ( $T = 27^{\circ}$  to  $31^{\circ}$  C). Research is underway to optimize the bath composition.
- Advantages:** CN wastes are eliminated. The work place is safer.
- Limitations:** More precise process control of the chemical composition in the bath is required as compared with the CN process currently in use.
- Costs:** Plating costs are comparable, but treatment costs for CN wastes are eliminated.
- Availability:** Details of the method are available from NCEL.
- Status:** Bench-scale pilot testing was conducted at Naval Air Depot Center, Warminster, PA.
- References:** Pearlstein, F., V.S. Agarwala and D.B. Chan. **Development of Non-Cyanide Electroplating of Cadmium.** Presented at the 1989 Tri-Service Corrosion Conference, Atlantic City, NJ, Oct 1989.
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## 79. NON-CYANIDE METAL STRIPPER REPLACEMENT PROGRAM

**Category:** II.c. Minimization or Treatment of Metal Finishing Wastes

**Purpose:** To evaluate non-cyanide metal stripper replacement technologies in a three-phase program: (1) evaluate currently used metal stripping technologies, (2) evaluate alternative commercial metal stripping technologies, and (3) develop new generic metal stripping technologies, evaluate precious metal recovery methods for metal stripping wastes, establish waste treatment procedures, and implement technologies that are beneficial to the Air Force.

**Application:** The acceptable non-cyanide metal stripping processes will be applied for stripping electroplated metal coatings or metal coatings applied by another process.

**Description:** Metal coatings are presently stripped from metal parts by immersion in a cyanide compound bath until the metal coating is removed. Waste from this process is harmful to personnel and the environment. Six commercial non-cyanide metal strippers and ten commercially available non-cyanide silver strippers were evaluated in pilot and laboratory tests at Kelly AFB, TX. These tests concluded that metal coatings may be removed from substrate metals with a tradeoff in time.

**Advantages:** No cyanide is used, the processes tested are cleaner, they pose no health or safety hazards, and the waste may be treated on site with no offsite disposal.

**Limitations:** Production time for coating removal is increased. Enhancement techniques of using mechanical agitator may help reduce coating removal time.

**Cost:** Not available.

**Availability:** The technology is commercially available.

**Status:** Laboratory testing , bench-scale pilot testing, and field pilot testing have been conducted at Kelly AFB, TX. Two commercial non-cyanide nickel strippers have been implemented into the plating shop at Kelly AFB. A generic electrolytic nickel stripper has been developed.

**References:** Janikowski, S.K., et al. **Non-cyanide Stripper Replacement Program, Phase III, Final Report**, AFCESA, DE-AC07-76ID01570, Oct. 1990.

Janikowski, S.K. et al. **Non-cyanide Stripper Replacement Program, Phase II, Quick Look Report**, (Draft), AFESC, DE-AC07-76ID01570, Apr 1989.

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## 80. SODIUM SULFIDE/FERROUS SULFATE TREATMENT PROCESS FOR METALS RECOVERY

**Category:** II.c. Minimization or Treatment of Metal Finishing Wastes

**Purpose:** To reduce heavy metals, sludge production and treatment costs in industrial wastewater.

**Application:** The method is applicable to chromium and other heavy metals associated with industrial wastewater from electroplating.

**Description:** Sodium sulfide/ferrous sulfate ( $\text{FeSO}_4/\text{Na}_2\text{S}$ ) is used in place of lime/polymer flocculation of metal finishing wastes. This change improves metal removal and decreases the amount of sludge produced. Sludge is reduced by 90%. Waste is more hazardous since the concentration of sludge is higher. A schematic diagram of a pilot plant for this method is given in figure 80a, and a photograph of the unit at Tinker AFB, OK, is shown in figure 80b. The external sludge recirculation is started first in the solids contact clarifier at 10 to 20% of the plant influent flow, after which the polymer feed (Betz 1195 cationic polymer) is started to mixer basin 3. The feed is controlled by the streaming current detector to a streaming current reading of +1.0 to +2.0 units, which is approximately 2- mg/L of Betz 1195, depending on what other species are present in the wastewater. The Betz 1120 anionic polymer is fed to the center mixing well of the solids contact clarifier at 0.5 mg/L. The polymers are fed for approximately 1 week before starting the sodium sulfide and ferrous sulfate feed. The lime floc in the solids contact clarifier is light and fluffy, but the addition of the polymer causes the floc to compact, and the sludge depth decreased from greater than 7 ft to 2 ft in the solids contact clarifier at Tinker AFB. Before starting the  $\text{Na}_2\text{S}$  and  $\text{FeSO}_4$  feed, it is desirable to allow the sludge depth to build to 7 ft. This allows the sludge blanket to act as a filter for the fine precipitate or floc produced. After the sludge bed has been built with the sulfuric acid/sulfur dioxide/lime process with the polymer feeding and the external sludge recirculation, the ferrous sulfate feed is started to Mixer Basin 2 at six times the normally required ferrous concentration (9 mg/L  $\text{Fe}^{+2}$  per 1 mg/L  $\text{Cr}^{+6}$ ). At the same time, the sulfuric acid and sulfur dioxide feed to Mixer Basin 1 increases the pH so that  $\text{Na}_2\text{S}$  can be added without hydrogen sulfide offgassing. This requires approximately 20 to 30 minutes retention time of Mixer Basin 1. When Mixer Basin 1 is at pH 7 or greater, the  $\text{Na}_2\text{S}$  feed is started at 2 mg/L  $\text{S}^{-2}$  per 1 mg/L  $\text{Cr}^{+6}$ . At the same time, sulfuric acid feed is started to Mixer Basin 2 to control the pH at 7.2 to 7.5. After approximately 20 to 30 minutes retention time of Mixer Basin 1, the  $\text{FeSO}_4$  feed to Mixer Basin 2 is decreased to 1.5 mg/L  $\text{Fe}^{+2}$  per 1 mg/L  $\text{Cr}^{+6}$ , and the lime feed to Mixer Basin 3 is stopped. The system is then operating in the normal mode for the  $\text{FeSO}_4/\text{Na}_2\text{S}$  process.

**Advantages:** Retention time is shorter, and the amount of sludge to be handled is reduced compared to the lime/polymer flocculation method. The process is more cost effective. In many cases, heavy metals in the waste stream are reduced below detectable limits.

**Limitations:** Metals in the sludge are not recovered economically for recycling. Processes are being developed for economical recovery of metals from sludge for recycling.



**Cost:** Savings of \$370,000/year without reclamation of the water and \$655,000/year savings with reclamation of water can be realized for a 1.4 million gal/d facility..

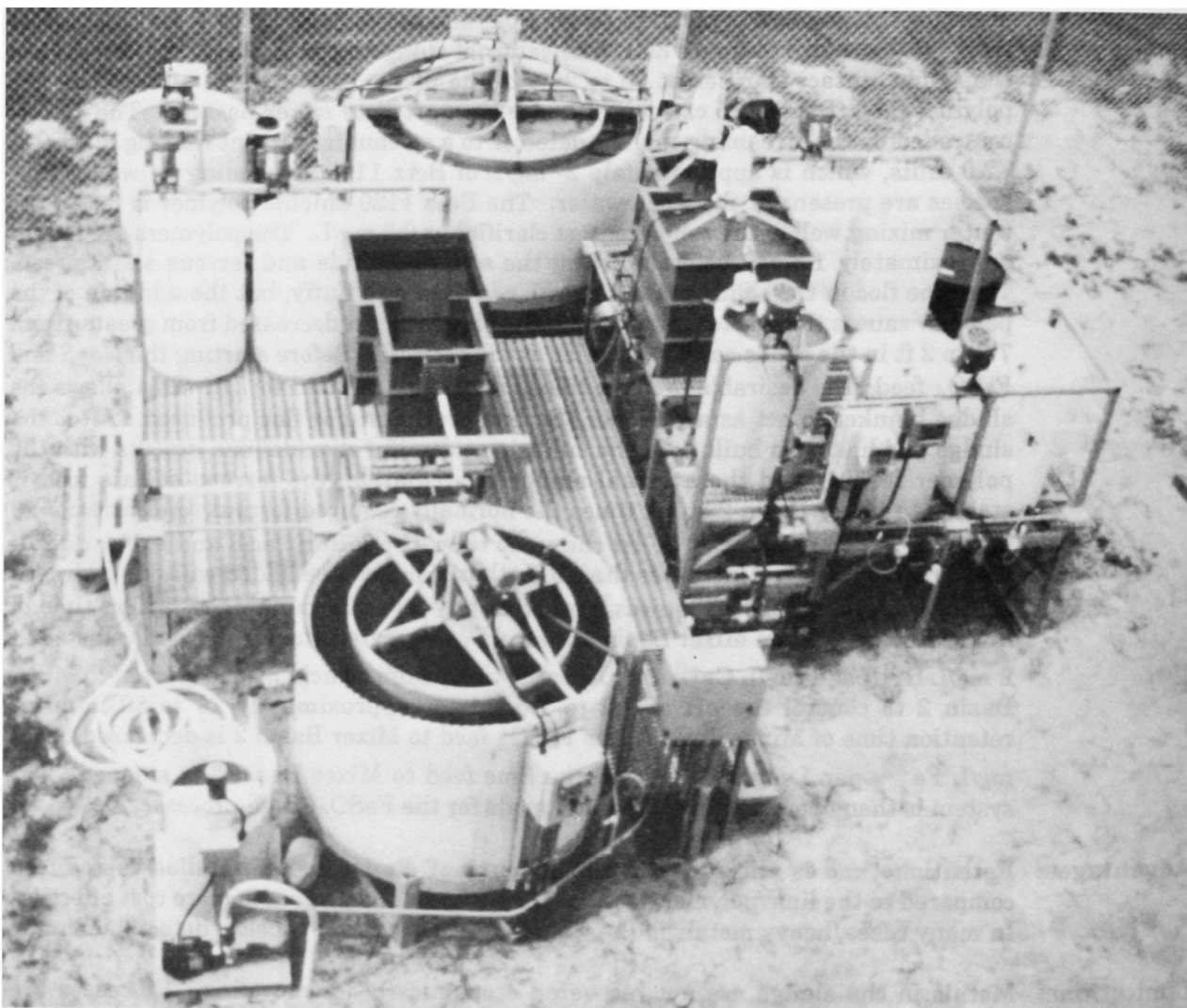
**Availability:** The technology is available through AFCESA Tyndall AFB, FL.

**Status:** Bench-scale pilot testing was conducted at NAS Pensacola, FL. Full-scale implementation has been conducted at Tinker AFB, OK in FY 89.

**References:** Wikoff, P.M. et al. **Full-Scale Implementation of The Sodium Sulfide/Ferrous Sulfate Treatment Process, Phase III Report, AFESC, Feb 1989.**

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*Figure 80b. Photograph of sodium sulfide/ferrous sulfate unit at NAS Pensacola, FL.*

## 81. SPRAY-CASTING TO REPLACE ELECTROPLATING

- Category:** II.c. Minimization or Treatment of Metal Finishing Wastes
- Purpose:** To design, construct, and test an alternative metallization process to minimize hazardous waste.
- Application:** The process has been used to place low-temperature tin coatings on low-carbon-steel templates. This process currently is being tested for high temperature applications for coating of chromium, nickel, cadmium, lead, etc.
- Description:** In this nebulization process, molten metal is drawn by aspiration into the throat of a converging/diverging gas nozzle. There the liquid stream is sheared by the gas flow into a spray of individual droplets that collect and solidify onto the surface to be coated. In principle, coatings can be sprayed directly from the melt with over 95% conversion efficiency. Small amounts of overspray can be collected and recycled. A spray chamber is shown in figure 81.
- Advantages:** Metallic and chemical waste associated with electroplating are eliminated.
- Limitations:** This is a line-of-sight process.
- Costs:** Cost/benefit information is being developed.
- Availability:** The method is still under development.
- Status:** Bench-scale testing has been conducted at the Idaho National Engineering Laboratory. Detailed coating characterization testing will be conducted in the spring of 1992. Prototype process tests will take place in FY93. at MSE, Inc., Butte, MT
- References:** Watson, L.D. and S.A. Ploger. **Spray Coating of Metals, Phase I, Quick Look Report.** Idaho National Engineering Laboratory, Prepared for the U. S. Air Force through DOE Contract No. DE-AC07-76ID01570, Apr 1989.
- Suciu, D. and L. Watson. **Low Temperature Metal Spray Coating, Quick Look Report Supplement,** Sep 1989.
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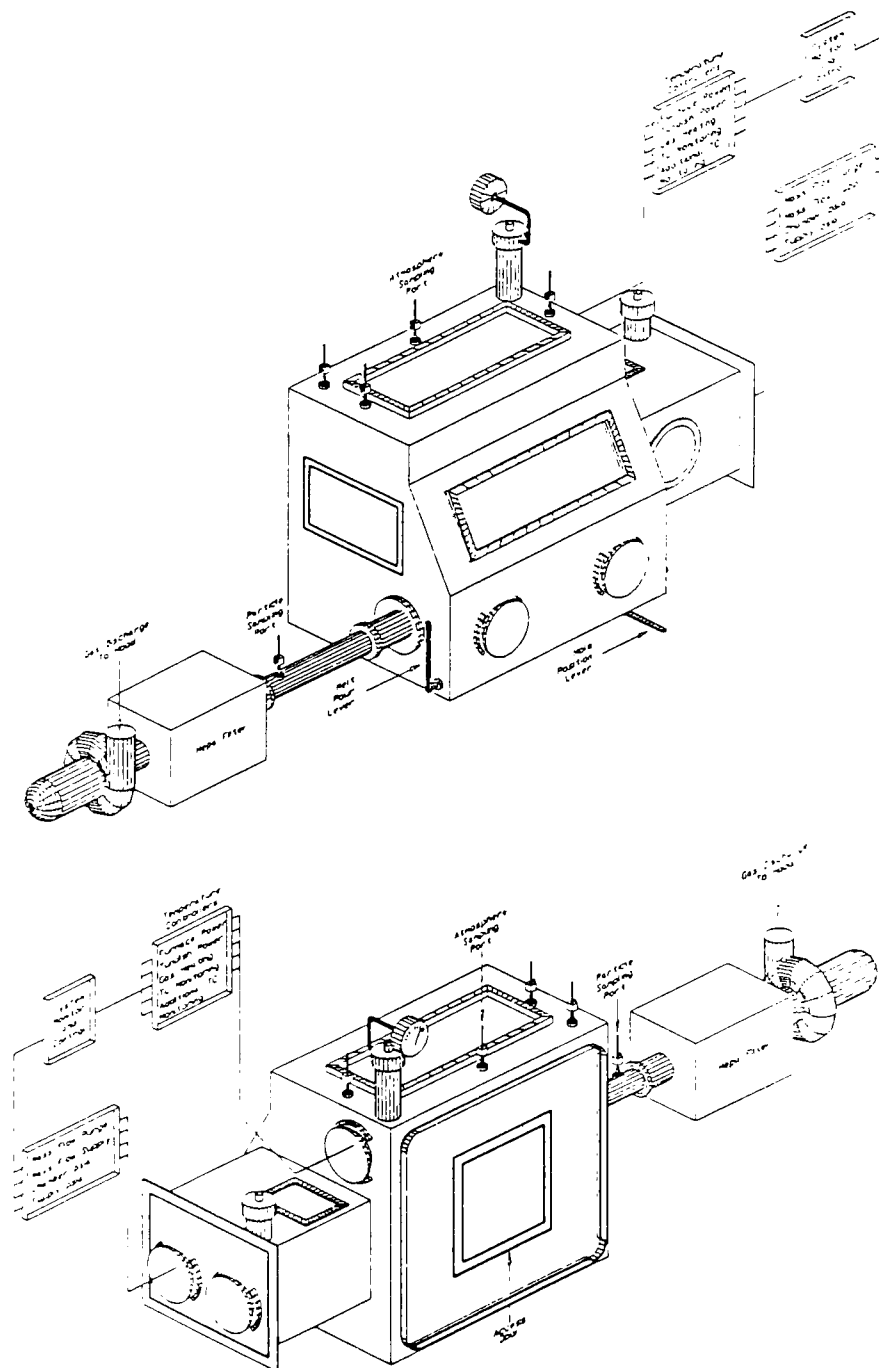


Figure 81. Spray chamber: viewing side (top) and access side (below).

## 82. MEMBRANE MICROFILTRATION

**Category:** II.c. Minimization or Treatment of Metal Finishing Wastes

**Purpose:** Extraction of hazardous waste suspensions, liquid heavy metal- and cyanide-bearing wastes (such as electroplating rinsewaters).

**Application:** This treatment technology is applicable to hazardous waste suspensions, particularly liquid heavy metal- and cyanide-bearing wastes (such as electroplating rinse waters), groundwater contaminated with heavy metals, landfill leachate, and process wastewaters containing uranium. The technology is best suited for treating waste with solid concentrations less than 5,000 ppm; otherwise, the coke capacity and handling become limiting factors. The developers claim the system can treat any type of solids, including inorganics, organics, and oily wastes with a wide variety of particle sizes. Moreover, because the unit is enclosed, the system is said to be capable of treating liquid wastes containing volatile organics.

**Description:** This microfiltration system is designed to remove solid particles from liquid wastes, forming filter cakes typically ranging from 40% to 60% 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 microfiltration system uses automatic pressure filter combined with special filter material made of spunbonded olefin (figure 82). The filter material is a thin, durable plastic fabric with tiny openings (about one ten-millionth of a meter in diameter) that allow water or other liquids, along with 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 surface, forming a filter cake, while filtrate is collected in the lower chamber. Air is fed into the upper chamber at about 45 pounds per square inch, and used to further dry the cake and remove any liquid remaining in the upper chamber. When the cake is considered to be 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 prior to disposal if necessary.

The demonstration was conducted over a 4-week period in April and May 1990. During the demonstration at the Palmerton Zinc Superfund site, the microfiltration system achieved the following results:

- Zinc and total suspended solids removal efficiencies ranged from 99.75% to 99.99%.
- Solids in the filter range from 30.5% to 47.1%.

- Dry filter cake in all test runs passed the RCRA permit filter liquids test.
- Filtrate met the applicable National Pollution Discharge Elimination System (NPDES) standard for zinc, but exceeded the standard pH.
- A composite filter cake sample passed the EPA Toxicity and toxicity characteristics leaching procedure (TCLP) tests for metals.

**Advantages:** The zinc and total suspended solids removal efficiency of this method is 99.75% to 99.99%. Dry filter cake in all test runs passed RCRA permit filter liquids test. Filtrate met the applicable NPDES standard for zinc.

**Limitations:** Additional treatment is needed after hazardous waste has been separated. The pH of the filtrate exceeded the NPDES standard after removing zinc from a hazardous waste sludge.

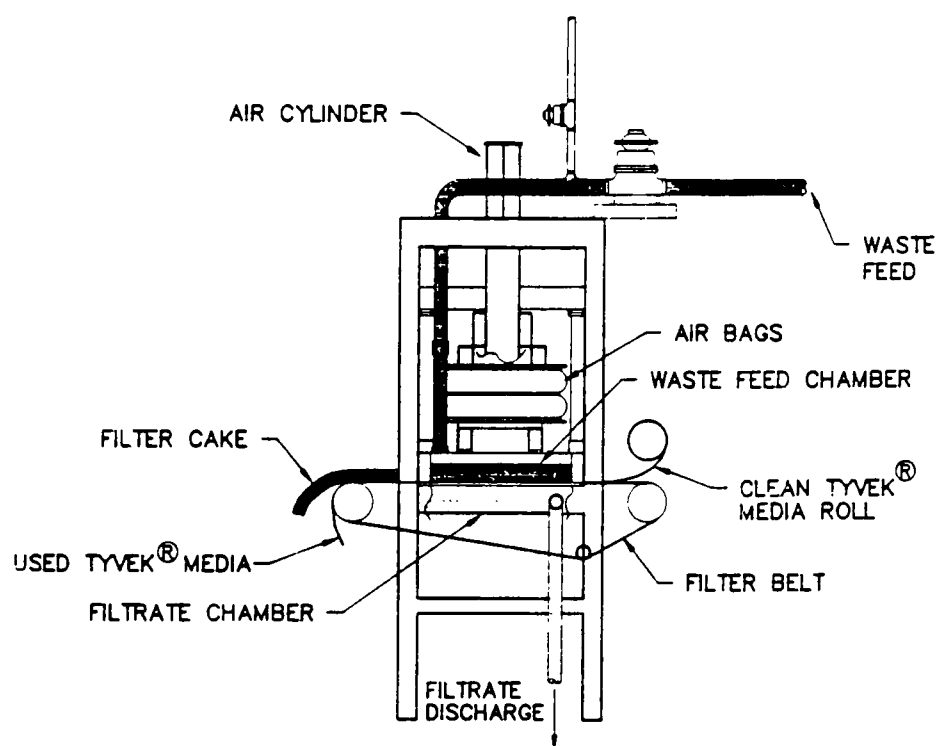
**Cost:** Not available.

**Availability:** Commercially available.

**Status:** The technology was demonstrated at the Palmerton Zinc Superfund site in Palmerton, PA. The shallow aquifer at the site, contaminated with dissolved heavy metals (such as cadmium, lead, and zinc), was selected as the feed waste for the demonstration. Pilot studies on the ground water have shown that the microfiltration system can produce a 35% to 45% solids filter cake and a filtrate with non-detectable levels of heavy metals.

**References:** **The Superfund Innovative Technology Evaluation Program: Technology Profiles**, U.S. Environmental Protection Agency Report EPA/540/5-90/006, Nov 1990, pp. 38-39.

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*Figure 82. Schematic diagram of DuPont/Oberlin microfiltration system.*

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## 83. ELECTROLYTIC RECOVERY OF METAL/CYANIDE WASTEWATERS

**Category:** II.c. Minimization or Treatment of Metal Finishing Wastes

**Purpose:** To recycle heavy metals and reduce cyanide wastes from plating operations.

**Application:** The method is applicable to cyanide containing wastewater from plating operations. With minor modifications, the method is applicable to cadmium/cyanide (Cd/CN), silver/CN (Ag/CN), copper/CN (Cu/CN), Cu/sulfate (Cu/SO<sub>4</sub>), and nickel/sulfamate wastewaters. The metal is recovered as a thin plate or foil and can be reused as an anode in the plating bath. The volume of wastewater generated from rinsing and the amount of toxic metals and cyanide discharges are reduced. Existing plating operations can be modified to incorporate an electrolytic unit .

**Description:** The electrolytic unit is connected to a segregated still rinse tank. The electrolytic process involves passing an electric current between an anode and cathode which are placed in an aqueous ionic solution. The application of direct current to the metal/CN rinse water results in the electrochemical reduction of metal ions to the elemental metal on the cathode. Oxidation of cyanide occurs at the anode. Rinse waters are recycled continuously between the electrolytic unit and the still-rinse tank. The volume of wastewater generated in the final rinse is reduced by 80 to 90%. Discharges of metals and CN are reduced up to 99% and 75%, respectively. The flow schematic for the process is shown in figure 83a; photographs of the exterior and interior of the electrolytic unit are shown in figures 83b and 83c, respectively.

**Advantages:** The volume of waste is reduced, the cost of waste treatment is reduced, sludge volume is reduced, metal is recovered and can be reused, and CN levels are reduced.

**Limitations:** The method requires shop space for two rinses following the plating bath: first rinse is a still rinse connected to the electrolytic recovery unit; the second rinse is a running rinse connected to the waste treatment facility.

**Costs:** Capital costs for implementation are about \$15,000. Operating costs are about \$9,700/yr.

**Availability:** Equipment tested is commercially available. Specifications and operating parameters are being documented. Technical details for cadmium recovery are available from NEESA. Information on other metals is available from NCEL.

**Status:** The field-scale pilot demonstration was conducted at NADEP, Norfolk, VA. Implementation of cadmium electrolytic recovery has been conducted at NADEP Pensacola and NAC Indianapolis in FY90. Additional implementation has been conducted at Long Beach Naval Ship Yard, FY91. Planned implementations include NADEP Alameda, NADEP North Island, and NADEP Pensacola.

**References:** Koff, J. *Minimization of Cadmium Cyanide Wastes Using Electrolytic Treatment*. *The Military Engineer*, No. 530, Aug 1989, pp. 37-9.



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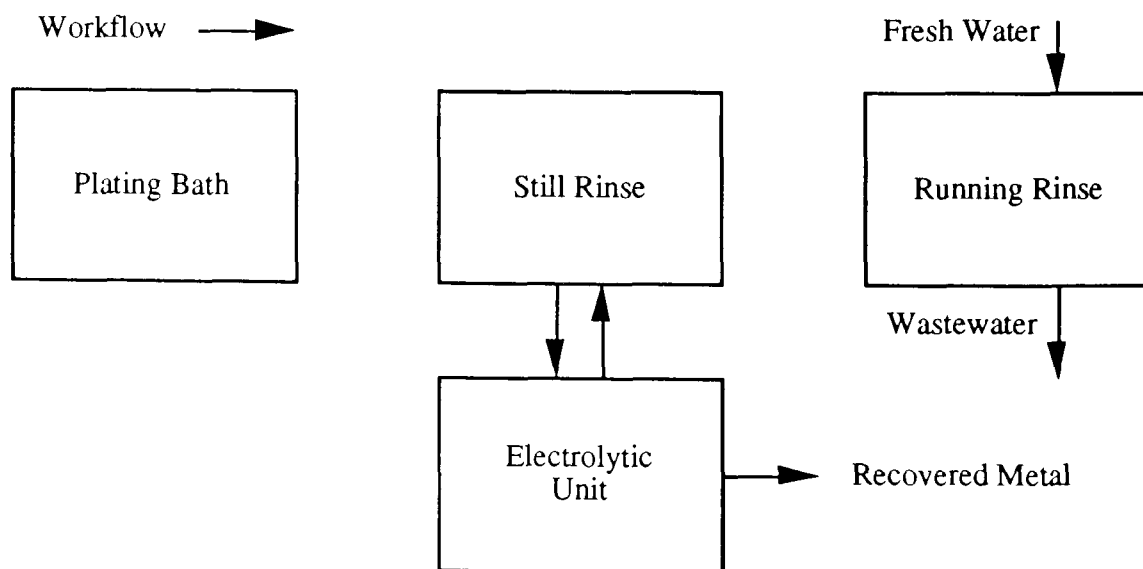
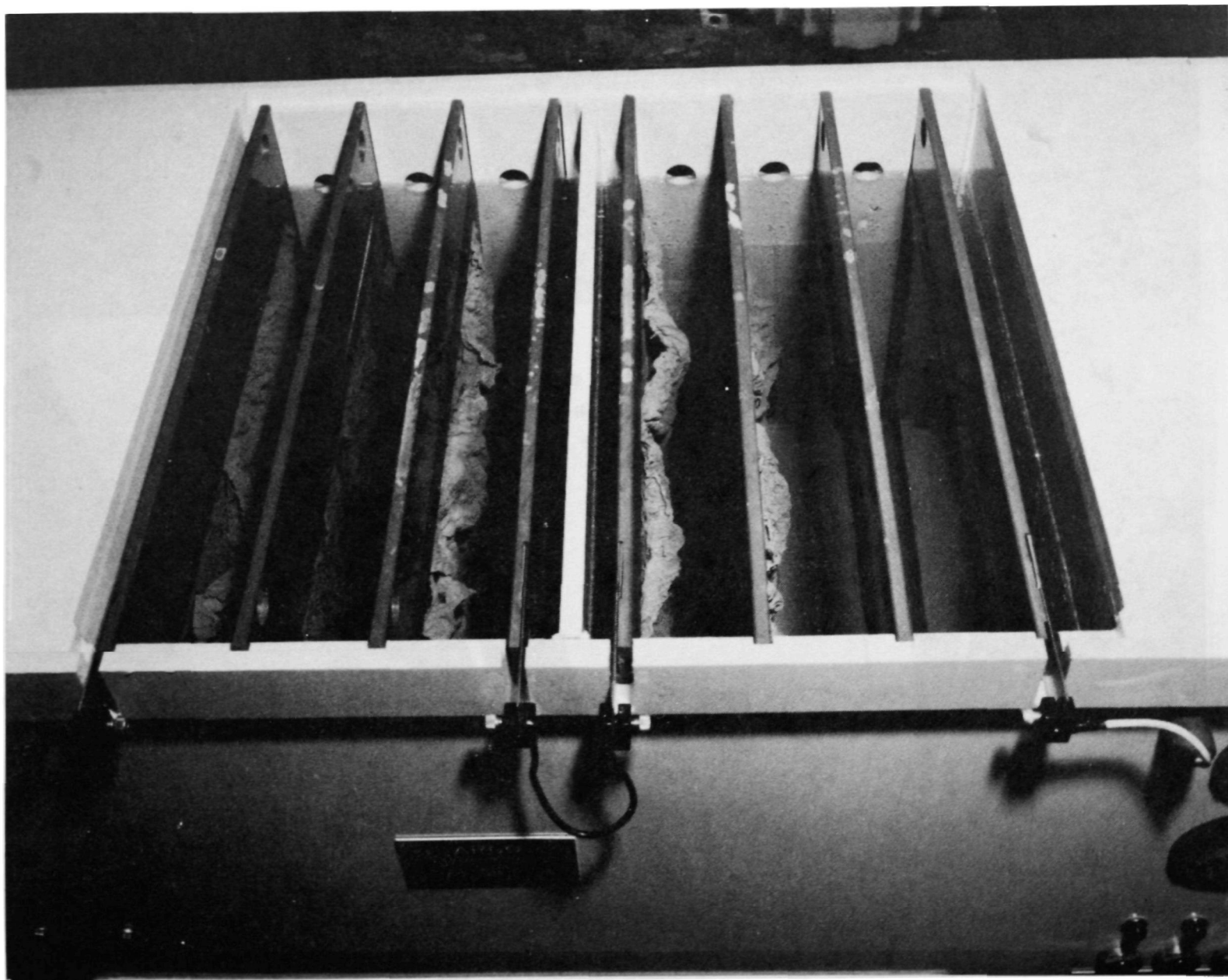


Figure 83a. Electrolytic treatment in cadmium plating (Koff, 1989).



Figure 83b. Exterior of electrolytic unit.



*Figure 83c. Interior of electrolytic unit.*

## 84. HARD CHROME PLATING

- Category:** II.c. Minimization or Treatment of Metal Finishing Wastes
- Purpose:** To reduce the generation of chrome sludge, to reduce water usage, and to improve plating quality at chrome plating operations.
- Application:** The method is applicable to buildup chrome plating, for example, bearing surfaces, shafts, and hydraulic components, as opposed to decorative plating.
- Description:** The system consists of four components (see figure 84): (1) two-buss-bar plating tank conversion, (2) zero discharge rinse system, (3) plating bath purifier, and (4) reclamation of ventilation losses. Rinse water and/or ventilation scrubber water is used to replace plating bath solution lost due to evaporation, thus achieving zero discharge of chrome-containing rinse waters. A conforming anode in the shape of the part to be plated is made from lead mesh. The conforming anode reduces the number of defective parts. When completed, the plated part is removed from the plating bath for rinse. If the flow in the rinse tank is countercurrent, then a spray rinse must be added – a series of spray rings using recycled water and a hand sprayer using new water. Rinse water and mist are recycled.
- Advantages:** The design is simple. Plating quality is improved while generation of plating sludge and water usage is decreased. The method is as much as five times faster than alternative plating methods. The reclamation is less expensive than other methods, and equipment maintenance is low. In existing systems with the flow rate through the rinse tank between 12 to 13 gal/min, the rinse water goes to the industrial treatment plant resulting in the generation of from two to three drums of sludge per week. In this method, if the scrubber water is included, all discharges are eliminated.
- Limitations:** The method is not applicable to room temperature plating such as that for cadmium or precious metals.
- Costs:** The conversion from conventional to hard-chrome plating costs about \$40,000 for materials and \$100,000 for engineering. These costs will be reduced through experience. Cost details are available from the Naval Energy and Environmental Support Activity (NEESA) or in the implementation reports mentioned below.
- Availability:** The technology is not commercially available but is available from NCEL or NEESA.
- Status:** The method has been implemented or is in the process of being implemented at Long Beach Naval Ship Yard (NSY), CA; Pearl Harbor NSY, HI; Naval Air Station (NAS) North Island, San Diego, CA; Mare Island NSY, CA; NAS, Alameda, CA; Naval Undersea Warfare Engineering Station (NUWES), Keyport, WA; NAS, Jacksonville, FL; Philadelphia NSY, PA; and Charleston NSY, SC. Plans are for five facilities to be converted each year for 3 years. Pilot plant testing was conducted by NCEL at Puget Sound NSY, WA; Naval Ordnance Station, Louisville, KY; NAS Pensacola, FL; and NAS Cherry Point, NC.
- References:** Carpenter, C., *Innovative Hard Chrome Plating Concept*, Technical Memorandum, Naval Civil Engineering Laboratory TM No. 71-85-12, Feb 1985.

# **Hard Chrome Plating Zero Discharge Rinse - Technology Transfer Document. NEESA Report 19-006, Oct 1991.**

Some reports of implementation plans are available from NEESA.

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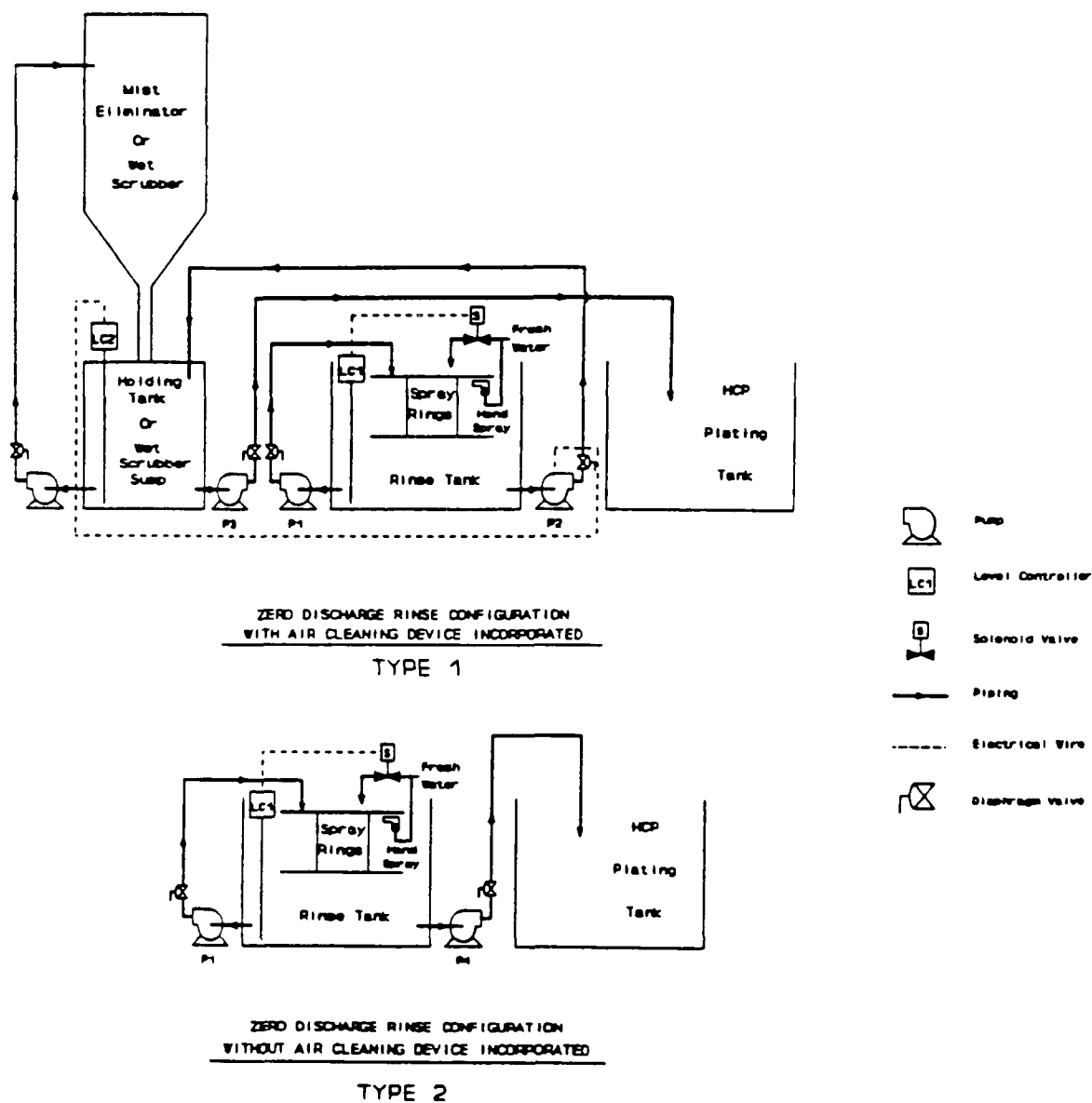


Figure 84. Hard chrome plating schematic.

## 85. ELECTRODIALYSIS OF CHROMIC ACID PLATING SOLUTIONS

**Category:** II.c. Minimization or Treatment of Metal Finishing Wastes

**Purpose:** To regenerate and reuse chromic acid plating solutions.

**Application:** The method is applicable to chromic acid-based stripping, plating, and conversion coating solutions.

**Description:** Electrodialysis employs a cation-selective membrane to control the transport of cations (chromium and other metal ions) from the anolyte (chromic acid solution) to a catholyte. In this unit, cations entering the catholyte are precipitated as metal hydroxides. Precipitation prevents a loss of conductivity, which occurs when an acidic catholyte is used, and eliminates the buildup of a deposit on the cathode. A sludge, much like that generated by an industrial wastewater treatment plant, is generated and must be disposed as a hazardous waste. The catholyte solution can be filtered and reused or treated in a conventional industrial wastewater treatment plant. A simplified schematic of the electrodialysis process to recover chromium is given in figure 85a. Although the metal sludge is considered a hazardous waste, the volume of the hazardous material is reduced. A three-compartment electrodialysis cell is depicted in figure 85b.

**Advantages:** The chromic acid solution is regenerated and can be reused. Contaminant metals are constantly removed, resulting in improved plating quality. The system requires little maintenance. The technology can be made applicable to other acidic solutions. The system can be combined with ion exchange columns in a closed-loop system for process solution regeneration and rinse water reclamation.

**Limitations:** The membrane is subject to leakage at high operation temperatures.

**Costs:** The cost for a unit is estimated at \$30,000.

**Availability:** The technology is commercially available.

**Status:** The method is being implemented at Corpus Christi Army Depot, TX.

**References:** Davis, J.S. **Evaluation of Electrodialysis for Chromic Acid Recovery and Purification at Corpus Christi Army Depot.** USATHAMA Report CETHA-TS-CR-91032, Sep 1991.

**Contact:** Ronald Jackson  
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410-671-2054

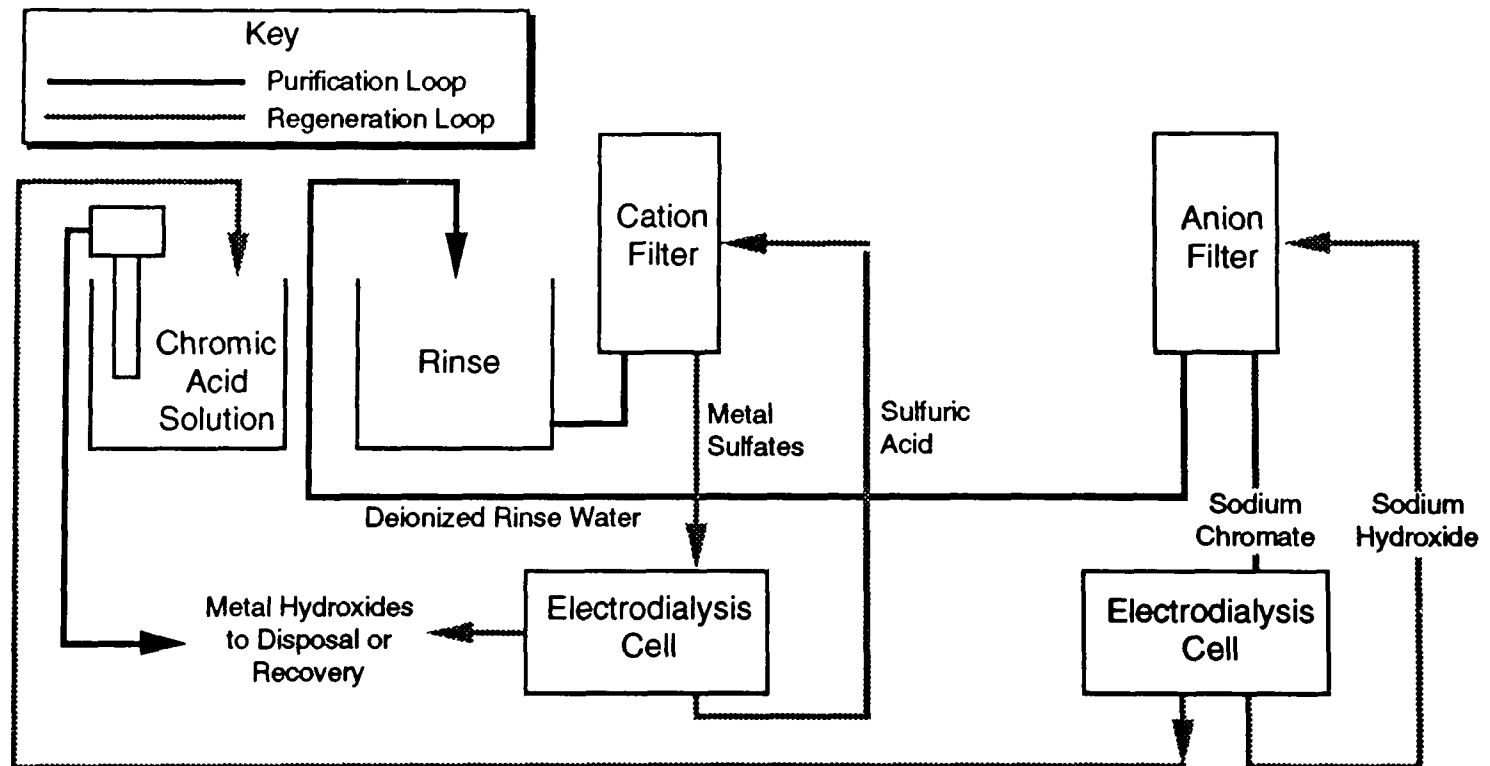


Figure 85a. Schematic diagram of a closed-loop electrodialysis system for chromium recovery

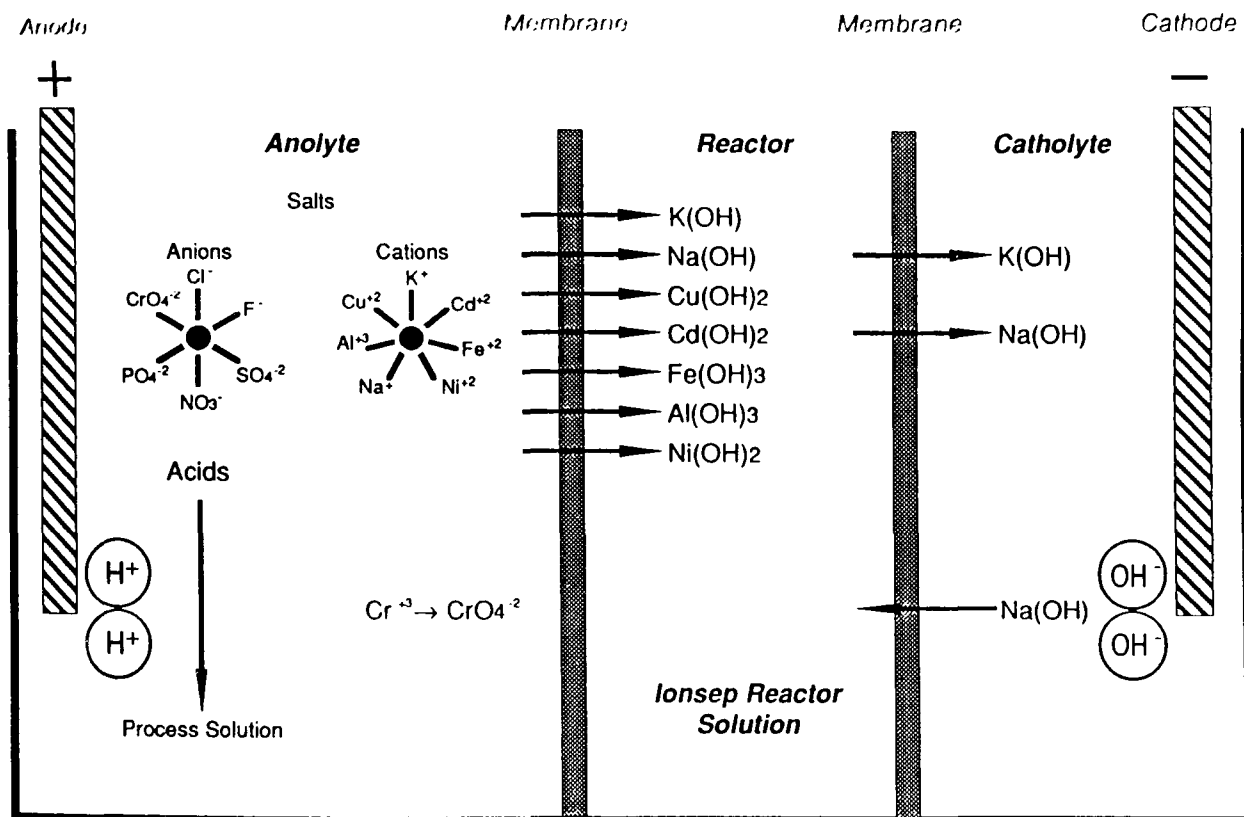


Figure 85b. Schematic diagram of a three-compartment Ionsep electro dialysis cell.



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## 86. ION VAPOR DEPOSITION (IVD) SUBSTITUTION OF ALUMINUM FOR CADMIUM

**Category;** II.c. Minimization or Treatment of Metal Finishing Wastes

**Purpose:** To reduce hazardous waste production and its associated adverse effect on the environment by substituting ion vapor deposition (IVD) aluminum as a replacement for cadmium where it is used as a corrosion-resistant finish on steel.

**Application:** IVD aluminum is applicable as a replacement for cadmium where it is used as a corrosion-resistant finish on steel.

**Description:** The IVD aluminum coating is applied in production coating equipment called Ivdizers. The basic equipment consists of a steel chamber, a pumping system, a parts holder, an evaporation source, and a high-voltage power supply. A schematic of an IVD coater is shown in figure 86. The IVD processing sequence consists of pumping the vacuum chamber down to about  $10^{-4}$  Torr. The chamber is then backfilled with argon gas, and a high negative potential is applied to the parts being coated. The argon gas becomes ionized and creates a glow discharge around the parts. The positively charged gas ions bombard the negatively charged surface of the parts and perform a final cleaning, which contributes to good coating adhesion. Following glow discharge cleaning, aluminum wire is evaporated by being continuously fed into resistance-heated crucibles. As the aluminum vapor passes through the glow discharge, a portion of it becomes ionized. This, in addition to collision with the ionized argon gas, accelerates the aluminum vapor toward the part surface, resulting in excellent coating adhesion and uniformity. Both the aluminum coating and the IVD process are environmentally clean.

**Advantages:** There is a reduction in hazardous waste. IVD aluminum out-performs cadmium in preventing corrosion in acidic environments and actual service test. Aluminum coatings can be used at temperatures up to 950° F, whereas cadmium is limited to 450° F. IVD aluminum coatings can be applied to high-strength steel without fear of hydrogen embrittlement. Aluminum coatings can be used in contact with titanium without causing solid metal embrittlement, and they can also be used in contact with fuels; cadmium is prohibited for these applications. IVD aluminum can be used in space applications whereas cadmium is limited because of sublimation. The coating requirements for IVD aluminum are specified in MIL-C-83488, the tri-service specification for pure aluminum coatings. After coating, the parts are generally chromate-treated in accordance with MIL-C-5541. This provides additional protection against corrosion, forms a good base for paint adhesion, and is a common treatment for aluminum alloy surfaces. It can also be applied thicker than cadmium where part tolerance permits; this results in additional corrosion resistance.

**Limitations:** The IVD process can only coat one diameter deep into a recess or cavity. IVD-coated nuts and bolts require significantly more torque to complete a threaded connection than does a cadmium-coated connection.

**Cost:** IVD costs for a generic part 36 X 12 X 8 in. are \$105. The IVD costs are competitive with "Bright" cadmium, low embrittlement cadmium, and diffused nickel-cadmium at \$105, \$142, and \$135, respectively. Annual costs of cadmium plating at Anniston

Army Depot (ANAD), AL, are about \$340,000 (\$4.47/ft<sup>2</sup>); whereas the estimated annual cost for IVD is \$505,330 (\$6.64/ft<sup>2</sup>).

**Availability:** The technology is commercially available.

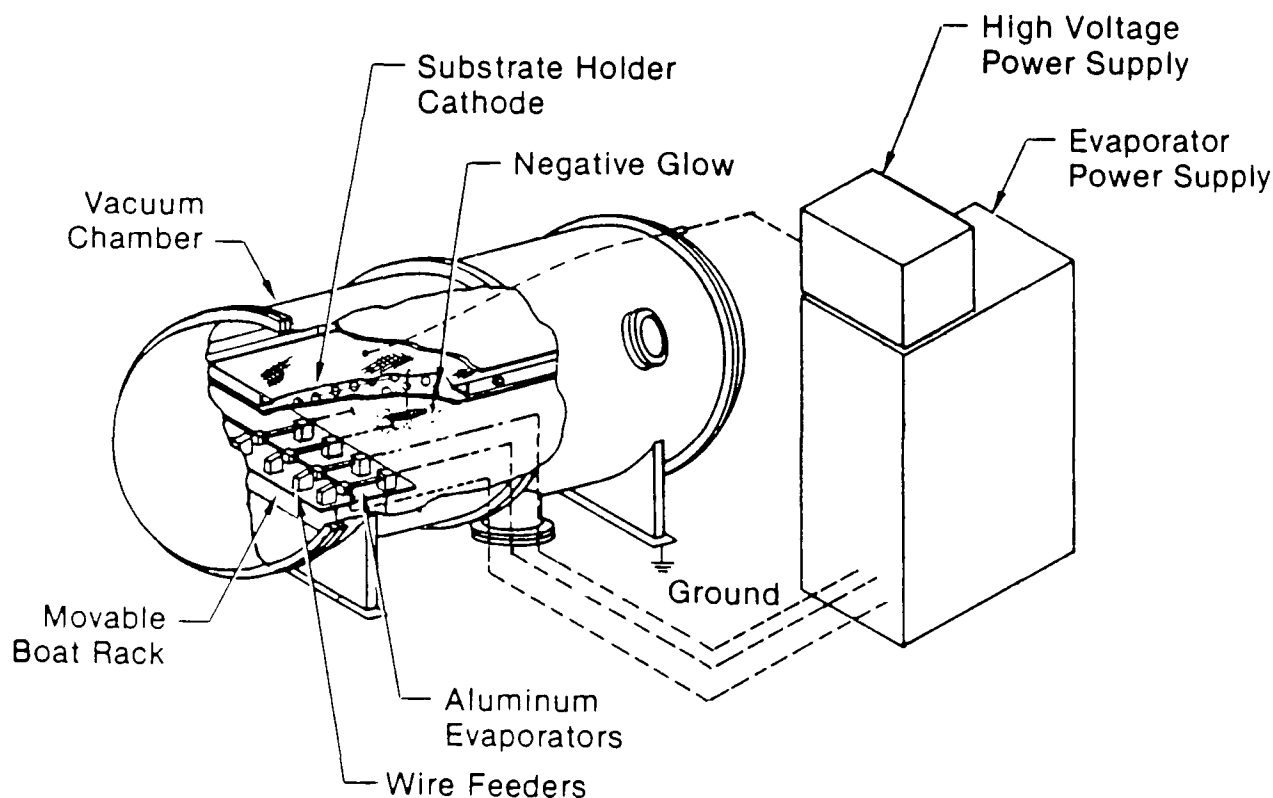
**Status:** Full-scale implementation is being conducted at Warner Robins AFB, GA. The technology is being implemented at ANAD.

**References:** Jackson, R.P. and T.C. Pollard. **The Evaluation of Aluminum Ion Vapor Deposition as a Replacement for Cadmium Electroplating at U.S. Army Depots.** Proc. 18th Environmental Symposium and Exhibition, Feb 1992.

Ressi, R. and J. Spessard. **Evaluation of Aluminum Ion Vapor Deposition as a Replacement for Cadmium Electroplating at ANAD – Final Report.** USATHAMA Report CETHA-TS-CR-91054, 1991.

Holmes, V.L., D.E. Muehlberger, and J.J. Reilly, **The Substitution of IVD Aluminum for Cadmium, Final Report,** U.S. Air Force Engineering and Services Center Report ESL-TR-ii-75, Aug 1989.

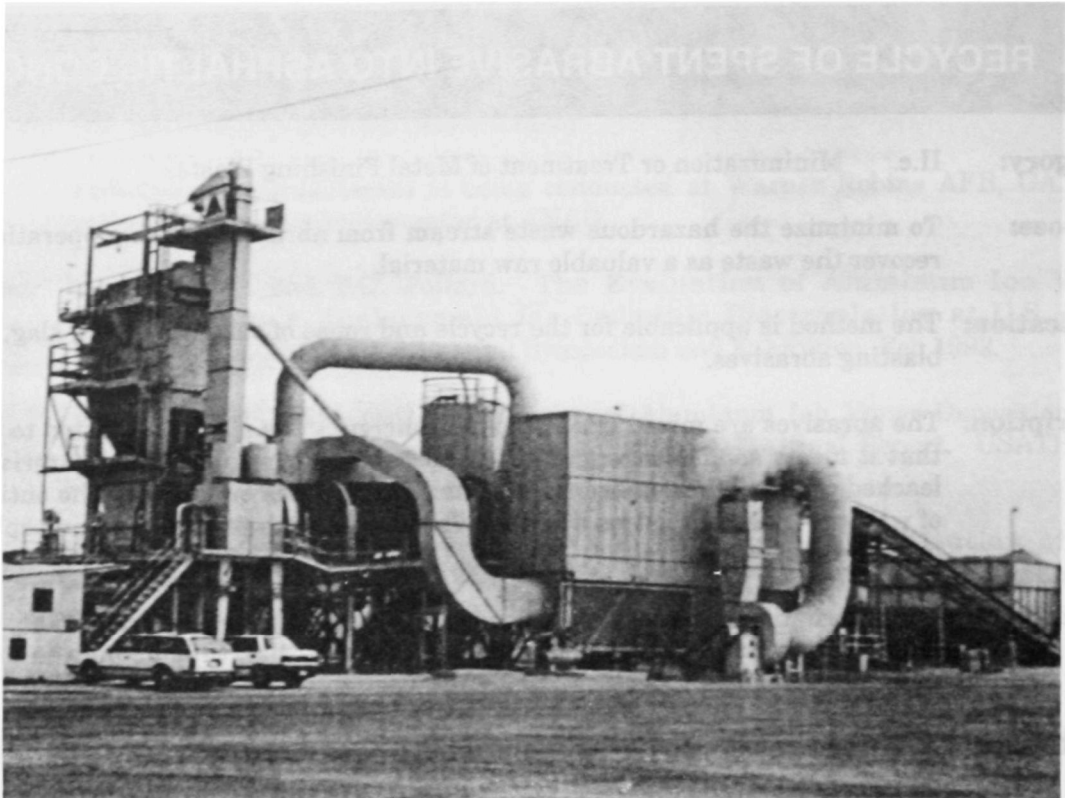
<b>Contact:</b>	Lt. Phillip P. Brown HQ AFCESA/RAVS Tyndall AFB, FL 32403-5319 904-283-6018 or Autovon 523-6018	Ronald P. Jackson USATHAMA CETHA-TS-D Aberdeen Proving Ground, MD 21010-5401 410-671-2054
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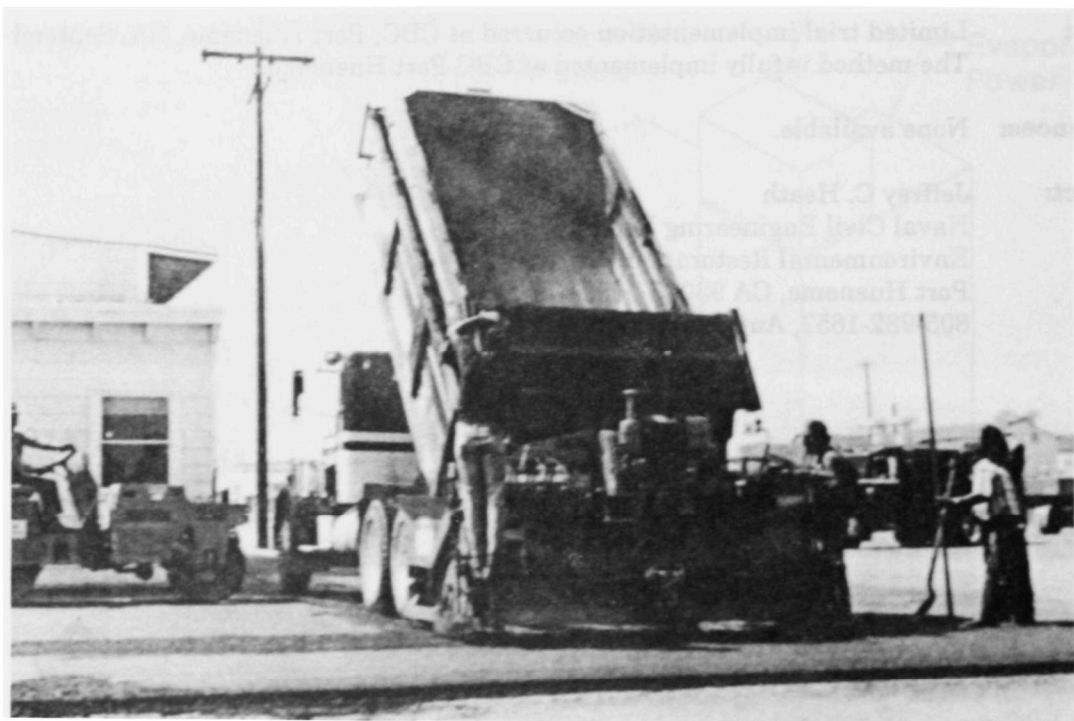
*Figure 86. Schematic diagram of an ion vapor deposition system.*

## 87. RECYCLE OF SPENT ABRASIVE INTO ASPHALTIC CONCRETE

- Category:** II.c. Minimization or Treatment of Metal Finishing Wastes
- Purpose:** To minimize the hazardous waste stream from abrasive blasting operations and to recover the waste as a valuable raw material.
- Application:** The method is applicable for the recycle and reuse of sand-blast grit, slag, and other blasting abrasives.
- Description:** The abrasives are mixed into asphaltic concrete. The asphalt is tested to determine that it meets asphalt strength specifications and that hazardous materials are not leached or pose other environmental hazards, such as emissions. The entire volume of waste is reused. Figures 87a and 87b show an asphalt plant and an asphalt paver being loaded, respectively.
- Advantages:** The alternative is disposal as a hazardous waste at about \$500/ton. This method is less expensive and the waste becomes a raw material, thus helping to meet waste minimization goals.
- Limitations:** A nearby asphalt plant is necessary.
- Costs:** Exact cost information is not available, but is estimated to be about \$50/ton including transportation and permit activity.
- Availability:** The technology is commercially available.
- Status:** Limited trial implementation occurred at CBC, Port Hueneme, CA, September 1991. The method is fully implemented at CBC Port Hueneme.
- References:** None available.
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*Figure 87a. Photograph of an asphalt plant utilizing spent blasting abrasives.*



*Figure 87b. Asphalt made using abrasive grit being loaded into a paver.*

## 88. RECLAMATION AND REPROCESSING OF SPENT SOLVENTS

- Category:** II.d. Minimization or Treatment of Other Liquid Wastes
- Purpose:** To recommend and evaluate simple tests to be used as criteria for evaluating the condition of cold-dipping solvents and vapor degreasers and to identify when these solvents should be changed.
- Application:** The method is applicable to maximize solvent use before disposal or recycle, to assure that recycled solvents meet cleaning specifications, and to minimize waste solvent generation. Applicable solvents include Stoddard solvent (PD680 – petroleum distillate) and degreasing solvents, mainly chlorinated solvents such as trichloroethylene.
- Description:** Standard tests are used that identify the condition of solvents. Tests include visible light absorption spectrometry, and measurement of viscosity, electrical conductivity, and specific gravity. Absorbance is the most sensitive test and can be used alone in most cases. Borderline cases can be distinguished by specific gravity and viscosity measurements.
- Advantages:** Use of the tests results in lower solvent costs and lower equipment maintenance costs. Unspent solvents are kept in use longer. Spent solvents are detected before equipment damage can occur.
- Limitations:** Testing criteria for only a few solvents have been established.
- Costs:** Test kits are supplied that contain the equipment and reagents necessary for facilities personnel to conduct the tests.
- Availability:** The method is still in development at the pilot-testing stage. The equipment expected for use in the tests is commercially available.
- Status:** Pilot testing is completed at several Army and Air Force facilities including Anniston Army Depot, AL and Robins Air Force Base, GA.
- References:** Tarrer, A.R., B.A. Donahue, S. Dharmavaran, and S.B. Joshi. **Reclamation and Reprocessing of Spent Solvents**, Published in U.S.A. by Noyes Data Corp., Mill Road, Parkridge, NJ, 1989.
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## 89. BIODEGRADABLE SOLVENTS

**Category:** II.d. Minimization or Treatment of Other Liquid Wastes

**Purpose:** To identify solvents for removing wax, grease, and oil that can be replaced by biodegradable solvents, identify the biodegradable solvents that can be used, and develop procedures for and implement their use.

**Application:** The method is applicable for the removal of wax, grease, and oil.

**Description:** Several methods have been developed to screen solvents for biodegradability, cleaning efficiency, and corrosiveness. About 200 chemical companies were contacted and samples obtained from them for tests as replacements for solvents currently in use. Biodegradability screening consisted of testing a bench-scale activated-sludge system and measuring chemical oxygen demand (COD) and adenosine triphosphate (ATP) over a 6-hour period to establish if the actions of the system can reduce the COD to below the limits imposed by the National Pollution Discharge Elimination System (NPDES). This is a modification of an existing ASTM method and is being developed into a new ASTM method. A 6-hour period was chosen for the test period for biodegradation because that is the shortest retention time in an U. S. Air Force Industrial Waste Treatment Plant. To screen candidate solvents for cleaning efficiency, the solvents were initially tested (solubility testing) to determine if they would dissolve or loosen the adhesion of the soils to metal. If effective, they were then tested for cleaning efficiency on that type of soil. Testing consisted of coating metal coupons with masking wax, oil, or grease and submerging them for a time in the solvent mixed according to the manufacturer's recommendation. The coupons were then removed from the solvent, and their weight loss was determined as a function of time. Corrosion testing was performed for each of the solvents that met the criteria established for biodegradation, solubility, and cleaning efficiency. These tests, each lasting a week, followed the ANSI/ASTM F 484-77 corrosion test method. Of the 200 plus solvents tested, 40 passed the cleaning and biodegradability tests. The solvents that were applicable to all the metals were corrosion-tested, and 10 passed the test criteria. Six solvents were selected for pilot-scale testing at Tinker AFB, OK. Five of the six solvents passed all tests and will help meet new volatile organic compound compliance requirements. These five solvents are also biodegradable within the 6-hour time frame in the Industrial Waste Disposal Facility.

**Advantages:** All five solvents selected are biodegradable in 6 hours. No landfill is needed for disposal of hazardous waste. Use of these solvents will result in lower disposal cost. These solvents are less toxic than those formerly in use.

**Limitations:** Costs are higher for solvents that meet all requirements including biodegradability in 6 hours. Additional processes may be needed for biodegradation. Enhancement techniques may be needed for some of the solvents.

**Costs:** Cost of solvents depends on the solvent and the manufacturer.

**Availability:** The solvents are commercially available.



**Status:** Full-scale implementation is planned for Tinker AFB in FY 90. Final report will be available in FY92.

**References:** Beller, J.M. et al. **Substitution of Cleaners with Biodegradable Solvents, Final Report.** AFCESA, DE-AC07-76ID01570, May 1991.

Beller, J.M. et al. **Substitution of Wax and Grease Cleaners with Biodegradable Solvents, Phase I.** U.S. Air Force Engineering and Services Center Report ESL-TR-89-04, Nov 1988.

**Contact:** Lt. Phillip P. Brown  
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## 90. BIODEGRADATION OF PHENOLIC PAINT STRIPPERS

- Category:** II.d. Minimization or Treatment of Other Liquid Wastes
- Purpose:** To remove phenol from paint-stripping wastewater.
- Application:** The method is applicable to any wastewater stream containing phenol. It potentially is applicable for the treatment of wastewater containing methylene chloride and other chlorinated hydrocarbons.
- Description:** The pilot plant, discussed in the status section below, consisted of two trickling filter bioreactors (600-gallon reinforced fiberglass tanks) containing Actofil® biorings for support of phenol-oxidizing microbes. Diammonium phosphate nutrient was added.
- Advantages:** This is a destructive method; that is, the waste is eliminated. The alternative has been to bury the waste at an approved landfill. Since relatively high concentrations of phenol can be treated, the amount of dilution required prior to treatment is small. The method can be used to minimize upsets from phenol to existing industrial treatment plants, that is, a pretreatment method for influent to a combined stream treatment plant.
- Limitations:** An upper phenol concentration limit must be established by laboratory tests before implementation.
- Costs:** Cost will depend upon factors that will be unique to specific installations. Further developmental research is required for detailed cost estimation.
- Availability:** The method is still in the development stage.
- Status:** Large-scale pilot testing (> 10 drums) has been conducted at Hill AFB, UT. Phenols were biodegraded successfully, but the continued use of phenolic paint strippers is under investigation. Therefore, the need for such a minimization method could be limited by the introduction of methods such as plastic media blasting for paint removal. The effects of pH, temperature, flow rate, aeration, nutrients, and phenol concentration were investigated. The pilot study reactors were operated in single-pass, series-flow, and recirculation modes for about 9 months. Reseeding the bed was not required. The biodegradation was successful over a phenol concentration range of 50 to 2,100 ppm. The degradation occurred over a temperature range of 10° to 37° C, with the optimum at about 20° C. The optimum pH was near 7, the natural pH of the system, so pH modification was not necessary. Biological activity was maintained at a cadmium concentration as high as 320 ppm.
- References:** Suciu, D.F. et al. **Pilot Plant Studies of Biological Phenol Degradation from Industrial Effluents, Final Report.** AFESC Report ESL-TR-85-60, Oct 1986.
- Contact:** Capt. Catherine Vogel  
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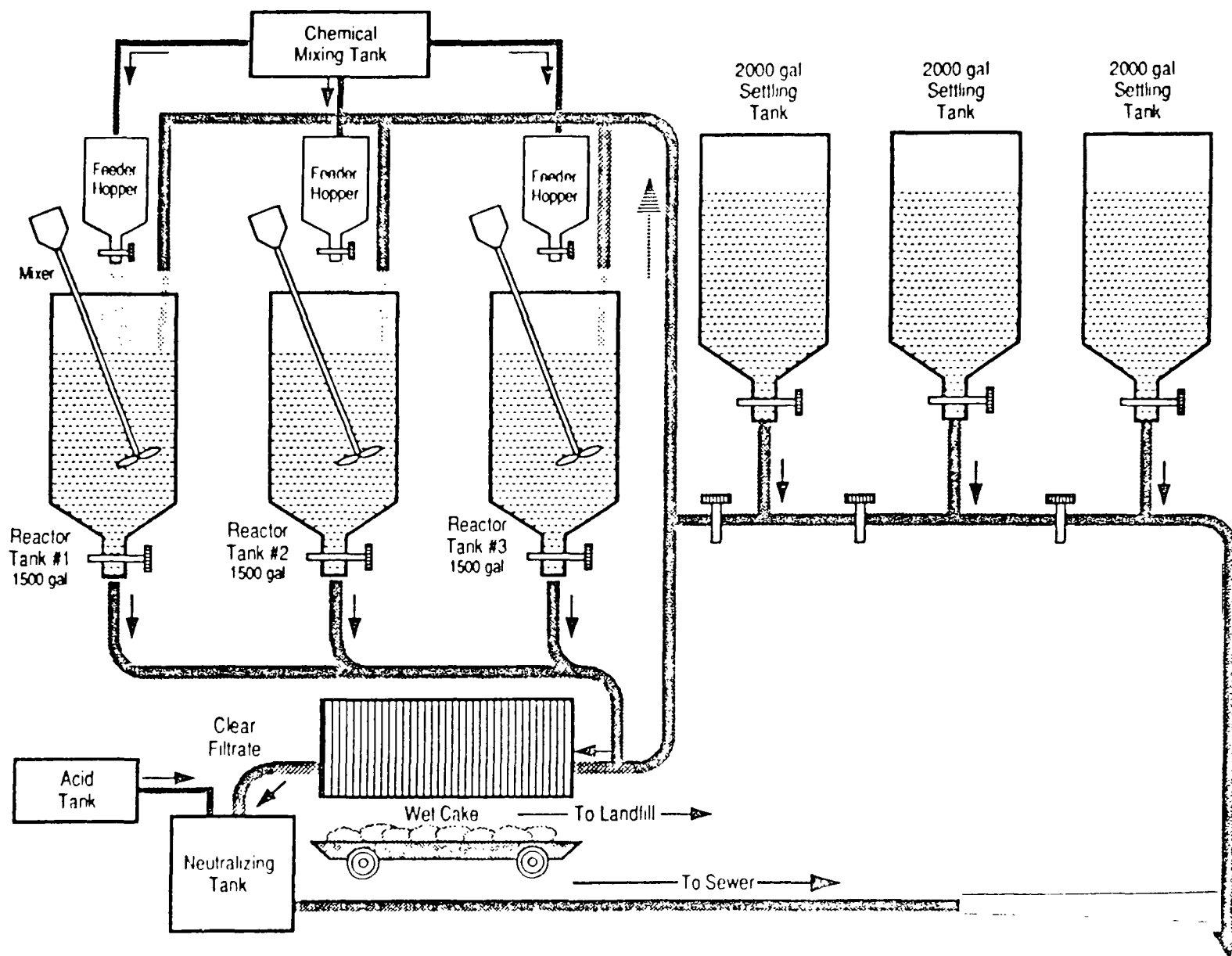
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## 91. SODIUM NITRITE WASTEWATER TREATMENT

- Category:** II.d. Minimization or Treatment of Other Liquid Wastes
- Purpose:** To reduce disposal costs of hazardous boiler sodium nitrite wastewater generated from Naval shipyards.
- Application:** Naval shipyards (NSY) generate hazardous sodium nitrite wastewater from three sources: (1) boiler tube hydroblasting, (2) boiler lay-up, and (3) boiler hydro-leak testing. The water solution used in these operations contains sodium nitrite ( $\text{NaNO}_2$ ), a corrosion inhibitor, with a concentration of 1,200 ppm. In addition, the wastewater also contains various heavy metals in ionic form, mainly, cadmium, copper, nickel, chromium, lead, and zinc, which are regulated as hazardous waste by the EPA. The shipyards generate about 3 million gallons of  $\text{NaNO}_2$  wastewater per year. At the Long Beach NSY alone, 800,000 gal of hazardous  $\text{NaNO}_2$  boiler wash were disposed of during 1990 at a cost of \$1.65 million. When  $\text{NaNO}_2$  wastewater is mixed with other wastes in the ship bilge, the disposal cost by contractor is about \$3.25/gal. If it is separated from other wastes in the ship bilge, the disposal cost is about \$2/gal. Many municipal wastewater treatment systems cannot handle  $\text{NaNO}_2$  wastewater and refuse to accept it. Naval waste treatment facilities, either industrial or sanitary, are likewise not equipped to treat this type of waste water. The need for a cost-effective treatment option for  $\text{NaNO}_2$  wastewater is clear.
- Description:** Laboratory studies conducted in FY90 showed that sulfamic acid ( $\text{NH}_2\text{SO}_3\text{H}$ ) administered stoichiometrically is capable of completely eliminating nitrite through denitrification without formation of nitrate ion. This occurs through direct nitrite conversion to nitrogen gas. During FY91, a bench-scale process of 100-gal capacity was successfully tested at the California State Polytechnic University, Pomona, CA. The results showed that the chemical process using  $\text{NH}_2\text{SO}_3\text{H}$  as a reducing agent can complete convert the nitrite ion to nitrogen gas, while successfully removing heavy metals and sludge, and meet the requirements for discharging the treated waster to NPDES channels.
- Advantages:** The proposed chemical process will not produce hazardous waste and the effluent produced can be safely discharged to the sanitary sewer.
- Limitations:** Additional testing is necessary to determine limitations of the method.
- Costs:** Exact cost information has not been determined; however the capital costs are estimated to be about \$100K.
- Availability:** Technical details are available from NCEL (see point of contact).
- Status:** A pilot plant has been constructed at the Long Beach NSY, CA (figure 91), and field-test runs are in progress.
- References:** Pan, B.Y.K. and Andy Law. **Initial Feasibility Study of Treatment of Sodium Nitrite Wastewater From Naval Shipyards**. NCEL Technical Memorandum TM 71-90-4, May 1990.

Lee, T.Y. Richard, B.Y.K. Pan, and Henry Sheng. **Final Feasibility Report on Chemical Treatment of Sodium Nitrite Wastewater.** NCEL Technical Note (in review).

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**Figure 91. Proposed waste minimization project – denitrification and demetalization of U.S. Navy boiler wastewater, Long Beach NSY.**

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## 92. CITRIC ACID WASTEWATER TREATMENT

- Category:** II.d. Minimization or Treatment of Other Liquid Wastes
- Purpose:** To reduce the volume and disposal cost of hazardous citric acid wastewater originating from naval ship yards (NSY).
- Application:** Citric acid is used at NSYs to remove rust from ship bilges and tanks. Because of the chelating effect of heavy metals, the resulting citric acid wastewater probably becomes immune to the usual biological and chemical treatment. Major components of this wastewater are citric acid (CA), triethanolamine (TEA), and iron. This ultraviolet (UV) light and hydrogen peroxide method is intended to decompose CA and TEA and break the chelating bond between iron and CA or TEA.
- Description:** UV light in combination with some oxidant, such as ozone or hydrogen peroxide ( $\text{H}_2\text{O}_2$ ), has been used widely in industry to destroy various organics (see the UV/Oxidation method discussed in notes #13, #14, and #15), but the technique has been limited to organics in the range of several hundred ppm or lower. The high concentrations of CA and TEA (at least 1% each to as high as 4%) in this CA wastewater are considered to be difficult to treat with the usual UV/ $\text{H}_2\text{O}_2$  method. With the proper selection of reaction conditions and a catalyst, wastewaters containing up to 1.5% CA and TEA have been treated successfully (figure 92).
- Advantages:** In the alternative method of removing the chelated iron using an exchange resin, the TEA interferes with iron removal because it occupies the resin sites preferentially.
- Limitations:** Additional work is necessary to determine the limitations of this method.
- Costs:** Not available.
- Availability:** Equipment and technical details are available from NCEL.
- Status:** Lab- and bench-scale pilot tests have demonstrated the treatment of wastewaters containing up to 1.5% CA and 1.5% TEA (NCEL and the University of Southern California). A field pilot was conducted at the Long Beach NSY, CA, in FY90.
- References:** Pan, B.Y.K., J.R. Chen, and T.F. Yen. **Initial Feasibility Study on Ultraviolet Light and Hydrogen Peroxide Method.** NCEL Technical Memorandum TM-90-5, Jun 1990.
- Field Tests of Ultraviolet Light/Hydrogen Peroxide System To Treat Citric Acid/Triethanolamine Wastewater.** Arthur D. Little Report, Reference 63183, Final Report to U.S. Naval Facilities Engineering Command, Port Hueneme, CA, Sep 1990.
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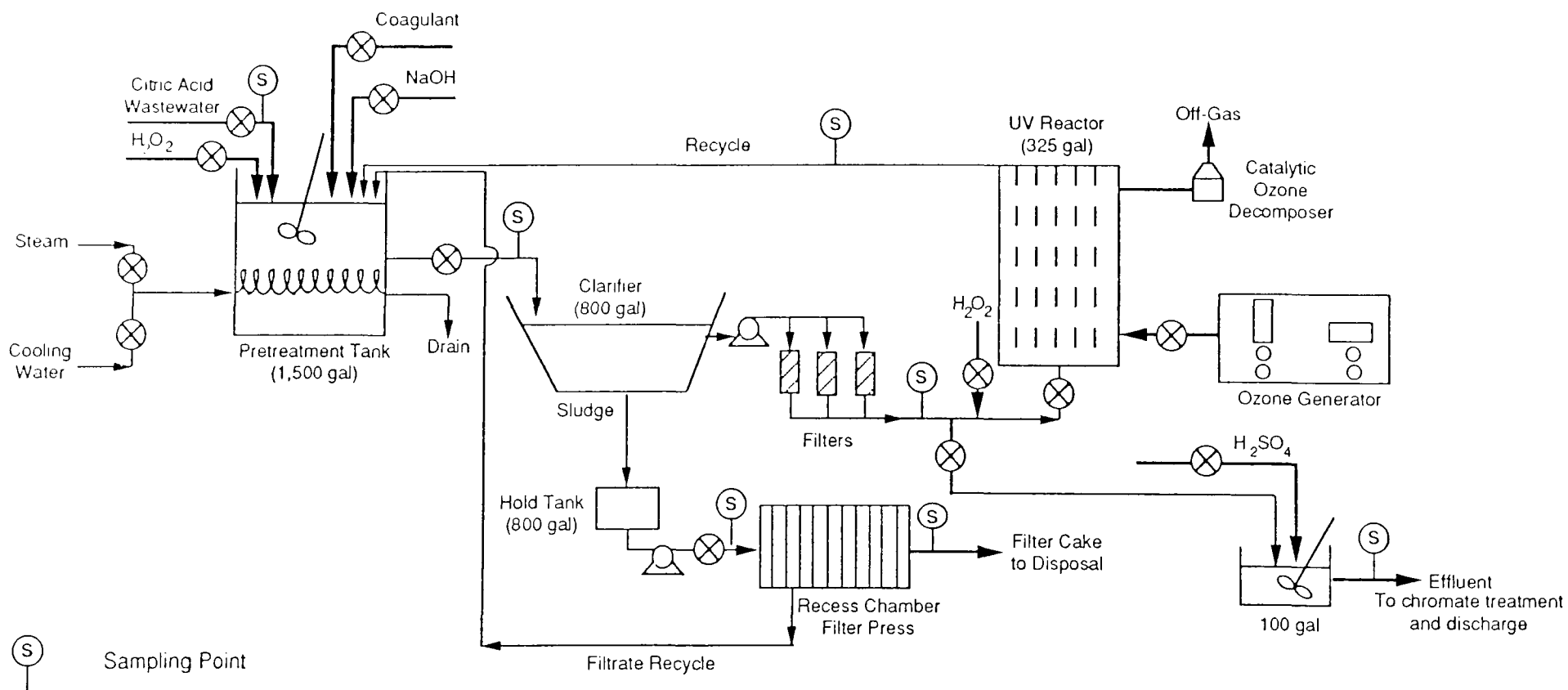


Figure 92. Conceptual design of full-scale citric acid treatment system using oxidation and UV light (source: Arthur D. Little, Inc.).

## 93. HAZARDOUS OILY BILGE WATER WASTE TREATMENT

**Category:** II.d. Minimization or Treatment of Other Liquid Wastes

**Purpose:** To develop a method for treatment of bilge water that costs less than the current method of bilge water disposal and to develop techniques to polish water from the oil/water separator.

**Application:** As originally developed, the method is applicable to treat the 1 to 1.5 million gallons of bilge water per year generated at the Naval Weapons Station Earle, Colts Neck, NJ. Bilge water is classified as hazardous in New Jersey, since it could contain hydrocarbons, fuels, lube oils, solvents, and heavy metals. The method may reduce the volume of bilge material that the facility will have to haul away for proper disposal and allow the reuse of separated oil.

**Description:** Bilge waste is transferred to tank cars on the pier. From the tank cars, the liquid goes to a parallel plate, gravity, oil/water separator (OWS), Navy Model OPB-10NP. From the separator, the oil is transferred to tank cars for subsequent reuse, burning, or disposal. Water from the separator goes to a bank of ultrafiltration membranes. Additional oil removed during the ultrafiltration is treated similarly to the oil from the separator. The water from the ultrafiltration membrane is disposed to the sanitary sewer. Current research is being conducted on methods and frequency for cleaning the membranes. The ultrafiltration technology is effective in separating both free and emulsified oil from bilge water. The ultrafiltration subsystem is partitioned into two branches each of which contains four parallel channels of two membrane cartridges connected in series. Each cartridge contains 40 ft<sup>2</sup> of membrane surface or 320 ft<sup>2</sup> per branch. Hollow-fiber, polysulfone membranes have been used, with flow through each channel of about 10 gal/min. The operating pressures are 30 psig at the head of the first membrane and 15 psig at the tail of the second membrane. The final design will be scalable to process flow rates of over 100 gal/min at Navy ports.

**Advantages:** The current bilge water disposal method required disposal of large volumes. The ultrafiltration method greatly reduces the volume of hazardous waste that must be disposed, and, when fully developed, will be fully automated, reducing labor costs and making bilge water disposal less costly.

**Limitations:** Operating personnel require more training.

**Costs:** Estimated costs are: capital – \$95,000 for buildings and \$200,000 to \$250,000 for equipment; operation – less than \$100,000/yr. The costs for the parallel plate separator are: 10 gal/min unit – \$70,000; 100 gal/min unit – \$100,000.

**Availability:** Equipment is off-the-shelf and requires very minimal operator skills and attention. The Navy parallel plate OWS is available from Quantek in Tulsa, OK. Ultrafiltration membranes are available from several vendors.

**Status:** A field-scale pilot demonstration was conducted at Naval Weapons Station, Earle, NJ in 1991. During August 1991, about 45,000 gal of bilge was processed – 40,000 gal of membrane permeate were discharged to the sanitary sewer, 5,000 gal of concentrate were collected for disposal, and 50 gal of oil were recovered. Full-scale

implementation is scheduled for FY93. The technology developed will also be applied to the design of a shipboard prototype for the Naval Sea Systems Command.

**References:** Not available.

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## 94. RECYCLING OF HYDROBLASTING WASTEWATER

**Category:** II.d. Minimization or Treatment of Other Liquid Wastes

**Purpose:** To reduce the volume of hydroblasting wastewater up to 90% by recycling.

**Application:** Hydroblasting wastewater is produced from a high-pressure water jet used to clean the boiler tubes of naval surface ships. Sodium nitrite, a corrosion inhibitor, is added to potable water to make the feed solution. In the usual practice, the spent hydroblasting solution overflows from the boiler to the ship bilge in a single pass. The wastewater combines with heavy metals, oils, grease, and dirt from other waste streams in the bilge. This combined hazardous wastewater resists available treatment methods and is hauled away by a contractor at a cost up to \$3.25/gal. This recycling technology can minimize significantly, up to 90%, the hydroblasting wastewater. This technology is applicable not only to naval shipyards, but also to commercial shipyards and ships.

**Description:** The recycling process for hydroblasting wastewater consists of wastewater collection, settling, filtration, recondition, and reuse. A process flow diagram of the recycling unit is given in figure 94a. A schematic diagram of the process is shown in figure 94b. A recycling unit is shown in figure 94c.

**Advantages:** The volume of wastewater is lowered significantly. Other waste streams to the bilge become more manageable.

**Limitations:** The 10% of the wastewater not recycled will have relatively high concentrations of contaminants. The concentrations of copper and lead can be higher than discharge limits.

**Costs:** Capital costs (settling tank, two filter trains, heat exchanger, pumps, pressure gages) are estimated to be below \$15,000. Operation of the recycle unit can be incorporated easily into existing hydroblasting operations and will require no additional labor.

**Availability:** Technical details are available from NEESA or Naval Ship Systems Engineering Station (NAVSES), Philadelphia, PA. A mobile recycling unit is available for implementation in FY92.

**Status:** The initial feasibility study involving bench-scale testing at NCEL and pilot-scale tests at Long Beach, CA, and Norfolk, VA, Naval Shipyards (NSY) were completed in 1988. Results confirmed the feasibility of recycling hydroblasting wastewater. Three series of field tests were conducted in 1989 at the Norfolk NSY. The first series provided a 75% reduction of wastewater. The second resulted in a 90% reduction. The third resulted in a 92% reduction. A separate project to treat the unrecycled wastewater that contains high concentrations of sodium nitrite is underway. Implementation has been accomplished at Long Beach NSY, Pearl Harbor NSY, HI, and Norfolk NSY. Additional units will be implemented in FY92 and FY93.

**References:** Pan, B.Y.K. and B. Swaidan. **Final Feasibility Report on Recycling of Hydroblasting Wastewater.** NCEL Technical Memorandum TM-74-91-01, Apr 1991.

Pan, B.Y.K. **Initial Feasibility Study on Recycling Hydroblasting Wastewater**, NCEL TM 71-89-01, Feb 1989.

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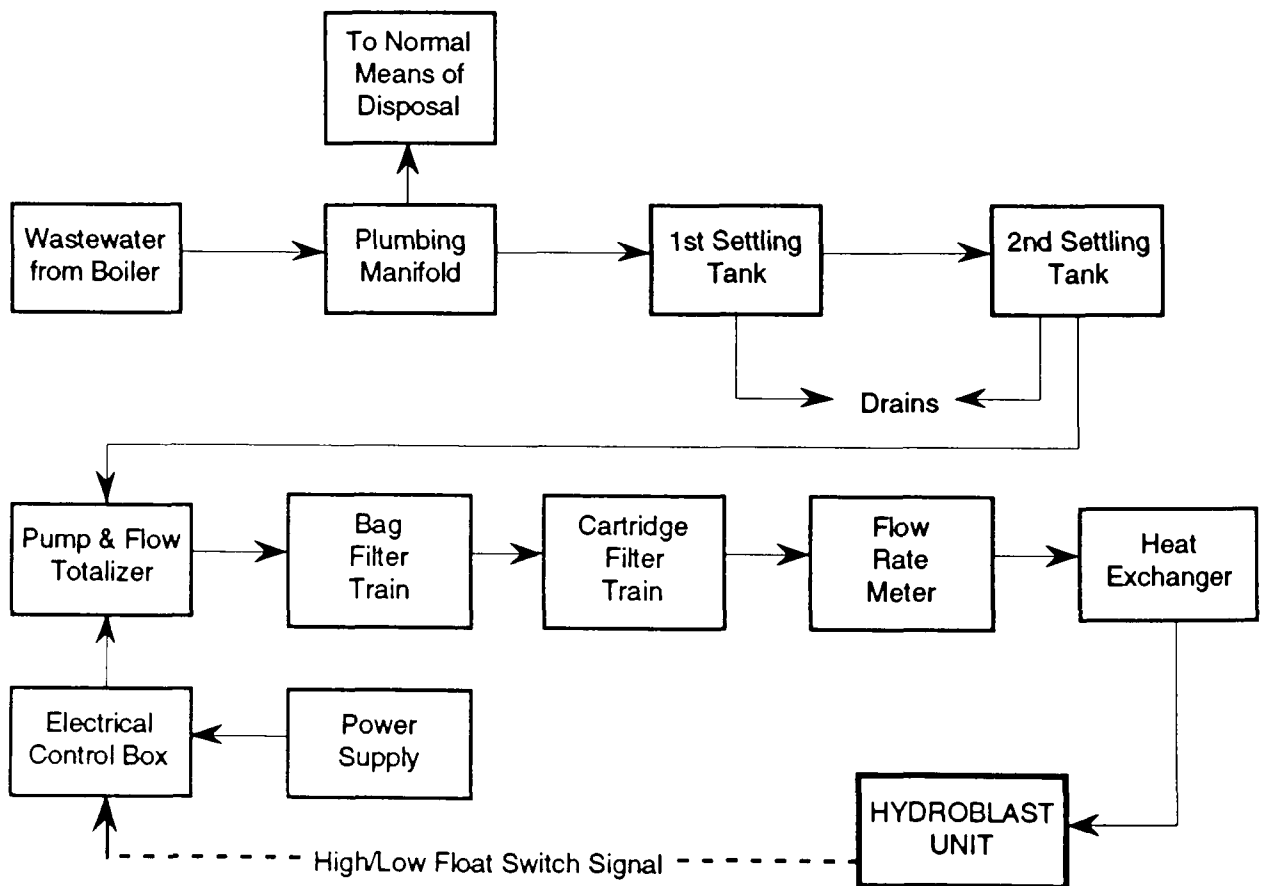


Figure 94a. Mobile Hydroblasting wastewater recycling unit – process flow.

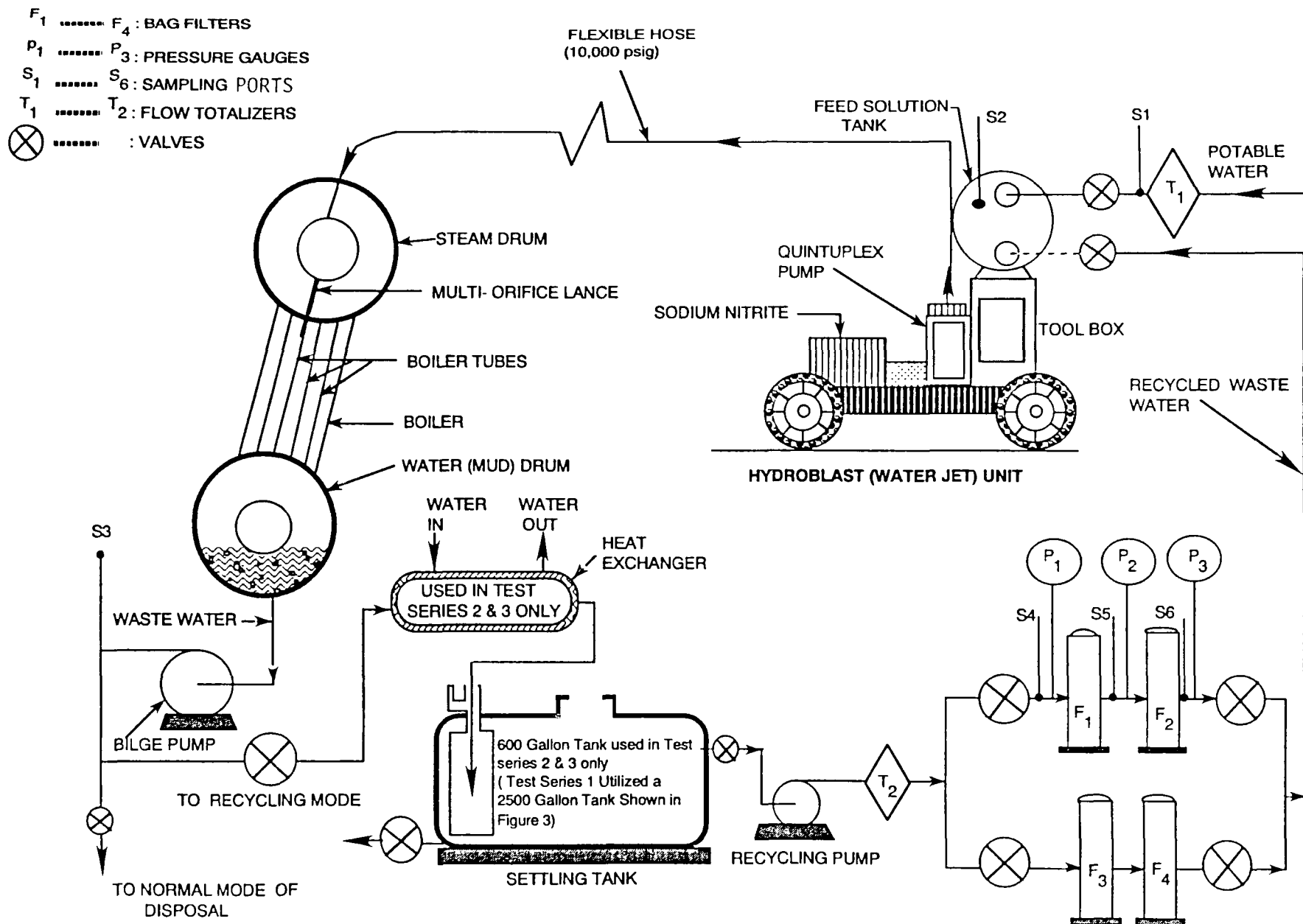


Figure 94b. Layout of recycling process for hydroblasting wastewater.

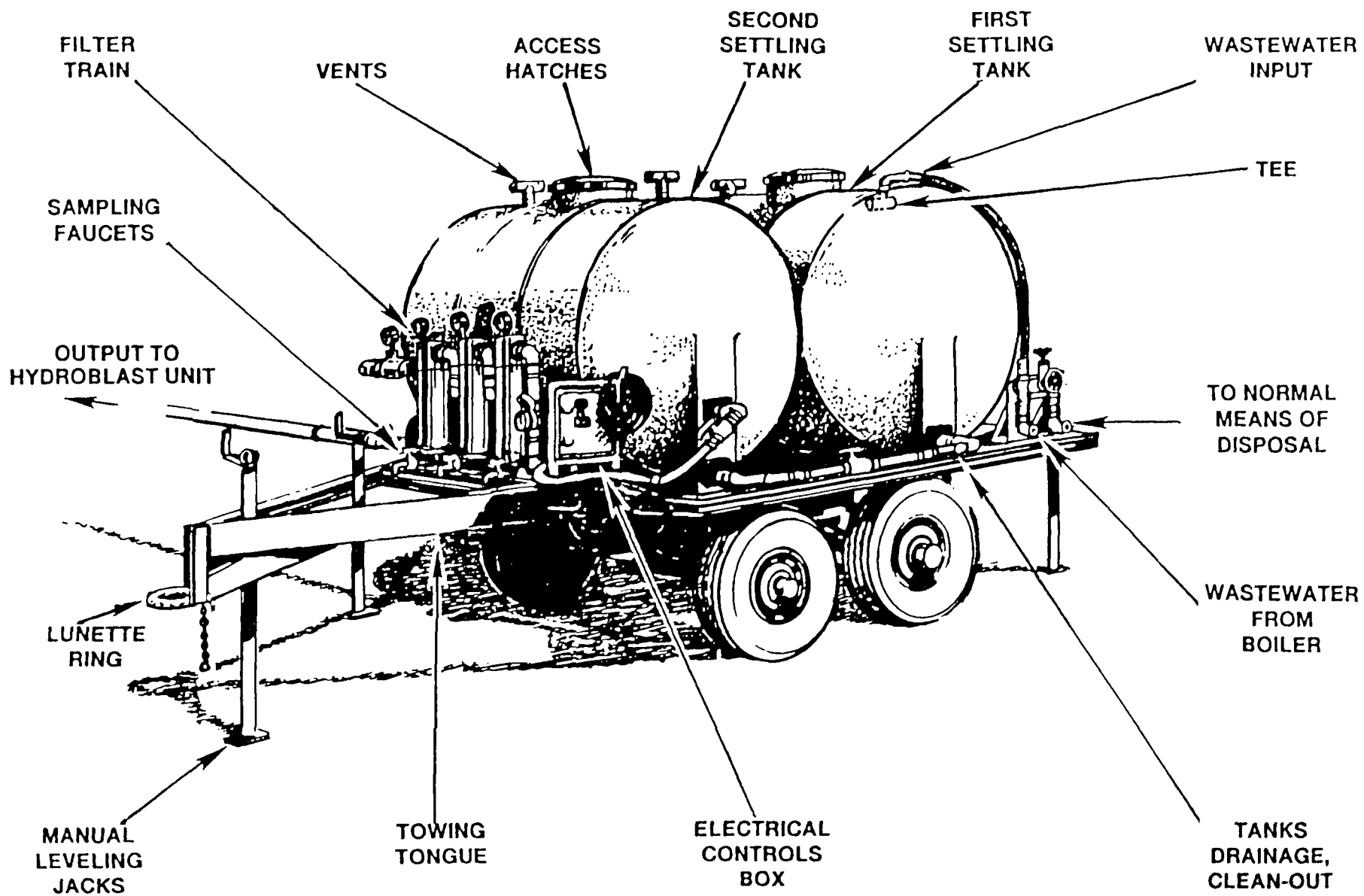


Figure 94c. Mobile hydroblasting wastewater recycling unit.

## 95. FILTRATION OF PAINT STRIPPING BATHS

- Category:** II.d. Minimization or Treatment of Other Liquid Wastes
- Purpose:** To extend the useful life of paint stripping solutions.
- Application:** The method is applicable to caustic and methylene chloride-based strippers.
- Description:** The filtration system removes paint residue that collects on the bottom of the bath limiting working space. Also, the life of the stripper solution is extended since paint residue can react with the solution, rendering it less effective. The filtration process consists of three bag-filtration units in series (see figure 95a). Bags of various mesh sizes ranging from 1  $\mu\text{m}$  to 400  $\mu\text{m}$  have been used. Figure 95b is a photograph of the alkaline paint stripper bath and the particulate filtration system.
- Advantages:** The system is relatively inexpensive, requires little maintenance, and is applicable to caustic and methylene chloride stripping solutions. Filter bags are reusable. Dragout of contaminants to other baths is reduced.
- Limitations:** Stripping solutions still must be disposed of as hazardous waste when spent. Particulates removed from baths are also hazardous waste.
- Costs:** The cost for the filtration system is estimated at \$25,000 to \$45,000.
- Availability:** This technology is commercially available.
- Status:** The process was demonstrated at Letterkenny Army Depot, PA. Implementation at other Army depots is underway.
- References:** Mathis, J. and J.S. Davis. **Evaluation of a Particulate Filtrations System for an Alkaline Paint Stripper at Letterkenny Army Depot.** U.S. Army Toxic and Hazardous Materials Agency Report CETHA-TS-CR-91033, Aug 1991.
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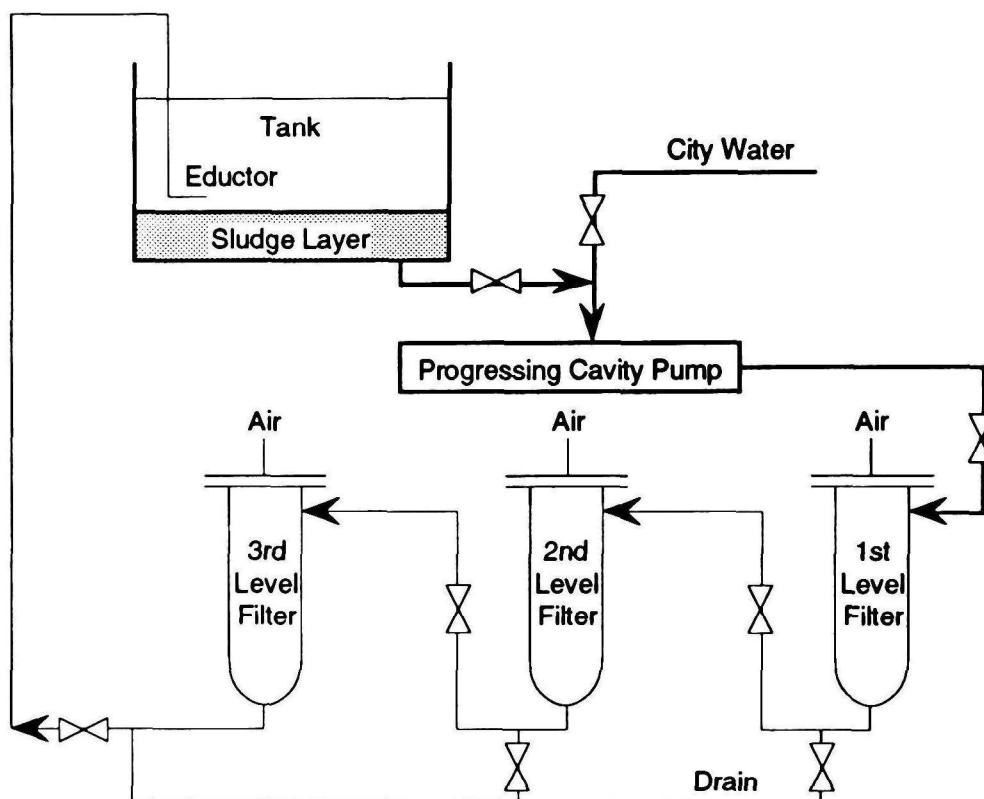


Figure 95a. Simplified process diagram of the particulate filtration system for alkaline paint stripping solutions (from Mathis, 1991).

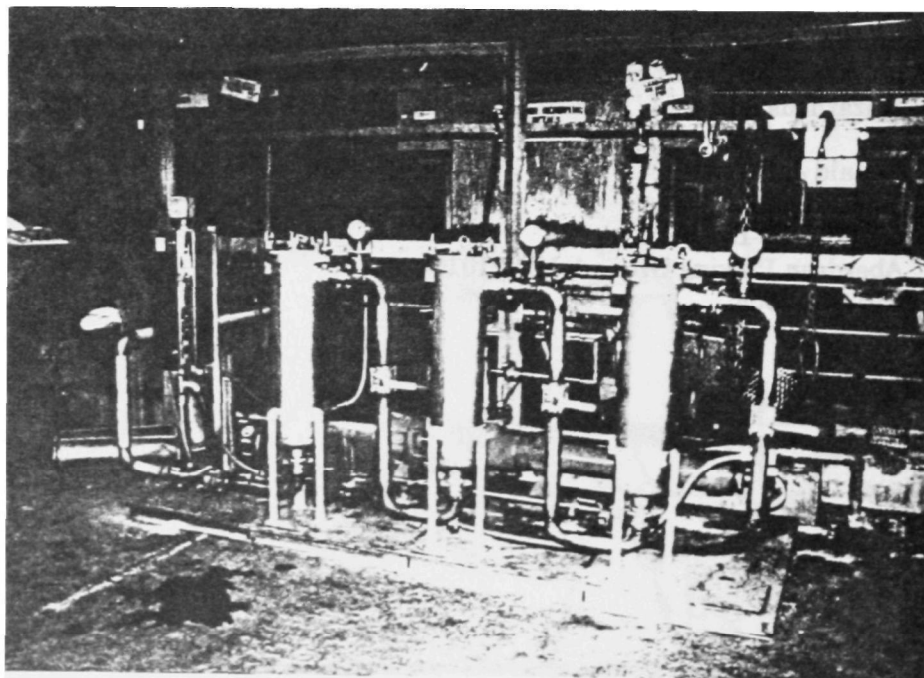


Figure 95b. Photograph of particulate filtration system and alkaline paint stripper bath.

## 96. CONVERSION OF PAINT BOOTH FILTRATION FROM WET TO DRY

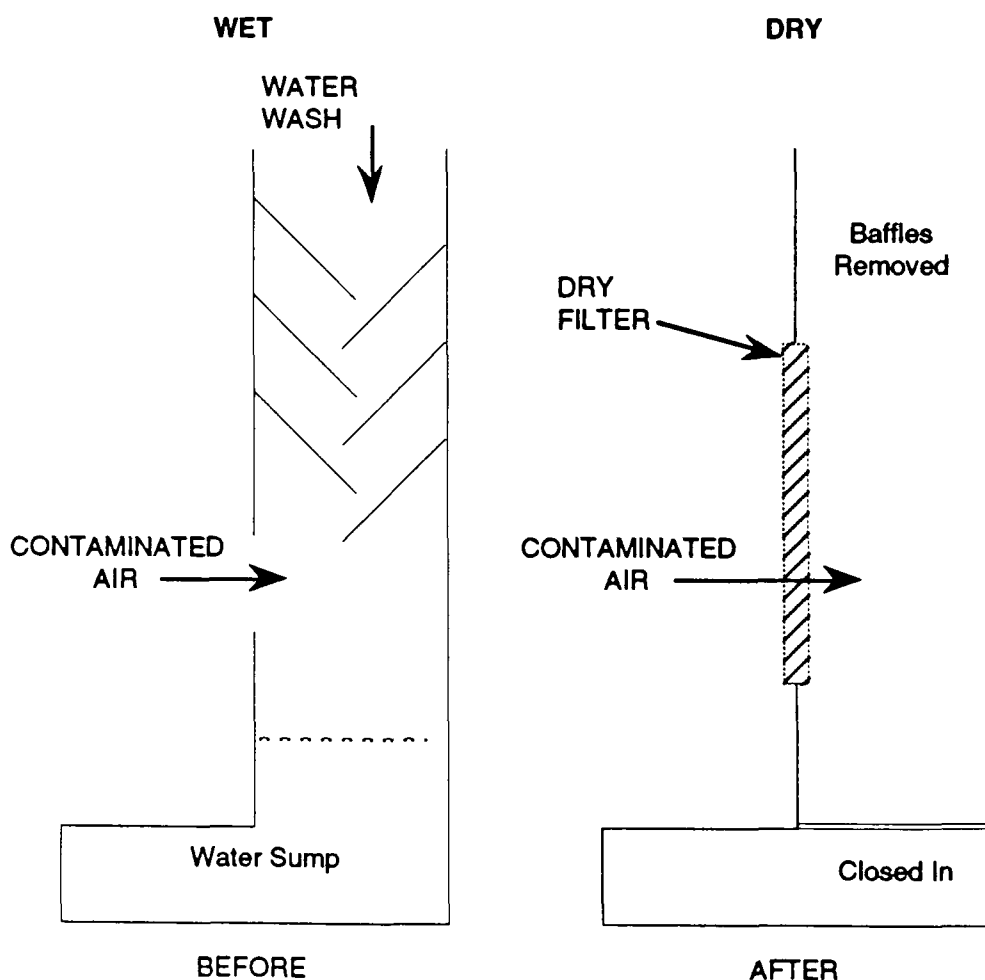
- Category:** II.d. Minimization or Treatment of Other Liquid Wastes
- Purpose:** To reduce wastewater and sludge generated from wet paint booths.
- Application:** The method is applicable for the conversion of water-wall spray booths to dry-filter particulate emissions control (PEC).
- Description:** The water scrubbing system is removed from the booths (see figure 96). Dry filters are installed to retain paint mist. Filters are selected based on local air quality requirements and types of paints. The air velocity in the booth should be 100 ft/min (60 ft/min for electrostatic operations as specified by 29 CFR 1910.107). Paint dries on the filter. In most cases the filter can be disposed as a nonhazardous waste to a landfill. Filters are disposed as a solid waste or as a hazardous waste depending on the results of the toxicity characteristics leaching procedure (TCLP). In some cases, the filter must be baked to attain nonleachable requirements. Air flow in the spray booth may be improved. Overspray problems are reduced.
- Advantages:** Waste may be converted to a nonhazardous waste. Waste stream to the wastewater treatment plant and sludge handling are eliminated. Ventilation and paint filtration efficiency may be improved. Dry filter systems will not rust and deteriorate, as is possible with wet systems.
- Limitations:** Large down-draft booths may be more difficult to convert, but can prove to be quite cost-effective. Neither water-curtain or dry filter systems reduce volatile organic compounds emitted to the atmosphere.
- Costs:** Costs for sludge handling and water treatment are reduced. Maintenance and operations costs for the spray booth are reduced. Cost to convert a small cross-draft booth is about \$2,000 to \$4,000 or less depending on the size of booth.
- Availability:** Technical support is available from the Naval Energy and Environmental Support Activity (NEESA).
- Status:** Pilot-scale tests were conducted at the Naval Industrial Reserve Ordnance Plant, Pomona, CA, Travis AFB, CA, and McClellan AFB, CA. Conversions have been implemented at many activities Navy-wide.
- References:** **The Replacement of Paint Spray Booth Water Curtains with Dry Filters as a Hazardous Waste Minimization Measure.** NEESA Report 19-007, Jun 1992.
- Paint Spray Booth Wet-to-Dry Conversion.** NCEL Techdata Sheet 90-02, Apr 1990.
- Ayer, J. **User's Guide for the Conversion of Navy Paint Spray Booth Particulate Emission Control Systems from Wet to Dry Operation.** Acurex Corporation report submitted to NCEL, Contract No. 68-02-4285 WA 2/026, Sep 1989.

**Navy Paint Booth Conversion Feasibility Study. NCEL Contract Report CR 89.004, Jan 1989.**

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*Figure 96. Schematic of wet to dry spray booth conversion.*

## 97. PLASTIC MEDIA BLASTING

- Category:** II.d. Minimization or Treatment of Other Liquid Wastes  
II.e. Minimization or Treatment of Other Solid Wastes
- Purpose:** To remove paint without the use of solvents. This is a method for the reduction of solid/chemical waste due to paint stripping.
- Application:** Blasting of painted surfaces with plastic media (beads) allows a dry method of paint removal. This process reduces the volume of hazardous liquid waste solvents. Plastic media may be recycled after separation. The method is applicable to stripping paint from sensitive substrates such as aluminum and composites. A primary application is in aircraft rework.
- Description:** Plastic media blasting (PMB) is a method to remove paint from substrates by bombarding the surface with plastic media. The media may be thermoplastic or thermoset depending upon the application. Media may be recycled several times for reuse until it falls below some critical lower limit mesh size. When the media falls below the critical lower limit mesh size, it is disposed of as a hazardous waste due to the heavy metal contamination from paint pigments.
- In one application, the PMB unit with hoses, beads, etc. is 8 x 5 x 15 ft high. Blasting is performed inside an enclosure that is 10 x 10 x 20 ft. Plastic beads are recycled approximately 10 times with mechanical sieve separation after each use. With the use of this process there is a 90% reduction in waste and 4 to 6 times increase in production.
- Advantages:** The waste stream is in the form of a solid. The potential exists for waste volume reduction by separating the hazardous component from the non-toxic plastic media. The potential also exists for media reprocessing, resulting in savings in operational costs. PMB minimizes labor and down-time for aircraft. Media is non-toxic when compared to toxic chemicals used in chemical stripping. The blast process is computer-controlled. Recycling of media for reuse is automated. Robotics are being developed to perform the blasting. The process is faster, reduces waste, and increases production.
- Limitations:** Plastic media are potentially explosive and good ventilation is required. Noise control during the process of blasting may be a problem. Media waste is considered hazardous due to heavy metal contamination. Paint pigment may be considered a hazardous waste, until recycled, due to the heavy metal content of the pigment. Supplied air respirators are required for operators.
- Cost:** Both European and American blast systems are available commercially. The cost is dependent on the size and complexity of the unit and the manufacturer.
- Availability:** The technology is commercially available.
- Status:** Technology currently is in use at approximately 15 to 20 Navy activities and others are planned. PMB waste treatment technology sponsored by the AFCEA is being developed at Oak Ridge National Laboratory (ORNL). Laboratory and bench-scale pilot testing of the process have been completed at ORNL. Second generation PMB

blast booths have been installed at Ogden Air Logistics Center, Hill AFB, UT. Limited trial implementation was conducted by the Navy at NADEP, Cherry Point. Four complete, full-scale, room size units are being constructed over the next 1.5 years; there are plans to construct eight additional units .

**References:** **Technology Transfer Manual for Plastic Media Blasting Walk-In Booth Installation.** NEESA Report 19-005, Jun 1992.

Tapscott, R. E., G.A. Blakut, and S.H. Kellogg. **Plastic Media Blasting Waste Treatment.** New Mexico Engineering Research Institute, July 1989.

Lindstrom, R.S., C. d'Agincourt, C. Scholl, and A. Balasco. **Demonstration Testing of Plastic Media Blasting at Letterkenny Army Depot, Final Report.** USATHAMA Report CETHA-TE-CR-89004, Jan 1989.

**Installation and Implementation Plan for Plastic Media Paint Stripping Facility at Naval Aviation Depot, Marine Corps Air Station, Cherry Point, North Carolina, Prepared By ORNL, May 1988.**

**Plastic Media Blasting Regulatory Equipment Study,** NCEL Contract Report, Oct 1988.

Cash Dollar, K. L., M. Hertzberg, J.A. Alochomer, and R.S. Conti. **Explosibility and Ignitability of Plastic Abrasive Media.** Naval Civil Engineering Laboratory Report CR 87.011, June 1987.

**Plastic Media Blasting Monitoring at Hill AFB, Utah and NARF, Pensacola, Florida Final Test Report,** Naval Civil Engineering Laboratory, Feb 1987.

**Plastic Media Blasting Data Gathering Study: Final Report,** CR87.006, Naval Civil Engineering Laboratory, Port Hueneme, CA, Dec 1986.

Childers, S., D.C. Watson, P. Stumpff, and J. Tirpak. **Evaluation of the Effects of a Plastic Bead Paint Removal Process on Impurities of Aircraft Structural Materials.** Final Report for Period, Oct 1984 to Aug 1985, Materials Laboratory, Wright Aeronautical Laboratories, Wright-Patterson AFB, OH.

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## 98. TACTICAL VEHICLE MAINTENANCE

- Category:** II.d. Minimization or Treatment of Other Liquid Wastes
- Purpose:** To eliminate solvents and surfactants from vehicle wash water thereby simplifying the waste.
- Application:** Considerable volumes of water are used as a result of training and maintenance activities at Army facilities. This method is applicable wherever water is used as a part of vehicle or engine maintenance -- either scheduled maintenance or at external washing facilities.
- Description:** For external washing, a central facility will have bays to handle the largest vehicles, such as trucks and main battle tanks, that include wash towers on both sides of the vehicle using cold water at moderate pressures of around 90 psi; optional tank bath prewash basins, 3 to 4 ft deep, to remove heavy soils; trenches to move water to sedimentation basins for solids removal; oil skimmers; equalization ponds; intermittent sand filtration; and recycle pumps. The external, central washing facility will have a zero discharge. Engine washing will not be centralized, but will be located at the maintenance shops. Hot water, about 150° F above ambient temperatures, at 800 psi is used. The wastewater goes to an oil/water separator and a sedimentation basin before entering the sanitary sewer system. Because of the high temperature and pressure of the water, large volumes are not required for engine washing.
- Advantages:** Emulsifying agents are eliminated from the wash water. Purchase of chemicals is not necessary. Treatment of the wastewater is simplified because it consists only of water and oil. The operation is more efficient for the personnel who do the washing. Water demand is reduced. Special precautions because of chemicals added to the wash water are not required. The hazard from harsh washing chemicals to the troops who wash the vehicles is eliminated.
- Limitations:** An additional expense is necessary for new construction, but the expense can be recovered in labor and water savings. Cold weather might limit operations.
- Costs:** The cost of a central washing facility at Ft. Bragg was \$5 million. The cost of a central washing facility along with an industrial waste treatment plant at Ft. Carson was \$7.6 million. Not enough experience has been gained to evaluate the operating costs. Cost information was obtained from the Construction Engineering Research Laboratories (CERL).
- Availability:** The technology is available from CERL. Engineering would be involved in the design of a central wash facility. Facilities personnel could handle the retrofit of engine washing operations.
- Status:** The method is implemented and in regular use at Ft. Lewis, WA (washing and maintenance); Ft. Carson, CO (washing and maintenance); Ft. Hood, TX (washing and maintenance); Ft. Polk, LA (washing and maintenance); Ft. Indiantown Gap, PA, Ft. Bliss, TX, Ft. Benning GA, Ft Riley, KS, Ft. Stewart, GA, Aberdeen Proving Ground, MD, and Ft. Bragg, NC (washing and maintenance).

**References:** A number of Engineering Technical Letters are available from CERL, such as **Central Vehicle Wash Facilities for TOE Vehicles and Equipment**, TM 5-814-9, 1992.

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## 99. ABRASIVE GRIT RECYCLING

- Category:** II.e. Minimization or Treatment of Other Solid Wastes
- Purpose:** To reduce the disposal costs of used abrasive grit and to reduce the disposal of a potentially hazardous waste.
- Application:** The method is applicable to paint-grit mixtures that result from paint removal by abrasive blasting. The method is applicable to process landfills containing abrasives. The grit is a crushed slag from nickel or copper smelters or from coal-fired power plants. Recycling may make the use of less friable, more expensive abrasives, such as aluminum oxide or garnet, cost-effective.
- Description:** The method concentrates the paint-grit fines, enabling the recycle of usable grit. Grit purchases are reduced. The usable grit is maintained in a non-hazardous state by the elimination of fines and paint particles. The method involves the use of a heated, fluidized bed separator (see figure 99). Single units are expected to handle between 2,000 and 10,000 lb/hr. The fines are disposed as hazardous or nonhazardous waste in accordance with local, state, and Federal regulations.
- Advantages:** The volume of waste that requires disposal is reduced thus reducing disposal and compliance costs. The cost of new grit is reduced because usable grit is recycled. Recycling may make the use of less friable, more expensive abrasives, such as aluminum oxide or garnet, cost-effective. Based upon pilot-scale testing, the unit meets the requirements of (1) destruction of organic compounds that exist mainly in the form of paint chips, (2) the removal of fines smaller than 70 mesh that are generated by particle fracture during the blasting operation, and (3) the levels of toxic metals in the reclaimed abrasive do not exceed their total threshold limit concentration (TTLC) and soluble threshold limit concentration (STLC) limits.
- Limitations:** The method is not applicable to other blasting media such as plastic beads. The resulting waste is more concentrated and may require disposal as a hazardous waste. The method requires a relatively large facility to take advantage of an economy of scale due to the considerable up-front capital costs. Depending upon local regulation, the fines discharged from the separator may require disposal as a hazardous waste.
- Costs:** Excluding design, development, and land, the cost of a 5-ton/hr unit was estimated to be \$985,700 (in 1990 dollars). The unit operating costs were estimated to be \$17.04/ton of spent abrasive processed (details of the basis for the cost estimates can be found in the reference cited). A 3-ton/hr unit in a NAVFAC study, project P-316, cost \$2.25 million including design, development, and testing.
- Availability:** Most of the equipment is off-the-shelf. The fluidized bed must be custom designed and constructed. IGT, the developer of the process, has a patent on the fluidized bed separator.
- Status:** Laboratory and bench-scale pilot testing was conducted by IGT at its Chicago facilities and IGT continues to fine-tune the fluidized bed design. Pilot-scale tests demonstrated that grit having copper- or tin-based paint contaminants could be recycled. A field-scale demonstration will be conducted at Mare Island NSY, CA, during FY94.



**References:** NAVFAC Facility Study: Mare Island Naval Shipyard, Vallejo, CA; "Abrasive Recycling Demonstration Facility," Project Number P-316, Category Code 831-14, Jul 1991.

Bryan, B.G., W.M. Thomas, and C.M. Adema. **Thermal Reclamation of Blasting Abrasives.** Proc. 17th Environmental Symposium, Atlanta, GA, Apr 1990.

Bryan, B.G. **Thermal Reclamation of Spent Blasting Abrasives With a Fluidized Bed Sloped Grid Calciner.** David Taylor Research Center Report DTRC/SME-CR-03-89, July 1989.

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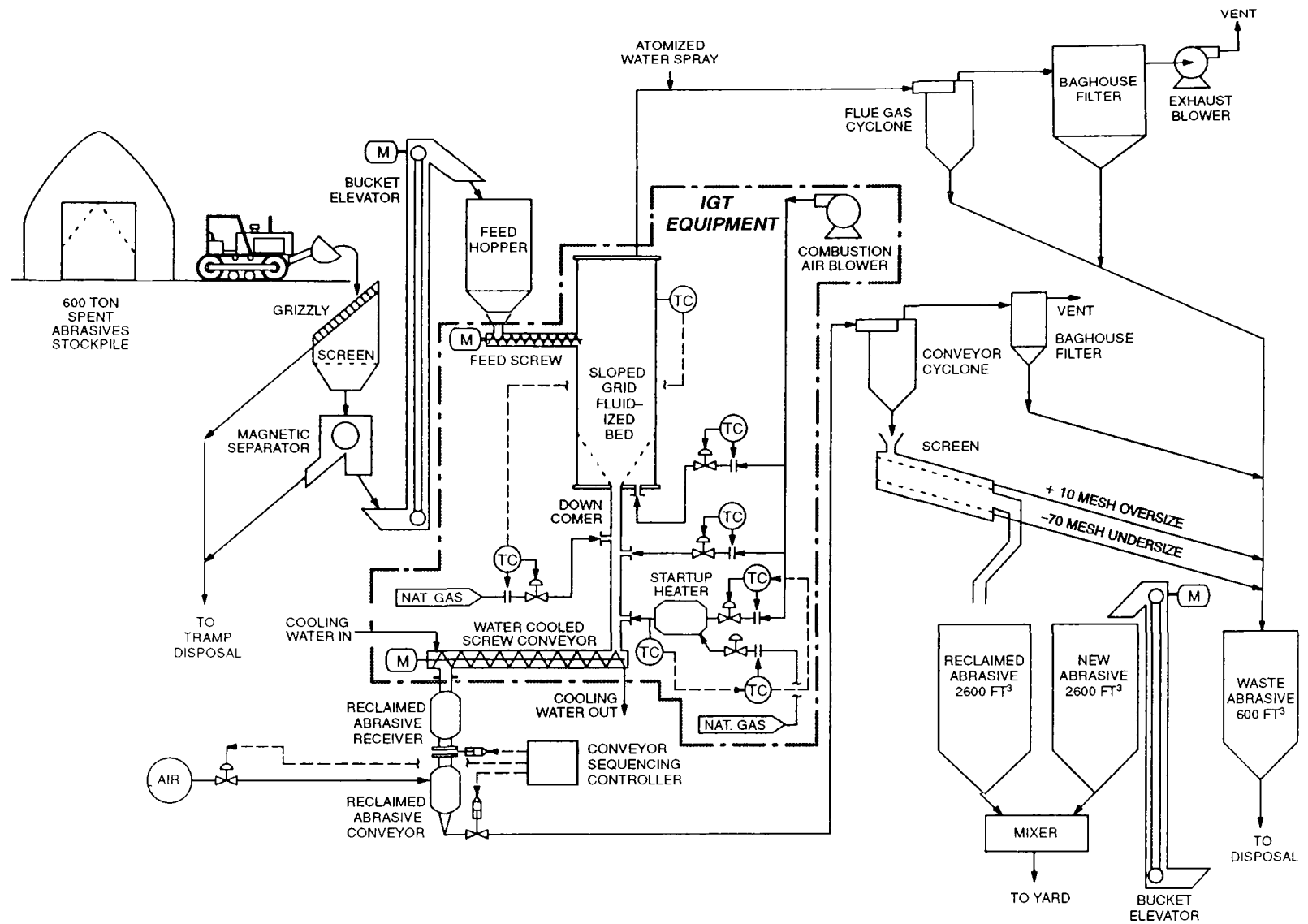


Figure 99. Schematic diagram of a 5-ton/hr prototype fluidized bed sloped grid (FBSG) mineral reclamation plant

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## 100. COATINGS REMOVAL USING ULTRA HIGH PRESSURE WATER WITH GARNET ABRASIVE

- Category:** II.e. Minimization or Treatment of Other Solid Wastes
- Purpose:** To reduce the quantity of hazardous waste generated through ship abrasive blasting (paint removal and surface preparation).
- Application:** The method is applicable for the reduction of slag abrasive waste.
- Description:** The method includes ultra-high pressure water (greater than 35,000 psi) with the addition of garnet blasting abrasive. The two are combined to make a slurry. The water and garnet are mixed in a four-nozzle rotating blasting head. The slag abrasive is replaced by garnet, but the amount of abrasive should be reduced by approximately 75%. Spent copper slag abrasive, containing copper anti-fouling paint particles, is considered hazardous in California.
- Advantages:** The amount of hazardous waste is reduced by between 75% and 100%. The amount of waste sent to landfills is reduced by 75%. The cost of this method is comparable to that using copper slag. Garnet abrasive is about four times more expensive than slag, but the reduction in disposal cost offsets the increase material cost.
- Limitations:** If disposal costs for the slag are not as large as in California, the material cost will be higher than the current method.
- Costs:** Exact cost information is not available; however, the estimated cost for the ultra-high pressure systems is about \$150,000. Garnet costs about \$300/ton compared to slag at \$70/ton.
- Availability:** Approximately half of the naval shipyards have ultra-high pressure equipment, and it is likely that all shipyards will have the equipment within the next few years due to its many uses in shipyard cleaning and hydro-destruction.
- Status:** A large-scale demonstration of a hand-held ultra-high-pressure abrasive slurry (UHPAS) blasting head was conducted at Tampa Ship, Inc. on a Military Sealift Command ship in September 1991. The results of this demonstration, documented in DCNSWC report TM-28-92-09 (scheduled for release in September 1992), indicate that paint removal rates in excess of 150 ft<sup>2</sup>/hr can be achieved. A semi-automatic system has been designed and assembled in which the blasting head is mounted on a hydraulic manipulating arm and remotely controlled by a commercially available "man-lift" or "hi-reach." A semi-automatic demonstration will be conducted at Tampa Ship, Inc. during September 1992.
- References:** Carderock Division, Naval Surface Warfare Center Report TM-28-92-09, Sep 1992.
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## 101. CRYOGENIC REMOVAL AND SIZING OF CLASS 1.1 SOLID PROPELLANT

- Category:** II.e. Minimization or Treatment of Other Solid Wastes
- Purpose:** Removal and rendering to an inert state of Class 1.1 solid rocket propellant for demilitarization of rocket motors.
- Application:** This process is for solid propellant of Class 1.1 rocket motors.
- Description:** A stream of liquid cryogenic liquid N<sub>2</sub> (-196° C) is sprayed onto the interior surface of a rocket motor. At this low temperature solid rocket propellant will spall (erode) off of the interior surface of a rocket motor. Cryogenic cooling at this temperature causes nitrate esters to become inert. The process removes all of the interior surface of the motor. The now inert nitrate esters are washed out into a recovery basin for treatment. There is no waste from the process because inert propellant is either recovered as less hazardous and less reactive material or disposed of into a recovery basin for treatment.
- Advantages:** The process is safer than explosion and burning of propellants. There is no disposal of propellants and casings in landfills. Process sites do not need remediation. This process allows safe removal of propellant from casing, size reduction of propellant for processing, recovery and reuse of salvageable ingredients, and RCRA – terminating destruction of hazardous residues.
- Limitations:** Class 1.1 propellant is unstable, becoming an explosive upon impact. It is also poorly soluble in water. Removal technology requires subsequent destruction of inert propellant.
- Costs:** Not available.
- Availability:** Small scale demonstration during 1992.
- Status:** Bench-scale pilot phase during 1992 at a rocket manufacturing facility in Utah. A demonstration of the process will be on an 80 lb rocket motor.
- References:** Cornette, Jimmy C., Mark D. Smith, and Joseph D. Wander, **Alternative Technologies for Disposal of Solid Rocket Propellants**. HQ Air Force Engineering Services Center, Tyndall Air Force Base, FL, H & WMA MLG, Vancouver, BC 1991.
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## 102. BIODEGRADATION USING WHITE ROT FUNGUS FOR PCP-TREATED WOOD

**Category:** II.e. Minimization or Treatment of Other Solid Wastes

**Purpose:** To develop a safe, cost effective method of treating (cleaning-up) pentachlorophenol- (PCP) treated ammunition boxes (~1 million pounds stockpiled that was treated before 1985).

**Application:** This technology is for biotreatment of ammunition boxes that have been treated with PCPs and biotreatment of other organic compounds in reactors (see note #26).

**Description:** Lignin-degrading fungus (white rot) is used for biodegradation of PCPs in this process. An aerobic system using moisturized air on wood chips is used in a reactor for biodegradation. In the bench-scale trial of the process a reactor was utilized. In the pilot scale project an adjustable shredder was used for making chips for the open system used in this project. The open system is similar to composting, with wood chips on a liner or hard contained surface that is covered. Temperature is not controlled in this type of system. The optimum temperature for biodegradation with lignin degrading fungus is 30° C. The heat of the biodegradation reaction will help to maintain the temperature of the process near the optimum.

Through biodegradation there is about a 60% reduction of PCP content of the wood rendering it less hazardous. At the end of 30 days during the bench scale demonstration, PCPs in the treated wood were reduced by about 60%. As wood mass degrades, more PCP is degraded.

**Advantages:** Disposal of PCPs in hazardous waste landfill is eliminated. Therefore, the landfill space can be used for other purposes. Incineration, which could create dioxins, is not used for destruction of PCPs. Waste is rendered to carbon dioxide and water through biodegradation along with decomposition of contaminated wood chips. The biodegradation area can be recycled for other purposes after completion of the project.

**Limitations:** There is only 60% degradation of PCPs and wood chips during a 30 day period in the laboratory.

**Cost:** Cost of bench scale project not available. Cost of a field pilot project is <\$20,000.

**Availability:** Not commercially available.

**Status:** Bench-scale pilot phase at USACERL during 1991. Field pilot phase at Sierra Army Ammunition Depot (AAD), CA and at Letterkenny AAD, PA, during 4th quarter of 1992.

**References:** Lamar, Richard T. and Richard J. Scholze, **White-Rot Fungi Biodegradation of PCP-Treated Ammunition Boxes**, Presented at National Research and Development Conference on the Control of Hazardous Materials, San Francisco, CA, Feb. 4-6, 1992



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## 103. SMALL ARMS RANGE MANAGEMENT

- Category:** II.e. Minimization or Treatment of Other Solid Wastes  
II.g. Management Strategies
- Purpose:** To manage small arms ranges having high levels of lead.
- Application:** The method is applicable to outdoor small arms ranges, excluding skeet ranges, i.e., rifle, pistol, and machine gun.
- Description:** Soil at older ranges can contain high levels of lead requiring disposal as hazardous waste. Rain-water runoff can contain high levels of lead and zinc that could be transported to surface water as a non-point source. This method consists of spiral separators, water elutriators, water tables jigs – techniques that rely on density differences between soil and lead particles. High clays could reduce the level of lead reduction, thus, soil stabilization could be required. Excavation is required for abandoned sites. Trees may have to be cleared. Decontaminated material is returned to the site at close to background levels. The pilot unit has a capacity of 10 tons/hr. Metals are recycled to smelters as a raw material. The work is performed by contractors using portable and trailer-mounted units. At current ranges, management is accomplished by a combination of runoff control, retention basins, and a polishing step using bio-beads (peat moss encapsulated in plastic) on which lead is adsorbed.
- Advantages:** The current method is to use a sieve to separate soil from bullets leaving high concentrations of lead fragments. This method results in much lower lead levels. Costs are lower because heating is not involved. The equipment is easy to operate.
- Limitations:** Heavily vegetated sites may be difficult to excavate economically to recover lead.
- Costs:** Costs are not documented, but are estimated to be about \$100/ton, including excavation.
- Availability:** Most of the equipment is commercially available through the mining industry. Specially trained operators are necessary.
- Status:** Laboratory testing, conducted by the Bureau of Mines in Salt Lake City, was completed in 1991. Bench-scale pilots (a few tons/hr) are underway at Camp Pendleton, CA. Field-pilot testing (10 ton/hr) is planned for Camp Pendleton for FY93.
- References:** Heath, J.C. et al. **Environmental Effects of Small Arms Ranges**. NCEL Report N-1836, Oct 1991.
- Karr, L. et al. **A Biogeochemical Analysis of Metal Contamination at a Small Arms Firing Range**. NCEL Report TN-1823. Marine Corps Combat Development Command, Quantico, VA 1991.
- Karr, L. et al. **Memo to Files – Characterization of Metals in Soil and Vegetation of a Small Arms Impact Berm, NAVAMPHIBASE, Little Creek, Jun 1990**.

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## 104. DISPOSAL OF OXYGEN BREATHING APPARATUS CANISTERS

**Category:** II.e. Minimization or Treatment of Other Solid Wastes

**Purpose:** To render the active agent in oxygen breathing apparatuses innocuous.

**Application:** The method is applicable for potassium superoxide ( $\text{KO}_2$ ), greater than 200,000 pounds per year of which from oxygen breathing apparatuses (OBA) must be disposed.

**Description:** The process is accomplished in seven steps (figure 104a): (1) perforate the OBA canister either by spiked clamshell or spiked rollers (figure 104b); (2) rack canisters in the reactor in baskets, a spiral-slide rack, or vertical racks; (3) complete slaking reaction using either a water spray or water flooding; (4) caustic neutralization using recirculation with addition of acid to bulk fluid or recirculation with addition of acid in-line; (5) solids filtration using cartridge filtration; (6) discharge of liquid effluent to sanitary sewer; and (7) canister recovery by removal of canisters from reactor and storage in drums or transfer of canisters to compaction system for volume reduction and packaging for storage or recycle. The slaking reaction consists of contacting the  $\text{KO}_2$  in the canisters with water producing aqueous potassium hydroxide (KOH) and oxygen. A small amount of barium ions ( $\text{Ba}^{2+}$ ) will be in solution after the slaking reaction. The acid neutralization is accomplished with sulfuric acid, which neutralizes the KOH and combines with the  $\text{Ba}^{2+}$  to form a precipitate, which is filtered from the solution by cartridge filters. The spent filters may be drummed for disposal as a hazardous waste. Process efficiency is high; the conversion of superoxide to potassium hydroxide is complete and the subsequent neutralization eliminates the hazard associated with caustic solutions.

**Advantages:** An alternative method is not available to render the material non-toxic and non-reactive.

**Limitations:** None known.

**Costs:** Detailed cost information is not available; however, the results of the laboratory study indicate the cost of chemicals would be about \$0.06 per canister, excluding the cost of water. Current disposal costs are between \$8 and \$12 per canister.

**Availability:** The method is under development.

**Status:** Laboratory testing was conducted by the National Institute of Standards and Technology (NIST). Field-pilot testing is planned for FY92.

**References:** Hurley, James A. et al. **Proposed Process for Conversion of Potassium Superoxide to Innocuous Compounds - Task 1 Report**. NIST Report, Jul 1991.

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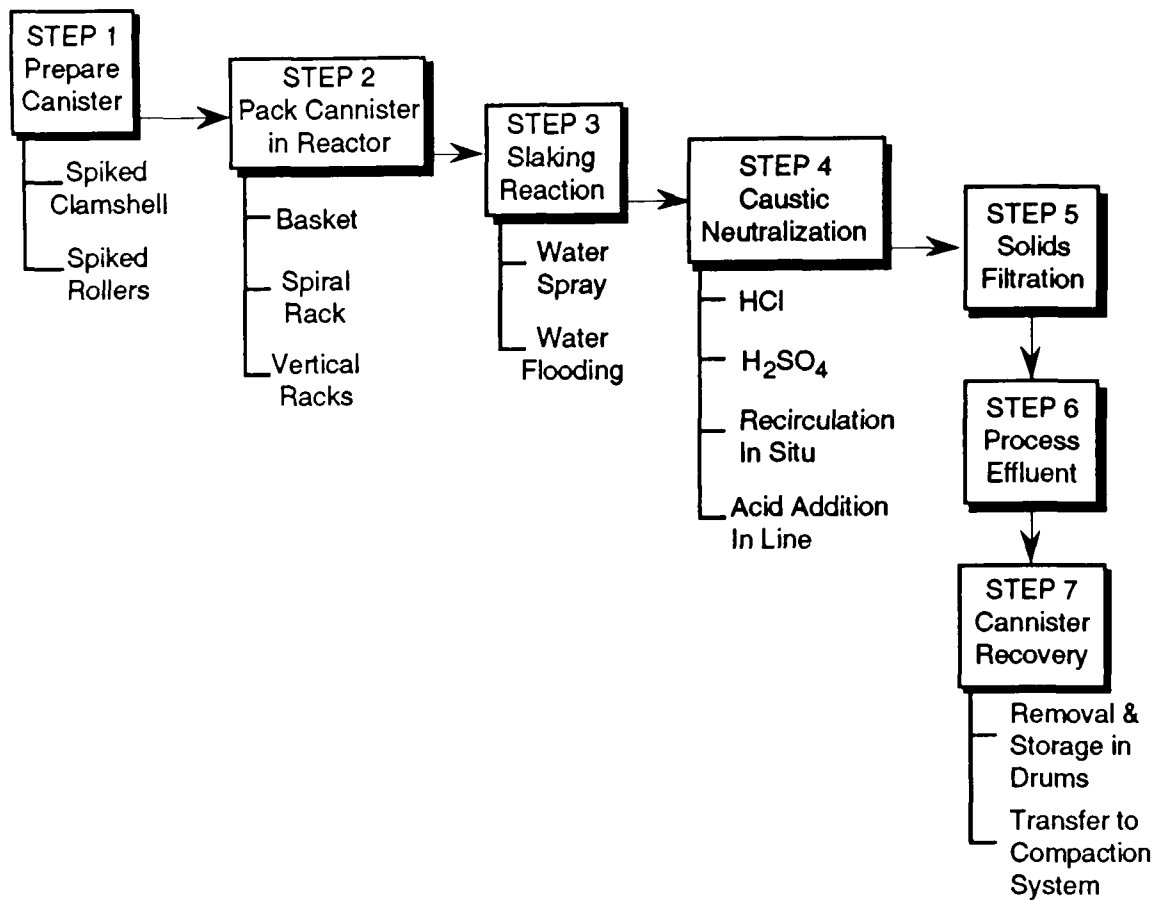


Figure 104a. Seven steps in the oxygen breathing apparatus disposal process.

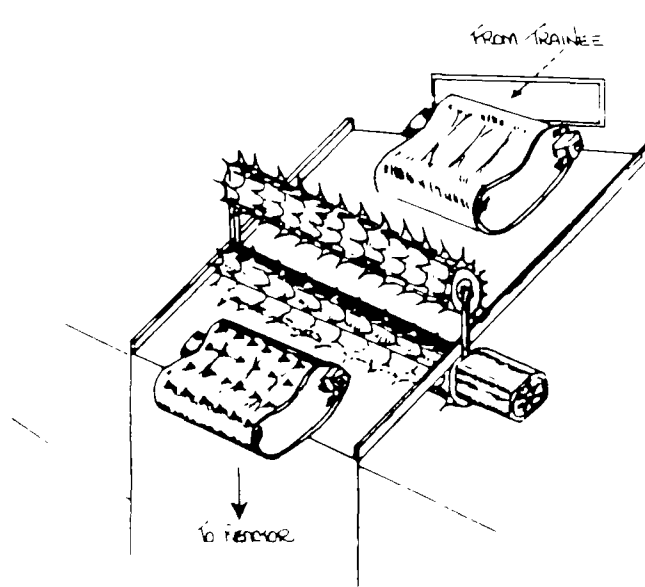


Figure 104b. Spiked rollers used in canister preparation (Step 1 in figure 105a).

## 105. LOW NO<sub>x</sub> BURNER RETROFITS

**Category:** II.f. Minimization or Treatment of Gases

**Purpose:** To bring existing natural gas and oil fired boilers into compliance with new air pollution emission regulations for nitrogen oxides (NO<sub>x</sub>).

**Application:** This method is applicable for the retrofit of boilers in the size range of 10 MM Btu/hr to 250 MM Btu/hr oil and natural gas fuels, fire tube and water tube boilers.

**Description:** The Dunphy burner uses an axial turbine fan to compress combustion air and force it through swirl chambers for optimum air distribution. The air quantity is controlled by a cylindrical drum with slots that rotates axially in front of another identical concentric stationary drum. Gas and oil flow are corrected for variance in combustion air conditions by pressure balanced valves with pneumatic sensor lines for gas, oil, and combustion chamber pressures. In the combustion chamber, a characterized gas ring or oil gun creates fuel-rich pockets that later mix with additional air for complete combustion and NO<sub>x</sub> reduction. The manufacturer specifications indicated NO<sub>x</sub> levels of 28-38 ppm and a 4:1 turndown ratio with natural gas and 36-41 ppm NO<sub>x</sub> and a turndown ratio of 4:1 for No. 2 oil. This burner was demonstrated at Fort Knox, KY.

In the Hague Transjet burner, furnace gas rather than flue gas is internally recirculated. The recirculated gas encapsulates the flame in a sheath with little or no recirculation occurring at the center of the flame front. Combustion air is supplied from an integral windbox through nozzles in the burner housing. This high velocity creates a depression at the point of discharge and induces products of combustion to be recirculated and mixed with the incoming combustion at the point of discharge and induces products of combustion to be recirculated and mixed with the incoming combustion air. A sheath of combustion air and recirculated gas surrounds and mixes with the fuel rich core flame to complete combustion as the flame travels down the furnace. The manufacturer specifications indicated NO<sub>x</sub> levels of 40-50 ppm and a 10:1 turndown ratio with natural gas and 45-50 ppm NO<sub>x</sub> and a turndown ratio of 8:1 for No. 2 oil.

**Advantages:** New burners have a 35% to 50% reduction in NO<sub>x</sub>, 1% to 2% increase in efficiency of burners, and are more fuel efficient by reduction of fuel burned.

**Limitations:** High efficiency burners have a higher capital cost. Retrofit of new more efficient burners have physical limitations of fitting older burner boxes.

**Costs:** Cost of new energy efficient, low NO<sub>x</sub> burners is contingent upon the Btu rating of the burner.

**Availability:** Commercially available.

**Status:** Demonstration projects have been conducted by burner retrofits on boilers at Fort Knox, KY, and Yakima Firing Center, WA, from 1990 – 1992.

**References:** Potts, Noel L. and Martin J. Savoie. **Low NO<sub>x</sub> Burner Retrofits: Case Studies**, U.S. Army Construction Engineering Research Lab, Presentation at the Air & Waste

Management Association 84th Annual Meeting & Exhibition, Vancouver, British Columbia, June 16-21, 1991.

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## 106. NO<sub>x</sub> EMISSION CONTROL FOR JET ENGINE TEST CELLS

- Category:** II.f. Minimization or Treatment of Gases
- Purpose:** Compliance with title IV Clean Air Act Amendments.
- Application:** This method is applicable for the removal of combustion byproducts from exhaust stack of stationary jet engine test cells.
- Description:** This pollution control device is made of a reactive filter containing expanded vermiculite coated with magnesium oxide. The magnesium oxide reacts with nitrous oxide (NO) and nitric oxide (NO<sub>2</sub>) to form magnesium nitrate. The filtration system reactive materials are regenerated by heating in a reducing atmosphere. The process emits carbon dioxide (CO<sub>2</sub>) and water while nitrogen oxides (NO<sub>x</sub>) react with the magnesium oxide and metals react with the vermiculite. There is a 50% to 70% reduction in NO<sub>2</sub> emission. There is not an alternative technology at the present time. A drawing of a high-temperature test system is shown in figure 106.
- Advantages:** Stationary jet engine test cells are permitted to operate because they are in compliance with title IV Clean Air Act Amendments.
- Limitations:** An external blower is needed to maintain air flow in jet engine test cells.
- Costs:** \$100,000 per test cell.
- Availability:** Available in June 1992.
- Status:** Field-pilot testing was conducted at Tyndall AFB, FL, 475th Weapons Evaluation Group (WEG)/XRM, 1992.
- References:** Nelson, B.W., S.G. Nelson, M.O. Higgins, and P.A. Brandum **A New Catalyst for NO<sub>x</sub> Control**, Sanitech, Inc., Final Report, for Air Force Engineering Center, Engineering & Services Laboratory, Tyndall AFB, FL, Jun 1989.
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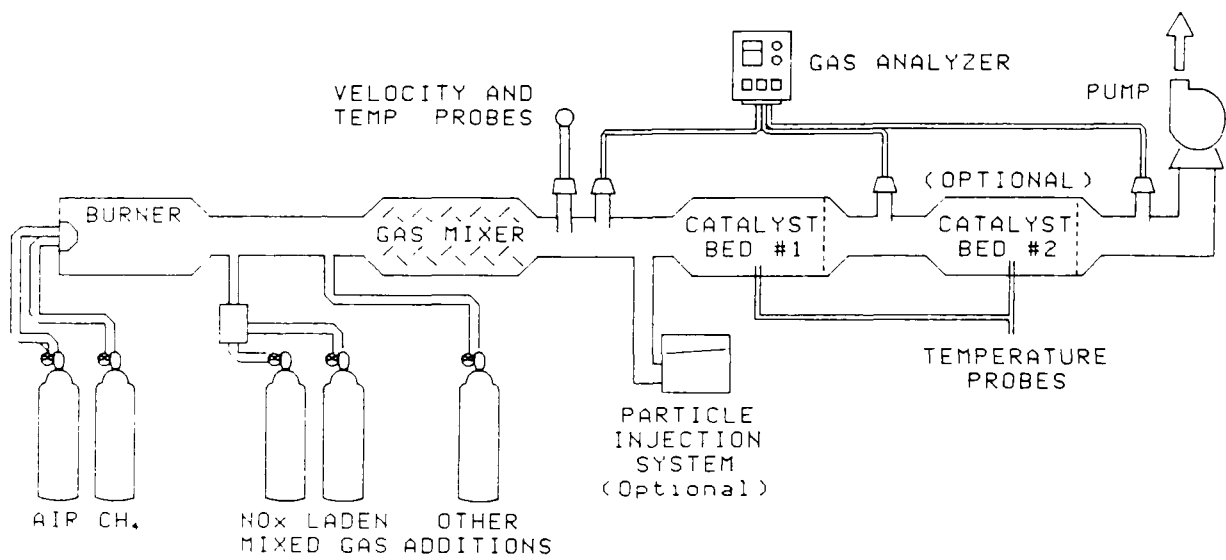


Figure 106. Drawing of a high-temperature test system for NO<sub>x</sub> emission control.

## 107. CATALYTIC DECONTAMINATION OF AIR STREAMS

**Category:** II.f. Minimization or Treatment of Gases

**Purpose:** To decontaminate the air stream from air stripping process.

**Application:** The process is applicable to volatile organic compounds (VOC) from groundwater, process streams from air stripping operations, or VOCs from soil vapor extraction.

**Description:** The mini-pilot unit was built in such a way that the system has the capability to readily change and control many variables such as using different catalysts during the run, and controlling air flow, water flow, ozone input, etc.

The continuous water-feeding system is a source of providing constant VOCs and halogenated VOCs (VHOCs) concentration levels in air saturated with water vapor. It is controlled by a pump which gives variable occlusion and provides accurate flow into the stripper cylinder at a broad flow range. The water level inside the stripper cylinder stays constant since inlet water flow equals to outlet flow at about one gallon level, which is the initial volume.

The VOCs and VHOCs are stripped off by air using a diaphragm air compressor at a desired flow rate provided with a needle valve bypass system. The air delivered into the stripping cylinder through a gas dispersion tube provides better stripping efficiency and gives even distribution of air through the water. Also, the air reservoir tank has been installed to eliminate the fluctuations of any air flow from the diaphragm compressor which pulsates during the operation. For prevention of any backflow, several water trap units have been installed to avoid damaging the compressor and the catalytic unit by eliminating any possibility of water droplets going into the system.

To check the initial VOCs and VHOCs concentrations in the air, gas sampling tubes have been installed upstream of the catalysts. By taking aliquots of the gas flow and passing the gas through two hexane traps in series, the concentrations of VOCs and VHOCs can be determined by direct injection onto gas chromatograph equipment with either electron-capture detector or flame-ionization detector, depending upon the nature of the compound.

To heat the catalyst in the catalytic decontamination system, heavily insulated heating tapes are wrapped around the stainless steel tubes (preheating) and insulated with glass wool and aluminum foil. The heat tapes are controlled by variable-voltage controllers. The temperatures are checked by using Analog temperature analyzers with thermocouple probe and by thermometers placed inside the catalysts.

Ozone is fed through the top of silica gel cylinder at 2 % and its mass flow can be adjusted by varying the flow of  $O_2 - O_3$ . The ozone output is calibrated by using the potassium iodide titration method. To deliver and control the flow of  $O_2 - O_3$  accurately, two needle valves are used to stabilize any flow changes from the pressure change in the catalytic unit.

The direction of air flow can be easily controlled by turning the valve on and off. In this way, the catalytic destruction of VOCs and VHOCs in the air can be determined after passing through each catalyst and trapping the off gas. Also, one extra catalyst cylinder has been installed to check a different catalyst's activity of organics in air without modifying the system.

**Advantages:** There is a 99% reduction of contaminants in the air stream, rendering them less harmless. The reaction is with ozone and catalyst in the reactor. The process does not have cross-media contamination, treatment chemicals are not lost to the environment, the waste stream from air stripping is not vented to the atmosphere, and incineration is not necessary.

**Limitations:** Ozone generation is not easy and personnel must have more specialized training to operate the equipment and process.

**Cost:** Operating cost is \$254/day for 98.4% destruction of trichloroethylene. Capital equipment costs range from \$160,000 to \$185,000.

**Availability:** Commercially available.

**Status:** Pilot testing at USACERL during 1991.

**References:** Leitis, Eriks, Mike Chung, and Jack D. Zeff. **Catalytic Decontamination of Effluent Air Streams From Stripping Towers, Progress Report Phase II.** SBIR Contract DACA-90-C00003, for USACERL Champaign, IL, Feb 1991.

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## 108. TREATMENT OF CONTAMINATED OFF GASES

**Category:** II.f. Minimization or Treatment of Gases

**Purpose:** To treat organic contaminated off gases from process equipment such as air strippers, low temperature thermal units, and aerobic bioreactors. Candidate processes include granular activated carbon (GAC), resins, chemical oxidation/ photolysis, and biofilters.

**Application:** These technologies are used to decontaminate off gases from treatment processes that produce a waste gas stream. The GAC and resins do not result in the destruction of the gas phase contaminants; however, resins have potential for product recovery. Chemical oxidation/photolysis and biofilters do have potential to destroy the contaminants making some nondestructive technologies, air stripping, contaminants destruction technologies. However, many of these technologies are developmental with the exception of GAC.

**Description:** GAC treatment of contaminant gas streams is a proven technology. Typically, if the gas stream has a high relative humidity an in-line heat exchanger is used to reduce the humidity thereby significantly increasing bed-life.

Resins have potential for removing organic compounds from contaminated air streams based on their effectiveness in treating some simple matrix based aqueous streams.

Chemical oxidation/photolysis is a mechanism by which much of the airborne organic compounds are destroyed in the atmosphere. The concept of the technology is to treat the off gas stream by passage through an oxidative, UV irradiated system. Biofilters have been used to treat some organic contaminated air streams. Most of the applications have been done by the Europeans for treating of industrial process streams and odors from municipal sewage plants.

**Advantages:** GAC treatment of organic contaminated gas streams is more cost effective and much more politically palatable than using a secondary combustion unit. GAC treatment is also an off-the-shelf technology. Resins may be more efficient than GAC for some gas streams and may also have potential for product recovery. Chemical oxidation/photolysis and biofilters are destruction technologies.

**Limitations:** These technologies result in increased treatment costs. Except for GAC, these technologies are developmental, and actual limitations have not yet been defined.

**Cost:** For GAC, costs vary with gas stream flowrate and contaminant concentration and type. The other technologies are under development, and costs have not been estimated; however, based on aqueous phase treatment rules of thumb, biotreatment is usually more cost effective than GAC.

**Availability:** The GAC technology is commercially available. Resin technology is commercially available, but applications in this context are not known. Chemical oxidation/photolysis and biofilters are under development.

**Status:** WES has been involved with various Corps of Engineers (COE) Districts on application and design of GAC systems. WES under the Army's Environmental Quality and Technology Program is currently assessing the capability of resins for treatment of contaminated gas streams and is currently developing chemical and biological systems capable of destroying gas phase organic contaminants.

**References:** Lith, C.V. **Design Criteria for Biofilters**, Air and Waste Management Association's 82nd Meeting and Exhibition, 1989.

Kosky, E.P. and Neff, C.R. **Innovative Biological Degradation System for Hydrocarbon Treatment**. Biofiltration Brochure, 1990.

MacFarlane, J.C., Cross, A., Frank, C., and Rogers, R.D. **Atmospheric Benzene Depletion by Soil Microorganisms**. Environmental Monitoring and Assessment, 017-6369/0011, 1981.

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## 109. ASBESTOS SURVEY AND ASSESSMENT PRIORITIZATION SYSTEM

**Category:** II.g. Management Strategies

**Purpose:** To determine the extent of the risk that asbestos containing materials (ACM) may pose, a thorough survey of ACM coupled with an assessment methodology can be used to prioritize the relative risk potential for a given asbestos situation.

**Application:** The system is applicable to areas on military installations that contain asbestos that must be removed.

**Description:** This is a computerized assessment system for prioritizing asbestos abatement and risk potential of asbestos that has been damaged. The system allows input of data from asbestos surveys on military installations for prioritization for abatement.

The following minimum hardware is required:

1. IBM Personal Computer or 100% compatible equipment.
2. One hard disk and at least one floppy disk drive.
3. Minimum 640K bytes of internal memory
4. Compatible monochrome or color monitor
5. Optionally, a compatible printer.

The following minimum software is required:

1. DOS 2.0 or higher.
2. High-level database management system software.

**Advantages:** The system is menu-driven which allows the user to enter new data, view and edit existing data, print reports to either a file or printer, and backup the existing database to a mass storage device (e.g., diskette). A menu-driven system will allow most system operations to be performed by personnel who are not computer professionals.

**Limitations:** An asbestos survey is needed in order to use this computerized system.

**Cost:** None.

**Availability:** Available through USACERL.

**Status:** The system is operational.

**References:** Cole, Robert H., *Asbestos Survey and Assessment Prioritization System*, TR-1113-11, Jan 1990.

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## 110. ENHANCED LANDFILL COVER

**Category:** II.g. Management Strategies

**Purpose:** To provide a permanent cap (target: greater than 100-years life) for hazardous waste landfills to keep animals out, reduce water infiltration, and reduce waste leaching.

**Application:** The method is applicable to landfills, impoundments, and pits. The cap could also be temporary.

**Description:** The exact configuration is under investigation. Testing is occurring in high-precipitation areas. The probable structure will be a combination of soil, native vegetation, cobble, and other indigenous materials.

**Advantages:** The method conforms to current EPA guidance, but is not specific. The result will be a procedure designed for areas having precipitation greater than 20 inches per year. The cap will have a longer design life and lower maintenance, and will be easy to install. Contamination will be contained until a treatment method can be developed. This type of cap is cheaper than clay.

**Limitations:** Areas having a high water table would not be helped by a cap. Freezing conditions have an unknown effect.

**Costs:** Exact cost information is not available, but costs are estimated to be an order of magnitude less expensive than current technology.

**Availability:** The method is under development.

**Status:** Field-pilot testing is underway at Whidby Island Naval Air Station, WA.

**References:** None available.

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## 111. IN SITU CAPPING OF CONTAMINATED SEDIMENT

**Category:** II.g. Management Strategies

**Purpose:** To restrict contaminant migration from containment into sediment to water column or biological receptors in waterways.

**Application:** This technology may be used for less contaminated sediment and non-hazardous waste contaminants. It is applicable for medium to low energy streams or lakes with appropriate engineering control.

**Description:** This technology is applied without disturbing contaminated sediment or with insignificant disturbance of contaminated sediment. The cap is placed by hydraulic dredging. Thickness of the cap is approximately 3 ft. Capping material is similar to or identical to uncontaminated sediment in the area. Contaminated sediments are analyzed as to type of sediment, then uncontaminated sediment that most nearly matches the contaminated sediment is dredged for use as an in situ cap. In streams with high turbulence, armoring with gravel or other large-grained sediment may be needed for use as a cap, but silt or sand are the more common capping materials. No excavation of contaminated sediment is necessary for containment by in situ capping (see figure 111).

**Advantages:** This technology effectively contains organic and inorganic contaminants in sediment. Removal of contaminated sediment is not necessary; therefore, contaminated sediments have little or no disturbance. Land disposal sites are needed for disposal of contaminated sediments in streams. Maintains chemical conditions favorable for contaminants to remain adsorbed to contaminated sediment particles.

**Limitations:** In situ capping of sediments reduces water depth in the area of the cap. Reduction in water depth in navigable streams could become a hazard to navigation, which could cause additional contamination of sediments. The technology does not alter the contaminant, but leaves chemical contaminants adsorbed to sediments. Contaminants stay in place and are covered by similar sediments from a nearby source.

**Cost:** Site specific, near cost of dredging if capping material is in close proximity.

**Availability:** Commercially available. Special equipment is needed to distribute capping materials uniformly over contaminated sediments to a thickness of 3 ft. Hydraulic dredge outlet or a sandbox-sieve can be used for placing capping material.

**Status:** WES at Vicksburg, MS has field-tested this technology.

**References:** Averett, Daniel E., Bret D. Petty, Elizabeth J. Torrey and Jan A. Miller. **Review of Removal, Containment and Treatment Technologies for Remediation of Contaminated Sediment in the Great Lakes.** USAE Waterways Experiment Station Miscellaneous Paper EL-90-25, 1990.

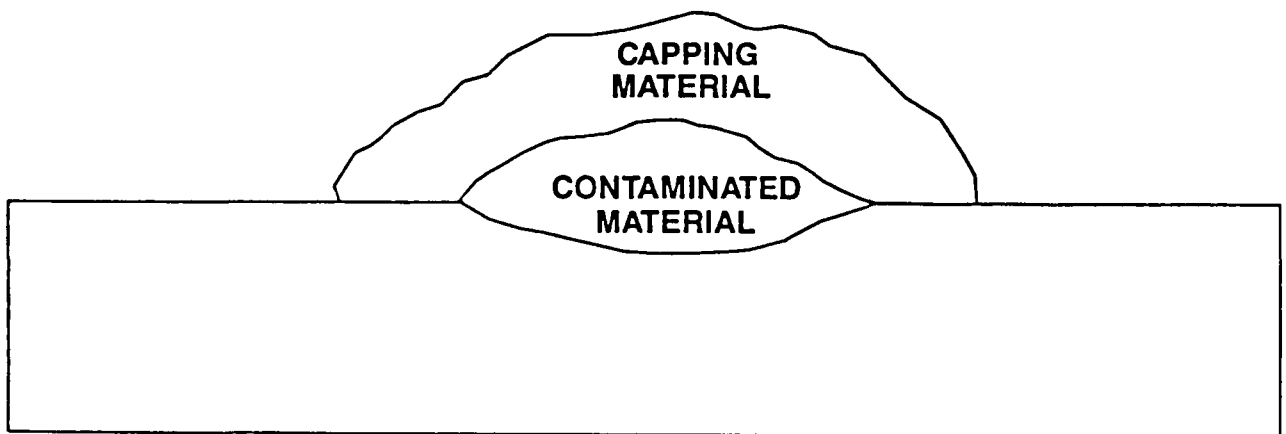
Palermo, Michael R. and E. Clark McNair, Jr. **Dredging Research Technical Notes, Design Requirements for Capping.** U.S. Army Engineer Waterways Experiment Station Report DRP-5-03, 1991.

Zappi, Paul A. and Donald F. Hayes. **Innovative Technologies for Dredging Contaminated Sediments, Improvement of Operations and Maintenance Techniques Research Program.** USAE Waterways Experiment Station Miscellaneous Paper EL-91-20, 1991.

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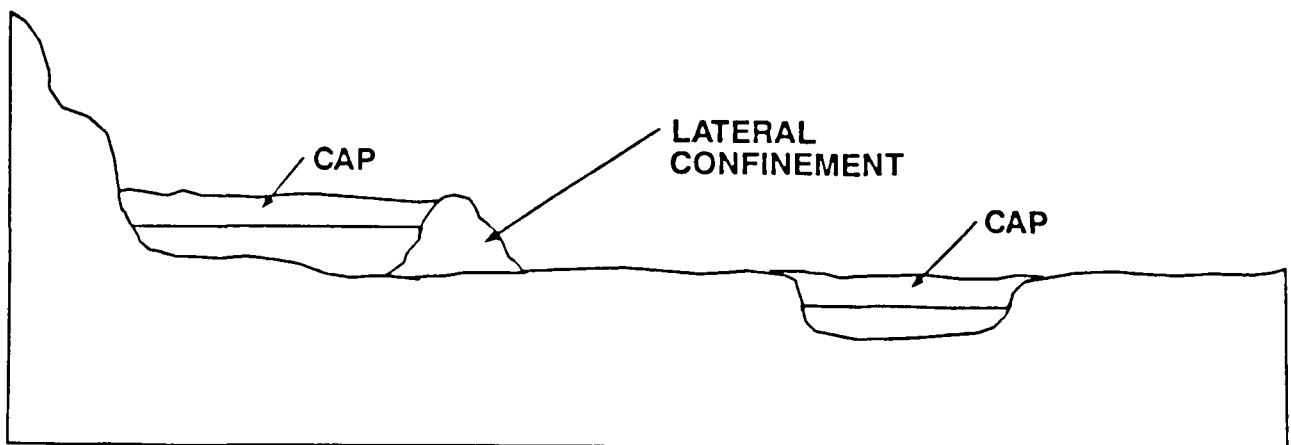
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- NO LATERAL CONFINEMENT
- DISCRETE MOUND NECESSARY



*Figure 111a. Level bottom capping.*

- LATERAL CONFINEMENT
- MOUND LESS CRITICAL



*Figure 111b. Contained aquatic disposal.*

## 112. ASBESTOS MANAGEMENT PROGRAM VIDEOTAPES

- Category:** II.g. Management Strategies
- Purpose:** To assist Army installations to develop effective asbestos management programs to eliminate health hazards.
- Application:** The videotapes provide the information necessary to develop and implement an effective asbestos management program: identification of potential asbestos health hazards, assessment of health risks, when and where to obtain expert analysis of asbestos, and how to find competent contractors who can correct asbestos-related problems.
- Advantages:** The method provides Army specific guidance on handling asbestos. Health risks will be reduced by training installation personnel in effective asbestos management techniques.
- Limitations:** The program is limited only by the information available about asbestos-related problems and management techniques.
- Description:** A series of four videotapes is available: general guidelines, asbestos survey, special operations and maintenance, and asbestos abatement.
- Costs:** About \$30 per tape.
- Availability:** The videotapes are available through Construction Engineering Research Laboratories (CERL).
- Status:** The general guidelines and asbestos survey tapes are complete and available. The script for the special operations and maintenance tape is complete, and available.
- References:** **Asbestos Management Program Videotape.** Fact Sheet, U.S. Army Corps of Engineers CERL, Mar 1987.
- Contact:** Bernie Donahue  
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## 113. HAZARDOUS WASTE MINIMIZATION SURVEYS

**Category:** II.g. Management Strategies

**Purpose:** To characterize processes generating hazardous waste and recommend measures that reduce or eliminate hazardous materials usage and/or hazardous waste streams.

**Application:** The survey is applicable to any activity or facility managing hazardous wastes.

**Description:** An investigation team goes to an activity, assembles the available data on waste streams and industrial processes, evaluates the activity and makes recommendations.

**Advantages:** The survey provides guidance for achieving hazardous waste minimization goals.

**Limitations:** The effectiveness of a survey is limited only by the motivation of facility management and staff.

**Costs:** Costs will be site specific.

**Availability:** Technical support is available from NEESA. A standard package has been prepared to enable activities to conduct this type of survey (see reference).

**Status:** Surveys have been conducted at 12 sites.

**References:** Camacho, N., R. Klopp, and W. Venable. **Comprehensive Hazardous Waste Minimization Survey Guide**. NEESA Report 19-002, Jul 1990

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## 114. HAZARDOUS WASTE MINIMIZATION ASSESSMENT

**Category:** II.g. Management strategies.

**Purpose:** Development of a hazardous waste minimization plan for Army installations to include the actions necessary to accomplish reduction in volume and toxicity of hazardous wastes generated.

**Application:** This protocol was developed for waste minimization of items disposed of on military installations such as storage batteries, solvents, used oils, antifreeze, paint waste, etc.

**Description:** The strategy for minimization on Army installations is the development of a protocol for surveying each installation for hazardous waste streams and methods of disposal. These major categories are the approach taken for surveying installations with this protocol:

1. Review information available at the installation.
2. Talk to several groups of individuals.
3. Develop a list of waste streams and rank them.
4. Develop information on each waste stream.
5. Identify minimization options for each waste stream.
6. Evaluate and rate options (preliminary or first screen) for each waste stream.

**Advantages:** There has been a reduction in hazardous waste generation and disposal on Army installations where it has been used.

**Limitations:** It can not be used on all types of waste.

**Cost:** A survey at Ft. Riley, KS, cost \$70,000 for a 1 year study. Cost at other military installations will be site specific.

**Availability:** Available at USACERL.

**Status:** This protocol has been applied at several Army installations: Ft. Ord, CA, Ft. Campbell, KY, Ft. Meade, MD, Ft. Carson, CO, and Ft. Sam Houston, TX. A full-scale survey will be implemented at Ft. Riley during 1992.

**References:** Dharmavaram, S., D.A. Knowlton, and B.A. Donahue. **Hazardous Waste Minimization Assessment: Ft Carson, CO**, USACERL Technical Report N-91/02, Jan 1991.

Dharmavaram, S. and B.A. Donahue. **Hazardous Waste Minimization Assessment: Fort Meade, MD**. USACERL Technical Report N-91/03, Jan 1991.

Dharmavaram, S. and B.A. Donahue. **Hazardous Waste Minimization Assessment: Fort Sam Houston, TX**. USACERL Technical Report N-91/07, Jan 1991.



Dharmavaram, S., D.A. Knowlton, C. Heflin, and B.A. Donahue. **Hazardous Waste Minimization Assessment: Fort Campbell, KY.** USACERL Technical Report N-91/09, Jan 1991.

Dharmavaram, S., D.A. Knowlton, and B.A. Donahue. **Hazardous Waste Minimization Assessment: Fort Meade, MD.** USACERL Technical Report N-91/14, Jan 1991.

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## 115. HAZARDOUS MATERIALS IDENTIFICATION SYSTEM (HMID)

**Category:** II.g. Management Strategies

**Purpose:** To inform the Director of Engineering and Housing (DEH) officer at military installations of hazardous material (HM) brought onto an installation and that HM can be processed into hazardous waste (HW).

**Application:** This system can be used on all hazardous material entering a military installation that can be processed into hazardous waste.

**Description:** This system is used in conjunction with the Hazardous Waste Management Information System (HWMIS). The HMID system is a computer-based identification system. The minimum system requirements for running the HMID program are an IBM/XT or compatible system with 512K of free RAM, a 5 1/4" 360K floppy disk drive, a 10 MB hard disk, and DOS 3.2 or greater.

The Hazardous Materials Identification System (HMID) is a tool developed by the Construction Engineering Research Laboratories (CERL) to aid the Environmental Management Officer (EMO) in achieving the goals of the United States Army Hazardous Materials (HM) and Hazardous Waste (HW) management programs, including:

- Complying with all Federal, Department of Defense (DOD), State, and Local regulations governing HM and HW.
- Protecting the health and well-being of its personnel, the general public, and the environment.
- Minimizing expenditures for HM and HW management.

More specifically, HMID is a system which allows the Environmental Management Officer (EMO) to account for HMs on an installation by processing and reporting data received from Logistics Control Activity (LCA) with minimal amount of additional data entered by the EIM.

As an aid to the EMO in HM management, HMID can be integrated into the Hazardous Waste Management Information System (HWMIS) to allow for the accounting of HM through the stages of its use: procurement, use, and disposal or recycling.

**Advantages:** This system for identification of hazardous materials is a simplification over paper method. The system is user friendly. A system for downloading from a mainframe using C or DBXL is in development.

**Limitations:** Downloading data from a mainframe computer to a PC is cumbersome. Older sets of data menus must be transferred by hand to new facilities because of the Base Closure Act.

**Cost:** Free to DOD installations.

**Availability:** Available from USACERL. Contact USATHAMA to obtain data.

**Status:** Limited trial implementation was conducted from 1990 to present at White Sands, NM. Approximately 75 installations are using this system.

**References:** **The Hazardous Materials Identification System (HMID).** USACERL, Champaign, IL, Jul 1991.

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## 116. HAZARDOUS WASTE MANAGEMENT INFORMATION SYSTEM

**Category:** II.g. Management Strategies

**Purpose:** The Hazardous Waste Management Information System (HWMIS) is a management tool developed to aid the environmental coordinator (EC) at an installation in the management of HW and minimization programs. Help in tracking HMs and HW from cradle to grave is the impetus behind HWMIS. The ease of formulating the upward reporting requirements to EPA, HQDA, and MACOMs is also an important function of HWMIS.

**Application:** This management system is applicable to all hazardous waste and hazardous materials.

**Description:** HWMIS is a user-friendly system created to aid an EC at an installation. There are many uses and benefits. One of the main benefits is to aid ECs in managing HW and HM on installations. With the impetus being minimization, ECs must know what HMs are used, what HWs are generated, what has been treated/processed, what has been stored for less than 90 days, and what HW has been disposed.

Environmental engineers from all levels of the Army have helped design HWMIS to meet the needs of an installation's environmental coordinator. HWMIS captures data at critical points of HM use, HW generation, treatment/process, interim storage, and disposal. HWMIS also provides employee training record keeping, spills record keeping (reportable and non reportable), permit/violation record keeping, system maintenance utilities, and the ability to send summaries to MACOM/DA level.

Through HWMIS, the standard unit of measures include gallons (GL), pounds (LB), and kilogram (KG), with kilograms the preferred unit of measure. HWMIS provides conversion from pounds to kilograms automatically. With the user inputting the appropriate density, gallons are also converted to kilograms. Using a standard unit of measure provides more accurate comparisons and more easily understood reports and summaries.

HWMIS is designed to provide the environmental coordinator with internal management reports based on the data entered. Some of the reports include who is producing HW, how much HW is treated/recycled, what quantity of HW is going off the installation, where is it going, and when it reached its destination. Other reports include who has had the proper training and who needs training. Internal management reports are a vital part of HWMIS and help ECs at an installation get a better picture of HW management. Also, quantities needed for external reports (e.g. Biennial and DESR) are provided to aid the EC in fulfilling regulatory requirements.

**Advantages:** This management system is faster than paper tracking. It allows near cradle to grave tracking of HW and HM and is user friendly.

**Limitations:** The computer language used is dBase III+ or DBXL. It is limited to the storage space on the computer used.

**Cost:** Free to DOD installations.

**Availability:** This is a full running program at USACERL. The system using C language program will be available by December 1992.

**Status:** Limited trial implementation has been conducted at White Sands Missile Range, NM, since 1990.

**References:** Webster, R., L. Mikulich, and C. Corbin. **Hazardous Waste Management Information System (HWMIS) User Manual.** USACERL, Champaign, IL, Draft Feb 1989.

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## 117. HAZARDOUS MATERIAL AND HAZARDOUS WASTE BAR CODE TRACKING SYSTEM

**Category:** II.g. Management Strategies

**Purpose:** To track hazardous-material consumption, hazardous waste generation, hazardous-waste storage, and hazardous-waste disposal on Army installations.

**Application:** This hazardous waste-tracking system is applicable to all hazardous materials and waste generated from these materials, that can be placed in containers, from the point of delivery and storage on the installation to the time that the material as a hazardous waste is removed from the military installation.

**Description:** The HM/HW tracking system uses dBase IV on an IBM PC or compatible personal computer and a programmable bar code reader to monitor the location and ownership of HM/HW containers. The personal computer must have 640 K RAM and a hard disk drive. The bar code reader is the point of transaction data collection device and the temporary storage location for tracking information. The personal computer is used for permanent storage of tracking data, HM/HW forms editing, and HM/HW tracking report generation.

The Hazardous Material and Hazardous Waste (HM/HW) tracking system has the following characteristics:

1. Documents the chain-of-custody (or life history) of HMs from the point of issue at warehouse to point of use, and HWs from the point of generation to final disposition.
2. Maintains data on relevant physical and chemical characteristics including chemical names and quantity of HM/HW involved.
3. Employs automated identification technologies to minimize cost, staff time, and paperwork necessary to implement the system.
4. Provides a database that is flexible, easy to use, large in capacity and capable of producing reports of different contents and formats.
5. Compatible with existing HM/HW management procedures at Army installations.

**Advantages:** There is greater accuracy of the chain-of-custody with documentation. There is less human error. The system has easy access to data for reporting purposes and saves time in reporting.

**Limitations:** Users need to be trained. At the present time this system can not be used on liquid waste streams. Also, at the present time it is not set up for hazardous materials.

**Cost:** Costs incurred in setting up this system include the cost of a bar code scanner and a PC computer. Contingent upon the type of computer and scanner purchased for the system.

**Availability:** Commercially available.

**Status:** The bar code tracking system has been demonstrated at the Army Depot in Corpus Christi, TX. Full-scale implementation during 1992 will be at Ft. Lewis, WA.

**References:** **Hazardous Material and Hazardous Waste Bar Code Tracking System.** Fact Sheet, EN 42, U.S. Army Corps of Engineers Construction Engineering Research Laboratories, Champaign, IL, May 1990.

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## 118. ECONOMIC ANALYSIS MODEL FOR HAZARDOUS WASTE MINIMIZATION CAPITAL INVESTMENT

**Category:** II.g. Management Strategies

**Purpose:** Economic analysis decision making.

**Application:** The model is for use with hazardous waste generated from: paint and paint waste, waste solvents, batteries and battery acid, industrial waste treatment sludges, electroplating waste, lubricating oil, and generic waste.

**Description:** A computer program in C language has been developed for use by the Department of Defense (DOD) for economic evaluation of hazardous waste remediation. The program is classified and not for civilian use but could be adapted for civilian use with permission of the DOD and U. S. Army Corps of Engineers.

**Advantages:** Very fast information available without research. The generic model is applicable for either DOD or civilian uses.

**Limitations:** DOD applicable only in present form.

**Cost:** A computer disc, instruction manual, and labor.

**Availability:** Available to U.S. Government agencies or to civilians.

**Status:** The model has been field tested at 25 DOD installations.

**References:** None available.

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## 119. LIFE-CYCLE COST ANALYSIS FOR SOLVENT MANAGEMENT OPTIONS

**Category:** II.g. Management Strategies

**Purpose:** To identify the most economical means of eliminating solvents under the used solvent elimination (USE) program.

**Application:** The method is applicable for the calculation of life cycle costs for four recycle options: (1) recycling on-post, (2) recycling with a commercial recycler, (3) recycling with a full service contractor, or (4) recycling by burning in an industrial boiler. Solvents for which the method is applicable include chlorinated and petroleum distillate solvents.

**Description:** Life cycle cost (LCC) calculations for solvent management consist of six steps: (1) determine the cost of new solvent to be purchased each year, (2) determine the cost of capital equipment or investment for each year, (3) determine recurring costs for each year, (4) calculate cost-reduction factors such as heating and salvage values, (5) calculate the present value for each year by multiplying the total annual costs by the present value factors for each year, and (6) add the annual present value factors for the lifetime of the project to arrive at the LCC.

**Advantages:** Enables the user to identify the most economical means of eliminating solvents under the USE program.

**Limitations:** The method is limited to the options covered and the applicable solvents.

**Costs:** This management options will save money in design and management of solvent streams..

**Availability:** The method is available in Technical Note 86-1 cited below. Technical assistance is available from the Construction Engineering Research Laboratories (CERL).

**Status:** The program has been implemented. Two facilities that use the program are Rock Island Arsenal, IL and Ft. Bragg, NC.

**References:** Life Cycle Cost Analysis for Solvent Management Options, Fact Sheet, U.S. Army Corps of Engineers CERL, Apr 1987.

Watling, E.T., Economic Analysis of Solvent Management Options. Department of the Army, Office of the Chief of Engineers, DAEN-ZCF-U Technical Note No. 86-1, May 1986.

Neathammer, R.D., Economic Analysis Description and Methods. U.S. Army CERL Technical Report P-151/ADA135280, 1983.

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## 120. STORAGE TANK MANAGEMENT SYSTEM

**Category:** II.g. Management Strategies

**Purpose:** To collect and store information about U.S. Army Storage Tanks, both underground and aboveground storage tanks, develop management plans, and assess the risk associated with tank leakage.

**Application:** The method is applicable for all underground and aboveground storage tanks.

**Description:** The system (TANKMAN) maintains a database of tank physical characteristics, compliance, status, testing data, and related information. Full historical tracking of all information is provided. A full feature SQL report facility is also provided. The system runs on IBM PC compatible hardware under MS DOS and is a module of the AAEMIS System (Army Automated Environmental Management Information System).

**Advantages:** Using the system facilitates management of tank data and makes access and updates more efficient and accurate. Reporting capabilities allow liquid level record management, identification of possible problems with tanks, work schedule reports, and non-compliance reports. Data rollup utilities are provided, allowing higher level global database maintenance and reporting.

**Limitations:** Risk assessment and compliance status require accurate information input by the user.

**Costs:** Program disks are free to U.S. Army facilities.

**Availability:** Tank Management System is available from:

Commander  
USATHAMA  
CETHA-ECD-S/Captain Steve Chetty  
Aberdeen Proving Ground, MD 21010-5401

**Status:** The program has been implemented. User training is planned. Current users include Department of the Army Headquarters, the Army Environmental Office, and Army major commands. The management system for decisions related to maintaining, upgrading, or replacing underground storage tanks is available.

**References:** Haw. R.C., and J.E. Lorenzen. **A Computerized Underground Storage Tank Management System.** Proc. 18th Environmental Symposium and Exhibition, Feb 1992.

Pautz, J.F. and R.E. Porter. **Underground Storage Tanks Management Decision Tool for MACOMs.** U.S. Department of Energy Report NIPER-394, Nov 1988.

**Underground Storage Tank Data Management Program and Leak Potential Index.** Fact Sheet, U.S. Army Corps of Engineers CERL, Feb 1987.

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## 121. ECOLOGICAL RISK ASSESSMENT METHODOLOGY

**Category:** II.h. Risk Assessment

**Purpose:** To develop biological and chemical methods for direct measurement of ecological health as a basis for deciding whether remediation is necessary.

**Application:** The method is applicable for any type of site contaminated with any type of waste. It can be done in conjunction with measurement of contaminant levels and lab toxicology. Methods can be used in developing site closure plans and in verifying the effectiveness of clean up.

**Description:** At the Naval Air Station (NAS), Whidbey Island, WA, toxicological impacts are being evaluated using starling nesting and reproductive biology as an indication of contaminant migration into the food chain. Toxicological impacts are also being monitored in small mammals, hawks, owls, herons, and selected prey species located on or near the hazardous waste disposal sites (fire fighting training area, pesticide disposal site, and runway ditches). At the Naval Construction Battalion Center (NCBC), Davisville, ecological impacts are being assessed by characterizing the sediment and water quality and evaluating the toxicological impact on quahog clams, soft shell clams, oysters, mussels, polychaetes, and amphipods. The ecological risk assessment model is depicted in figure 121a. An arrangement for deploying and retrieving mussels is shown in figure 121b. An approach for sampling large volumes of water is illustrated in figure 121c. Efforts will soon be underway in San Diego Bay to examine impacts of Navy hazardous waste landfills on the aquatic environment.

**Advantages:** The method (1) provides a direct measure of environmental health, (2) allows identification of the source and extent of a problem, (3) allows an understanding of the ecological toxicity of contamination, and (4) allows verification of environmental safety.

**Limitations:** Ecological risk assessment is an emerging, evolving, scientific discipline that attempts to extrapolate toxicity data on selected individual animal species to ecosystem health.

**Costs:** Costs to implement the method would be site specific. Two case histories provide example costs: (1) NCBC, Davisville, RI – about \$1MM; (2) NAS, Whidbey Island, WA – about \$1MM; and (3) San Diego, CA – estimate about \$400,000.

**Availability:** Guidance is available from NCCOSC RDT&E Division.

**Status:** Trial implementations are ongoing at NCBC, Davisville, RI and NAS, Whidbey Island, WA. Efforts will soon be underway in San Diego Bay to examine impacts of a Navy hazardous waste landfill on the marine environment.

**References:** Mueller, C., et al. editors. **Standard Operating Procedures and Field Methods Used for Conducting Ecological Risk Assessment Case Studies**. Naval Construction Battalion Center Davisville, RI, and Naval Shipyard Portsmouth, Kittery, ME, Technical Document 2296, May 1992.

Munns, Wayne R. et al. **Marine Ecological Risk Assessment at Naval Construction Battalion Center, Davisville, Rhode Island.** NOSC Technical Report 1437, May 1991.

Kendall, R.J. et al. **Toxicology Demonstration Project: Environmental Toxicology Assessment for Three Hazardous Waste Disposal Sites at NAS Whidbey Island.** NOSC Work Plan, May 1989.

Johnston, R.K. et al. **Assessing the Impact of Hazardous Waste Disposal Sites on the Environment: Case Studies of Ecological Risk Assessments at Selected Navy Hazardous Waste Disposal Sites.** Paper presented at the 14th Annual Army Environmental R&D Symposium, Williamsburg, Nov 1989.

Johnston, R.K. and D. Lapota. **A New Approach for Evaluating Biological Toxicity at Aquatic Hazardous Waste Sites.** Proc. of the 6th Symposium on Coastal and Ocean Management/ASCE, Charleston, SC, July 1989.

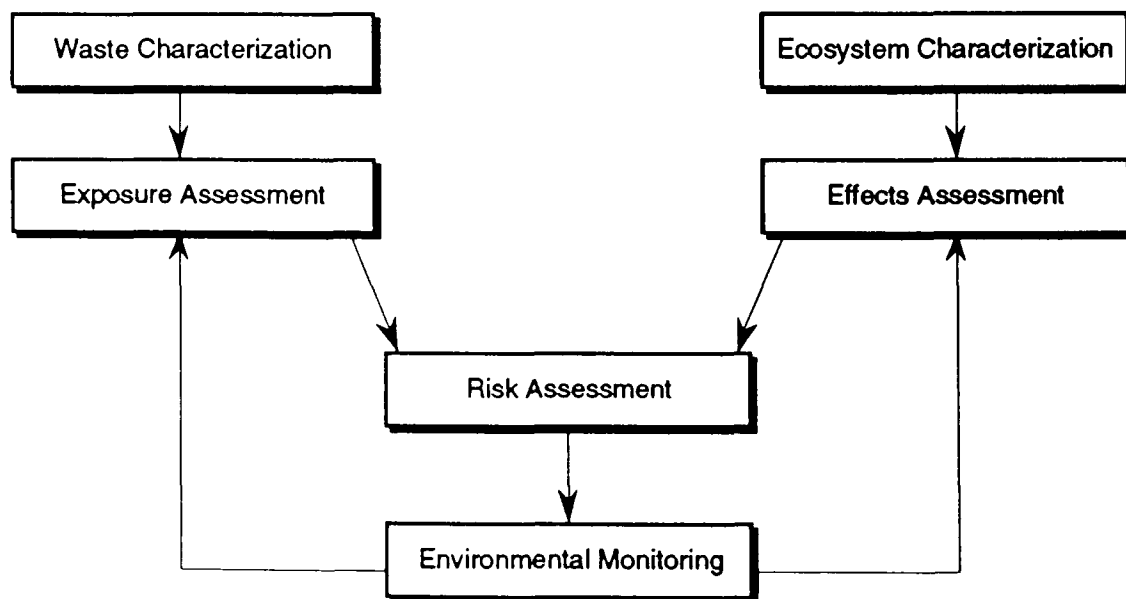
Lapota, D. R.K. Johnston, and D.E. Ronsenberger. **Survey of Methods to Assess the Toxicological Impact of Hazardous Waste Disposal Sites on Aquatic Ecosystems,** NOSC Technical Report 1305, 1989.

Johnston, R.K. et al. **Navy Aquatic Hazardous Waste Sites: The Problem and Possible Solutions.** NOSC Technical Report 1308, 1989.

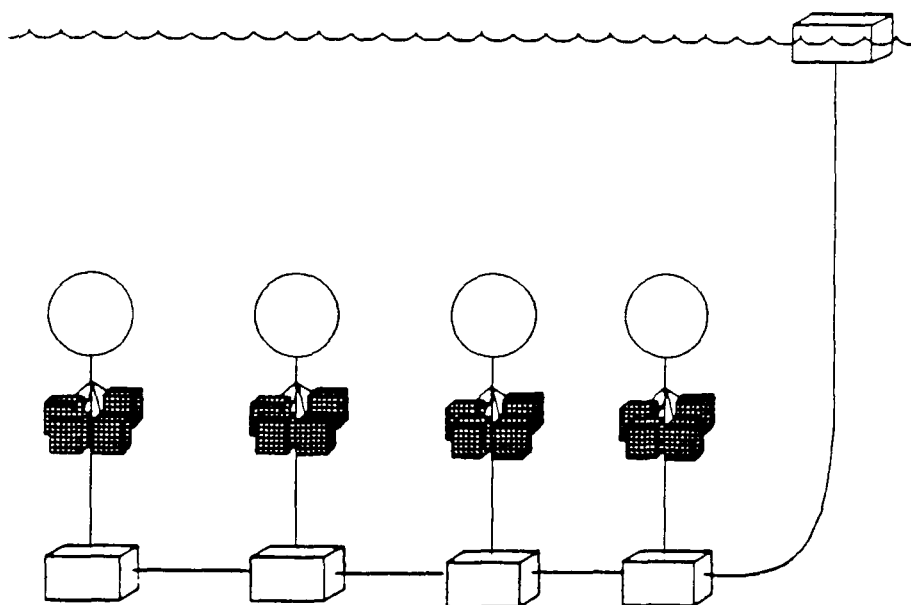
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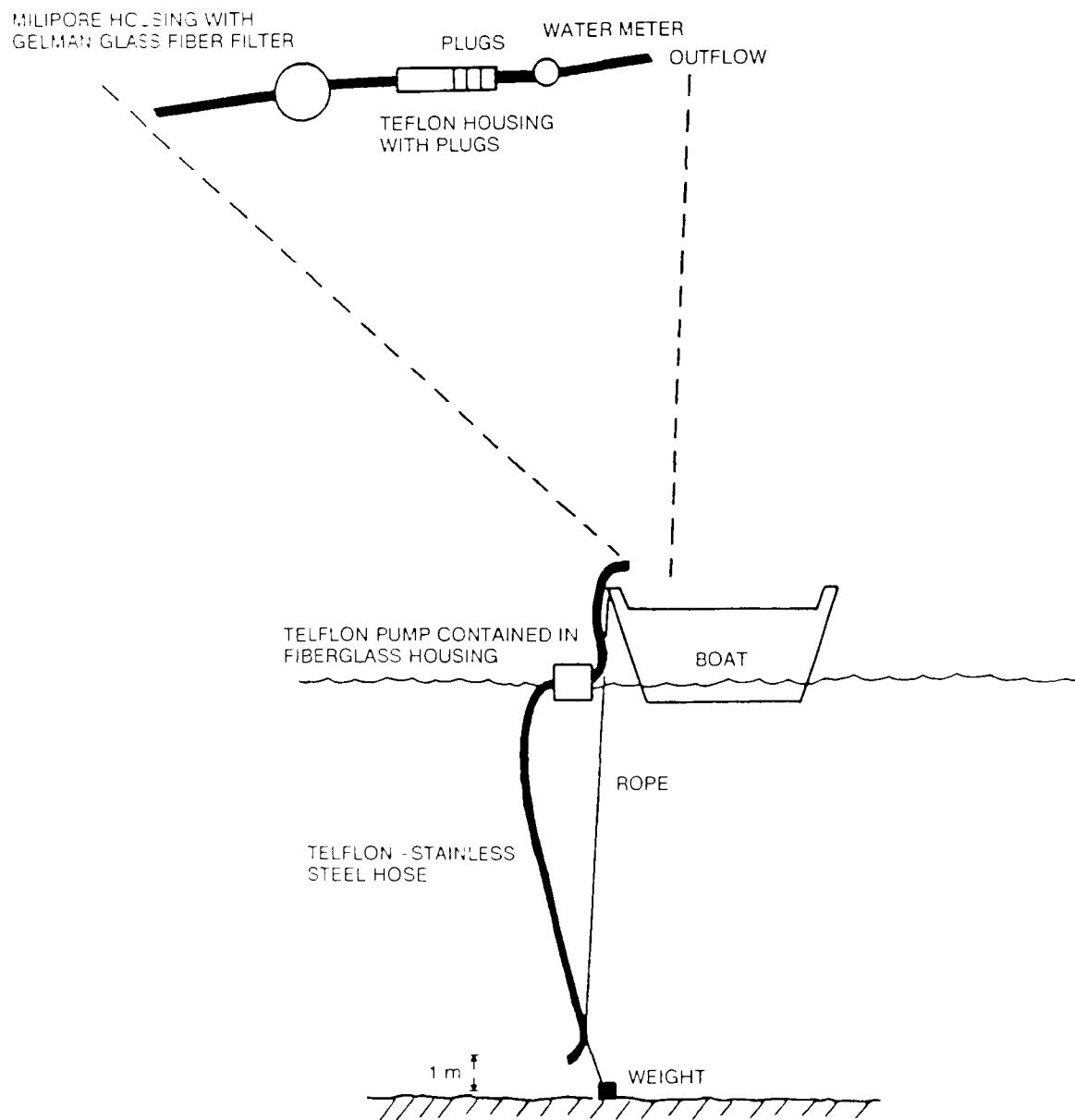


*Figure 121a. The ERLN ecological risk assessment model.*



*Figure 121b Deployment arrangement for Mytilus edulis.*





*Figure 121c. Schematic of large volume water sampling approach.*

## 122. ENVIRONMENTAL RISK ASSESSMENT FOR CONTAMINATED SEDIMENTS

**Category:** II.g. Risk Assessment

**Purpose:** To determine the environmental risk associated with contaminated sediments at Army installations containing hazardous and toxic wastes.

**Application:** The method can be used at any installation where contaminated sediments exist and pose a potential environmental hazard. This method is especially useful in setting risk-based clean-up levels for sediment restoration and remediation activities.

**Description:** The environmental risk posed by contaminated sediments is a function of toxicity and exposure. Site-specific information is gathered regarding the extent and magnitude of sediment toxicity as well as the spatial/temporal variation in contaminated sediment exposure potential. Populations of important human and non-human target receptors are identified. Environmental risk is characterized by integrating the toxicity and exposure data. Uncertainty is addressed explicitly for the site manager via probability density analysis.

**Advantages:** The method helps the site manager establish a technically sound basis for risk-based clean-up criteria for contaminated sediments. The method may represent a substantial cost-savings over the more common cleanup to background approach. The method can effectively deal with complex mixtures of environmental contaminants and Military-unique compounds.

**Limitations:** Depending on the site, the method can be data-intensive. An interdisciplinary team approach is required. The latter characteristic could be construed to be an advantage.

**Cost:** Costs are site-specific.

**Availability:** Guidance is available from WES.

**Status:** This is an emerging technology.

**References:** Dillon, T.M. **Risk Assessment: An Overview of the Process**. Technical Note EL-EEDP-XX-XX, U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, MS, (in press), 1992.

Dillon, T.M. and F. Reilly. **Environmental Risk Assessment for Contaminated Sediments**. Technical Report EL-XX-XX, U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, MS, (in press), 1992.

Palermo, M.R. et al. **Long-Term Management Strategy for Dredged Material Disposal for the Naval Weapons Station, Yorktown, Virginia: Naval Supply Center, Cheatham Annex, Williamsburg, Virginia; and Naval Amphibious Base, Little Creek, Norfolk, Virginia. Phase II: Formulation of Alternatives**. Miscellaneous Paper EL-XX-XX, U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, MS, (in press), 1992.

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## 123. FIELD PREPARATION TECHNIQUES

- Category:** III. Analytical Methods and Instrumentation Development
- Purpose:** To develop a technique to prepare environmental samples for field analysis.
- Application:** Currently, the method is applicable for metals. Future work will be directed toward volatile organic compounds.
- Description:** Soil samples are taken and dried for moisture determination. About 1 g of sample is mixed with nitric acid and placed in a Teflon holder in a Parr bomb. The bomb is placed in a microwave oven and digested for 20 to 30 minutes. No special training is required.
- Advantages:** The method results in savings of time and money. The method is simple and can be conducted in the field. It is portable. Good recovery has been demonstrated for volatile metals such as mercury, lead, and selenium. Many more digestions can be done in a given time than can be done using conventional heating.
- Limitations:** The method is applicable only to extractable metals.
- Costs:** The only equipment is the microwave oven, which is modified only slightly from those commercially available.
- Availability:** Microwave ovens are commercially available. Some modifications are required. Technical details are available from USATHAMA.
- Status:** The method has been tested at the U.S. Army Cold Regions Research and Engineering Laboratory, NH.
- References:** Not available.
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## 124. ANALYTICAL METHODS TO MONITOR REMEDIATION

**Category:** III. Analytical Methods and Instrumentation Development

**Purpose:** A rapid tool to (1) map the extent of a hazardous site before, during, and after the application of remedial measures; and (2) monitor cleanup measures in the field.

**Application:** The effort has been directed initially toward measurement of fuel oils in contaminated soils and groundwater.

**Description:** Related chemical substances have structural characteristics in common. These structural characteristics can be the basis for the identification and estimation of the substance by, for example, the presence or absence and intensity of distinctive ultraviolet or infrared absorption bands. Table 124 indicates components, characteristics, degradation products, and potential measurement techniques for typical pollutant categories.

**Advantages:** The method has the potential for being rapid, inexpensive, and useful in the field.

**Limitations:** The limitations are not yet known.

**Costs:** Not available.

**Availability:** Under development.

**Status:** The method is under development (see also note #149).

**References:** Not available.

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*Table 124. Analytical Methods To Monitor Remediation Of Fuel Hydrocarbons*

	<u>Alkanes</u>	<u>Aromatics</u>	<u>Heavy Metals</u>
Characteristics	-CH <sub>2</sub> -	Ring	Colored Complex
Measurement	IR	UV	Colorimetry
Degradation Products	-COOH -C=O	-COOH -C=O Ring	None
Measurement	IR Colorimetry	IR, UV Colorimetry	—

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## 125. GLOW DISCHARGE MASS SPECTROMETRY (GDMS)

- Category:** III. Analytical Methods and Instrumentation Development
- Purpose:** To develop quicker analytical turnaround times using mass spectrometry (MS) techniques.
- Application:** The method is applicable for the screening of samples for volatiles or semi volatiles.
- Description:** Glow discharge MS (GDMS) uses an atmospheric pressure electromagnetic interface to a quadrapole gas chromatograph/MS (GC/MS) to analyze environmental samples. Using the glow discharge source and sampling inlet, analysis of soil and water samples can be done in 2 to 5 minutes. Results for benzene, toluene, methylene chloride, chloroform, trichloroethylene, and tetrachloroethylene have been comparable to standard GC/MS analysis.
- Advantages:** The use of GDMS can reduce the time necessary to obtain accurate analytical results and increase the number of analytical samples analyzed by a laboratory. As a field tool, GDMS can reduce the expense of sending samples to a laboratory by providing an indication on a near real-time basis of those samples that are contaminated, so that only the samples of interest will be sent to the laboratory.
- Limitations:** Problems differentiating multiple compounds have been encountered.
- Costs:** Cost information has not been developed.
- Availability:** The method is still under development.
- Status:** Laboratory testing is being conducted at Oak Ridge National Laboratory (ORNL) to apply the method to all 33 listed volatile compounds and 30 to 40 semi-volatiles. The laboratory is investigating ion trap mass spectrometry (ITMS) to overcome limitations on multiple compounds. Both techniques will be evaluated, with continuing effort expended on the method that will provide the most usable results.
- References:** Wise, M.B., M.V. Buchanan, and M.R. Guerin. *Rapid Environmental Organic Analysis by Direct Sampling Glow Discharge Mass Spectrometry and Ion Trap Mass Spectrometry: Summary of Pilot Studies - Final Report*. USATHAMA Report CETHA-TE-CR-90029, ORNL Report ORNL TM-11538, Mar 1990.
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## 126. LEACH TESTING FOR HAZARDOUS WASTES

- Category:** III. Analytical Methods and Instrumentation Development
- Purpose:** Determine mobilization characteristics of contaminants from contaminated solids into aqueous phase.
- Application:** Leachate testing procedures are applicable for evaluation of contaminant mobility in soils and sediments and potential impacts of leachate from soils and sediments on groundwater. Leachate testing will also generate data which can be used to determine the degree of contaminant immobilization gained through solidification/stabilization (S/S) processing (see notes 45 to 50).
- Description:** Contaminants found in controlled and uncontrolled hazardous waste sites can be leached, resulting in groundwater contamination. Laboratory tests for evaluating hazardous material generally possess limited potential for extrapolating results to field situations because the tests were not designed on the basis of a mass transport model of leachate generation. Procedures developed at the Waterways Experiment Station utilize results from batch tests and column tests, coupled with mass transport equations, to describe mobilization of contaminants from sediment and soil. Once a reasonable description of interphase contaminant transfer (desorption from solid media to water) has been found, contaminant migration by leaching can be evaluated by solving the mass transport equations for the initial and boundary conditions that apply in the field. Tests are conducted in a chemical environment that simulates important conditions anticipated for disposal of the sediment or soil. The leaching tests can also provide information needed to determine the effectiveness of S/S in reducing the potential hazard of contaminated material.
- Advantages:** The mobility of contaminants can be determined in soils, sludges, and treated residuals.
- Limitations:** Not available.
- Cost:** Costs will vary with contaminants and length of testing.
- Availability:** The method is under development.
- Status:** WES has assisted the New Bedford Superfund Project (see note #70) with evaluation of leachate for Superfund material to be placed in a confined disposal facility. Research is underway in many areas to evaluate the mobility of metals and organic contaminants from sediments subject to dredging. WES has also assisted the Office of the Program Manager (PM) at the RMA in determining the degree of immobilization gained through propriety S/S processing of Basin F liquid. Finally, WES has determined the potential for increasing the desorption of explosives compounds from soils using aqueous solutions with and without surfactants.
- References:** Myers, T.E. and J.M. Brannon. New Bedford Harbor Superfund Project, Acushnet River Estuary Engineering Feasibility Study of Dredging and Dredged Material Disposal Alternatives, Report V: Evaluation of Leachate Quality. USAE Waterways Experiment Station Technical Report EL-88-15, 1988.

**Myers, T.E. and M.E. Zappi. Laboratory Investigation of Organic Contaminant Immobilization by Proprietary Processing of Basin F Liquid, Rocky Mountain Arsenal, Denver, Colorado. USAE Waterways Experiment Station Technical Report EL-87-11, 1987.**

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## 127. LABORATORY AND FIELD BIOINDICATOR SYSTEMS

**Category:** III. Analytical Methods and Instrumentation Development

**Purpose:** To develop sensitive laboratory and field bioindicator systems that can be used simultaneously to evaluate contamination associated with Naval facilities and operations.

**Application:** The method is applicable for any contaminant in an effluent or receiving water providing that the contaminant causes stress to organisms.

**Description:** Bioassay procedures are based on protocols utilizing a suite of invertebrate and vertebrate organisms known for their sensitivity to toxicants. New bioassay methodologies will be developed using bioluminescence, chlorophyll fluorescence, and adenosine triphosphate (ATP) levels for contaminant stress indication via light measurement (QWIK-LITE, see figures 127a and 127b). Candidate organisms include phytoplankton, amphipods, mysids, mussels, worms, and fish. Bioassay protocols are evaluated for their efficiency and predictive capabilities and include life-cycle tests, embryo survival, larval survival and growth, and reproductive capacity. Studies of a variety of sublethal responses have been conducted on mussel growth rate, reproductive capacity, metamorphosis, and bioaccumulation in mussels, mysids, worms, and fish. Sublethal assays on fluorescence and bioluminescence light output in phytoplankton have been used to detect effects at the part-per-billion level. Complementary laboratory and field studies have been conducted with several contaminants.

**Advantages:** This method provides the best possible scientific data for making environmental compliance decisions. It provides a direct means of measuring impact of pollutants on marine and aquatic environments. The techniques covered by this method can provide effluent discharges with a rapid and inexpensive assay to facilitate the NPDES permitting process. The limitations of existing methods include lack of combined laboratory and field approaches, inadequate calibration of existing systems, and inappropriate extrapolations to and from real-world environments. This technology could easily be transferred to commercial, private, and regulatory sectors.

**Limitations:** The method cannot be used to identify or quantify specific contaminants or concentrations.

**Costs:** Cost information is not available.

**Availability:** The method is under development.

**Status:** Laboratory and field testing is underway at the NCCOSC. Plans are to finalize procedures and transition to compliance applications by FY94.

**References:** Lapota, D. et al. A Bioassay Method to Assess Acute and Sublethal Effects of Storm Drain Discharges, Diesel Marine Fuel, and Heavy Metals on Stimulatable Bioluminescence from Marine Dinoflagellates. Presented at the 2nd Symposium on Environmental Toxicology and Risk Assessment: Aquatic, Plant, and Terrestrial, Pittsburgh, PA, Apr 1992.

Huggett, R.J., M.A. Unger, P.F. Seligman, and A.O. Valkirs. **The Marine Biocide Tributyltin – Assessing and Managing the Environmental Risks.** *Environ. Sci. Technol.*, **26**(2):232-7, 1992.

Johnston, R.K. and D. Lapota. **A New Approach For Evaluating Biological Toxicity at Aquatic Hazardous Waste Sites.** Proc. 6th Symposium on Coastal and Ocean Management/ASCE, Jul 1989.

Lapota, D., R.K. Johnston, and D.E. Rosenberger. **Survey of Methods To Assess the Toxicological Impact of Hazardous Waste Disposal Sites on Aquatic Ecosystems.** NOSC Technical Report 1305, 1989.

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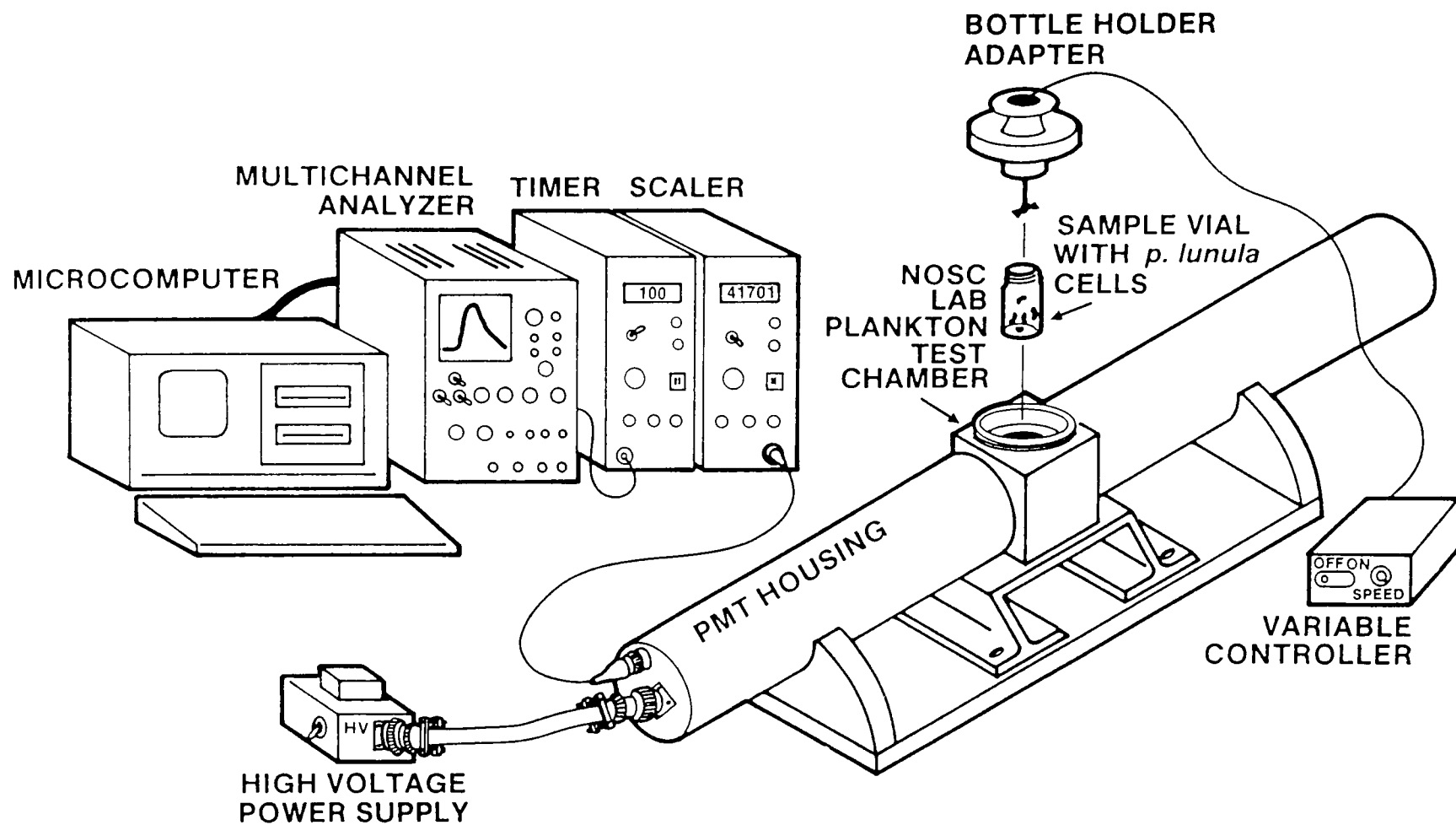
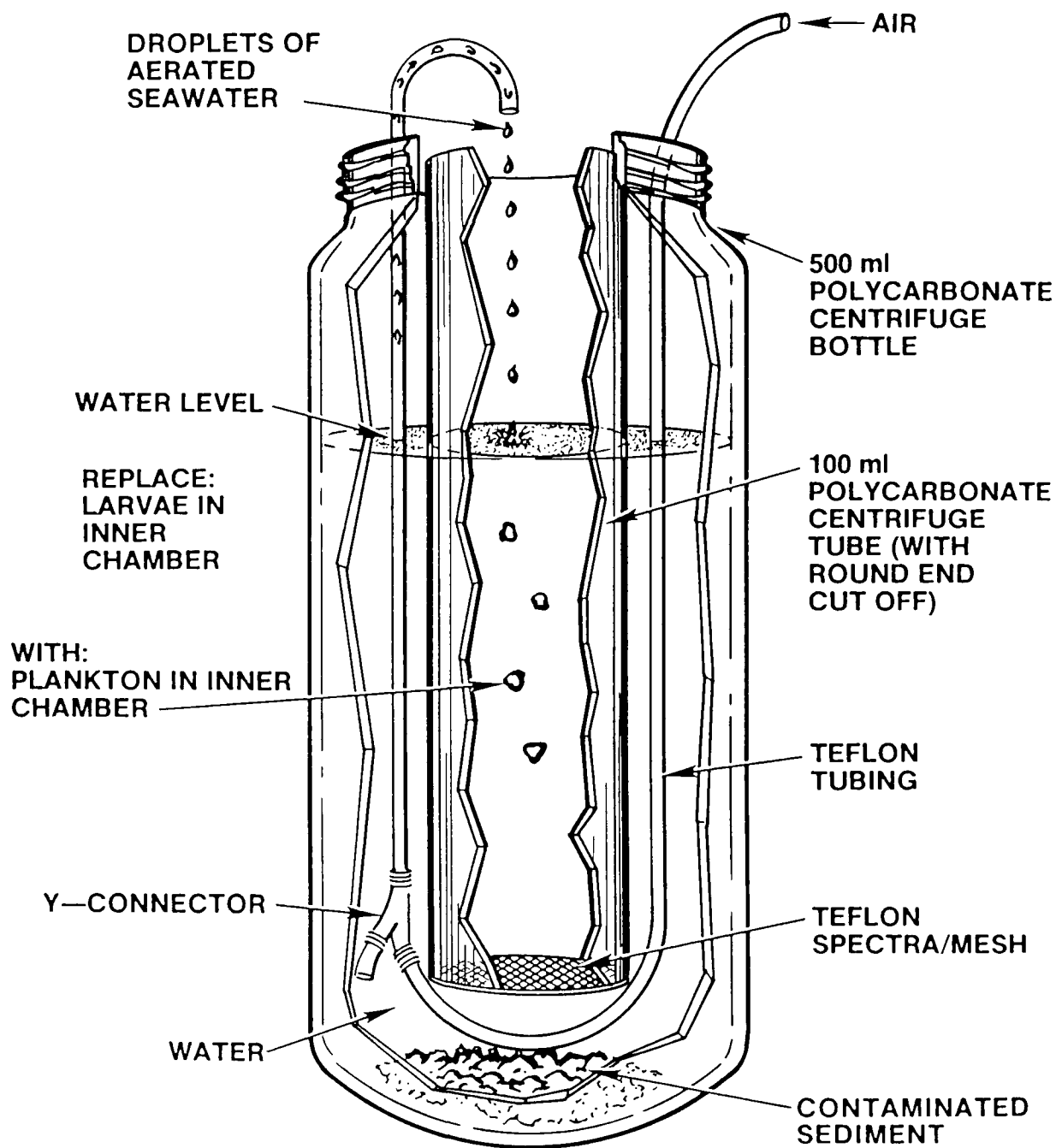


Figure 127a. Bioluminescence assay instrumentation.



*Figure 127b. Cutaway of laboratory assay chamber.*

## 128. BENTHIC FLUX SAMPLING DEVICE

**Category:** III. Analytical Methods and Instrumentation Development

**Purpose:** To determine in situ release rate (flux of toxicants) of chemical toxicants from contaminated sediment in aqueous environments.

**Application:** The method is applicable for any organic or inorganic contaminant in aquatic sediments.

**Description:** The Benthic Flux Sampling Device (BFSD) is deployed using a boat and left in place for a period of time ranging from hours to days after which it is retrieved (figure 128). The BFSD forms a seal with the sediment. Toxicants in the sediment below the BFSD that are released into the water column are monitored. The BFSD collects samples at a prearranged rate for analysis in the laboratory. Also, flow-through sensors monitor temperature, salinity, and oxygen, and store the data on a commercially available RAM device. The device as tested is applicable to a depth of 50 m. The water samples are analyzed by conventional laboratory procedures.

**Advantages:** No alternative method is available. Only a short training period is required.

**Limitations:** Excessively rocky sites would preclude establishing a seal. The depth to which the device can be deployed is limited to 50 m (164 ft).

**Costs:** Capital costs are about \$40,000. A boat, length of about 20 to 40 ft with a boom, is required to deploy the device.

**Availability:** Specifications are available from NCCOSC RDT&E Division. The control unit is commercially available.

**Status:** The device has been field tested in San Diego Harbor. A demonstration project was performed at Puget Sound Naval Shipyard, WA, in FY91.

**References:** Not available.

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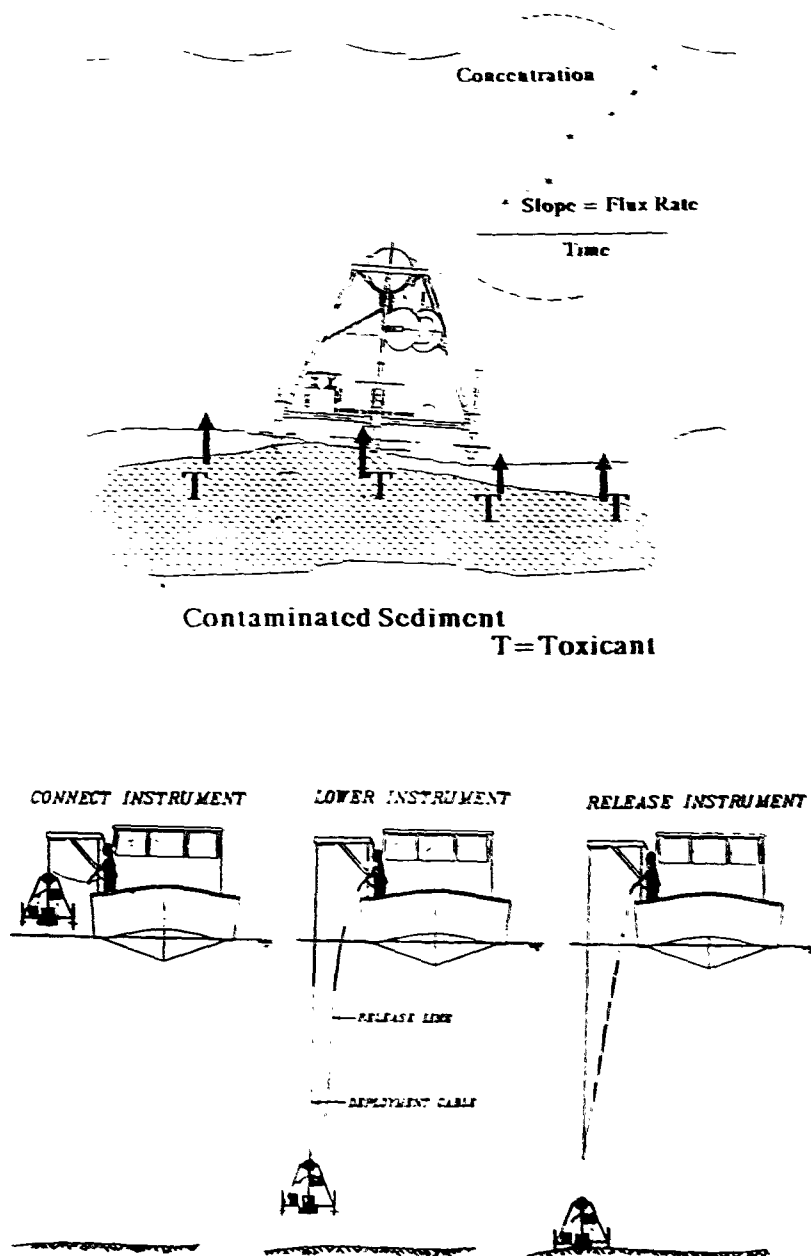


Figure 128. Benthic contaminant flux sampling: device (top) and deployment method (below).

## 129. FIBER OPTIC SENSORS

- Category:** III. Analytical Methods and Instrumentation Development
- Purpose:** To develop a technology to screen/map contaminants at hazardous waste sites for use in conjunction with cone penetrometer.
- Application:** The method is applicable for detection of aromatic hydrocarbons and some metals in soil or water.
- Description:** Measurement of laser-induced fluorescence – called emission spectra – via fiber optic cable coupled to a diffraction grating/photodiode array. Time resolved fluorescence can be used to improve specificity. It can use chelating agents to detect metals. These sensors may be deployed using the cone penetrometer from a land vehicle or from an ocean platform. At sea, the sensors may be used for analysis by pumping water through the sensor or by towing the sensor behind a ship. The equipment is mobile and may be used to locate or monitor waste streams (see figure 129).
- Advantages:** High spatial resolution can resolve contaminant concentration changes on the order of centimeters. High speed analysis is made on contaminants in a fraction of a second. Remote or in situ measurements are possible.
- Limitations:** The analytical process is not as rigorous as laboratory procedures. At the present time, it is a screening technique rather than a standard analytical measurement. Detectable limits for petroleum, oil, and lubricants are about 10 ppm.
- Cost:** Potentially low cost on a cost/sample basis. Approximately \$50,000 capital would purchase a package for use by technicians.
- Availability:** The equipment components are commercially available. Hydrocarbon detection equipment has been developed. Metal detection equipment is under development.
- Status:** Bench-scale pilot testing for hydrocarbon detection was conducted by NOSC, AFCESA, and WES. Field testing was completed at Jacksonville NAS, FL, Tyndall AFB, FL, DOE Savannah River Plant, GA, Philadelphia NSY, PA, and Tinker AFB, OK. The petroleum hydrocarbon penetrometer system (see note #134) is being transitioned to Navy and Army engineering field divisions.
- References:** Gillispie, G.D. and R.W. St. Germain. **In Situ Tunable Laser Fluorescence Analysis of Hydrocarbons.** In *Environmental Process Monitoring Technologies*, Tuan Vo-Dinh, Editor, Proc. SPIE 1637, 1992, pp. 151-62.
- St. Germain, R.W. and G.D. Gillispie. **Transportable Tunable Dye Laser for Field Analysis of Aromatic Hydrocarbons in Groundwater.** Proc. 2nd International Symposium of Field Screening Methods for Hazardous Wastes and Toxic Chemicals, 1991, pp. 789-92.
- Seitz, W.R. et al. **Membranes for Optical In Situ Detection of Explosives in Groundwater.** Proc. 14th Annual Army Environmental Symposium, U.S. Army Toxic and Hazardous Materials Agency Report CETHA-TE-TR-90055, Apr 1990.

Lieberman, S.H., S.M. Inman, and G.A. Theriault. **Use of Time-Resolved Spectral Fluorometry for Improving Specificity of Fiber Optic-Based Chemical Sensors.** Proc. SPIE Optoelectronics & Fiber Optic Devices & Applications, Env. and Pollution Measurement Syst., Boston, 1989.

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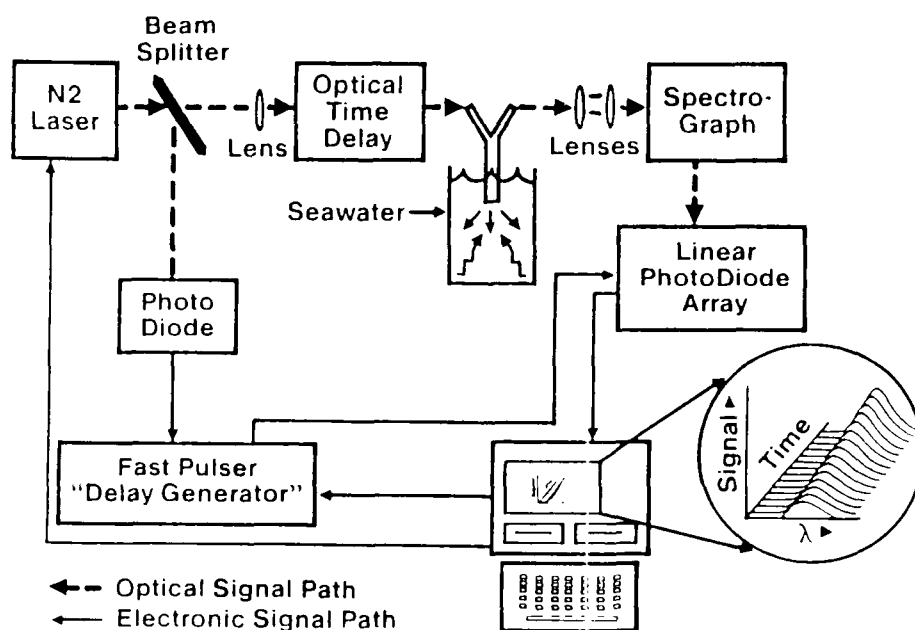


Figure 129. Fiber optic system configuration.

## 130. HIGH RESOLUTION FOURIER TRANSFORM INFRARED (FT-IR) FOR ENVIRONMENTAL MONITORING

- Category:** III. Analytical Methods and Instrumentation Development
- Purpose:** Development of a field screening method for ambient air quality analysis.
- Application:** This method is applicable for the detection, measurement, and monitoring of volatile organic compound (VOC) concentration, in parts per billion (ppb), in the atmosphere.
- Description:** A mobile system has been developed at Kansas State University to measure VOCs in the atmosphere using a Fourier transform infrared (FT-IR) spectrometer. The mobile FT-IR spectrometer system was developed to conduct on site measurements and analyses so that results can be obtained and reported more quickly. Field measurements at path lengths up to 600 m have been conducted at industrial sites. Estimates of detection limits as an average concentration over a path length of 100 m are made for 26 mid-infrared absorption bands of 21 compounds. These estimated detection limits vary from 5 to 76 ppb.
- Advantages:** This technology is a quick screening method for VOCs. A large distance, up to 1 km<sup>2</sup>, may be covered with one pass to analyze the atmosphere for VOCs.
- Limitations:** No point-sampling is possible with the present technology, only sampling along a straight or folded pathway.
- Cost:** Not available.
- Availability:** All components used in this technology are off-the-shelf items that are commercially available. The end product for this technology is developmental.
- Status:** Field-pilot testing was conducted through Kansas State University, Manhattan, KS, and the University of Kansas, Lawrence, KS.
- References:** Report on Preliminary Evaluation of a High Resolution Fourier Transform Infrared (HR-FT-IR) for Environmental Monitoring, U.S. Environmental Protection Agency, EPA/600/X-89/225, Aug 1989.
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## 131. DETECTION OF EXPLOSIVES AND RELATED COMPOUNDS BY FOURIER TRANSFORM INFRARED SPECTROSCOPY

**Category:** III. Analytical Methods and Instrumentation Development

**Purpose:** To determine the availability and effectiveness of Fourier transform infrared spectroscopy (FTIR) for the detection of explosive degradation products and other organic compounds.

**Application:** This method is applicable for the field-detection of explosives and other organic compounds in soil and groundwater.

**Description:** This system (figure 131) can be used in the field for a quick screening method for the detection of volatile organics, semi-volatiles, and explosives. It is capable of analyzing areas as large as 1 km while still achieving reasonable quantitative results for wet soil and contaminated groundwater in the 5 to 100 ppb range. The analytical procedure is as follows: (1) place weighed soil in tip of desorption probe, (2) evacuate cell, (3) insert desorption probe into TDU (thermal desorption unit), (4) evacuate TDU and inlet assembly, (5) thermally desorb contaminants from soil, (6) explosives vaporize and enter the cell, (7) collect spectral data and perform computerized data analysis.

**Advantages:** Time and shipping costs are saved by performing analyses in the field.

**Limitations:** None identified at this time.

**Cost:** Not available.

**Availability:** Under development.

**Status:** Research and development are ongoing.

**References:** Demirgian, J. A Quantitative Method to Detect Explosives and Selected Semivolatiles in Soil Samples by Fourier Transform Infrared Spectroscopy. Proc. 1992 JANNAF Safety and Environmental Subcommittee Meeting, Naval Postgraduate School, Monterey, CA, Aug 1992.

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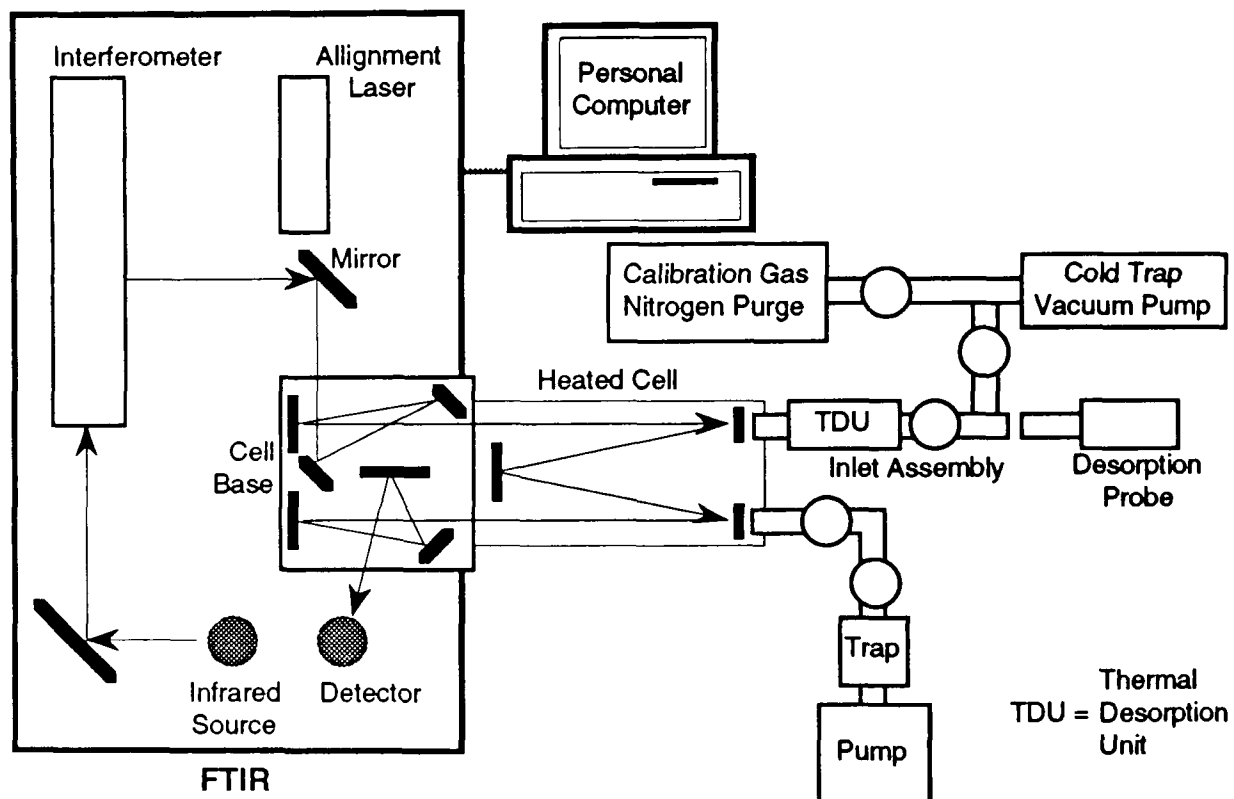


Figure 131. Detection of explosives in soils using FTIR.

## 132. TRANSPORTABLE GAS CHROMATOGRAPH/MASS SPECTROMETER (GC/MS)

- Category:** III. Analytical Methods and Instrumentation Development
- Purpose:** To field test the thermal desorption gas chromatograph/mass spectrometer (GC/MS) technology and to determine its effectiveness and its use for sampling activities.
- Application:** The technology is applicable for screening and quantifying organic compounds in water and soil matrices, including polychlorinated biphenyls (PCB), volatile organic compounds (VOC), phenols, and pesticides.
- Description:** The method involves analyte introduction by thermal desorption followed by fast GC separation and MS detection. The MS used initially was designed as a chemical agent detector and was manufactured from the outset as a field instrument. The unit weighs about 300 pounds. It is transported to the field in a mid-sized truck and is battery-operated for 8 to 10 hours at ambient conditions. Samples have been obtained at ambient conditions ranging from 10° F to 90° F in rain, snow, and in high humidity. Gas cylinders are not necessary since charcoal-filtered ambient air serves as the carrier gas.
- Advantages:** The method enables obtaining real-time, accurate analytical results.
- Limitations:** The method is applicable to organic compounds only.
- Costs:** Not available.
- Availability:** The instrumentation is commercially available.
- Status:** The method was developed at Tufts University and field tested at Ft. Devens, MA.
- References:** Robbat, A., Jr., T-Y. Liu, B. Abraham, and C-J Liu. **Thermal Desorption Gas Chromatography-Mass Spectrometry Field Methods for the Detection of Organic Compounds**. Second International Symposium on Field Screening Methods for Hazardous Waste and Toxic Chemicals, Feb 1991.
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## 133. VOLATILE ORGANIC COMPOUND MONITOR

**Category:** III. Analytical Methods and Instrumentation Development

**Purpose:** The method is applicable for the on site, same-day analysis of volatile organic compounds (VOC) in water. Application has been filed with the U.S. Environmental Protection Agency (EPA) for approval of this method and instrumentation as an alternative method for analysis of VOCs in the field.

**Application:** The instrumentation was developed for on site monitoring of VOCs and enables same-day analysis of contaminated water. Prior to the development of this method, several days were needed for analysis of contaminated water at an off site location. The instrumentation for this method may be used to monitor VOC contamination in aquifers, spill sites, monitoring wells, effluent treatment facilities, tracking of pollution plumes in monitoring wells, efficiency of air stripping, etc.

**Description** Prototype instrumentation consists of a liquid sample concentrator with a 10-position autosampler, a gas chromatograph, and a personal-computer-based data acquisition system (figure 133). The system design for determination of trichloroethylene (TCE) in groundwater is based on an initial purge-and-trap concentration step. The purge-and-trap procedure effects extraction of VOCs from aqueous solution in a stream of inert gas and concentrates the extracted volatiles on an adsorbent trap; in this application, the adsorbent is Chromosorb WHP (60/80 mesh). Once the VOCs are deposited on the adsorbent trap, the trap is heated quickly to 180° C and flushed with nitrogen. The gas stream carrying the desorbed analytes is swept through heated transfer lines into the gas chromatograph, where separation and detection are accomplished. The hardware for the next phase of development of this method is a Wang 386 Computer, OI 4460A Sample Concentrator, Dyna Tech PTA 30 Auto Sampler, and Capillary GC Column DB 624. This method is a minor modification of EPA Methods 601, 602, and 624. The instrumentation for this method was developed for field analysis for TCE in groundwater after air stripping. The instrumentation and method are applicable for aromatic and chlorinated hydrocarbons. TCE is detectable in parts per billion (ppb) using this method and instrumentation. It was accepted as an alternate technical procedure (ATP) for analysis of TCE at the demonstration site, Wurtsmith AFB, Michigan. Minimal experience and training are needed for conducting this procedure. Internal blanks and matrix spikes are required for quality control. The system is automated. Conventional purge-and-trap technology is used. State-of-the-art technology is used in instrumentation and recording. Flame detection method used varies from EPA approved detection method; it was chosen because it is more rugged. Close to ppb in sensitivity is acceptable because it may detect false highs but does not give false low readings.

**Advantages:** The procedure and method are automated except for sample collection and preparation of standards. Only infrequent cleaning is necessary and annual maintenance is required. Thirty (30) minute turnaround time for analysis, fixed front-end cost for sample analysis for annual budgeting (380 samples per week), used on site as an analytical method, and minimal training and no experience needed for operators (mechanical aptitude needed).

**Limitations:** Access to repair support, sensitive to dust, and reasonable security is necessary in non-laboratory environments.

**Cost:** Cost of operator(s) plus an estimated \$10,000 annual operating cost. Startup cost of \$75,000 is estimated for instrumentation and installation on site.

**Availability:** All instrumentation used in the prototype is commercially available with the final prototype installation in the field during July 90.

**Status:** Phase I was accepted by the EPA as a local ATP in the installation at Wurtsmith AFB, MI. Phase II has begun with installation of instrumentation as described above at Wurtsmith AFB and Castle AFB, CA.

**References:** Wander, J.D., B.L. Lentz, L. Michalec, and V. Taylor. **Prototype Volatile Organic Compound (VOC) Monitor.** First International Symposium: Field Screening Methods for Hazardous Waste Site Investigations, Oct 11-13, 1988, USEPA, pp. 319-23.

Taylor, V. and J. Wander. **Prototype Technology for Monitoring Volatile Organics, Volume I,** Engineering & Services Laboratory, Air Force Engineering & Services Center, Tyndall Air Force Base, FL, Final Report ESL-TR-88-01, Vol. I, Mar 1988.

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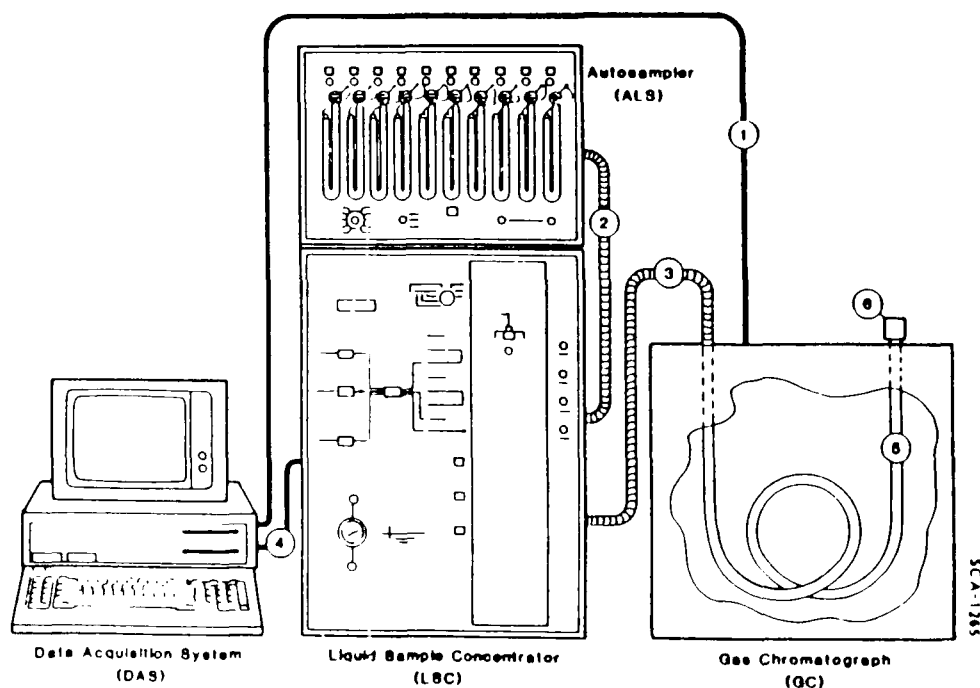


Figure 133. Schematic diagram of computer-controlled instrument for purge-and-trap analysis of volatile organics.

## 134. SITE CHARACTERIZATION AND ANALYSIS PENETROMETER SYSTEM (SCAPS)

**Category:** III. Analytical Methods and Instrumentation Development

**Purpose:** To enable better characterization of the geology and extent of contamination of hazardous waste sites for more effective emplacement of monitoring wells.

**Application:** The method will be applicable for any site with sand, silt, or clay deposits. Penetration in gravels and cemented soils is limited. The wastes for which the method will be applicable will depend upon the analytical capabilities that can be incorporated within the penetrometer. Currently this technology is applicable to waste which can be found with the electrical resistivity geophysical method and fluorescence. In the future this technology will be applied to detection of explosives, heavy metals, solvents, and radioisotopes (also see notes 135 and 136).

**Description:** The site characterization and analysis penetrometer (SCAPS) apparatus is truck-mounted. Surface scanning with ground-penetrating radar, electromagnetic induction, magnetometer instruments, or other geophysical techniques for location of buried metal objects is necessary to avoid damage to the cone tip. The SCAPS rod with the instrumented cone tip is pushed into the soil by a hydraulic ram. Three persons are required for operation: one to operate the hydraulic system equipment, the second to assist the first and to operate the grouting equipment, and the third to monitor the analytical equipment and data collection systems. Depending on the site and the penetration depth, approximately 10 to 20 test penetrations can be made per day. A truck should be able to collect 600 to 700 ft of soil data per day. Several analytical techniques are possible with three modes now available: (1) real time soil and contaminant analysis or screening, (2) sampling, and (3) monitoring when a device is deposited in the subsurface by the SCAPS. Soil gases can be analyzed by a gas chromatograph connected by a tube through which the gases can be drawn to a sensing device pushed into the ground by SCAPS. The resistivity sensor provides real time monitoring of subsurface geophysics, resistivity, and some contaminant detection. Qualitative information about soil types and underground structure can be obtained by measuring soil strength parameters, such as point resistance, frictional sleeve resistance, and soil electrical resistivity. A penetrometer cone has been developed with laser-excited fluorescence via a dual fiber optic pathway connected to an optical multi-channel analyzer [U.S. Patent 5,128,882 assigned to Department of the Army]. This cone can detect changes in fluorescence in real time. Subsurface liquid and soil/waste samples can be taken using commercially developed samplers. The system has been successfully field tested at several waste sites during 1990 – 92 for detection and 3-D visualization of hydrocarbon contaminant plumes. The SCAPS may be used to identify or monitor contaminated soil or groundwater to depths as great as 150 ft below the surface.

**Advantages:** The better a site can be characterized, the fewer monitoring wells are required and fewer wells are misplaced. This method will assist the preliminary determination of the vertical and horizontal extent of the contamination. This technology offers two-fold cost savings: (1) fewer monitoring wells needed and (2) elimination of the cost of sampling and chemical analysis of samples from misplaced wells. A high degree of operator safety on hazardous waste sites is achieved with the self-contained SCAPS

unit. By providing two separate compartments, each with its own air supply, data collection is separated from push rod operations that can be contaminated.

**Limitations:** The penetrometer will be limited by the location of bedrock or other solid obstructions. The types of waste detectable will be limited by the types of analytical equipment incorporated within the penetrometer.

**Cost:** A SCAPS rig costs approximately \$10/ft of penetration to operate. Future site monitoring costs are reduced because of the better 3-D site characterization. This method is more cost effective in real-time mode. Original capital cost for the truck/penetrometer system is estimated to be about \$500,000. This capital expenditure compared favorably to a cost of \$5,000 to \$10,000 for the installation of a single monitoring well because the SCAPS can be used in delineating many contaminated sites.

**Availability:** The method has been tested and is being further developed. A prototype system is available at WES. Three SCAPS systems are being built for the Corps of Engineers and one for the Department of Energy (DOE). Currently, SCAPS is capable of developing data on site geophysics, soil resistivity, and soil fluorescence. Sensors to detect explosives and chlorinated hydrocarbons should be available in 1993.

**Status:** The method has been tested in the field at Tyndall Air Force Base, Savannah River Site (DOE), GA, Jacksonville Naval Air Station, FL, the Philadelphia Naval Shipyard, PA, and the Louisiana Army Ammunition Plant, LA. Future DOD, DOE, and EPA site visits are in the planning stage.

**References:** Malone, P.G., et al. **Cone Penetrometer Surveys of Soil.** in Usmen, M.A. and Y. Acan, eds. *Environmental Technology*, Balkema, Rotterdam, 1992, pp. 251-7.

**Device for Measuring Reflectance and Fluorescence of In Situ Soil.** U.S. Patent 5,128,882, Jul 7, 1992.

Cooper, S.S. et al. **Development of an Innovative Penetrometer Technology for the Detection and Delineation of Contaminated Soils.** Proc. 14th Annual Army Environmental Symposium, U.S. Army Toxic and Hazardous Materials Agency Report CETHA-TE-TR-90055, Apr 1991

Cooper, S.S. and P.G. Malone, **Three Dimensional Mapping of Contaminant Distribution in Soil Using a Soil Penetrometer,** *The Military Engineer*, 83(544):54-5, 1991

Lucero, D.P. **A Soil Gas Sampler Implant for Monitoring Dump Site Subsurface Hazardous Fluids.** *Hazardous Materials Control*, 3(5):36-44, Sep-Oct 1990.

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## 135. TERRATROG

- Category:** III. Analytical Methods and Instrumentation Development
- Purpose:** To develop a safer, more effective method to identify and track contaminants in soil and water.
- Application:** The method is applicable for identifying and monitoring volatile organic compounds (VOC) in soil and water.
- Description:** The TerraTrog system (figures 135a and 135b) consists of two modules: (1) an implant of small dimensions containing a gas-permeable membrane of high diffusion impedance that is deployed to subsurface levels, and (2) a surface module that functions as the regulator for carrier gas as well as an interface for sampling and calibrating the system. Traditional soil gas sampling techniques collect samples with a vacuum. In contrast, this system relies on soil gas diffusion through a semi-permeable membrane and an inert carrier gas stream that is flowing at a slight positive pressure for lifting the sample to the surface. The sampling is diffusion-limited by a membrane of known impedance. Therefore, the sampling rate and size are independent of soil permeability.
- Advantages:** The method is safe – human contact with contaminants is decreased since deployment of the implant using a cone penetrometer does not involve drilling which would bring contaminants to the surface in the drill cuttings. The method is efficient – a sample can be obtained either in the static mode within 6 to 7 days or the dynamic mode in real time allowing 5 to 10 minutes to start up. When deployed in a monitoring well, bailing and water collection are not required. Since this is a closed system, the sample analysis is more representative of contaminant levels than those obtained by traditional methods.
- Limitations:** In soil, the deployment is limited to the capability of the cone penetrometer.
- Costs:** Costs are estimated at \$120,000 in FY93 and \$180,000 in FY94.
- Availability:** TerraTrog is still under development.
- Status:** TerraTrog has been field tested at two sites. Cone penetrometer deployment was carried out at the Department of Energy's Savannah River Site, GA, in 1992. The implant was also deployed in groundwater wells at the U.S. Army Phoenix Nike Site, Baltimore County, MD, in 1992.
- References:** Madden, M.P, Daniel P. Lucero, and S. K. Hendrickson. **Preliminary Field Characterization of TerraTrog in Soil and Groundwater Wells – Final Report.** USATHAMA Report, National Institute for Petroleum and Energy Research, Dec 1991.
- Lucero, D.P. **A Soil Gas Sampler Implant for Monitoring Dump Site Subsurface Hazardous Fluids.** *Hazardous Materials Control*, 3(5):36-44, Sep/Oct 1990.

Lang, K.T., D.T. Scarborough, M. Glover, and D.P. Lucero. **Quantitative Soil Gas Sampler Implant for Monitoring Sump Site Subsurface Hazardous Fluids.** Second International Symposium on Field Screening Methods for Hazardous Wastes and Toxic Chemicals.

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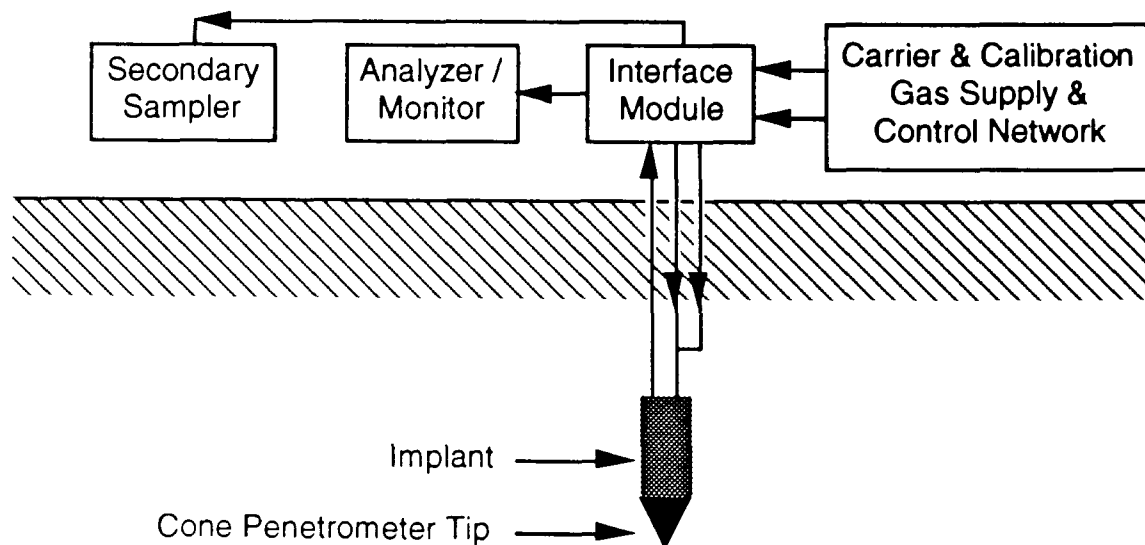
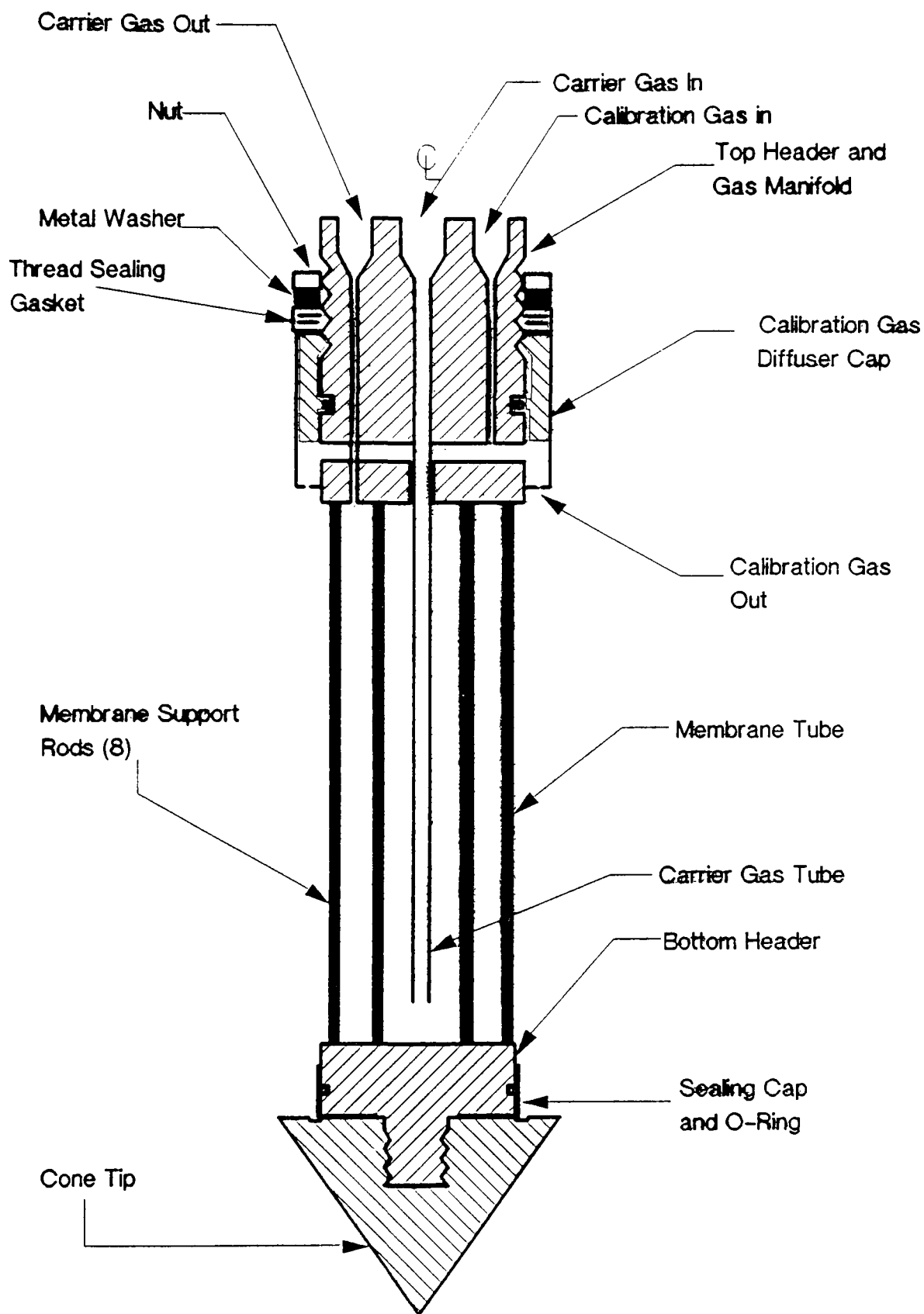


Figure 135a Schematic diagram of the TerraTrog implant and surface module system as deployed by a cone penetrometer.



*Figure 135b Schematic diagram of the TerraTrog implant .*



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## 136. CHLORINATED HYDROCARBON DETECTOR FOR CONE PENETROMETER SYSTEM

- Category:** III. Analytical Methods and Instrumentation Development
- Purpose:** To detect, quantify, and map subsurface chlorinated hydrocarbon contamination, even in the presence of salt water intrusion, at hazardous waste sites utilizing the cone penetrometer as a rapid and cost-effective delivery vehicle.
- Application:** The method is applicable for the detection of liquid-phase chlorinated hydrocarbons in soil or groundwater.
- Description:** The method is based on gamma-ray spectrometry of emissions from neutron capture by hydrogen and chlorine nuclei present in the chlorinated hydrocarbon (CHC) compounds. Energetic neutrons are produced by an electronically produced collision of deuterium and tritium in a miniature accelerator located within the penetrometer. The gamma-ray energies generated by the capture are unique for each of these elements. The ratio of H:Cl identified can be used to differentiate CHC from other chlorinated compounds such as salt in water.
- Advantages:** This technique will enable in situ detection of CHCs without additional chemical analysis. When coupled with the cone penetrometer, this technique provides rapid and economical screening and mapping of hazardous waste sites. The electronically produced neutron flux removes the inherent danger normally associated with the use of radioisotopes to accomplish this type of gamma-ray spectrometry.
- Limitations:** This technique is not as sensitive as some analytical techniques, and the minimum detectable concentration limits have not been determined for the final deployed system. At present, this system is considered a screening technique only. The primary application will be to aid in the placement of standard analytical test wells at hazardous waste sites.
- Costs:** Capital investment for a field-deployed system for use in conjunction with the cone penetrometer delivery system is estimated at \$85,000. This system would be operated by the same technicians operating the penetrometer. Estimated hourly cost for operation would be less than \$100.
- Availability:** The technique is a refinement of current well logging technology. Most of the effort is in developing the analysis algorithms and engineering the final package to be compatible with the cone penetrometer. Most of the individual components are commercially available.
- Status:** The technique will be initially funded in FY92, and a system to be integrated in the cone penetrometer is expected early in FY95.
- References:** Smith, R.C., C.H. Bush, and J.W. Reichardt. **Small Accelerators as Neutron Generators for Borehole Environment.** *IEEE Transactions on Nuclear Science*, 35(1):859-62, Feb 1988.

Snyder, D.D. and D.B. Fleming. **Well Logging - a 25-Year Perspective.** *Geophysics*, 50(12):2504-29, 1985.

Fletcher, J.W. and J. Walter. **A Practical Shale Compensated Chlorine Log.**  
SPWLA 19th Annual Logging Symposium, Jun 1978.

Peatross, R.F. **A New Lithology Compensated Capture Gamma-Ray System.**  
SPWLA 17th Annual Logging Symposium, Jun 1976.

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## 137. ENVIRONMENTAL GEOPHYSICS – SITE CHARACTERIZATION

**Category:** III. Analytical Methods and Instrumentation Development

**Purpose:** Non-invasive characterization methodology for hazardous and toxic waste sites, to include geology, hydrogeology, and the presence of contaminants.

**Application:** This technology can be used for contaminant plume detection and mapping, underground storage tank location and condition assessment, disposal trench mapping and characterization, mapping of buried metallic objects (drums, cylinders, unexploded ordnance, etc.), characterization of subsurface geologic structure and stratigraphy, and groundwater flow characteristics.

**Description:** This technology is a state-of-the-art application of shallow, high resolution geophysical surveying (see notes 155 and 156). The methods include ground penetrating radar, electromagnetic methods (terrain conductivity), microgravity, magnetic surveys, seismic refraction and reflection, electrical resistivity (surface and borehole), and surface airborne and waterborne instrumentation and data gathering. Computer processing of data collected using these geophysical methods is needed for best interpretation and utilization of methodology and data collected.

Instrumentation is mobile and non-invasive. Fundamentally there is no depth limitation on data collection and recording using these technologies, but a 200 ft depth of investigation is generally considered the maximum depth of data utilization for site characterization of contaminated substrata.

**Advantages:** Geophysical methodologies complement drilling, sampling and testing by optimizing location and number of drilling and sampling points needed to characterize a site. The final interpretation of these geophysical data results in overall lower cost.

**Limitations:** Quantitative indication of contaminant concentration in soil or groundwater is not generally an end result of geophysical technologies. Invasive sampling after geophysical survey interpretation is needed for quantitative evaluation of contaminant plumes.

**Cost:** Costs are site specific because of the difference in areal extent of each site.

**Availability:** Skilled operators are required for data collection using off-the-shelf equipment and instrumentation. Geophysical methodology is commercially available or available through government laboratories. Skilled, experienced personnel are required in all phases of planning, surveying, data processing, and interpretation.

**Status:** At WES, these technologies are available, and their results are accepted.

**References:** Butler, Dwain K, *Environmental Geophysics – Applicability, Physical Principles, Capabilities and Limitations for Hazardous and Toxic Waste Site Assessments and Monitoring*, Draft Guidelines, USATHAMA and WES, 1991.

Benson, R.C., R. Glaccum, and M.R. Noel, *Geophysical Techniques for Sensing Buried Wastes Migration*, National Ground Water Association, Columbus, OH, 1982.

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## 138. PORTABLE X-RAY FLUORESCENCE ANALYZER INTERFACED TO AN AUTOMATED POSITIONING SYSTEM FOR IN SITU DETERMINATION OF HAZARDOUS METALLIC COMPOUNDS

**Category:** III. Analytical Methods and Instrumentation Development

**Purpose:** Development of a field screening method for elemental analysis of soil.

**Application:** This method is applicable for the detection, measurement, and monitoring of hazardous inorganic (metallic) compounds.

**Description:** A portable ultrasonic ranging and data system (USRADS) developed earlier at the Oak Ridge National Laboratory (ORNL) was combined with a sodium iodide detector and used by ORNL to measure levels of radioactivity rapidly in a large number of uranium mill tailings sites around the U.S. (in response to the Uranium Mill Tailings Radiation Control Act of 1978). USRADS, interfaced with any appropriate detector or sensor, is capable of on site field measurements in situ, providing rapid reporting of results.

The U.S. EPA, through an Interagency Agreement to ORNL, funded the further development of the USRADS versatility so that it could be interfaced with any X-ray fluorescence (XRF) analyzer, of a type used by EPA for field screening of Superfund, RCRA or other hazardous waste sites. Detection limits with the XRF are highly matrix dependent and site specific but range from 100-500 mg/Kg when analyzing arsenic, chromium, copper, iron, lead, and zinc in soil. The particular XRF instrument interfaced to the USRADS is a HAZ-MET 880™ (formerly X-MET 880™).

**Advantages:** Provides a very rapid field screening method for inorganic (metallic) contaminants at Superfund, RCRA, or other hazardous waste sites.

**Limitations:** This instrumentation is still in the development stage. This advanced prototype, a modification of the earlier-developed USRADS, is expected to be subsequently available commercially under the provisions of the Federal Technology Transfer Act.

**Costs:** EPA purchased basic USRADS for \$50K and X-MET 880 for \$47K.

**Availability:** Components used in prototype are commercially available. End product is developmental.

**Status:** Field testing of this advanced prototype will be done at EMSL, through its prime, on site contractor, Lockheed Engineering and Sciences Company.

**References:** Nyquist, J.E. and M.S. Emery, **Adaptation of a Prototype data Telemetry-Locator System to a Portable X-ray Analyzer**. U.S. EPA, Environmental Monitoring Systems Laboratory Report EPA 600/X-91/146, 1991.

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### 139. PORTABLE SYNCHRONOUS UV-VIS SPECTROFLUOROMETER WITH FIBER-OPTIC PROBE FOR IN-SITU DETECTION OF HAZARDOUS ORGANIC COMPOUNDS

- Category:** III. Analytical Methods and Instrumentation Development
- Purpose:** Development of a field screening method for water and soil quality analysis.
- Application:** This method is applicable for the detection, measurement and monitoring of polyaromatic hydrocarbons (PAH), polychlorinated biphenyls (PCB), most pesticides and other hazardous hydrocarbons, and some heterocyclic compounds.
- Description:** A portable system has been developed at the Oak Ridge National Laboratory to measure very low levels of polyaromatic or polynuclear hydrocarbons in environmental water or soil samples using an ultraviolet/visible (UV-Vis) spectrofluorometer with synchronous and emission capabilities. The portable system was developed to do on site measurements and analysis in situ so that the field results could be reported quickly. Field measurements in 1992 will be done with a 2-meter fiber-optic probe for reaching into shallow monitoring wells, streams, and other environmental water samples (longer fiber-optic probes will be subsequently used). Alternatively, a 1-cm cuvette with a water sample or soil extract can be inserted into the instrument after detaching the fiber-optic probe. Estimates of detection limit run from the ppb to ppm range, depending on the fluorescent yield of the analyte.
- Advantages:** Provides a very rapid field screening method for PAH contaminants and can spectrally distinguish mixtures of compounds with varying numbers of fused rings.
- Limitations:** This instrumentation is still in the development stage. This advanced prototype, developed from the earlier-commercialized unit, will subsequently be commercially available under the provisions of the Federal Technology Transfer Act.
- Costs:** Expected not to exceed \$20,000.
- Availability:** Components used in prototype are commercially available. The end product is developmental.
- Status:** Field testing of this advanced prototype will be done at EMSL-LV, through its prime on site contractor, Lockheed Engineering and Sciences Company.
- References:** Eastwood, D. and T. Vo-Dinh, **Molecular Optical Spectroscopic Techniques for Hazardous Waste Site Screening**, U.S. EPA, Environmental Monitoring Systems Laboratory Report EPA 600/4091/011, 1991.
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## 140. UV-VIS LUMINESCENCE SPECTROMETRY FOR IN SITU FIELD SCREENING AND MONITORING OF HAZARDOUS WASTE SITES

**Category:** III. Analytical Methods and Instrumentation Development

**Purpose:** Development of low-cost spectroscopic field screening techniques and methods for detecting and monitoring of various polycyclic aromatic hydrocarbons (PAH), polychlorinated biphenyls (PCB), pesticides, phenols, and other hazardous aromatic and polyaromatic or heterocyclic compounds in water or soil.

**Application:** This method is applicable for the detection, monitoring and measurement of virtually all types of hydrocarbon compounds (noted above).

**Description:** Ultraviolet-visible (UV-Vis) photoluminescence techniques (i.e., fluorescence and phosphorescence) are beginning to be of interest as low-cost alternatives for field screening and /or monitoring of Superfund or RCRA sites for the U.S. EPA (EPA). Examples are: (1) a fixed-wavelength excitation while recording the fluorescence emission spectrum, and (2) synchronous fluorescence in which both excitation and emission monochromators are scanned simultaneously with a small wavelength offset to produce a simplified spectrum with usually one sharp peak per compound.

**Advantages:** (1) Provides a rapid and low-cost alternative (compared to gas chromatograph/mass spectrometer (GC-MS)) field screening method for very low levels of hazardous aromatic or polyaromatic hydrocarbons, noted above. (2) The simplified, sharp spectra, specific for each compound, enables easier identification of the classes present in mixtures of PAHs or PCBs. Spectral separation into classes is roughly according to the number of fused rings. (3) Little or no sample preparation is required. (4) Techniques are also powerful for fluorescent metal chelates and uranyl ions.

**Limitations:** Field screening methods are in both early and advanced stages of development (see Status section, below). Also, the methods do not apply to all classes of compounds.

**Costs:** Instrumentation cost is relatively low. Also, relatively low sample preparation costs, over that for traditional method (e.g., GC-MS), since little or no sample preparation is required.

**Availability:** ASTM (when published) and subsequently as EPA methods.

**Status:** A PAH field screening method using fluorescence spectroscopy is in the final stage of development for ASTM. Round-robin test results have been incorporated into the draft method.

A PCB field screening methods using room temperature phosphorescence is in an early stage of development for ASTM. This method development is being conducted for the EPA at the Environmental Monitoring System Laboratory in Las Vegas (EMSL-LV). The prime on site contractor, Lockheed Engineering and Sciences Company (LESC), is the developer of the PAH method, described above (D. Eastwood, Principal investigator); the PCB method is being developed by Oak Ridge National Laboratory through an Interagency Agreement (T. Vo-Dinh, Principal Investigator),

in collaboration with on site LESC staff (the reference below indicates other collaborative studies).

**References:** Eastwood, D. and T. Vo-Dinh, **Molecular Optical Spectroscopic Techniques for Hazardous Waste Site Screening**, U.S. EPA, Environmental Monitoring Systems Laboratory Report EPA 600/4-91/011, 1991.

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## 141. PORTABLE ELECTROMAGNETIC SENSOR FOR DETECTION OF UNDERGROUND STORAGE TANKS

**Category:** III. Analytical Methods and Instrumentation Development

**Purpose:** This method is applicable for the detection of metallic and nonmetallic underground storage tanks (UST) with a hand-held electromagnetic sensor.

**Application:** The method is applicable for the detection of buried metallic tanks and of voids representing non-metallic tanks.

**Description:** The basic principle of a frequency-domain electromagnetic (EM) system involves the measurement of change in mutual impedance between a pair of coils moving over the earth. A transmitter coil sets up a sinusoidally varying primary field that induces a system of currents within the earth below. These induced currents, in turn, generate a secondary magnetic field that is measured by a receiver coil (figure 141).

**Advantages:** This is a hand-held detection instrument for metallic and nonmetallic underground storage tanks.

**Limitations:** The method cannot be used to determine if tanks are intact or leaking.

**Cost:** The costs are indeterminant until the prototype is delivered, but the target range is less than \$15,000.

**Availability:** Not yet commercially available.

**Status:** Prototype delivery under Phase III of the Small Business Innovative Research program is scheduled for October 1992.

**References:** None available.

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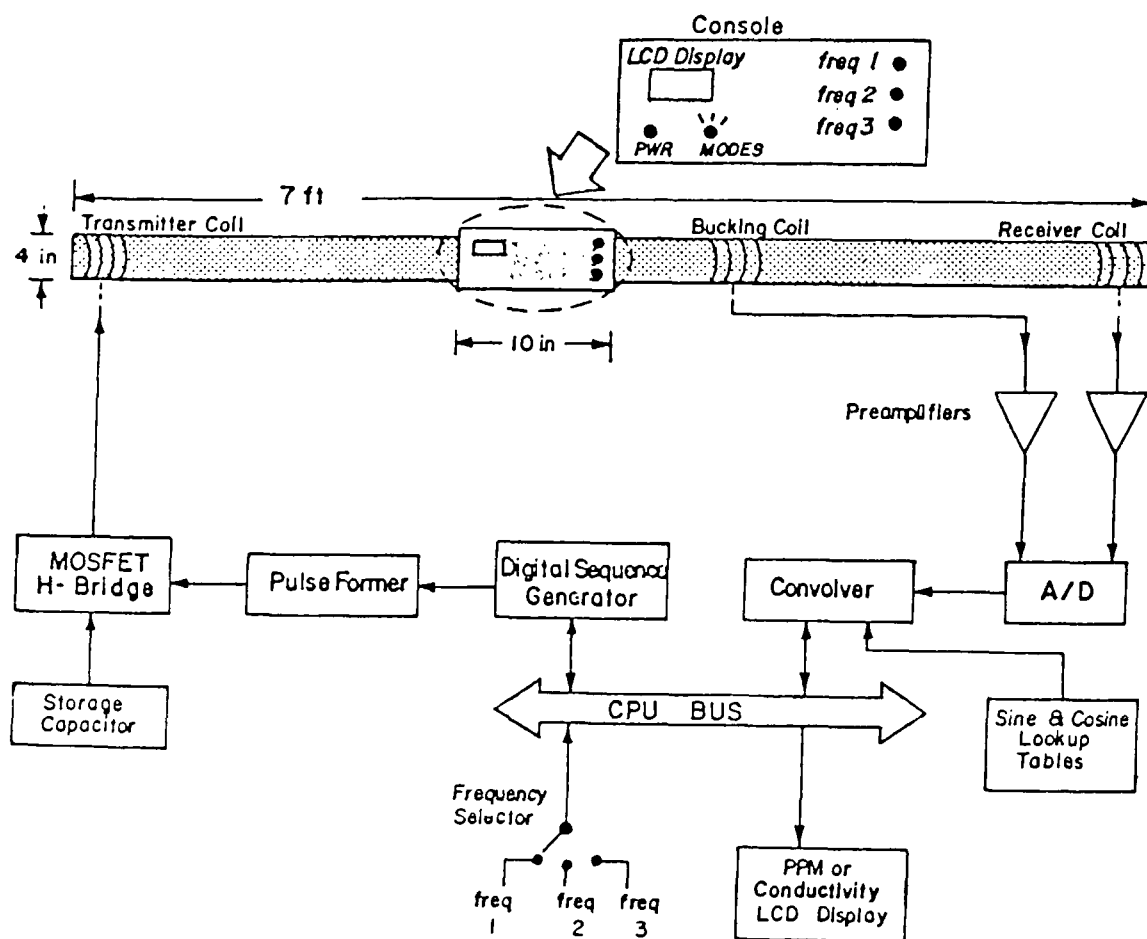


Figure 141. Electronic block diagram and a possible packaging of the proposed portable EM sensor.

## 142. SOIL GAS SAMPLING FOR DETECTION OF SUBSURFACE ORGANIC CONTAMINATION

**Category:** III. Analytical Methods and Instrumentation Development

**Purpose:** To detect subsurface organic contamination by sampling of soil gas for volatile organic compounds (VOC).

**Application:** This method is applicable for the sampling of soil gas above suspected groundwater contamination. This technique may be used to detect the extent of groundwater contamination without installation of monitoring wells. It may detect movement of VOCs in groundwater from a contaminated hazardous waste site without installation of monitoring wells.

**Description:** In active sampling, a hollow pipe is driven into the ground to a prescribed depth, and soil gases are pulled through it to the surface. The sample is then analyzed by gas chromatography (GC) at or near the sampling location. This method offers the benefit of immediate results as the survey progresses, an attractive feature which allows the sampling plan to be changed on the basis of results. In addition, preliminary measurements can be performed to allow investigators to optimize certain survey parameters, such as sampling depth.

An analytical field van was equipped with two Tracor GCs with flame ionization detectors (FIDs) and two computing integrators for real-time sampling and analysis of the soil gas. This van was also equipped with a specialized hydraulic ram mechanism used to drive and withdraw the sampling probes. The probes consisted of 2.1-m (7-ft) lengths of 1.9-cm diameter (3/4-in.) steel pipes fitted with detachable drive points. A hydraulic hammer was used to assist in driving the probes through hard soil.

Soil gas samples are collected from depths ranging from 0.6 to 2.4 m (2 to 8 ft) in the ground. The above-ground ends of the sampling probes are fitted with a steel reducer and a length of polyethylene tubing leading to a vacuum pump. Approximately 5 to 10 liters of gas are evacuated with the vacuum pump to assure a representative sample. Samples are collected by inserting a syringe needle through a silicone rubber segment, just above the reducer, in the flowing evacuation line and down into the steel probe. Ten milliliters (mL) of soil gas are collected for immediate analysis with one of the GCs. The soil gas is subsampled in volumes ranging from 1 to 2 mL, depending on the expected concentrations of volatiles. The syringe needles are used once and discarded and the syringes are cleaned and autoclaved after each use.

Specialized sophisticated equipment for gas sampling and analysis are required. The presence of this equipment requires a specialist to operate and maintain it, and associated support systems such as generators and gases. This technique has been used successfully at a large number of sites.

**Advantages:** This method offers the benefit of immediate results as the survey progresses, an attractive feature which allows the sampling plan to be changed on the basis of results. In addition, preliminary measurements can be performed to allow investigators to optimize certain survey parameters, such as sampling depth. An

additional advantage of this approach is the presence of analytical equipment to perform on site screening of soil and groundwater samples.

**Limitations:** Specialized sophisticated equipment for sampling and analysis are required. Specialists are required for operation and maintenance of this equipment. Support systems such as generators and gases are required.

**Cost:** The cost per sample location is approximately \$150.

**Availability:** The technology is commercially available.

**Status:** Field trials have been conducted at Holloman AFB, NM, Robins AFB, GA, and Tinker AFB, OK.

**References:** Pitchford, A.M., A.T. Mazzella, and K.R. Scarborough. **Soil-Gas and Geophysical Techniques for Detection of Subsurface Organic Contamination**, AFESC Report ESL-TR-87-67, Nov 1987.

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## 143. GROUNDWATER MODEL ASSESSMENT

**Category:** III. Analytical Methods and Instrumentation Development

**Purpose:** To provide a repository of Army experience on the use of numerical models for groundwater flow and transport of hazardous or toxic materials and an assessment of the combinations of classes of problems and particular models which can be expected to give useful results.

**Application:** Numerical models can, in principle, be used to guide site investigations, evaluate the feasibility of remediation alternatives, and provide a framework for evaluating data obtained during the monitoring of a remediation process. Their effective use is complicated by difficulty in defining boundary conditions and parameters describing flow and transport processes for a given somewhat heterogeneous site.

**Description:** Results of USATHAMA, HQ USACE, and WES sponsored workshop on any groundwater model use held 30 March – 1 April, 1992 are documented in a report that includes conclusions on what has and has not worked and user-specified required improvements in capability. A report describing assessment of the most used groundwater models is also in preparation for late FY93.

This technology deals with the solution of partial differential equations governing flow and transport in ideal media by numerical methods.

**Advantages:** This assessment and the associated user's workshop provided the Army with (a) clearly defined user needs, (b) improved in-house technical assistance capabilities relative to modeling, and (c) initial guidance on model limitations and capabilities.

**Limitations:** Certain specialized classes of models were not reviewed. Additional model evaluation with increased depth is advisable.

**Costs:** Model application is site specific in nature. Thus, the costs are strongly contingent upon the site and circumstances modeled.

**Availability:** A workshop report will be available from NTIS and WES early in FY93.

**Status:** Workshop proceedings are in final draft form and will be published by WES early in FY93. Model assessment is on course and will be documented in late FY93.

**References:** Workshop proceedings are in final draft form and will be published by WES early in FY93. Model assessment is on course and will be documented in late FY93.

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## 144. ACOUSTIC SURVEYING IN TOXIC WATER

**Category:** III. Analytical Methods and Instrumentation Development

**Purpose:** To measure non-invasively the thickness of precipitated salts in a covered-lined containment pond for mixed salts and organic contaminants.

**Application:** This technology can be used to measure sediments/precipitants in covered-lined containment impoundments without invasion. It is also used to measure the thickness of sediments for dredging in streams, lakes, and bays.

**Description:** An Odom Echotrak dual frequency (24 kHz and 200 kHz) depth sounder was adapted and attached to a hydro sports board with an outrigger, for stability. This device was developed on site to float atop the 45 mil Hypalon floating cover over the contaminated liquid. A non-invasive hydrographic survey by utilization of sound as sonar in shallow liquid containments is made possible by the use of this technology. The depth sounder measured the depth of the liquids overlying precipitated salts and sediments in a covered-lined surface impoundment. This technique can be used in covered/lined or uncovered/lined impoundments for determination of precipitant or sediment thickness underlying contaminated water.

To manipulate the sounder and floatation device, cables must be placed across the impoundment to be measured. The sounder is pulled across the impoundment while attached to cables by pulleys. The number of parallel and intersecting surveys that are taken is contingent upon the accuracy needed to estimate the thickness of the contaminated water and of the salts/sediment on the bottom.

**Advantages:** This technology is a non-intrusive technique for measuring the thickness of contaminated water and salts/sediment on the bottom of cover-lined or uncovered-lined containment ponds. The low frequencies record depths exceptionally well in shallow contaminated water (> 2 ft). Knowledge of the construction of the containment area is an advantage during the planning and construction stage of the instrumentation.

**Limitations:** With the low frequencies, recording at a minimum depth of 1-2 feet at 200 kHz and 3-4 feet at 24 kHz.

**Cost:** The cost of the one demonstration project was \$20,000 , but the cost of other projects will be site specific.

**Availability:** Available at WES on a site specific basis.

**Status:** Demonstrated in the Basin F Hazardous Waste Storage Pond A at the Rocky Mountain Arsenal, CO, September 17-21, 1991.

**References:** Francingues, N.R., M.P. Alexander, and B.W. McCleave. **Acoustic Surveying in Toxic Waste at the Rocky Mountain Arsenal**, USAE Waterways Experiment Station, 1991.

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## 145. CHRONIC SUBLETHAL SEDIMENT BIOASSAYS

- Category:** III. Analytical Methods and Instrumentation Development
- Purpose:** To determine the environmental impact of contaminated sediments on aquatic biota.
- Application:** The method can be used at all installations where contaminated sediments pose a potential environmental hazard to freshwater or saltwater organisms.
- Description:** Ecologically and/or commercially important organisms at the site are identified. They are exposed under environmentally realistic conditions to sediments collected at the installation. Biologically important endpoints such as survival, growth, and reproduction are monitored. Results are expressed in terms of the health and well-being of the indigenous field populations of concern. The accuracy, precision, and quality control of this method depend on the specific organism-test combination selected.
- Advantages:** A major advantage of this method is that it is not limited to any particular chemical or class of chemicals. It deals effectively with contaminant mixtures as well as military-unique compounds. Use of sublethal endpoints increases method sensitivity and ecological interpretability.
- Limitations:** Training and experience required to conduct this method are not insignificant. Causal associations between individual chemicals and observed sublethal effects are difficult to establish.
- Costs:** Costs are site-specific.
- Availability:** Equipment and supplies are available from commercial vendors. Some test methods are available while others are under development. Guidance is available from WES.
- Status:** Varies with method selected.
- References:** Dillon, T.M., D.W. Moore, and A.B. Gibson. **Initial Development of a Chronic Sublethal Sediment Bioassay With the Marine Polychaete *Nereis* (Neanthes) *arenaceodentata***. Environ. Toxicol. Chem. (in press), 1992.
- Moore, D.W. and T.M. Dillon. **Sediment Bioassays Supporting Base Realignment and Closure (BRAC) at the Indiana Army Ammunition Plant**. Miscellaneous Paper EL-XX-XX, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS (in press), 1992.
- Dillon, T.M., A.B. Gibson, and D.M. Moore. **Development of Chronic Sublethal Sediment Bioassays: Proceedings of a Workshop**. Technical Note EL-EEDP-01-22, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, 1990.
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## 146. CONTAMINANT DISPERSION MODELS

- Category:** III. Analytical Methods and Instrumentation Development
- Purpose:** To predict the dispersion and fate of contaminants released into the water column.
- Application:** The method is applicable to many contaminants and has been tailored for a number of harbors. Currently, it is best suited for organic contaminants.
- Description:** Several computer models for predicting hydrodynamic dispersion of a released contaminant and its subsequent partitioning into water column, sediment, and biological fractions are being investigated. A vessel-mounted acoustic doppler current meter is used to validate hydrodynamic predictions. Water column and sediment sampling from the vessel are used to validate partitioning predictions. The models are iteratively tuned to match field observations (figure 146).
- Advantages:** Model predictions are faster, cheaper, and more spatially resolved than repeated field sampling and analysis. They can be used to investigate the impact of hypothetical situations and the relative impact of many simultaneous sources.
- Limitations:** Model accuracy depends on the completeness and quality of field data collected. The models assume a homogeneous water column.
- Costs:** Model software is commercially available and most models will run on IBM-compatible microcomputers. Additional equipment required includes a vessel with precise navigation, a current meter (\$75,000), and sampling gear (\$5,000).
- Availability:** All equipment and models are commercially available.
- Status:** The models are being validated through FY93 in San Diego Bay in cooperation with the U.S. Geological Survey.
- References:** Ambrose, R.B., S.B. Vandergrift, and T.A. Wool. **WASP4, a Hydrodynamic and Water Quality Model**. U.S. Environmental Protection Agency Report EPA/600/3-06/0-34, 1986.
- Cheng, R.T., J.R. Burau, and J.W. Gartner. **Interfacing Data Analysis and Numerical Modeling for Tidal Hydrodynamic Modeling Phenomena**. In *Tidal Hydrodynamics*, B.B. Parker, Editor, John Wiley, 1991, pp. 201-19.
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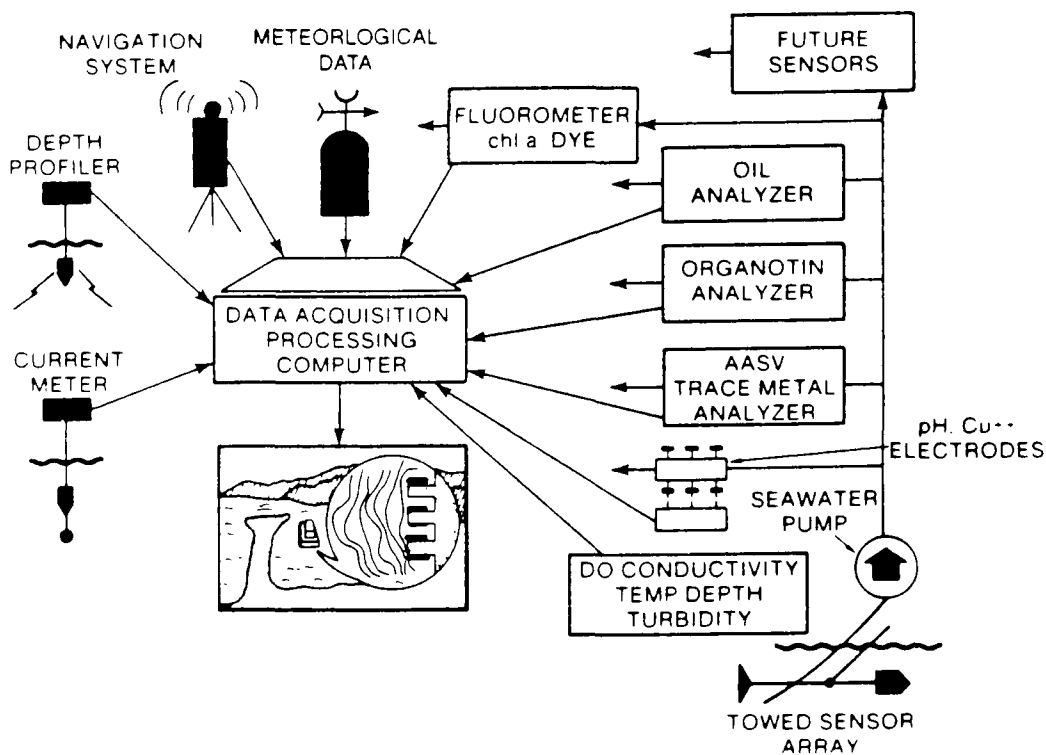


Figure 146. Additional major sensor systems aboard vessel (current profiler and sediment sampler not included in this figure). The vessel is part of Naval Ocean System Center's marine environmental survey capability. Most water column sensors are designed for continuous, underway mapping.

## 147. QUALITY ASSURANCE (QA) PROGRAM

- Category:** III. Analytical Methods and Instrumentation Development
- Purpose:** To provide a consistent framework for the generation of analytical data, to establish standard practices that permit inter-laboratory comparison of data, and to establish procedures for demonstrating that analytical systems are within established limits.
- Application:** The program applies to activities that generate analytical chemical data including aspects of field sampling that can affect the chemical integrity of samples as well as chemical laboratory activities.
- Description:** A quality assurance (QA) manual (see cited reference) has been published that provides specific requirements for the sampling and chemical analysis of groundwater, surface water, soil, and sediment samples. The general principles described in the manual are applicable to most field and laboratory activities. Air sampling, biological sampling, radiological analyses, and geotechnical parameter analyses are not specifically addressed in the manual, but many of the guidelines in the QA program apply.
- Advantages:** Data generated by facilities that ascribe to an accepted and effective QA program are reliable and defensible. Different laboratories can generate data that are mutually consistent. The customer for the data will know the accuracy and precision of the data and can make educated decisions.
- Limitations:** The applicability of any QA program is limited to the tests for which QA procedures have been established. The program is limited by the consistency with which it is applied in the laboratories that participate.
- Costs:** Not available.
- Availability:** The manual is available from U.S. Army Corps of Engineers Toxic and Hazardous Materials Agency (USATHAMA).
- Status:** The QA program is implemented. The use of the QA program is incorporated as a requirement into all USATHAMA contracts that require laboratory data. The program is being phased out. It will be replaced by the Corps of Engineers Regulation 1110-1-263 and an implementation document for use on USATHAMA projects. The QA Program will continue to be used for ongoing investigations.
- References:** USATHAMA QA Program, USATHAMA PAM 11-41, Jan 1990.
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## 148. STANDARD ANALYTICAL REFERENCE MATERIALS (SARMS)

- Category:** III. Analytical Methods and Instrumentation Development
- Purpose:** To supply consistent reference standards to USATHAMA contract laboratories.
- Application:** The repository includes soils, organic compounds, and explosives. Standard analytical reference materials (SARMS) are traceable to the National Institute of Science and Technology.
- Description:** Purity checks of SARMS are made every 6 months. Interim SARMS are only checked for purity and identification initially upon receipt.
- Advantages:** Reference standard materials are available.
- Limitations:** The number of compounds within the repository is limited.
- Costs:** Not available.
- Availability:** Further information about SARMS is available from USATHAMA. Non-explosive SARMS are available only to USATHAMA contractors; explosive SARMS are available to any government contractor with USATHAMA approval.
- Status:** The use of SARMS is required for USATHAMA contractors.
- References:** USATHAMA QA Program, USATHAMA PAM 11-41, Jan 1990.
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## 149. ANALYTICAL METHOD FOR AROMATIC COMPOUNDS AND BIODEGRADATION BYPRODUCTS

- Category:** III. Analytical Methods and Instrumentation Development
- Purpose:** To develop improved analytical protocols for analyzing for aromatic organic compounds and degradation byproducts during anaerobic biodegradation (see note 20).
- Description:** A technique has been developed based on injecting gaseous headspace from sample bottles directly into a gas chromatograph (GC). 200 mL of inoculated media are transferred using anaerobic techniques into 250 mL screw cap bottles with Mininert closures. The bottle is spiked with the aromatic mixture of interest and placed in an anaerobic glove box. To analyze for organics, the bottle is moved to a shaker table for a minimum of 10 minutes prior to sampling (the aromatic compounds being investigated come to equilibrium with the headspace within about 5 minutes). A 300- $\mu$ L sample of headspace is withdrawn from the bottle and injected into the GC. The GC is equipped with a Megabore fused-silica capillary column and a photoionization detector. Calibration of the instrument is accomplished by sampling external standards (bottles with equivalent headspace and liquid volumes, and spiked with a known amount of the organic compound).
- Advantages:** Little change in the individual sample bottle itself since no liquid must be withdrawn from the system. Decreased labor and improved efficiency of sampling since no sample liquid-liquid extraction must be performed.
- Limitations:** Headspace vapors may not be comparable directly to hydrocarbon content of the liquid.
- Costs:** Not available.
- Availability:** Instrumentation and other equipment described in the process are commercially available.
- Status:** This protocol was developed during research on the Seal Beach, CA, gasoline-contaminated site.
- References:** Ball, H.A., M. Reinhard, and P.L. McCarty. **Factors Influencing the In-Situ Biodegradation of Gasoline Hydrocarbons by Groundwater Bacteria: Anaerobic Processes**, Progress Report, NCEL, May 1989.
- Contact:** Carmen Lebron and Mary Pat Huxley  
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805-982-1616 (Lebron); 805-982-1615 (Huxley)

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## 150. DETERMINATION OF EXPLOSIVES IN ENVIRONMENTAL SAMPLES

- Category:** III. Analytical Methods and Instrumentation Development
- Purpose:** To provide standard methodology for the determination of explosives in soil.
- Application:** The method is applicable to explosives in soil. Applicable explosives are HMX, RDX, TNB, DNB, Tetryl, TNT, and 2,4-DNT.
- Description:** Briefly, the method involves extraction of soil using acetonitrile in an ultrasonic bath followed by determination using reversed-phase high-pressure liquid chromatography with an ultraviolet detector (HPLC-UV) at 254 nm. Certified reporting limits are: HMX – 1.6 µg/g; RDX – 1.8 µg/g; TNB – 1.5 µg/g; DNB – 0.5 µg/g; tetryl – 5.5 µg/g; TNT – 0.8 µg/g; and 2,4-DNT – 0.8 µg/g. About 24 samples can be extracted and analyzed over a 2-day period if stock solutions have been prepared in advance. The major item of equipment is an HPLC having a 100-µL sample loop injector and a fixed wavelength 254-nm detector. Soil samples should be refrigerated in the dark as soon as feasible after collection.
- Advantages:** The method has been tested and evaluated and allows for consistency of results across laboratories.
- Limitations:** Not available.
- Costs:** Capital costs are for the HPLC instrument and detector. Operating costs include reagents and glassware.
- Availability:** Equipment is available commercially. Analysis protocol is in the references cited.
- Status:** The method has been promulgated, and the results using this method are accepted.
- References:** **Method for Analysis of Nitroaromatic and Nitramine Explosives in Soil by HPLC.** Method D5143-90, ASTM, 1991.

**Munition Residues in Soil, Liquid Chromatographic Method.** Official 1st action, Sep 1990. Method 991.09, 2nd Supplement to the 15th Edition of *Official Methods of Analysis*, pp. 78-80, Association of Official Analytical Chemists.

Jenkins, T.F. et al. **Development of an Analytical Method for the Determination of Explosive Residues in Soil: Part III. Collaborative Test Results and Final Performance Evaluation.** U.S. Army Cold Regions Research and Engineering Laboratory, May 1989.

Jenkins, T.F. et al. **Development of an Analytical Method for the Determination of Explosive Residues in Soil: Part II. Additional Development and Ruggedness Testing.** CRREL Report 88-8, July 1988.

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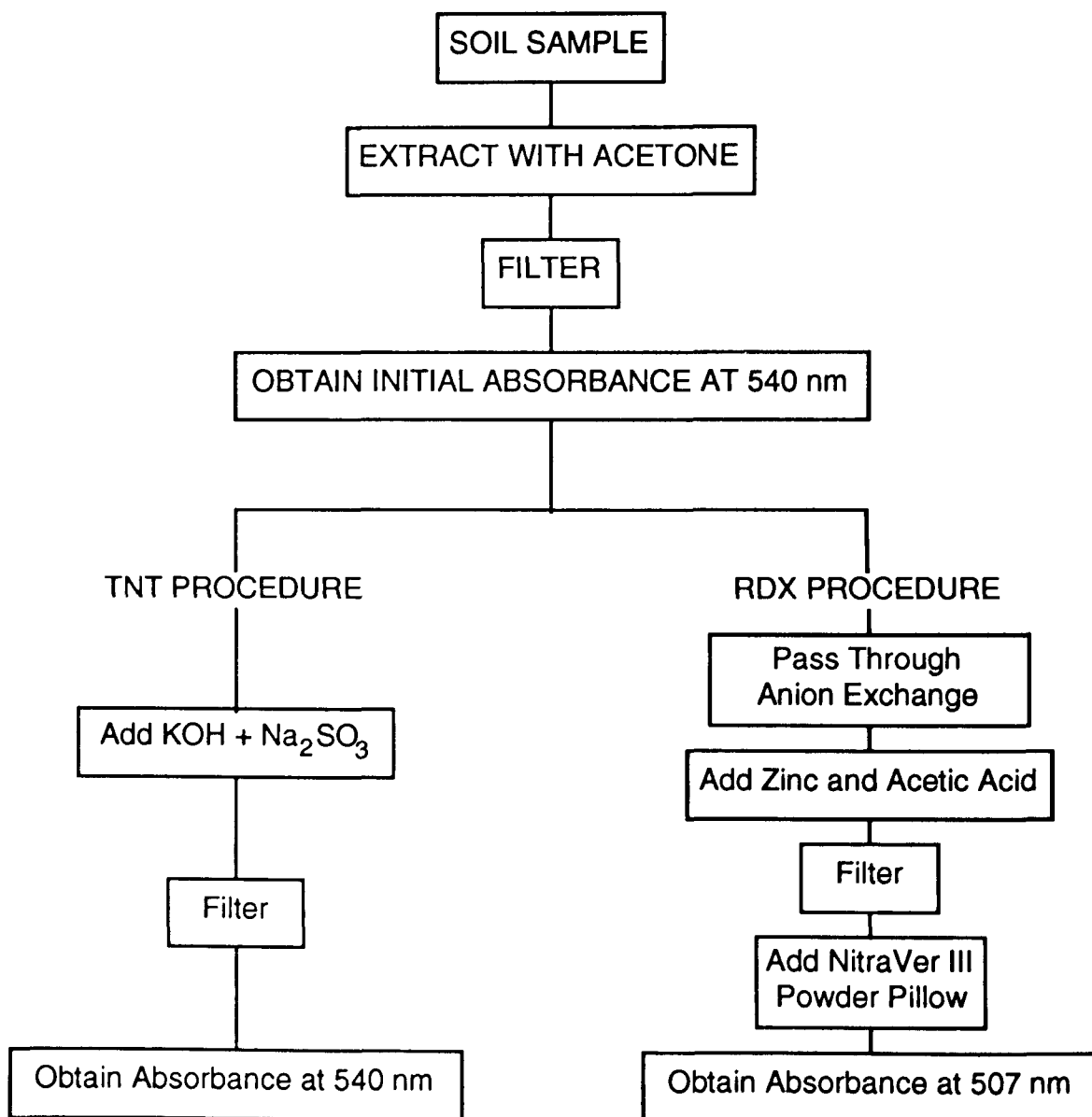
## 151. FIELD PORTABLE INSTRUMENTATION – X-RAY FLUORESCENCE

- Category:** III. Analytical Methods and Instrumentation Development
- Purpose:** To develop a rapid method to determine explosives in environmental samples in the field.
- Application:** The method is applicable for the determination of TNT, RDX, DNT, nitroaromatics, and nitramines in soil and water.
- Description:** Soil is shaken with acetone to extract munitions residues and the extracts are filtered. The method then depends on the production of colored reaction products when these extracts are subjected to two reaction sequences. For TNT, the extract is reacted with a strong base, with development of a red color indicating the presence of TNT. For RDX, the extract is passed through a disposable anion exchange cartridge, acidified, and reacted with zinc metal. The resulting solution is filtered and a Hach NITRA VER II™ powder pillow is added. The development of a red or orange color indicates the presence of RDX. These colored reaction products are then analyzed with a small, field-portable spectrophotometer to measure accurately the degree of color formed (figure 151). The method is semi-quantitative – concentrations in the range of  $\mu\text{g/L}$  in water and  $\mu\text{g/g}$  in soils can be determined.
- Advantages:** The method is rapid, low-cost, does not require highly trained personnel, and can be used with a low volume of contaminated material.
- Limitations:** The method is not specific, i.e., color development will not differentiate between the various nitroaromatics.
- Costs:** The cost of the method is around \$50 per sample, excluding initial costs for the analytical equipment.
- Availability:** Equipment and chemicals to perform the method are readily commercially available.
- Status:** The method was developed at the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL), Hanover, NH. Initial field testing for RDX detection was performed at Eagle River Flats, AK. The method has been promulgated, and results using the method are accepted.
- References:** Walsh, M.E. and T.F. Jenkins. **Development of a Field Screening Method for RDX in Soil.** CRREL Special Report 91-7, 1991.
- Walsh, M.E. and T.F. Jenkins. **Field Screening Method for 2,4-DNT in Soil.** CRREL Special Report 91-17, 1991.
- Soil Contamination.** *Army Environmental Sciences*, 9(2):12-13, Winter 1991.
- Jenkins, T.F. **Development of a Simplified Field Method for the Determination of TNT in soil.** CRREL Special Report 90-38, 1990.



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*Figure 151. Schematic diagram of procedures for determining TNT and RDX in the field.*

## 152. EXTERIOR LEAK DETECTION FOR UNDERGROUND STORAGE TANKS

**Category:** III. Analytical Methods and Instrumentation Development

**Purpose:** To provide early leak detection of leaks associated with underground storage tanks (UST).

**Applications** The methods are applicable for early detection of fuel leaks in USTs and possibly plume monitoring. A review of technical and marketing literature identified monitoring devices that were representative of the technologies available in 1987 and is the basis for the information in this technical note.

**Description:** 1. **Continuous, Saturated Zone (Liquid Phase) Monitors.** The Leak-X™ System is a continuous liquid-phase detection technique. The operation of the sensor is based on the principle of thermal conductivity. It monitors the fluid conductivity at the air-water interface, and the manufacturer claims that it can detect a 0.125-inch layer of oil-on-water. The system has been used in the field for more than 10 years. It may be subject to interferences such as ice or biofouling (for example, float mechanism may fail because of ice or physical obstacles). The system includes an audible and visual alarm and can be interfaced with computers, central alarms, strip chart recorders, shutdown valves, and telephone lines. It does not measure concentration. Each monitor can handle 10 sensors. Depending on the number of sensors, the maximum distance between monitor and sensors ranges from 1,000 to 4,000 ft.

The TCI™ Leak Detector is a continuous liquid monitoring system whose sensor is product soluble. The monitor continuously reads a 100K-ohm resistor that has been placed at the end of the sensing probe. When the probe is immersed in fuel, the insulation jacket dissolves causing the conductor wires to make contact and signal an alarm. The sensor cable reaction time for fuel oil No. 1 is 4 hours; it can detect a 1/100 inch layer of hydrocarbon liquid. The sensor jacket is not affected by water and, therefore, this device may be particularly useful for areas with saturated or variable water tables. The TCI system has been on the market since 1971 and has a 10-year warranty. TCI also makes a sensor cable which may be installed in the annular spaces of piping systems. Sensor cables need to be replaced after exposure to hydrocarbons. The system does not have data collection capability but only activates an alarm. It does not measure concentration and is not capable of distinguishing between a new release and past contamination. Each monitor can handle up to 10 sensors. The system can be used to monitor for fuel release for pipelines.

The Petrochemical Release Monitor (PRM) is a continuous product device for detecting liquid hydrocarbons. The sensors can detect less than 0.1-inch of hydrocarbons at the water/air interface. An audio alarm indicates the presence of a leak, and a visual alarm identifies the sensor which detected the leak. The system will also respond to vapors. For gasoline vapors, it is activated after 5-hour exposure to 500 ppm or 1-hour exposure to more than 25,000 ppm. Sensors need to be replaced after exposure to hydrocarbons. The sensor cannot distinguish between previous and new releases. The system does not have data collection capability but only activates an alarm. It does not measure concentration. The system can handle up to

eight monitoring points. The maximum distance between sensors and monitor is more than 1 mile.

FiberChem, Inc. is developing a gasoline sensor which consists of a fiber optic chemical sensor (FOCS) and a reader. The FOCS consists of an inexpensive fiberoptic cable which has a chemical coating (sensor) at the end. The reader consists of a light source which sends the light down the fiber optic to the chemical sensor. There, the light characteristics are changed and return up the same fiber to the reader for a reading of the ppm of gasoline. The device could possibly be used for monitoring JP-4 vapors in the vadose zone as well. The system has data-collection capability. The response to hydrocarbons is reversible with approximately 2 to 3 seconds time lag. It measures concentrations for both dissolved and vapor-phase hydrocarbons. It is sensitive down to ppm level (possibly ppb). Having the capability to measure both dissolved and vapor-phase concentrations gives this system the potential to distinguish new releases from past contamination. Size of sensor is very small, approximately the size of a pencil tip. One reader is capable of supporting many devices and is dependent on the switching or multiplexing device.

**2. Continuous, Vadose Zone (Gas Phase) Monitors.** USD manufactures the Leak Alert™ system which is a vapor phase continuous monitoring system with both visual and audible warnings. It detects vapors generated by leaking fluids. The level at which the warning system is activated can be field adjusted for background vapor correction. The sensor is a metal oxide semiconductor (MOS) type. Components of an MOS system include a heater and a collector embedded in a solid state cell. The cell is composed of metal and nonmetal oxides of transition elements. Hydrocarbon vapor molecules are dissociated into charged ions or ion complexes on the surface of the sensor, changing the electrical resistance of the junction. The vapor concentration can be determined from the proportional change in resistance. Depending on the vapor type, the sensor has a detection limit of approximately 200 ppm. The system can be computer interfaced for data handling. It measures total vapor concentration but not specific component concentration. The sensor may be subject to interferences, such as methane. It may not be suitable for sites with very high hydrocarbon vapor background from past contamination. The detector may saturate at vapor concentrations above 7,500 ppm. The option available for sites with background above 5,000 ppm is to use a catalytic sensor with the same Leak Alert/Software System manufactured by the same company. The maximum distance between monitor and sensors is 3,000 ft. It can accommodate up to 48 monitoring locations. It has data collection and computer interfacing capability as well as visual and audible alarms.

The Arizona Instruments system, Oil Sentry 17-100 Lhis™, is a vapor-sensing system consisting of an aspirator pump for vapor collection, a bulk semiconductor (metal oxide semiconductor, MOS) vapor analyzer, a manifold assemble with solenoid valves allowing selective sampling at multiple locations, a microprocessor, an alarm system, and printer. The monitoring probes consist of 0.5-in. id PVC pipe with 0.01-in. slots. Tubing (1/4 in. id.) is used to connect the module to the remote probes. Air samples from the probes are analyzed in the module for vapor content. The detection limit is approximately 100 ppm (depending on product type). An optional software package allows storage and display of vapor concentrations versus time on any monitoring well, as well as monitoring of alarm events. The device may be subject to interferences such as methane and vapor losses in the tubing. It is suitable for sites with very high hydrocarbon vapor background concentrations from past contamination. The saturation level of the detector is higher than 30,000 ppm. It measures total vapor concentration but not specific compound concentration. The

maximum distance between monitor and sensor is 500 ft. It has data collection and computer capability as well as audible and visual alarm. It can accommodate up to 12 monitoring locations. Sub-zero degree temperature may cause operational problems.

The model PM 3000™ is a microprocessor-based program control unit equipped with eight independent diffusion sensors (adsistor type). Hydrocarbon vapors diffuse into the sensor. When they contact the adsorptive material, a resistance change occurs. No heating element is used. The major atmospheric gases are not detected and are not interferants. The sensor measures total vapor concentration but not specific component concentration. The claimed detection limit is 150 ppm, and the sensor active radius is 20 ft. The device may not be suitable for sites with high vapor background. The saturation level of the detector is 4,000 ppm. The maximum distance between monitor and sensor is 2,000 ft. The system has data collection capability and can activate a visual or audible alarm. It can accommodate eight monitoring locations (up to 128 with a multiplexer).

**3. Intermittent Vadose Zone (Gas Phase) Monitoring.** This type of monitoring was not evaluated for the AFCESA research project because it could not identify past contamination. It has been used for identification of active leaks in USTs. The system described below has been tested with some success at a number of Air Force installations. Tracer Research Corp. (TRC) developed a tracer leak detection method for monthly tank leak testing and monitoring. This technology offers several options that have not been possible with many existing techniques. In particular, the tracer method has the unique ability of testing tanks without being filled or emptied of product or taken out of service for leak test. The monthly leak test is able to detect very small amounts of leakage (0.01 gallon per hour). The tracer leak detection system uses a volatile chemical (tracer) placed in the stored fuel (product). The tracer is continuously added to the fuel from a dispenser that is placed inside the tank. If the fuel leaks out of the tank, the tracer evaporates out of the fuel and diffuses into the air spaces of the soil. A vapor probe is placed in the backfill adjacent to the tank. Air is continuously evacuated from the vapor probe. The air is analyzed for the tracer on a regular basis, typically each month. A leak located in the saturated zone can also be detected, but additional labor-intensive measures may be necessary, such as emptying the tank, use of water sensitive pastes, and examination of ground water samples. The frequency of sample analysis (every 30 days) may not be sufficient for prompt leak detection.

**Advantages:** These methods are less labor intensive, more cost effective, and give information in relatively real-time to provide immediate detection of problems. Centralized and continuous monitoring provide a historical record.

**Limitations:** Instrumentation may not differentiate between old and new storage tank leaks. Detection devices may not detect leaks within the regulatory limitations on vapor monitoring. Monitoring devices may detect leaks only, not providing a quantitative analysis on the leak detected.

**Cost:** Costs given here are based on information from 1987.

Leak-X System -- Suggested costs for the monitor and annunciator are \$2,145 and \$825 per sensor.

TCI Leak Detector -- The monitor console is approximately \$1,000 and the sensors are \$100 to \$160 each.

Petrochemical Release Monitor (PRM) – The cost for a remote station with four probes is approximately \$1,600.

FiberChem -- Prototype version was used for the test. No cost is available.

USDs Leak Alert System -- The total cost for 16 sensors, the monitor, the software, and the PC is \$12,300.

Arizona Instruments Soil Sentry 17-100L – The suggested cost of the system is \$4,850 plus the cost of the PVC tubes for 12 monitoring wells.

PPM 3000 -- is priced at \$1,395/monitor plus \$510/sensor, i.e., approximately \$10,000 for 16 monitoring points.

TRC -- The cost involved for implementing the system is \$1,000 per 3 to 4 monitoring points, plus \$35 per sample analysis per Remote Sensing.

**Availability:** All systems are commercially available.

**Status:** These devices have been laboratory tested by Battelle in Columbus, OH.

**References:** Hokanson, L.D. **Exterior Leak Detection for Underground Storage Tanks, Status Report.** Tyndall AFB, May 1989.

Wickramanayake, G.B., et al. **Testing of Monitoring Devices for JP-4 Releases in the Subsurface.** Environics Division, USAF Engineering & Services Laboratory Report ESL-TR-89-46, 1989.

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## 153. PORTABLE ASBESTOS MICROSCOPE

- Category:** III. Analytical Methods and Instrumentation Development
- Purpose:** To provide a field-portable means for the qualitative identification of asbestos materials.
- Application:** The method is applicable for the field identification of asbestos materials.
- Description:** The system includes a customized, commercially available microscope having polarized light capabilities and a manual that describes how to prepare samples and conduct the microscopic examination. Reference slides of asbestos and non-asbestos fibers are provided. The entire system is packed in a small, padded case for transportation to the field.
- Advantages:** Traditionally, samples have been shipped to a laboratory for analysis. Depending upon the laboratory, turnaround time can be on the order of weeks or months. This method enables on-the-spot identification of asbestos materials, so that a course of action can be determined more rapidly. Savings in time and money will result from the availability of such a system. Job interruptions while waiting for analytical results will be eliminated. The polarized light microscopy method of asbestos identification is authorized by the EPA.
- Limitations:** The capability of the method would be limited by the completeness of sample collection and training of the technician.
- Costs:** The system is expected to cost about \$5,000 and training. About 1 week will be required to train a technician (see cited references).
- Availability:** The asbestos microscope is available from Hygeia, Inc.
- Status:** Field testing is underway.
- References:** Spooner, C.M., **Polarizing Light Microscopy Manual**. Hygeia, Inc., Nov 1986.  
**Asbestos Microscope**. U.S. Army Corps of Engineers CERL Fact Sheet, Feb 1987.
- Contact:** Bernard A. Donahue  
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## 154. GEOSTATISTICAL ENVIRONMENTAL ASSESSMENT SOFTWARE VERSION 1.2.1

**Category:** III. Analytical Methods and Instrumentation Development

**Purpose:** To perform geostatistical analyses on spatially distributed data collected during site investigation and remediation.

**Application:** The software package is public domain software collected since 1986 for geostatistical evaluation of data collected at hazardous waste sites. These may be used as a data management system or to interpret data that are collected during investigation.

**Description:** Geostatistical methods are useful for site assessment and monitoring situations where data are collected on a spatial network of sampling locations, and are particularly suited to cases where contour maps of pollutant concentration (or other variables are desired. Examples of environmental applications include lead and cadmium concentrations in soils surrounding smelter sites, outdoor atmosphere nitric oxide (NO<sub>2</sub>) concentrations in metropolitan areas, and regional sulfate deposition in rainfall. Kriging is a weighted moving average method used to interpolate values from a sample data set onto a grid of points for contouring. The kriging weights are computed from a variogram, which measures the degree of correlation among sample values in the area as a function of the distance and direction between samples. Estimation of the variogram from the sample data is a critical part of a geostatistical study. The procedure involves interpretation and judgment, and often requires a large number of trial and error computer runs. The lack of inexpensive, easy-to-use software has prevented many people from acquiring the experience necessary to use geostatistical methods effectively. The software is designed to make it easy for the novice to begin using geostatistical methods and to learn by doing, as well as to provide sufficient power and flexibility for the experienced user to solve real-world problems. The software package is called Geostatistical Environmental Assessment Software (Geo-EAS) Version 1.2.1, released in June 1990. The software package includes:

- (1) Data Files – The Geo-EAS programs use a simple ASCII file structure for input;
- (2) Menu Screens – All Geo-EAS programs are controlled interactively through menu screens which permit the user to select options and enter control parameters;
- (3) File Utilities – The DATAPREP and TRANS programs provide capability for manipulating Geo-EAS data files;
- (4) Variogram Analysis – The PREVAR program creates an intermediate binary file of data pairs for use in VARIO, which computes and displays plots of variograms for specified distance and directional limits. XVALID is a cross-validation program which can test a variogram model by estimating values at sampled locations from surrounding data and comparing the estimates with the known sample values;



- (5) Interpolation – The KRIGE program provides kriged estimates for a two-dimensional grid of points or blocks;
- (6) Contour Maps – CONREC is a program which generates contour maps from a gridded Geo-EAS data file, usually the output from KRIGE;
- (7) DATA Maps – POSTPLOT creates a map of a data variable in a Geo-EAS data file;
- (8) Univariate Statistics – STAT1 computes univariate statistics such as mean, standard deviation, etc. for variables in a Geo-EAS data file, and plots histograms and probability plots;
- (9) X-Y Plots – SCATTER and XYGRAPH both create x-y plots with optional linear regression for any two variables in a Geo-EAS data file; and
- (10) Pen Plotting – The POSTPLOT, XYGRAPH, and CONREC programs are all based on subroutines originally developed by the National Center for Atmospheric Research (NCAR) and produce graphics metafiles which can be saved and replotted later. HPLOT reads a metafile and produces a file of HPGL commands which can be plotted on Hewlett-Packard compatible plotters.

VIEW reads a metafile and displays the plot on the monitor for review.

**Advantages:** The software is easily used by the beginner.

**Limitations:** Not available.

**Costs:** The cost of postage and discs provided for transfer of the software.

**Availability:** The Geo-EAS software in its executable form is entirely in the public domain, and can be obtained free of charge by sending the appropriate number of pre-formatted diskettes to the contact below.

**Status:** Not applicable.

**References:** GEO-EAS 1.2.1 User's Guide, U.S. Environmental Protection Agency Report EPA/600/8-91/008, Apr 1991.

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## 155. GEOPHYSICS ADVISOR EXPERT SYSTEM

- Category:** III. Analytical Methods and Instrumentation Development
- Purpose:** The expert system is designed to assist and educate non-geophysicists in the use of geophysical methods at hazardous waste sites.
- Application:** This is another decision making tool to assist in selection of the geophysical method(s) that may be used in hazardous waste site assessment/delineation.
- Description:** The program asks questions about a site and the contamination problem. Questions about the types of cultural noise are also addressed. Over 90 questions are in the program. The total number of questions asked, however, varies depending upon the answers to initial questions. The program considers the following geophysical methods: electromagnetic induction, d.c. resistivity, ground penetrating radar, magnetic, seismic, soil gas, gravity, and radiometric techniques (see notes 137 and 156). Based upon the answers given, the program recommends what types of geophysics will most likely be useful at the site to solve problems such as contaminant location and hydrogeological characterization of the site. A relative numerical ranking of the various methods is produced, with a method receiving a recommended, not recommended, or uncertain effectiveness evaluation. The program also annotates why the various geophysical techniques will likely work or not work at the site.
- Advantages:** The expert system allows the non-geophysicist to select the geophysical method needed to evaluate the site.
- Limitations:** Not available.
- Cost:** Not available.
- Availability:** The software is available through U.S. EPA, Las Vegas, NV.
- References:** Olhoeft, G.R., *Geophysics Advisor Expert System*, U.S. Environmental Protection Agency Report EPA/600/X-88/257, Jun 1988.
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## 156. GEOPHYSICAL TECHNIQUES

**Category:** III. Analytical Methods and Instrumentation Development

**Purpose:** To locate organic contamination in the subsurface without drilling core holes or monitoring wells. Pollution plumes in groundwater may be delineated by applying one or more of these techniques during site investigations. One or more of these techniques may be used in tracking movement of pollution plumes after detection and delineation.

**Application:** These techniques can be used for defining natural geologic features and locating conductive leachates, contaminant plumes, buried trenches, and metal objects.

**Description:** **Electromagnetic (EM) Induction.** A geophysical technique that is readily available commercially and quickly acquires data for electrical conductivity over a large area. Data are acquired by transmitting a signal from a transmitter coil and measuring the perturbation in the signal at the receiver coil (see figure 156a). The perturbation is due to the presence of nearby conductive materials such as metal objects and the earth, and is proportional to the conductivity of these materials. Depth of electromagnetic penetration is a function of coil spacing, signal frequency, and electrical conductivity. These depths are typically on the order of meters to tens of meters with hand-held instruments. A variety of commercially available instruments can be used to explore different depths, depending on the conductivity of the surface. If the site relief, i.e., change in surface elevation across the site, is greater than 1 meter, the data may require topographic correction. This correction accounts for the changing distance from the surface of the earth to the water table, which is a conductive feature. Nearby utilities, gas pipelines, power and telephone lines, radio and radar transmitters, and metal fences and debris can interfere with the measurements. Variations on an electrical conductivity map can represent changes in porosity, water saturation level, salinity of the ground water, or the presence of clay lenses. Such a map generally can illustrate the uniformity of a site subsurface.

**Direct Current (DC) and Complex Resistivity.** A commercially available geophysical technique. The DC resistivity method makes physical contact with the earth using shallow (< 0.3-meter) electrodes (see figure 156b). By establishing a current between two electrodes and measuring the potential difference between a second set of electrodes, the apparent resistivity of the earth is measured. Interpretation of these data can indicate various layers, which may correspond to the depths of the water table, aquitards, and bedrock. The geometry of the electrode arrays and spacing determines the depth of investigation. Increasing the electrode spacing samples a greater depth and volume of earth. The technique requires more time than EM to cover a given area. Resistivity soundings, however, can give more detailed depth profiles than commercially available EM methods. The technique requires topographic correction and may also be subject to interference from utilities. It is possible to perform DC resistivity measurements without interference nearer to metal objects such as fences, than EM measurements can be performed. The direct current resistivity method can be used with a single spacing or a series of spacings (as described above for EM method) for profiling and mapping, at one depth or a series of depths. Complex resistivity is the technique of measuring resistivity in both magnitude and phase as a function of frequency (sometimes called induced

polarization). The technique requires costly equipment and more time than conventional resistivity and is thus more expensive. However, the frequency-dependent measurement gives information about active chemical processes in the earth as well as the same information acquired by EM or conventional resistivity. This technique has shown the ability to detect and map organic materials in the presence of clay by mapping clay-organic reactions. There are few available commercial sources for this technique.

**Ground-Penetrating Radar (GPR).** Readily available commercially, GPR rapidly provides very high spatial resolution for a large area, can make useful measurements close to utilities, but is more expensive than EM or resistivity. GPR emits electromagnetic waves at frequencies selected in the range of 80 to 1,000 MHz. The wave fronts are reflected when they encounter contrasts in the dielectric constant, such as the water table, bedrock, and clay layers (see figure 156c). The reflected waves are plotted as a function of depth, and topographic correction is required. The depth of penetration is controlled by the intrinsic conductivity of the earth, the amount of inhomogeneity in the earth, and the amount of clay and water present. In clay-free sand with resistivity above 30 ohm-meters, the GPR can map bedding and stratigraphy, water tables, bedrock interfaces, and other features with dielectric contrasts at a resolution of a few centimeters to depths of 30 meters. Montmorillonite clay at a concentration of 5 to 10 % by weight will reduce the depth of penetration to less than one meter. As dielectric contrasts do exist between most earth materials and many organic substances, it is possible to detect certain kinds of organics with ground-penetrating radar.

**Seismic Techniques.** Seismic compressional and shear wave reflection and refraction techniques are readily available commercially and can be used to determine stratigraphic and lithologic layer thicknesses and depths (see figure 156d). Seismic waves in the subsurface travel at different speeds in various types of soil and rock and are refracted and reflected (bent) at interfaces between layers. Geophones spaced at intervals on the surface can detect these waves; from this information, travel time can be determined. This enables the number and thickness of layers as well as their depth and the seismic velocity of each layer to be determined also. Topographic correction is required. Seismic refraction works if each successively deeper layer has higher propagation velocity, i.e., is more dense. Both seismic techniques can provide information at great depths, but they do not easily provide information on features shallower than 3 meters (10 ft). Seismographs and geophones are commercially available. A sledge hammer striking a steel plate on the ground, or if there is no explosive danger, a specialized shotgun or explosives, are examples of suitable sources of seismic energy. Any nearby loud noise source such as a busy highway or construction may interfere with the survey. Seismic techniques are not as rapid as EM and GPR. The seismic techniques work best in competent materials and perform very poorly in loose materials. In clay-free sandy soils, GPR will work better than seismic techniques and with higher resolution. In clay-bearing soils, seismic techniques will work better than GPR. Marine seismic techniques are useful in mapping stratigraphy below rivers and lakes. As there are no acoustic contrasts between geological materials and organic contaminants, seismic techniques cannot directly map organic contamination.

**Magnetometry.** An inexpensive, readily available technique that measures the intensity of the earth's magnetic field. The presence of ferrous objects, such as iron drums, creates a perturbation in the local strength of the earth's magnetic field (see figure 156e). The change in the strength is proportional to the mass of the object. Detection of these ferrous objects depends on the mass, magnetic properties,

orientation, and depth of the object; the intensity and direction of the earth's magnetic field; and the sensitivity of the magnetometer. A large number of magnetometers are available commercially; two common types are the fluxgate and proton magnetometers. The fluxgate measures a component of the magnetic field, and the proton magnetometer measures the total magnetic field. Magnetic field measurements can be made in two ways: the magnetic field can be measured, or a difference, or gradient, can be determined between two different points. Total field measurements are more sensitive, but are also more susceptible to noise than the gradient measurements. Cultural features such as buried pipes, metal buildings, and magnetic properties of the soil may interfere with the measurements. This technique can detect buried drums, define boundaries of trenches filled with drums or other steel objects, and locate iron pipes or tanks.

**Geophysical Diffraction Tomography (GDT).** A seismic technique used in locating buried drums in landfills that are hazardous waste sites. Data collection is the same as refraction seismic. The process allows for bending of the waves that are propagated from the surface source as they pass from one subsurface formation to another subsurface formation instead of processing the waves as moving in straight lines as is usually done. This processing technique gives better definition of buried objects at shallow depths. Organic gases are not detected by this technique, but it allows better definition of possible point sources of pollutants.

**Advantages:** These techniques allow detection of organic contaminants and/or detection of buried drums that may contain organic contaminants without coring or drilling of monitoring wells. Movement of contaminants in an aquifer may be mapped without drilling monitoring wells. GDT is a self-contained system based on 386-PC software and may be integrated with use of the cone penetrometer.

**Limitations:** Specific organic contaminants are not identified using these techniques. Interpretation of the data gathered through geophysical techniques is slower than other methods because the data must be processed before interpretation. Cultural features may interfere with data gathering. Shallow resolution for processed seismic data may not be of the quality that can be interpreted (<3 meters) without special processing.

**Cost:** GDT is approximately \$1,000 per day to operate plus computer processing of data and interpretation by a specialist. Costs are not available for the other techniques.

**Availability:** All techniques are commercially available.

**Status:** Field testing has been conducted at Holloman AFB, NM, and Robins AFB, GA. GDT has been tested as follows: bench-scale phase, field-pilot phase, and limited-trial implementation at Oak Ridge National Laboratory and full-scale implementation at Ft. Rucker, AL, in Oct 1988.

**References:** Rudy, R.J., B.R. Levine, and S.O. Sanborn. **Integration of Several Geophysical Techniques to Optimize Sampling Resources at an 80-Acre Sanitary Landfill, Naval Air Station Pensacola.** Proc. 18th Environmental Symposium and Exhibition, Feb 1992.

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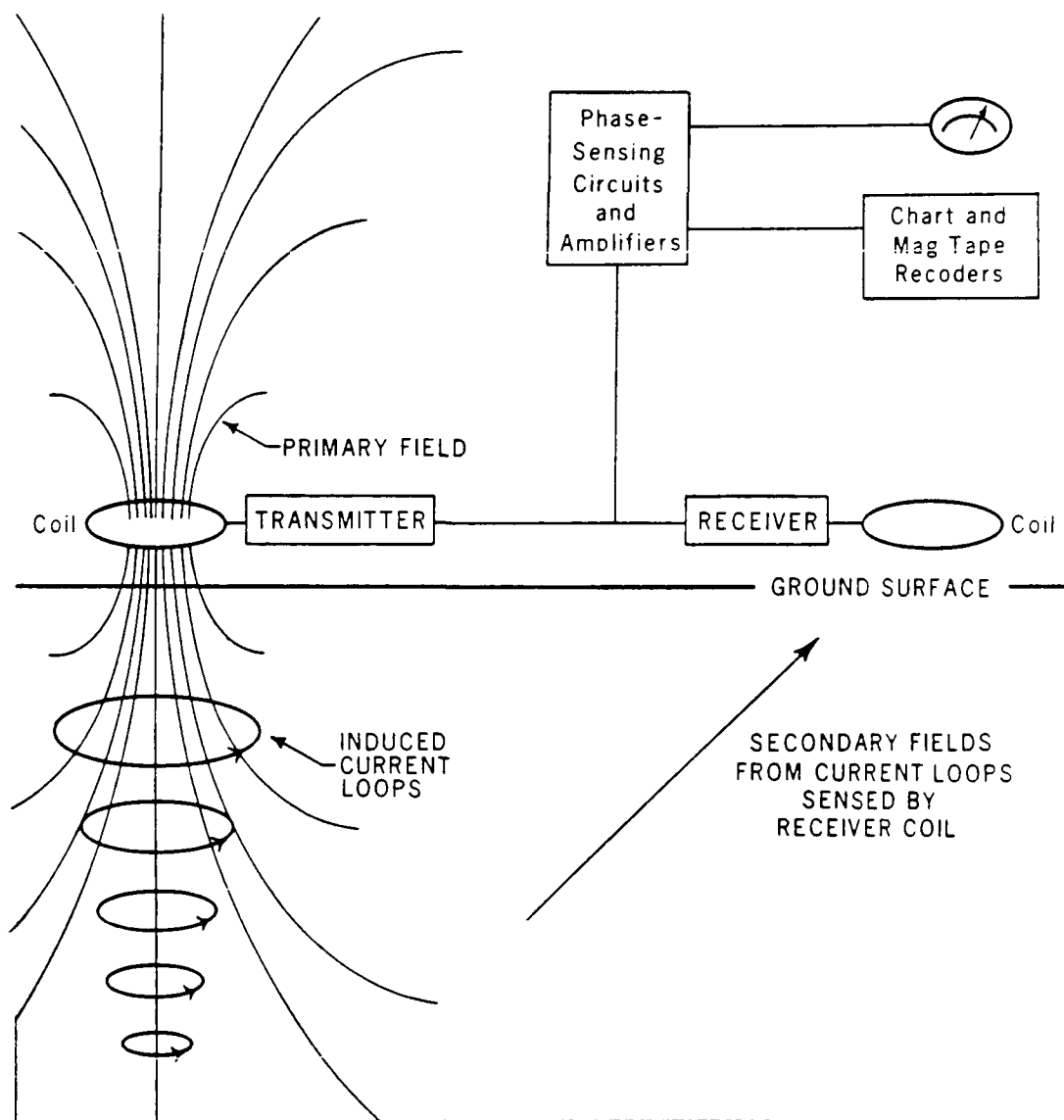
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*Figure 156a. Conceptual design for an electromagnetic induction system.*



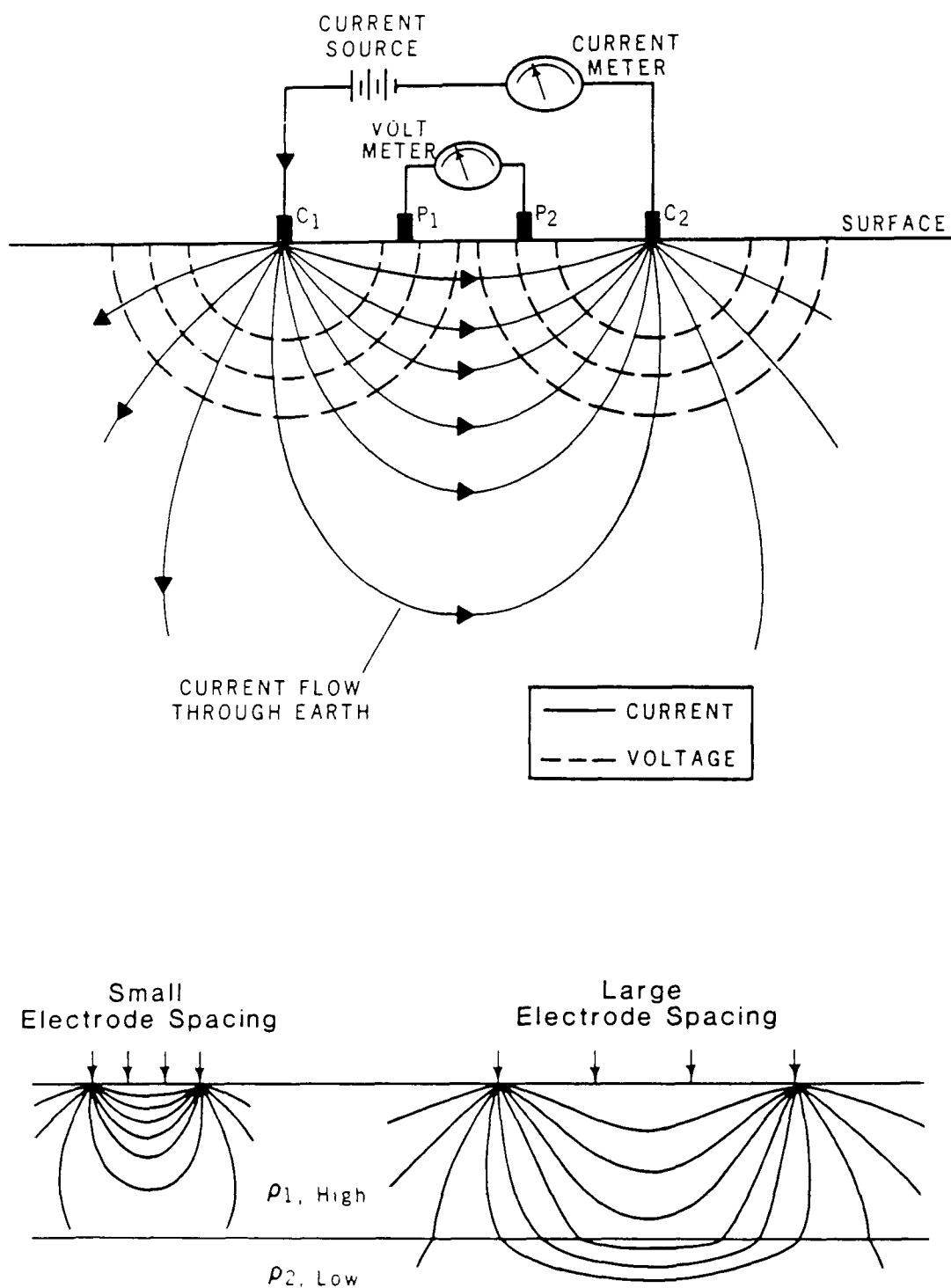
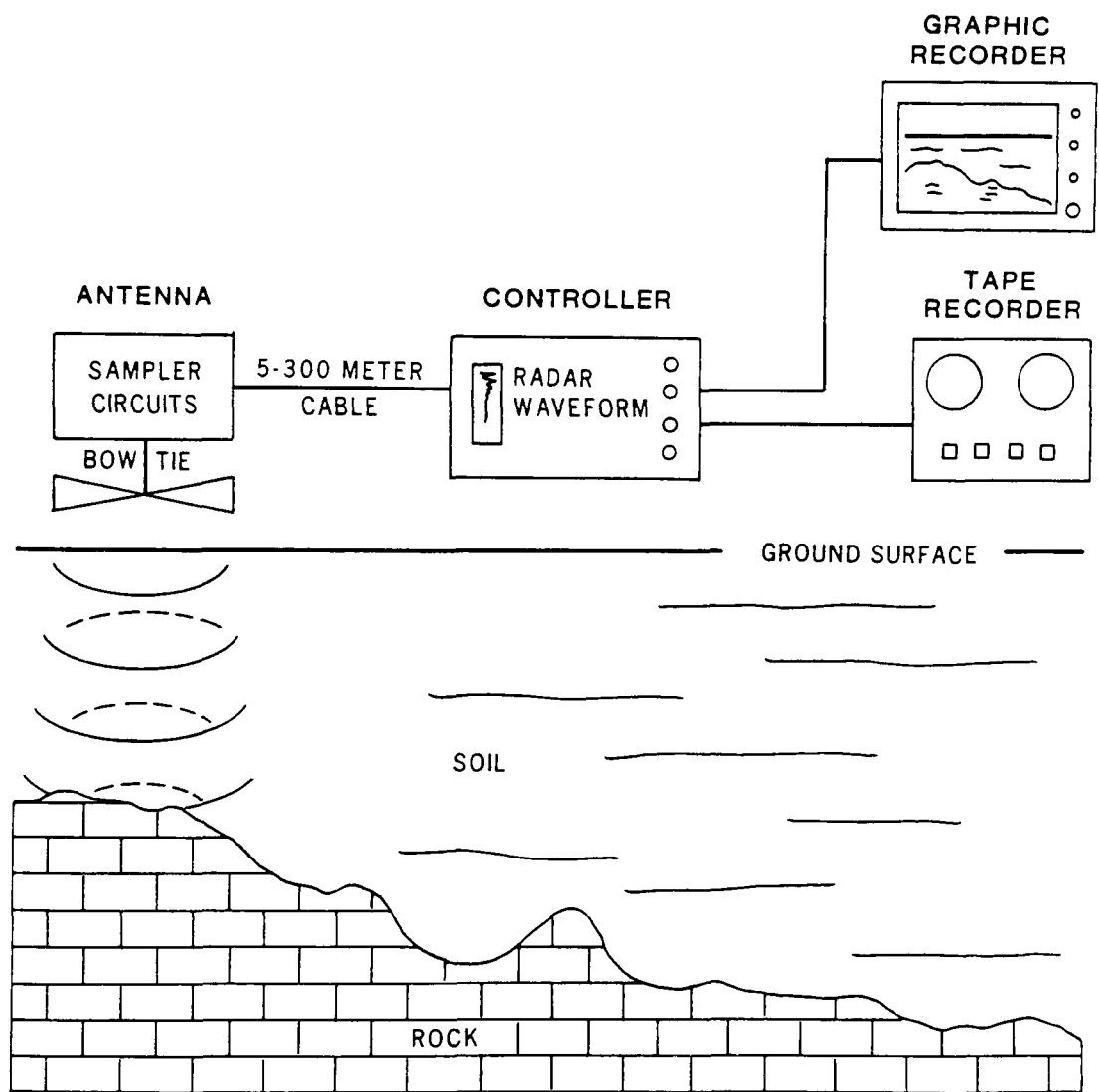
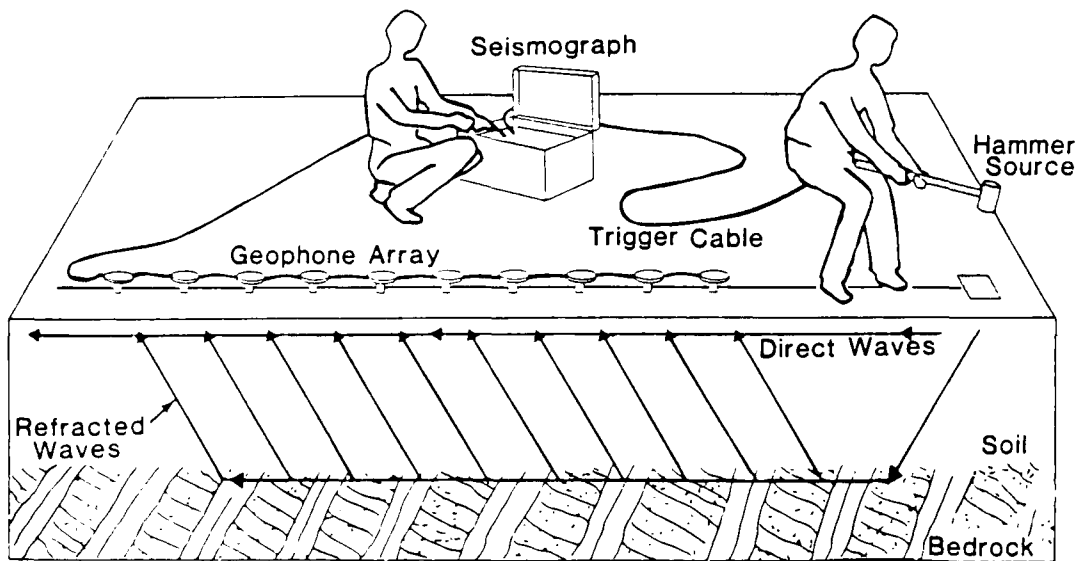


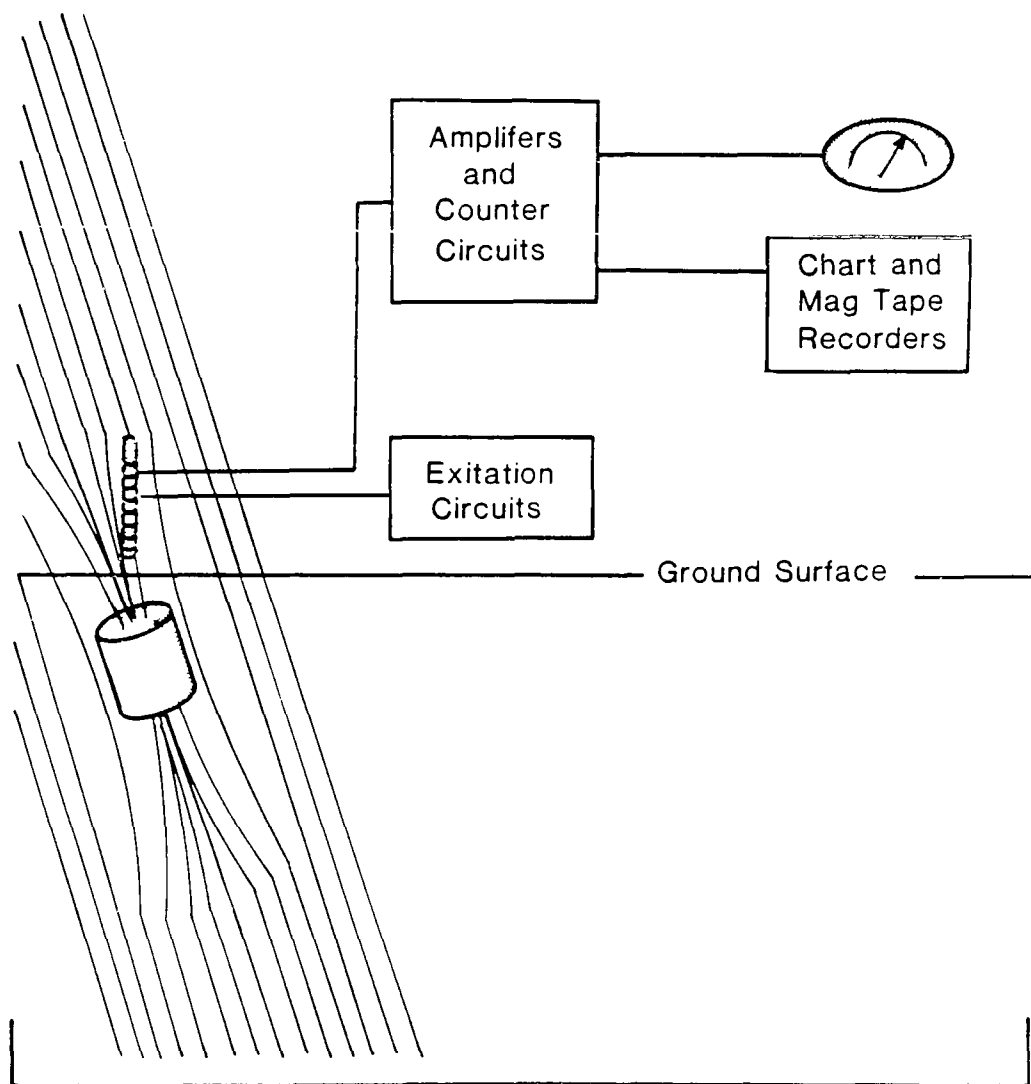
Figure 156b. Conceptual diagram for a direct current resistivity system (top) and effect of varying electrode spacing on volume of earth sampled (below)..



*Figure 156c. Conceptual diagram for a ground-penetrating radar system.*



*Figure 156d. Conceptual diagram of a seismic refraction system.*



*Figure 156e. Conceptual diagram for a magnetometer.*

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## 157. X-RAY FLUORESCENCE FIELD METHOD FOR SCREENING INORGANIC CONTAMINANTS AT HAZARDOUS WASTE SITES

- Category:** III. Analytical Methods and Instrumentation Development.
- Purpose:** Field screening method for inorganic contaminants.
- Application:** This method is applicable for the detection, measurement, and mapping of inorganic contaminants at low-to-moderate ppm levels in soils and waste.
- Description:** Methodology for rapid field screening of inorganic contaminants has been developed using portable X-ray fluorescence (XRF) analyzers. Measurements can be made *in situ* or in a field laboratory for a small fraction of the cost of conventional laboratory analysis. Detection limits vary depending on matrix effects, instrumentation, and sample particle size, but generally range from tens of parts per million to tenths of percent.
- Advantages:** Method is rapid and inexpensive.
- Limitations:** Sensitivity without extensive sample preparation.
- Costs:** Unavailable at the present time.
- Availability:** Commercially available.
- Status:** Widely used in mining exploration and used routinely for lead screening.
- References:** Simmons, M.S., Editor. **Hazardous Waste Measurements** – Chapter 9. Lewis Publishers, Inc., 1991.
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