United States
Environmental Protection
Agency

Office of
Solid Waste and
Emergency Response

Office of Program
Management and Technology
Washington DC 20460

Superfund | EPA/540/2-88/003 | September 1988

EPA

Assessment of International Technologies for Superfund Applications

EPA/540/2-88/003
September 1988

Assessment of International Technologies for Superfund Applications

Technology Review and Trip Report Results

by
Thomas J. Nunno
Jennifer A. Hyman
Alliance Technologies Corporation
Bedford MA 01730

Task Manager
Thomas H. Pheiffer

Office of Program Management and Technology
Office of Solid Waste and Emergency Response
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

Disclaimer

This Final Report was furnished to the Environmental Protection Agency by Alliance Technologies Corporation, Bedford, Massachusetts 01730, in fulfillment of Contract No. 68-03-3243, Work Assignment No. 2-16. The opinions, findings, and conclusions expressed are those of the authors and not necessarily those of the Environmental Protection Agency or the cooperating agencies. Mention of company or product names is not to be considered as an endorsement by the Environmental Protection Agency.

Contents

Figures

Tables

Acknowledgments

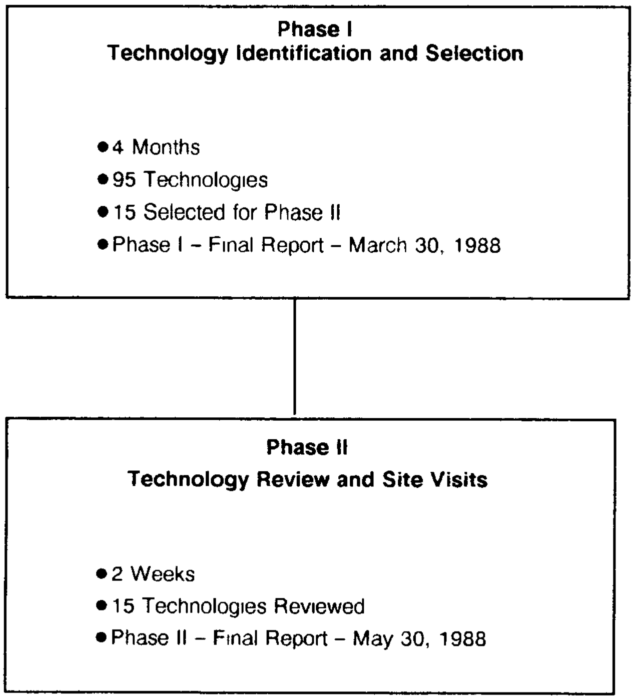
This project was sponsored by Mr. Thomas Devine, Director of EPA's Office of Program Management and Technology. The authors wish to express their appreciation for the efforts of Mr. Thomas Pheiffer of that office, for his participation in the Phase II field team and support throughout the project.

The authors acknowledge the cooperation of all the EPA research laboratory, enforcement, and regional personnel, who contributed to the Phase I document. The authors also wish to thank Ms. Margaret Brown Nels of Berlin, FRG, and all the foreign researchers and cleanup firm contacts who contributed to the Phase II field efforts.

Introduction

The purpose of this program was to identify and assess international technologies applicable to hazardous waste site remediation in the United States. As shown in Figure 1, the program was conducted in two phases: 1) Phase I - Technology Identification and Selection; and 2) Phase II - Technology Review. This report summarizes the results of Phase II of this program, a thorough investigation of the most promising technologies identified by Phase I efforts.

Figure 1. Program structure – The assessment of international technologies for Superfund applications.



General Approach

The in-depth investigation of the most promising technologies was accomplished by interviewing scientists and engineers who are researching or are knowledgeable of each technology. Laboratories, facilities and site installations were toured. These meetings were scheduled by Alliance or organized by the coordinators of treatment technology research in each country. These prominent coordinators include Ms. Esther Soczó, Coordinator of Soil Development at The National Institute of Public Health and Environmental Hygiene (RIVM), the major government research center in Holland; Dr. Ir. K.J.A. de Waal, Deputy Director of TNO (Netherlands Organization for Applied Scientific Research); and Mr. Christian Nels, Director of Research for Umweltbundesamt, (Federal Republic of Germany's equivalent to U.S. EPA). During the Phase II investigation, 15 technologies in three European countries were visited by the field team, which included Mr. Thomas Nunno and Ms. Jennifer Hyman of Alliance Technologies Corporation, and Mr. Thomas Pheiffer of the U.S. EPA, Office of Program Management and Technology.

Overview of Site Remediation Programs in Holland, Belgium and Federal Republic of Germany

Holland (The Netherlands)

The field team began in Holland, a very densely populated country where much land is below sea level. Since there is little open space in Holland, landfilling of wastes is restricted. Remediation of abandoned sites has become a priority in Holland. Holland's extensive experience with land and water management due to high ground water levels has brought about developments in soil and water management techniques useful for site remediation.

The Dutch government has set three specific levels for hazardous contaminants which are used as guidelines for prioritizing site remediation. Examples of these levels designated A, B and C, are shown in Table 1. Soils with contamination above the "C" level, if treatable at a cost below 250 Dfl/tonne ($135/ton), must be cleaned and to below "B" level concentrations. Soil below the "B" level but above the "A" level may be used as fill, not as farmland.

The Dutch government supports the development of innovative site remediation techniques by partially funding cleanup efforts and the research center TNO, and through the full support of the research and development center RIVM (National Institute of Public Health and Environmental Hygiene). Representatives from the Dutch government and industry are also active in the NATO/CCMS Pilot Study Demonstration

Table I. Dutch Reference Levels Used for the Judgment of Soil Contamination

Component	Concentration level (mg/kg dry weight) A	B	C
Polycyclic aromatic hydrocarbons (total)	1	20	200
Mononuclear aromatics (total)	0.1	7	70
Mineral oil	100	1,000	5,000
Cyanide (total complex)	5	50	500

A = Background level uncontaminated soil.
B = Level which necessitates further investigation.
C = Level which necessitates a sanitation investigation.

of Remedial Action Technologies for Contaminated Land and Ground Water.

Belgium

The Phase I report noted that although the three regions of Belgium are encouraging development of regional treatment facilities, little information was available concerning site remediation efforts. At this time, very little site remediation work is being conducted in Belgium due apparently to a lack of government spending and regulation in this area. However, a highly useful high-temperature technique for the treatment of low-level radioactive wastes was investigated for possible application to difficult-to-treat hazardous wastes.

The Federal Republic of Germany (West Germany and Berlin)

Unlike Holland, the Federal Republic of Germany (FRG) has not yet set limits for the concentrations of contaminants in soil. Using the Dutch tri-level system as a guideline, the German State governments collaborate with responsible parties on reasonable goals for final concentrations on a site-by-site basis.

Treatment technology development is promoted by Umweltbundesamt, the West German equivalent of the U.S. EPA, through a 50 percent funding program. Technologies that qualify can receive a 50 percent loan on capital costs for pilot-plant construction. If the pilot project is successful, the technology must be employed and the loan must be repaid. If the plant fails to reach preset performance goals, the company does not have to repay the loan. West German site remediation experts are also active in the NATO/CCMS Pilot Study Demonstration of Remedial Action Technologies for Contaminated Land and Ground Water.

One activity that has helped to stimulate site remediation in the Federal Republic of Germany was a mandatory insurance requirement beginning in the late 1960s for companies with oil and gasoline storage tanks. These policies have been broadened to include most hydrocarbon contaminations and have encouraged development and application of inexpensive and effective oil treatment techniques.

Summary of Results

The field team visited with 12 research groups, consultants, and manufacturers at 15 locations during visits to three countries in Europe. The site visits, conducted from March 21 through April 2, 1988, during the Phase II effort, are listed below by country:

1. THE NETHERLANDS

   A. TNO

      i. Electrochemical treatment of organohalogens
      ii. Bioreactors

   B. RIVM

      i. Overview of soil treatment research in the Netherlands
      ii. In situ biorestoration

   C. Heijmans Milieutechniek BV - soil washing by extraction

   D. TAUW Infra Consult BV

      i. In situ washing of Cd-polluted soil
      ii. Rotating Biological Contactors for treatment of pesticides in ground water

   E. HWZ Bodemsanering - soil washer especially for cyanides

   F. Heidemij Uitvoering BV.

      i. Mobile soil washer using froth flotation
      ii. Steam stripping in situ
      iii. Cum-Bac on-site composting technique

2. BELGIUM

   A. SCK/CEN High Temperature Slagging Incinerator

3. FEDERAL REPUBLIC OF GERMANY

   A. Hannover Umwelttechnik GmbH - Vacuum extraction of organics in soil

   B. Umweltbundesamt - overview of soil treatment research in the FRG

   C. Harbauer GmbH - soil washing using low frequency vibration

   D. TBSG Industrievertratungen GmbH - soil cleaning on-site using the surfactant "Oil CREP"

   E. Umweltschutz Nord GmbH

      i. On-site composting using bioreactors, special substrate and reed beds
      ii. In situ biorestoration

The results of the individual site visits are summarized below. Capsule summaries of each site visit, presented in Appendices A through M, include a brief process description, discussion of process limitations, performance data, costs, and status of process development.

In general, the Phase II efforts were successful at identifying site cleanup technologies not currently used in the United States, as well as unique applications of techniques used in the United States. Among the most important Phase II findings were five different soil washing techniques in Holland and the FRG. Another key finding was the High Temperature Slagging Incinerator (HTSI) technology reviewed in Belgium. In addition, the field team reviewed unique applications of in situ biological treatment and composting techniques, vacuum extraction and in situ air stripping, in situ extraction of cadmium from soils, application of rotating biological contactors, and electrochemical dehalogenation techniques. All of these unique applications and research should contribute significantly to our knowledge base of site cleanup technologies in the United States.

Soil Washing Equipment Findings

The field team reviewed five high throughput soil washing technologies in Holland and the FRG. Characteristics of these technologies are summarized in Table 2, including throughput, unit operations, reject particle size and costs.

Table 2. Soil Washing Installations Visited by Alliance/EPA Field Team in March 1988 in the Netherlands and the Federal Republic of Germany.

Installation	Rated Throughput	Principal Operations	Particle Reject Size	Fixed or Transportable	Pollutants Treated	Refractory Pollutants	Treatment Fee per Ton	Sludge Disposal Costs per Ton	Capital Costs
Heijmans Milieutechniek b.v. Rosmalen, the Neths.	11 tons/hr	• Particle sizing • Scrubbing with detergents and oxidants • Flocculation • Precipitation	< 63 µm	Transportable but fixed	Cyanides Heavy metals PCAs Mineral oil Kerosine	Cl-HCs Aromatics	$73-91 $102 at max 30% < 63 µm	$136	New 33 tons/hr plant planned, $4.5 million
HWZ Bodemsan-ering Amersfoort, the Neths.	22 tons/hr	• Particle sizing • Scrubbing with detergents • Flocculation • pH adjustment • Carbon filters	< 63 µm	Transportable but fixed	Cyanides Heavy metals aromatics Solvents Cl-HCs	Oily cmpds Br cmpds	$53 plus $2.50/ton for each % < 63 µm, up to 20%	$136	$3 million
Heidemij Uitvoering b.v.'s-Herto-genbosch, the Neths	30 tons/hr	• Particle sizing • Froth flotation with cleaning agents • Washing	< 50 µm	Mobile, but will be fixed in the future	Cyanides Heavy metals PCAs Oils Cl-HCs Pesticides	PAHs PCBs HCH Some heavy metals	$90-155, 2200 tons is min treated	as high as $182	$3 million
Harbauer GmbH Berlin, FRG	16.5-22 tons/hr	• Particle sizing • Low-freq. vibration with extrac-tants • Washing • Water treatment by flotation, air stripping, ion exch. and activated carbon	< 15 µm	Fixed	Organics Phenol PAH Org-Cl cmpds PCBs	Heavy metals	$136 (excludes residue disposal)	Sludge stored to date	$4.5-6 million
TBSG Industrievertretungen GmbH- Oil CREP System Bremen, FRG	44 gpm, New 88 gpm plant planned	• Particle sizing • Washing with Oil CREP I • Solid/liquid separation	< 100 µm	Mobile	Extractables HCs PAHs Extr. Hal-org.	PCBs Fl-HCs Cyanides Heavy metals	$82-109 excluding disposal of residues, 3920 cu yds min treated	$6K/day sludge treatment	Not known at this time

A key similarity among all of the units was that they operate on the principle that most of the contaminants are sorbed to the fine materials (< 63 µm) and segregation of these materials from the other size fraction "cleans" the soil. Some of the units (i.e., the Heijmans unit), employed very simple particle separation and wash water treatment technologies, while others (Harbauer and Oil CREP) employed more sophisticated extractants and cleaning agents. A major consideration of all washing techniques is the fact that as particle reject size decreases, so does sludge residue generation. Cleaning efficiency tends to decrease with decreasing particle size.

Most of the soil washing companies noted that their practical upper limit of fines (< 63 µm) was 20 to 30 percent in the soil to be cleaned. Because the proportion of fines present increases the generation of sludge, treatment costs tend to increase for finer grained soils. The Harbauer technology shows an advantage of potentially generating less sludge; however, the additional costs of wash water treatment employed for that technology make it slightly more expensive than the other soil washing technologies reviewed.

High Temperature Slagging Incineration (HTSI)

The Belgium HTSI technology shows promise as a transferable technology for high hazard waste streams and fibrous asbestos wastes. Details of this technology are summarized in Table 3. Very high combustion efficiency and off-gas cleaning efficiencies along with very stable slag residues make this technology very attractive. The high treatment costs $3.50/kg ($1.60/lb) associated with the low throughput 60 kg/hr (133 lb/hr) unit make the development of higher throughput units critical to its successful importation to the United States' market.

Other Unique Applications of Site Remediation Technologies

During the trip, many other successful applications of conventional and novel treatment technologies were observed, on both a research scale as well as full-scale. Table 4 outlines the important characteristics of these technologies.

Biorestoration research and full-scale applications of bioremediation technologies have advanced in European countries much as it has in the United States. During visits with two research organizations (TNO and RIVM) and three consulting companies, the field team observed many successful studies and applications of biological treatment technologies, (mostly aerobic systems).

In situ bioremediation was being researched and tested at RIVM and applied by Heidemij in Holland. RIVM found that hydrogen peroxide was a suitable oxygen source for in situ bioremediation. Biodegradation rates of 10 mg C/kg day were obtained by RIVM. At a contaminated gasoline site, bioremediation will be used for cleanup to the Dutch A limit of 20 mg/kg.

Ex situ or on-site bioremediation technologies are being researched and applied in both Holland and the FRG. TNO showed successful results from laboratory experiments for both wet slurry biological treatment systems and dry compost-type systems. This fundamental research showed diffusion of organics from the soil particles to be the rate limiting step. Full-scale applications of compost-type systems were being applied by both Heidemij (Holland) and Umweltschutz Nord (FRG). Costs for full-scale ex situ composting applications were found to be in the range of $82 to $136/ton.

A Rotating Biological Contactor (RBC) application employed by TAUW in Holland was used on pesticide-contaminated ground water containing chlorinated organics. TAUW found that the RBC system reduced activated carbon requirements by 92 percent, and decreased remediation costs by 30 percent.

Other physical/chemical treatment research reviewed included an in situ cadmium extraction project by TAUW and an electrochemical dehalogenation research project by TNO. The cadmium extraction

Table 3. Incineration Installation Visited by Alliance/EPA Field Team in March 1988 in Belgium

Company/ Institution	Technology	Pollutants Treated	Medium Treated	Principal Operations	Scale of System	Size and Time of Treatment	Treatment Costs	Capital Costs
SCK/CEN Mol, Belgium	High-Temperature Slagging Incineration	All (originally for low-level radioactive wastes)	All	• Waste shredding and full mixing • Combustion at 1400°C into molten slag • Slag granulation by quenching • Off-gas treatment by teflon bag filters, scrubber and HEPA filters	Full	133 lb/hr	$1 60/lb	$6 million (less if built w/out extensive off-gas treatments)

Table 4. Other Site Remediation Technologies Visited by Alliance/EPA Field Team in March 1988 in the Netherlands and the Federal Republic of Germany

Company/ Institution	Technology	Pollutants Treated	Medium Treated	Principal Operations	Scale of System	Size and Time of Treatment	Treatment Costs	Capital Costs
TNO-Dept. of Environmental Technology Delft, the Neths.	Electrochemical Dechlorination Treatment	Polar and Ionic Organo-halogens	Dilute Aqueous Waste Streams	• Titanium anode • Woven carbon fiber cathode • Membrane between • Surface active additives • About 10 A, 60 mins.	Bench	Pilot tests will be 26 gal/hr	$0.02/gal	Not yet determined
TNO- Dept. of Process Technology Apeldoorn, the Neths.	Bioreactors	Non-chlor-inated hydro-carbons	Slurried or dry soil	• Mixing and aeration • Nutrients • Detergents • Native microorganisms	Bench	Pilot tests will be 11 tons/day	$45/ton	Not yet determined
RIVM- Soil and Ground Water Research Laboratory Bilthoven, the Neths.	In Situ Biorestoration	Gasoline	Soil	• Infiltration of nutrients • Water, and • H_2O_2 as oxygen source • Iron extraction unit	Full	1961 cu yds, $1\frac{1}{2}$ years	$171/cu yd	$336,000
TAUW Infra Consult bv Deventer, the Neths.	In Situ Cadmium Removal	Cadmium	Soil	• Infiltration of acidic water to leach cadmium (pH = 3.5) • Ion exchange onsite	Full	39,200 cu yds, 1 year	$63/cu yd	$2.5 million
TAUW Infra Consult bv Deventer, the Neths.	Rotating Biological Contactors	Pesticides	Ground Water	• Metal honeycomb disks • Compost air filter • Sand filtration • Activated carbon	Full	110 gpm	Data not available	Data not available-total costs reduced 30% with RBC
Hannover Umwelt-technik GmbH Waldorf, FRG	In Situ Vacuum Extraction and Air Stripping	Volatile organics	Soil vadose zones and ground water	• PVC slotted wells extract from vadose • Small pump • Activated carbon column • Compressed air injected into ground water	Full	About 10,000 cu yds, 1 year	< $5/ton	$1500, depending on scale of project
Umweltschutz Nord GmbH Ganderkesee, FRG	On-site Composting	Non-chlor-inated hydro-carbons	Soils	• Unique substrate • Nutrients, microbes • PET liner with leachate collection • Aeration • Greenhouse cover	Full	131 cu yds per bed, 6 months with greenhouse	$90/ton	Varies

project employed in situ hydrochloric acid leaching of cadmium from over 30,000 m^3 of soil. The acid leachate was purified by ion exchange and reused. The treatment cost was estimated to be $75/ton of soil. The electrochemical dechlorination research is currently nearing the end of the bench-scale phase. The potential application to site remediation is in the detoxification of complex organohalogens in the aqueous phase. Current costs are projected to be $0.023/gal. Full-scale research will begin June 1988.

Numerous full-scale projects involving in situ vacuum extraction and air stripping of volatile contamination were reviewed in the FRG. Hannover Umwelttecknick (HUT) has installed over 300 vacuum extraction installations for vadose zone decontamination. HUT has also developed a unique in situ air stripping system for removing volatiles from ground water in conjunction with vacuum extraction. Treatment costs for the HUT system are less than 10DM/tonne ($5/ton).

Conclusions and Recommendations

Soil washing experience in the Netherlands and the Federal Republic of Germany (FRG) has shown that soil washing can be conducted on a large-scale at costs substantially lower than those of incineration (with notably less effectiveness). Although most of the technologies generate 10 to 20 percent of the initial volume as sludge, depending on the fines content, work is being conducted in the FRG to improve effectiveness of soil washing on fine materials and to reduce sludge generation. Typical cleaning efficiencies for soil washers ranged from 75 to 95 percent removal, depending on the contaminant. Although the authors believe that soil washing technologies could be used effectively in the United States to significantly reduce landfilling of CERCLA site soils, it is unlikely that domestic or foreign companies will invest in this market until a uniform set of soil cleanup criteria is developed.

Biological treatment technologies have been shown to be useful both for polishing to lower concentrations using in situ treatment, and for gross removals of organic materials using RBC and composting systems. Efforts should be made to encourage the use of these types of systems in the United States.

High temperature slagging incineration appears to be a viable technology for application towards high hazard wastes and asbestos wastes in the United States. The licensing and construction of units in the United States should be tracked to encourage evaluation of domestic installations.

In situ vacuum extraction of volatile organic compounds is a well-known technology in the United States. Applications in the FRG include the use of in situ air stripping of volatiles from ground water into the vadose zone and their subsequent removal by the extraction wells. Such vacuum extraction applications and other innovations such as bioaugmentation should be encouraged in the United States.

The apparent success of this relatively short-duration, technology assessment program indicates that despite the wealth of information available in the United States, there is much to be learned from ongoing work in foreign countries. The authors recommend that further efforts be made to encourage the transfer of European site remediation technologies through improved literature dissemination and seminar presentations at symposia. It is also recommended that results of research identified under this project and the NATO/CCMS Pilot Demonstration program be closely monitored over the next few years.

Appendix A
Research on Electrochemical Treatment of Organohalogens in Process Wastewater at TNO

TNO Division of Technology for Society
P.O. Box 217
2600 AE Delft
The Netherlands

Dr. - Ir. D. Schmal
Dept. of Environmental Technology
Tel.: 011-31 (15) 69 60 87

Process Description

This research project focuses on the electrochemical dechlorination of organohalogens. In the laboratory, simulated dilute wastewater was passed between a platinized titanium anode and a woven carbon fiber cathode (fiber diameter = 10 μm). The applied voltage causes the chlorine atoms of the organohalogens to be replaced by hydrogen atoms, thus reducing their toxicity and increasing their biodegradability. Electrochemical treatment is designed to treat ionic or polar organohalogens which are, in general, difficult to decontaminate by adsorption or stripping. It is also more appropriate for dilute wastewaters or wash waters, where destruction by incineration, for example, would be too costly.

A diagram of the apparatus used by Dr. Schmal in the laboratory at TNO is shown in Figure A-1. The reactor consists of two compartments separated by a Nafion 425 membrane. Each compartment is 10 cm long, 2 cm wide, and 0.5 cm deep.

Process Limitations/Performance Data

Electrochemical reduction is only practical for treating aqueous solutions of polar or ionic organohalogens. The process is only amenable to operation in solutions with low filterable solids content. Fouling problems may result from solids in suspension or from polymerization of organics. The process is currently limited to solutions containing up to 1 g/L chlorinated organics. Experiments have proven the technique using batch tests. Pilot-scale tests will be initiated soon on synthetic wastewater at a treatment rate of 100L/hr (26 gal/hr).

Another important factor necessary for treatment is that the contaminant be miscible in the solution. PCBs will not be treated by this method until a suitable solvent has been found.

Electrolytic reduction has been successfully applied at TNO to pentachlorophenol (PCP), p-chloronitrobenzene (CNB), and dichlorvos (DDVP). Results of electrochemical reduction of these three contaminants are provided in Table A-1. While it takes only 30 minutes to reduce PCP to below its detection limit, it takes considerably longer before all chlorinated secondary products are reduced to the non-chlorinated phenol. A graph of the formation and decay of by-products during PCP reduction is shown in Figure A-2.

The addition of small quantities of surface active agents improves efficiency, decreasing energy consumption by 45 percent. These micelle-forming compounds are patented by van Erkel, et al. (U.S. No.4,443,309).

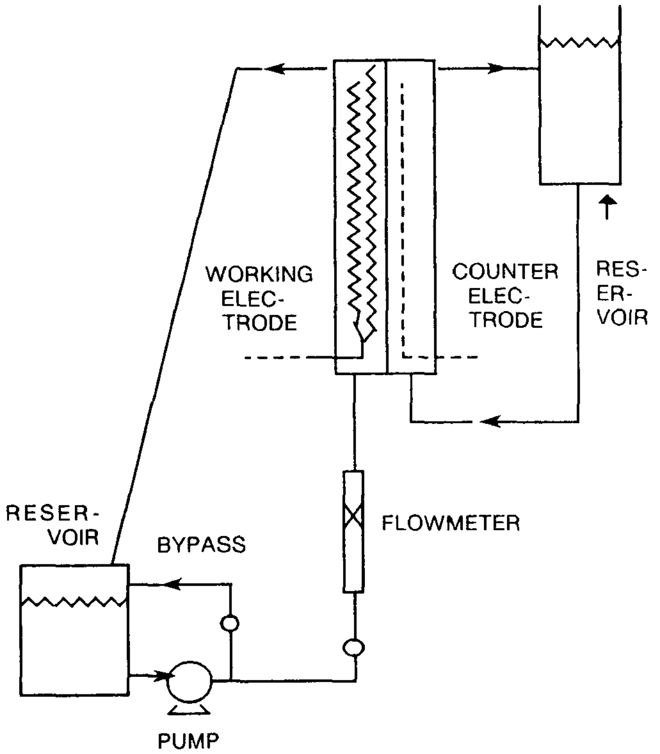
Cost

In comparison with electrolysis of metals, which costs 2-5 Dfl/m^3 (<$0.01/gal), electrolysis of organohalogens is expected to be more or less comparable in cost, about 10 Dfl/m^3 ($0.02/gal). The basis for these costs are 40 percent capital costs, 40 percent energy costs, and 20 percent operation and maintenance.

Process Status

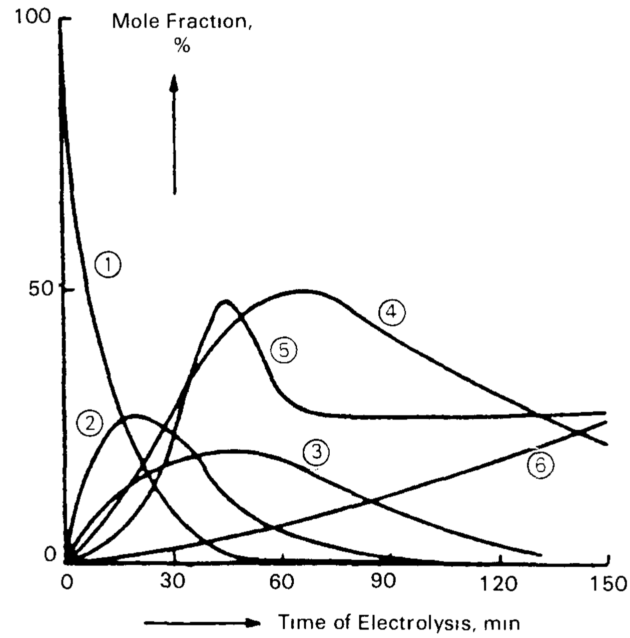
This bench-scale research on electrochemical dechlorination of organohalogens was sponsored by Pielkenrood-Vinitex, a Dutch producer of wastewater treatment equipment (along with the European Communities and various Dutch Ministries), so it has certainly been geared towards practical full-scale application. Since Phase I of this project has been so successful, Phase II, which will last from June 1988 through 1989, should show some progress towards the development of a full-scale continuous electrochemical reactor. The usefulness of this technology will probably be proven in Holland first before intentions for exportation or licensing abroad arise.

Figure A-1. Diagram of the apparatus for electrochemical treatment of organohalogens.



Source: Schmal, D., J. van Erkel, and P J. van Duin. "Electrochemical Reduction of Halogenated Compounds in Process Waste Water," Electrochemical Engineering, The Institution of Chemical Engineers Symposium Series No. 98. p. 262. April 1986.

Figure A-2. *Mole fraction of the phenols during electrolysis of 2 L of 50 ppm PCP solution (10A).*



1. PCP
2. Tetrachlorophenols
3. Trichlorophenols
4. Dichlorophenols
5. Monochlorophenols
6. Phenol

Source *Schmal, D., J van Erkel, and P J van Duin* "Electrochemical Reduction of Halogenated Compounds in Process Waste Wateer" Electrochemical Engineering, the Institution of Chemical Engineers Symposium Series No 98 April 1986

Table A-1. Results of Electrochemical Reduction of Three Organohalogens Tested at TNO

Contaminant	Initial Conc. (ppm)	Final Conc. (ppm)	Cathodic Current (amps)	Time (min)	Energy Consumption (kWh/gal)	Toxicity Notes	Remarks
PCP	50	<0.5	10	30	0.14	Toxicity reduced 95%	1 L in 0.1 M sodium sulfate/0.1 M sodium hydroxide solution
CNB	30	<0.1	10	60	0.11	---	1 L in 0.1 M sodium hydroxide solution
DDVP	560	<1	1	60	0.0030	value = 56 ppm	1 L in 0.1 M sodium sulfate solution

Source: Schmal, D., J. van Erkel, and P.J. van Duin. "Electrochemical Reduction of Halogenated Compounds in Process Waste Water," Electrochemical Engineering, The Institution of Chemical Engineers Symposium Series No. 98. April 1986.

Appendix B

Research on Decontamination of Polluted Soils and Dredging Sludges in Bioreactor Systems at TNO

TNO Division of Technology for Society
P.O. Box 342
7300 AH Apeldoorn
The Netherlands

Mr. Guus J. Annokkée
Dept. of Process Technology
Tel.: 011-31 (55) 77 33 44

Process Description

A bioreactor is primarily a mixing apparatus whose main function is to increase the availability of contaminants and nutrients to the microorganisms for accelerated biodegradation of these hazardous compounds. TNO studies have found that since the microorganisms are bound to the soil particles, mixing is one of two important contributors to high biodegradation rates. In their research on bioreactor systems, TNO also uses detergents to enhance the bioavailability of the contaminants.

The factor other than bioavailability which contributes to high biodegradation rates is the ability of the microorganisms to degrade the particular contaminants. Microorganisms specially suited to break down certain toxic compounds can be cultivated in the laboratory, but where a site is old, appropriate microorganisms are usually already present in the soil. The availability of nutrients and oxygen is not the controlling factor in accelerating the biodegradation rate but is necessary for maintaining it. The bioreactors are continuously mixing and aerating the soil and operate at ambient temperature. The bioreactor design employed by TNO could not be viewed because the technology is protected by their sponsors.

Two types of bioreactor treatments are employed by TNO: dry and wet bioreactor systems. The dry bioreactor system is similar to a composting type of operation, while the wet bioreactor is more closely compared to an aerobic activated sludge system. The dry bioreactor operates under an ambient moisture of 15 to 20percent and requires no dewatering step after treatment. In the wet bioreactor, the soil is handled as a slurry. Slurries are easier to process in that they can be pumped, but must be dewatered if the soil is to be reused. Both wet and dry bioreactor systems are effective. However, future TNO research is focusing on the dry (composting type system) due to the advantages noted above. A key finding of TNO's research has been that the biodegradation reaction is rate-limited primarily by diffusion of the organic material to the surface of the soil particles.

Bioreactors are naturally applicable to biodegradable contaminants such as mineral oils, PCAs, and other non-chlorinated hydrocarbons. Microorganisms that secrete acid are used to remove contaminants that are leachable, such as heavy metals. A wide variety of soil types, from sand to loam and clay, can be cleaned in the bioreactor.

Process Limitations/Performance Data

Bioreactors have been found to be effective on contaminants that are biodegradable. Chlorinated hydrocarbons, as a result, have not been effectively treated by this method. Results of TNO's bioreactor degradation of various organic pollutants in a variety of soil types are shown in Table B-1. These performance data are from batch laboratory studies on wet and dry bioreactors performed at TNO.

Table B-1. Some Results from the TNO Bioreactor System (Batch Process)

Bioreactor type	Soil type	Contaminant	Concentration (mg/kg dry soil) Day 0	Day 3	Day 14
Dry	Sand	Cutting oil	3,000	980	680
Dry	Sand	Diesel fuel	4,200	1,800	900
Wet/slurry	Loamy sand	Cutting oil	26,000	9,000	1,200
Wet/slurry	Loam	Cutting oil	65,000	--	12,000
Wet/slurry	Loam	PCAs	3,900	1,700	300

Source: Annokkée, G. "Status of TNO Bioreactor System for Soil and Subaquatic Soil Decontamination." Handout from meeting with Alliance field team. March 22, 1988.

One advantage bioreactors have over soil washing techniques is that they are able to treat large quantities of fines. Most problems that arise in bioreactor installations are operational in nature, such as pump failure or line clogging.

Cost

Because of the early stage of bioreactor research, actual capital, operational and maintenance cost data are not available. Prices are expected to be about 100 Dfl/tonne ($45/ton). Actual treatment costs are dependent on the period of treatment necessary. Bioreactor research at TNO has focused on minimizing of residence time necessary for effective treatment.

Process Status

TNO is nearing completion of 2 years of laboratory-scale studies. Pilot-scale experiments with a throughput of 10 tonnes/day (11 tons/day) are currently in preparation. Laboratory-scale studies have been batch-type. Since the microorganisms are bound to the soil particles, system configuration(batch or continuous) does not affect the biodegradation rate. TNO estimates that commercial systems will be batch-operated, have a capacity of 200 or 500 tons, and have treatment time of 10 to 14 days. Depending on the type of bioreactor, even larger systems are possible. Bioreactors can be constructed to be stationary or mobile.

Bioreactors are a simple technology and, therefore, scale-up of the system to allow high throughput should not be difficult. Research will continue at TNO on treating a greater variety of contaminants, increasing bioavailability of the contaminants, and scaling-up the bioreactor system. This research project is funded 30 percent by the Dutch government and 70 percent by Heidemij Uitvoering, a site cleanup contractor. Heidemij has the rights to the technology, and their intentions towards licensing or exporting the technology are not yet formulated.

Appendix C
In Situ Biorestoration of Contaminated Soil Research at RIVM

RIVM - National Institute of Public Health and Environmental Hygiene
P.O. Box 1
3720 BA Bilthoven
The Netherlands

Ir. Reinier van den Berg, Jos H.A.M. Verheul
Soil Biochemistry and Microbiology
Soil and Ground Water Research Laboratory
Tel.: 011-31 (30) 743338

Ms. Esther Soczó, Coordinator, Soil Development
Laboratory for Waste Materials and Emissions
Tel.: 011-31 (30) 743060

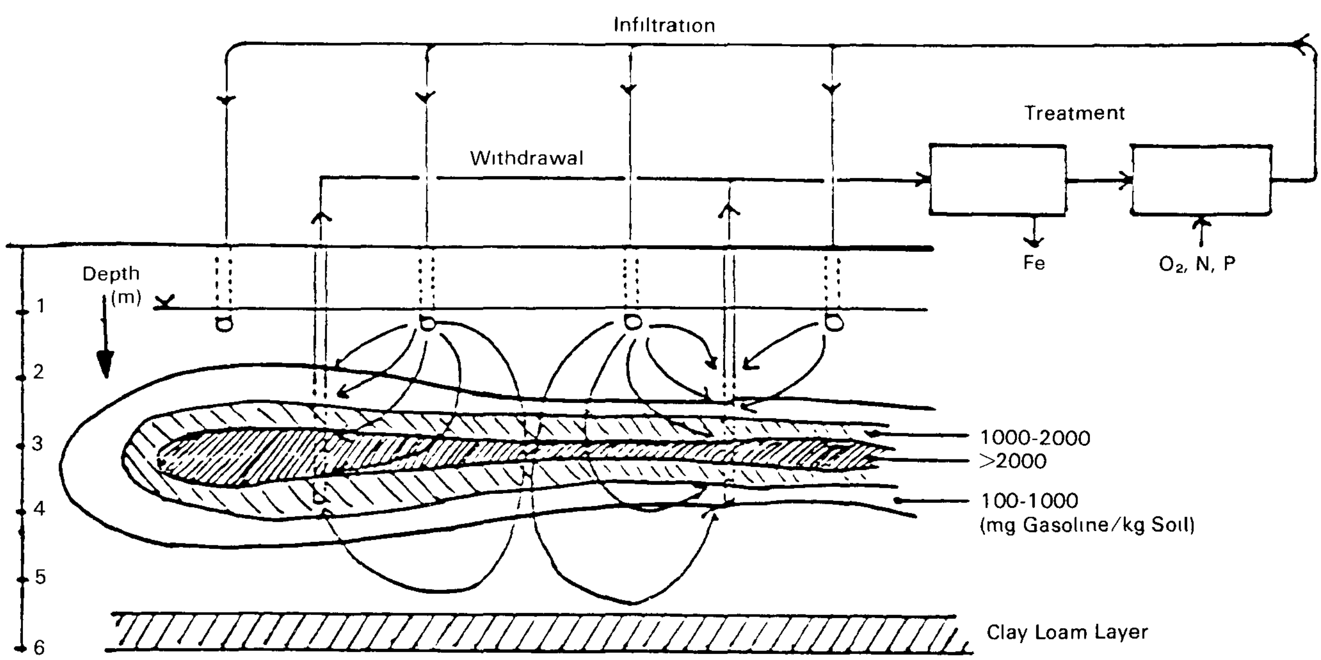
Process Description

The following discussion briefly presents the status of in situ biorestoration research currently being conducted at RIVM. Most of the research to date has been laboratory-scale, however, a NATO/CCMS demonstration study at Asten is scheduled to begin in June 1988.

Undisturbed soil columns were taken from deep layers in the Asten site contaminated with gasoline. Experiments were carried out by the Soil Biochemistry and Microbiology group at RIVM on these columns to determine the optimal conditions for biodegradation. In order to stimulate biodegradation, soil columns were percolated with a variety of nutrients and O_2 sources. pH and the addition of detergents, sodium acetate and microorganisms were all tested for their effects on biodegradation rate.

Results showed that it is possible to increase the biodegradation rate, measured as carbon dioxide production, from 1 to 10 mg C/kg day. The

Figure C-1 Infiltration, withdrawal and treatment setup proposed by RIVM for the Asten site.



Source van den Berg, R, E R Soczó, J H A M Verheul, and D H Eikelboom "In Situ Biorestoration of a Subsoil Contaminated with Oil" RIVM Report No 728518003 p 24 November 1987 degradation activity was most enhanced by the addition of seeding material from a landfarm. The addition of sodium acetate to build biomass, saturation with water, the addition of phosphate and nitrate, buffering, and a neutral pH all contributed to favorable conditions for biodegradation. Detergents had a negative effect, and the source of the nitrogen, whether it was KNO_3, NH_4NO_3, NH_4Cl, or $(NH_4)_2SO_4$, had no effect. As alternative oxygen sources, hydrogen peroxide (H_2O_2) was suitable, whereas nitrate slowed biodegradation. Results of the laboratory-scale research supported the assumption that the rate-limiting step was the availability of the oil components to the microorganisms.

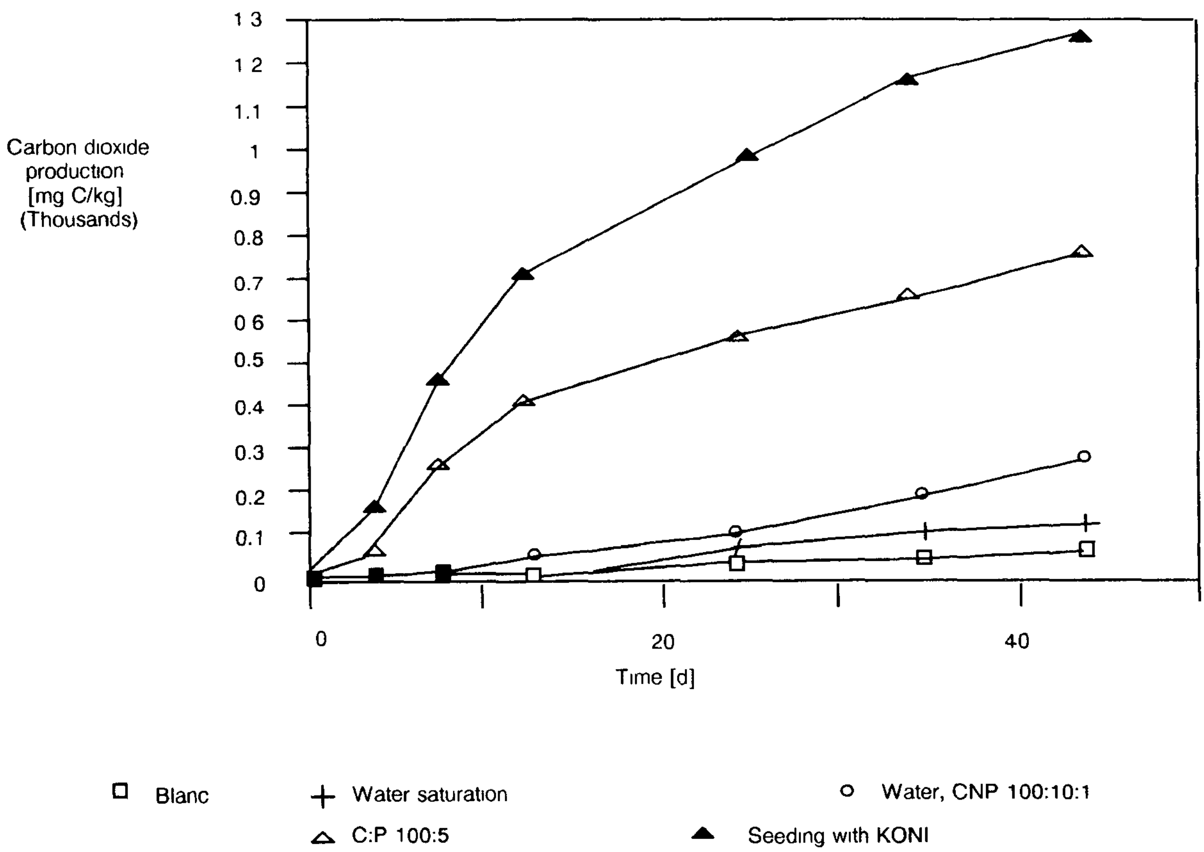
A diagram of the infiltration and withdrawal system proposed for the Asten site is shown in Figure C-1. This system will enhance the leaching and biodegradation of gasoline contaminating the site by the addition of nutrients and oxygen and extract iron from the withdrawn water using a small water treatment unit.

Process Limitations/Performance Data

Biorestoration, in general, is only effective on biodegradable contaminants and is difficult in soils with a high clay and/or organic carbon content. Experimental results from one laboratory-scale study are shown in Figure C-2. In this graph, the effects of water saturation, nutrient addition and seeding with KONI soil (from a landfarm) on biodegradation of gasoline is shown. Although acceleration of the biodegradation process from 1 to 10 mg C/kg day was found to be possible, this rate is still relatively slow. This is apparently due to the fact that very few microorganisms occur naturally in the site.

Some possible limitations that could arise in carrying out the treatment are problems due to cold or wet weather extremes, or mechanical problems with pumps or the ground water treatment unit. Clogging of the wells at the Asten site is not likely because the soil layers to be treated are mostly sand, with less than 0.05 percent organic material. Part of the installation includes hydrological isolation of the contamination vertically and horizontally. Special

Figure C-2. Biodegradation of gasoline measured as CO_2-production (mg C/kg). Gasoline concentrations: 3000-5700 mg C/kg. Effects of water saturation, nutrient addition (CNP ratio 100:10:1 and 100:10:5) and seeding with KONI soil: 50 g/kg.



Source: van den Berg, R., E.R. Soczó, J.H.A.M. Verheul, and D.H. Eikelboom. "In Situ Biorestoration of a Subsoil Contaminated with Oil." RIVM Report No. 728518003 p. 16. November 1987.

attention will be paid to the percolation under the buildings on the site, where the contamination has already begun to spread.

Cost

Conventional cleanup for this site, such as extraction or incineration, would typically cost 1.2 million Dfl (about $672,000). In situ biorestoration, including ground water treatment, is expected to cost half this figure or about $336,000. These figures do not include the costs of sampling and analysis necessary for monitoring the progress of the installation, or the cost of seeded soil which was determined not to be a cost-effective additive. Since 1500 m^3 (1961 cu yd) of soil is contaminated, costs will be 400 Dfl/m^3 ($171/cu yd).

Process Status

A full-scale system will be installed beginning in June 1988 in the gasoline-contaminated site at Asten, in the province of Noord-Brabant. This remediation is a NATO/CCMS Pilot Study demonstration project whose research began at RIVM in 1985. The cleanup operation is expected to take 1-1/2 years to reach the Dutch "A" limit of 20 mg/kg. This cleanup period is based on a daily circulation of water calculated at 1,850m^3 (488,400 gals) with a daily degradation rate of 10 mg C/kg.

The remediation program of RIVM at the Asten site will not provide any innovative technologies to be licensed for marketing abroad. It will provide, if successful, valuable information on soil chemistry and soil microbiology in the field, as well as a practical and less expensive alternative to extraction or incineration treatment for gasoline-contaminated soils.

RIVM is a government center for research and development of all aspects of public health. They also advise the various government Ministries and provide the service of information exchange for industry. The laboratory research done for this remediation project is just one part of a 4-year, 56 million Dfl ($31.4 million) Soil Research Program started in 1987. The Environment, Agriculture, Water Management, and Education Ministries are involved with this research program, which is part fundamental science research and part technological development.

Appendix D
Heijmans Soil Washing Operation

Heijmans Milieutechniek b.v.
Graafsebaan 13
Postbus 2 5240 BB Rosmalen
The Netherlands

Ing. W.P.J. Kemmeren, Assistant Director/Mr. C. Jonker
Tel.: 011-31-4192-89111

Process Description

Heijmans has developed a simple semi-transportable soil washer capable of handling 10 tonnes/hour (11 tons/hour) of soil. Like most soil washers, the Heijmans soil washer operates on the principle that most contamination is adsorbed to the fine soil particles. Thus, the Heijmans soil washer consists of several particle sizing steps with the goal of removing the fines < 63 µm and disposing of that fraction as a sludge byproduct, while the coarser fractions are further washed and used as clean soil.

The soil cleaning plant of Heijmans wet-sieves out coarse material > 100mm and rubble > 5 mm first to allow particles < 5 mm to be washed in the scrubber. The slurry is extensively mixed in the scrubber with extracting agents and oxidizing chemicals. A flotation unit is then used to separate out organic constituents, which must be disposed of. Finally, hydrocyclones separate out cleaned sand, 63 µm < x < 5mm, which is commonly used in asphalt by Heijmans' road-building division.

The scrubbing water and contaminated fines < 63 µm are passed through a tiltable plate separator in order to extract out oil and silt < 63 µm. The water is further treated by coagulation, flocculation and precipitation, and then Heijmans uses flotation to remove additional solids. The type of chemical additives used to initiate coagulation, flocculation, and precipitation varies with the types of contaminants present. Water is completely recirculated within the system. A flow diagram of the process is shown in Figure D-1.

Process Limitations/Performance Data

Heijmans' soil washer can be applied to soils containing:

- Cyanides;
- Water-immiscible and low-density (S.G. < 1.0) hydrocarbons;
- Heavy metals (such as Cr, Cd, Cu, Ni, Pb, Zn); and
- Combinations of these contaminants.

Heijmans accepts soils with fine fractions < 63 µm up to 30 percent, but their process works best on sandy soils with a minimum of humus-like compounds. Because no sand or charcoal filters are employed by Heijmans, the system is not able to treat such contaminants as chlorinated hydrocarbons or aromatics. Like most soil washing techniques, the throughput and cost of treatment is dependent on quantity of fine fractions (< 63 µm) in the soil to be cleaned.

The system has had its greatest success treating soil contaminated by cyanides (CN). Heijmans adds hydrogen peroxide (H_2O_2) into the scrubber to react with CN to form CO_2 + NH_4. In one experiment, CN at a concentration of 5,000 to 6,000 mg/kg dry soil was reduced to 15mg/kg. A table showing the results of the Heijmans soil washer on seven different types of contaminated soil is shown in Table D-1.

Costs

Operating costs at Heijmans average 140-180 Dfl/tonne ($73-91/ton) for typical soils with 10 to15 percent fines < 63 µm, but can go as high as 400 Dfl per tonne ($205/ton) for very heavy metal-laden soils. At their maximum accepted level of 30 percent fine fraction < 63 µm, costs would be about 200 Dfl/tonne ($102/ton). These costs include landfilling abroad of the toxic and organic residues at a cost of 250 Dfl/tonne ($136/ton).

Capital costs for a second generation plant being constructed by Heijmans, with a throughput of 30

Figure D-1. Process scheme of the installation of Heijmans Milieutechniek b.v. Adapted from: TNO - Assink, J.W. and W.J. van den Brink. 1st International TNO/BMFT Conference on Contaminated Soil. Utrecht, The Netherlands. November 11-15, 1985.

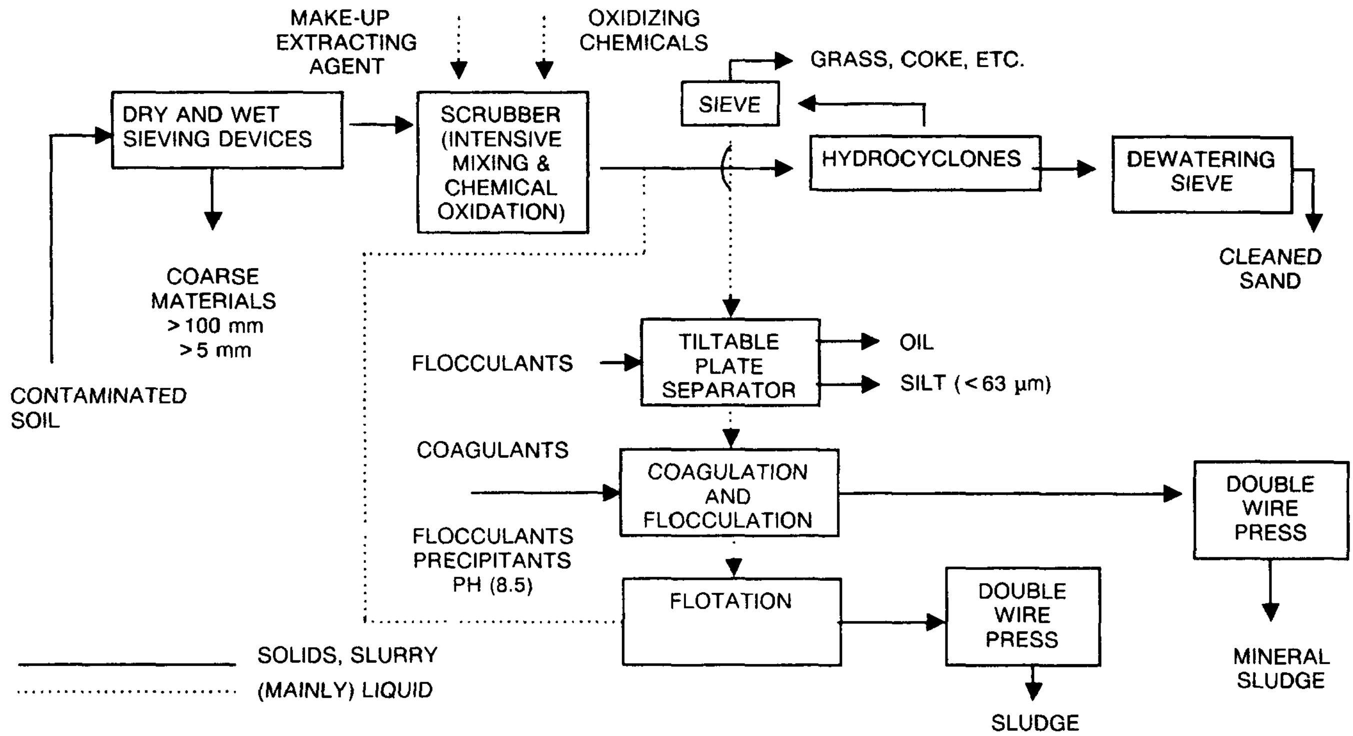


Table D-1. Results of Soil Cleanings Performed by Heijmans Milieutechniek b.v. (Analyses performed by an independent laboratory)

Site	Soil type	Contaminant	Before (mg/kg)	After (mg/kg)
Galvanizing	Silt	Total Cyanide	250-500	10-15
	Sand	Chrome	43-45	11-15
		Nickel	250-890	40-70
		Zinc	460-720	140-200
Fuel drilling	Coarse sand	Kerosine	5,000-7,000	80-120
Galvanizing	Fine sand	Total cyanide	400-1,000	6-10
		Chrome	100-2,500	70-120
		Cadmium	4-18	0.5-1.4
		Copper	100-250	25-60
		Nickel	100-600	50-80
		Lead	100-450	20-70
Gasworks	Fine sand	Total cyanide	80-220	5-15
Gasworks	Coarse sand	Total PCAs	250-400	0.5-10
Diesel fuel	Silt	Mineral oil	3,000-8,000	90-120
	Fine Sand			
Galvanizing	Coarse sand	Total cyanide	75-300	7-10
		Zinc	160-170	50-80

Translated from the brochure "Heijmans Milieutechniek b.v. Bodemsanering, Installatie Voor Het Reinigen Van Grond," January 1988.

tonnes/hour (33 tons/hour), is expected to be 8 million Dfl ($4.5 million). Included in this price is construction of a paved storage area for soils and a runoff collection and treatment system.

Process Status

The soil washing unit on the site of the Heijmans headquarters in Rosmalen was built in 1985 as a pilot-scale transportable unit. It has an average throughput of 10 tonnes/hour (11 tons/hour). Due to the complexities of attaining permits in Holland for the transport and operation of a mobile hazardous waste treatment unit, the soil washer has become a fixed operation. Heijmans will begin construction in May 1988 of a full-scale unit with a throughput of 30 tonnes/hour (33 tons/hour). This new facility will be a fixed unit, probably located in Moerdijk, near one of the most contaminated areas of Holland. Heijmans has not sought to license or import their soil cleaning technology abroad.

Appendix E
In Situ Cadmium Removal and Onsite Treatment by Ion Exchange

TAUW Infra Consult B.V.
P.O. Box 479
Handelskade 11
7400 AL Deventer
The Netherlands

L.G.C.M. Urlings - Head,
Research and Development
Tel.: 011-31-5700-99911

Process Description

TAUW Infra Consult B.V. has applied an in situ cadmium leaching technique to a 30,000 m^3 (39,200 cu yds) site in the Netherlands. The following discussion presents a brief synopsis of this successful project.

Cadmium is desorbed from the soil in situ by leaching with hydrochloric acid (HCl, 10^{-3} mol, pH = 3.5). Wells and drains were installed to establish a system for infiltration and withdrawal. Horizontal drains were used instead of vertical deep wells in order to get straight ground-water flow lines. A cross-section of the infiltration and withdrawal system installed by TAUW is shown in Figure E-1.

The Cd-containing percolate is pumped to a water treatment system housed on-site. Ion exchange was the technique chosen to remove the Cd from the acidic percolate. The resin used is a Rohm and Haas IMAC GT-73 and is regenerated with a 5 percent HCl solution. The cleaned acidic water is then infiltrated again into the cadmium-polluted soil. A schematic of the water treatment plant is shown in Figure E-2.

TAUW divided the site into five compartments. The first compartment was successfully cleaned between August and December 1987. By October 12, 1987, all the soil samples showed Cd concentrations equal or less than 1 mg/kg dry soil, and the Cd concentration in the percolate was 10 µg/L. Acidification of the infiltrate was stopped, and reneutralization of the soil was started with NaOH at a pH of 8.5. When the percolate Cd concentration of every drain was below the detection limit (< 10 µg/L), neutralization was stopped and the installation moved to the next compartment. Cleanup of the first compartment was so successful that the final four compartments are being treated together.

Process Limitations/Performance Data

TAUW expected to encounter problems with the installation due to freezing over the winter, however no problems were encountered. The thermal mass of the earth prevented the in situ operations from freezing up, apparently aided somewhat by a mild winter.

A limitation inherent to the use of ion exchange is the necessity to treat the concentrated regenerant. TAUW's infiltration and withdrawal scheme simply extracts the contaminant and concentrates it into a CdCl salt solution. The regenerant salt solution is then treated off-site. This system also has the risk of allowing or even encouraging further movement of the plume. If the remediation continues as scheduled, TAUW will have cleaned the area just before the plume would have reached a ground-water source of drinking water which is near the site. TAUW was fortunate to have found an ion exchange resin that removes cadmium effectively at a low pH.

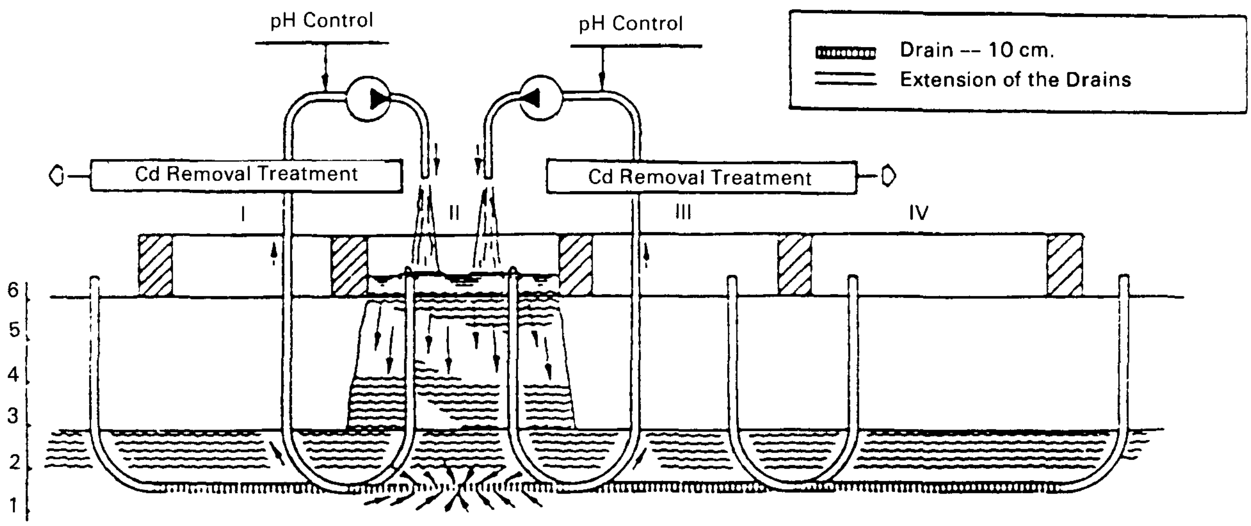
Cost

In situ remediation was selected over conventional sanitation for cost reasons. The entire project will cost approximately 4 million DM ($2.5 million). The whole treatment involves 30,000 m^3 (39,200 cu yds) of soil within an area of 6,000 m^2 (7,200 sq yds), and a total Cd content of the soil estimated at 725 kg (1,600 lbs). Thus the treatment cost is $83/$m^3$ ($63/cu yd) or approximately 80 percent of the cost of soil washing.

Process Status

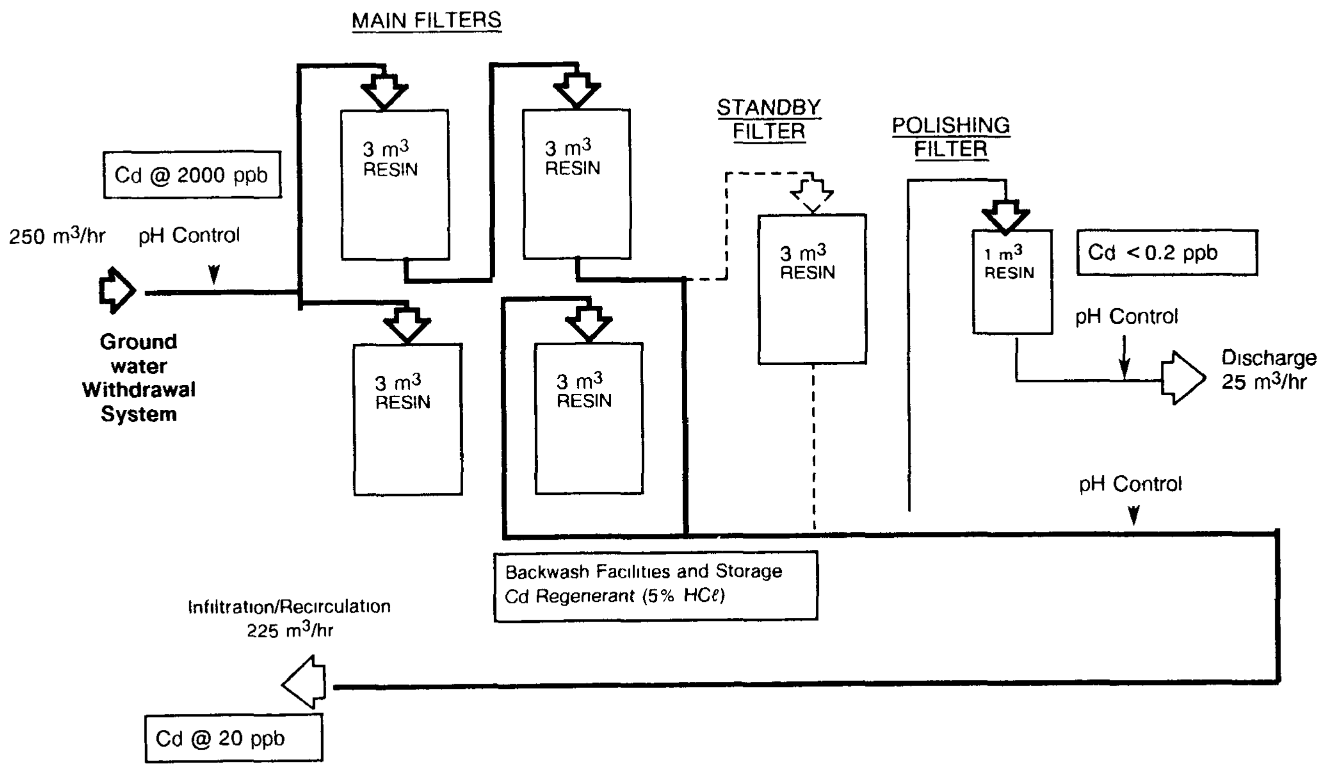
This operation is a full-scale, in situ remedial action, ongoing since June 1987, with completion anticipated for June 1988. In their capacity as a consultant for Mourik B.V. of Groot Ammers, Holland, TAUW is not able to license or export any of the techniques employed in this installation. Mourik, as the contractor, owns all the equipment and any technologies developed as a result of this cleanup.

Figure E-1. Cross-section of the infiltration and withdrawal system installed by TAUW for Cd leaching.



Source L G C M Urlings, "In Situ Cadmium Removal—Full-scale Remedial Action of Contaminated Soil" TAUW Infra Consult B V, undated)

Figure E-2: Scheme of the TAUW water treatment plant for ion exchange of Cd.



Source: L G.C.M. Urlings, "In Situ Cadmium Removal - Full-scale Remedial Action of Contaminated Soil." TAUW Infra Consult b.v., undated.

Appendix F

Rotating Biocontactor for Ground Water Pretreatment of Pesticide Contamination

TAUW Infra Consult B.V.
P.O. Box 479
Handelskade 11
7400 AL Deventer
The Netherlands

L.G.C.M. Urlings - Head,
Research and Development
Tel.: 011-31-5700-99911

Process Description

TAUW employs rotating biocontactors (RBC) for treatment of ground water contaminated with pesticides. Honeycomb metal disks with a diameter of about 1 meter, are rotated in the contaminated ground water. Microorganisms colonize on the disks and biodegrade the organic contaminants. Gaseous emissions from the RBC are exhausted through a compost filter to remove organics. To prevent shocking of the microorganisms, the contaminated ground water first passes through an equalization basin before it is pumped into the installation. A sketch of the on-site installation is shown in Figure F-1. Ground water from the equalization basin passes through two RBCs in parallel and as a polishing step, through two sand filters and three activated carbon filters.

The RBC can be applied to ground water or leachate polluted with organic contaminants. One unique aspect of the TAUW system is that no supplementary nutrients or microbes were required to initiate or maintain biodegradation. TAUW believes the age of the site at which this process is being applied has established an acclimated microbial population in the soil.

Process Limitations/Performance Data

RBCs are limited to applications involving contamination by biodegradable compounds. The RBC biomass may be susceptible to thermal and loading shocks.

TAUW applied RBCs to ground water from an old pesticide manufacturing site. The results from this cleanup, presented in Table F-1, show removals of benzene and chlorobenzene exceeding 98 percent. Figure F-2 shows the loading and removal efficiency of alpha and gamma HCH isomers. Note that after the 40th day, the loading was increased and the microbes adapted to the shock, returning to a high removal rate. The significance of these results is in the effectiveness of an acclimated aerobic biological treatment system with regard to chlorinated aromatic compounds.

Table F-1. Results of Water Treatment by the TAUW Biocontactor

	Influent (µg/L)	Effluent (µg/L)	Removed (µg/L)	Removed (%)
Benzene	440	6	434	99
Chlorobenzene	470	15	455	98

Source: TAUW Infra Consult B V article, untitled, undated, sent by L G C.M Urlings to J Hyman, March 2, 1988.

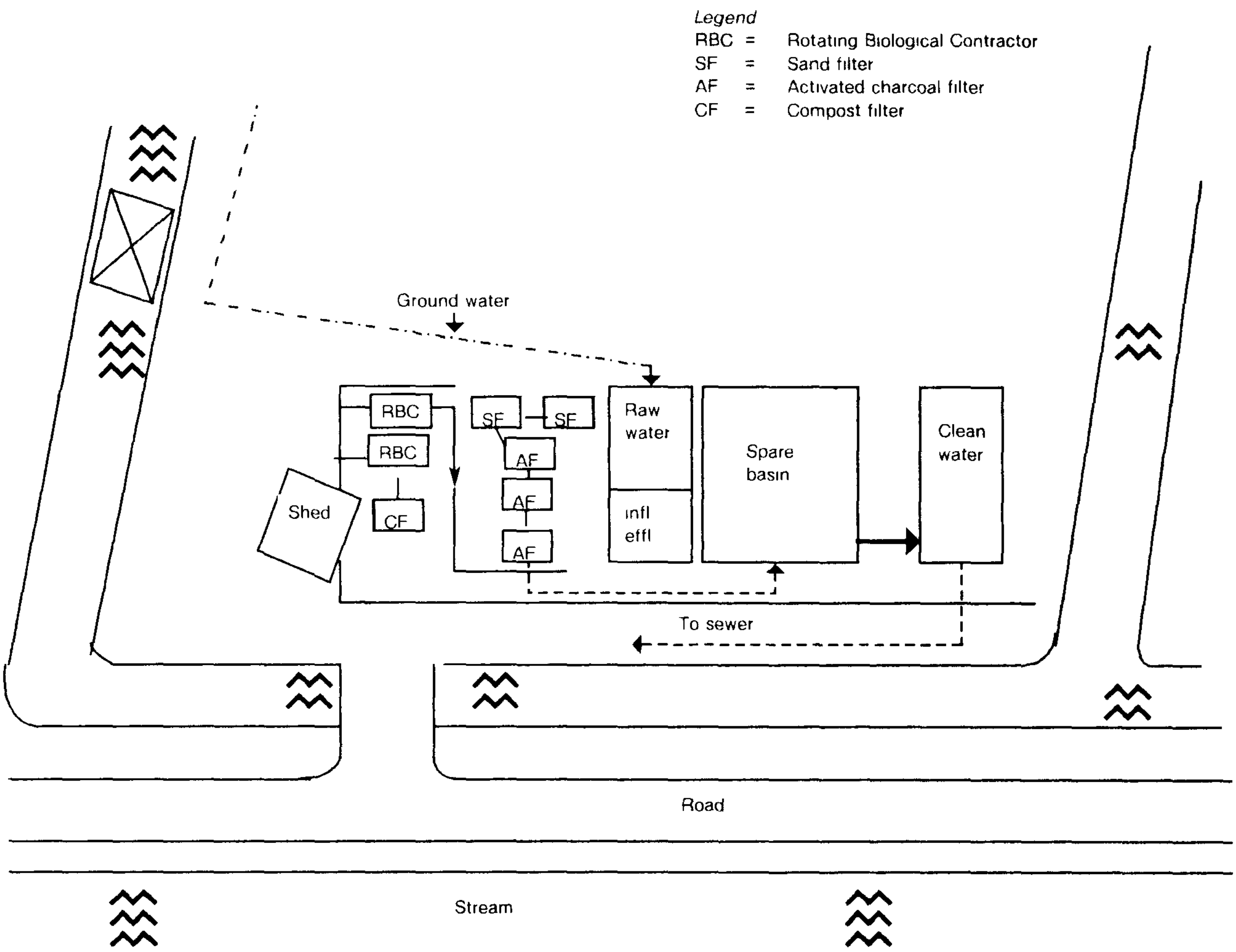
Cost

The purpose of the RBCs was to reduce the amount of contaminants reaching the carbon filters so that the life of the carbon would be extended, thus reducing costs of regeneration or new carbon. Although exact figures are not available, biological pretreatment reduced carbon costs to 7 percent of the cost without pretreatment. When factoring in the cost of the RBC system, the total costs of ground water purification were reduced by 30 percent. In addition, the RBC system would generate significantly less hazardous residue than the carbon system, consistent with the waste minimization goals stated in the SARA legislation.

Process Status

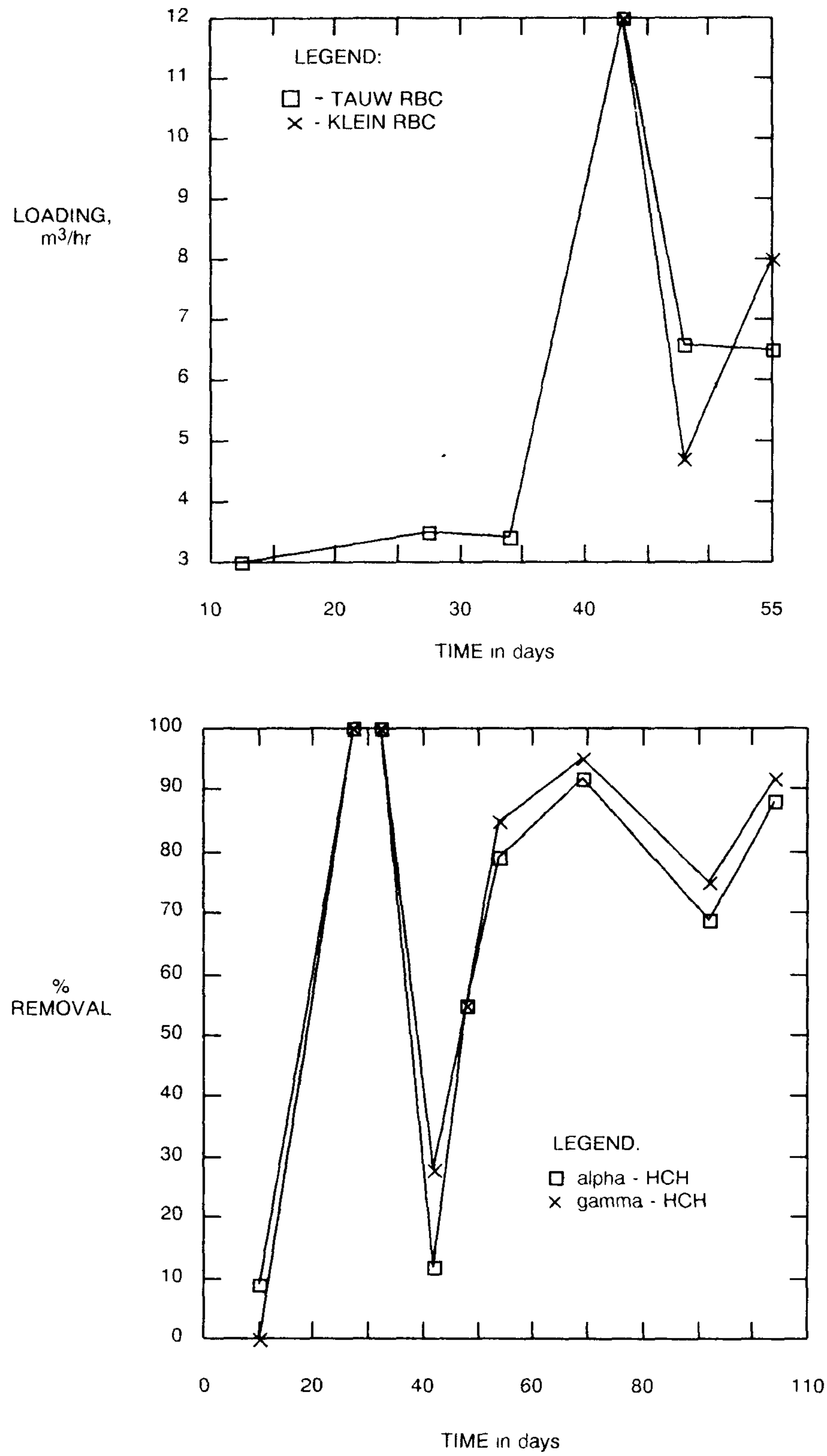
RBCs are mobile units that may be easily used on-site. The TAUW installation has been operating full-scale since November 1987. Its throughput is roughly 25 m^3/hr (110 gpm). As a consulting firm, TAUW is not in a position to license or export this technology. The success of this installation, however, will hopefully encourage the application of rotating biocontactors to site remediation in the United States.

Figure F-1. Sketch of the TAUW ground water treatment installation near Utrechtg.



Source: TAUW Infra Consult b.v. article, untitled, undated, sent by L.G.C.M. Urlings to J. Hyman, March 2, 1988.

Figure F-2. Loading and efficiency over time of the TAUW rotating biocontactor installation.



Source: TAUW Infra Consult B.V. article, untitled, undated, sent by L G C.M. Urlings to J. Hyman, March 2, 1988.

Appendix G
HWZ Soil Washing Operation

HWZ Bodemsanering
Vanadiumweg 5
3812 PX Amersfoort
The Netherlands

Ing. H.C.M. Breek/Ir. B. Spruijtenburg
Tel.: 011-31-33-1 3844

Process Description

The HWZ soil cleaning method is based on techniques of soil washing and particle sizing, along with a water treatment stream. A flow schematic of the system is shown in Figure 1. After first crushing the larger pieces of rubble, pieces 4 mm < x < 50mm are separated out of the stream by wet sieving. Soil particles 63 µm < x < 4 mm comprise the main soil stream. These particles are washed of adsorbed contaminants by scrubbing with detergents and adjusting the pH to 12-13 by addition of NaOH. The HWZ soil scrubber employs two mixing propellors, one mixing up and the other mixing down, with a net flow downward. A hydrosizer then removes low density organic and carbon particles such as wood and rubber. After a dewatering step, the remaining sand (63 µm < x < 4 mm) is often clean enough to be used in asphalt batching, or else it must be landfilled. The fines (< 63 µm) are separated by hydrocyclones and dewatered in a belt press. It is in this small volume of fines that the contaminants are concentrated, and so it must be disposed of as hazardous waste.

The contaminated scrub water and the overflow from the wet sieves, hydrocyclones and belt press are cleaned in the water treatment stream. After residual fines are removed by sedimentation, the water is treated in a tank by precipitation, neutralization, coagulation, and flocculation to remove the dissolved contaminants. CN can be removed here by the addition of ferrous sulfate. In the last steps of the water treatment stream, floating iron hydroxide particles are removed by sand filtration, and dissolved organics by activated carbon. The cleaned water is then discharged or recycled.

Process Limitations/Performance Data

Depending on the chemical additives used in the flocculation tank, this system can successfully remove:

- Complex and free cyanides;
- Heavy metals, Pb, Zn, Ni, Cr, As, Hg;
- Aromatics;
- Chlorinated aliphatic hydrocarbons/solvents; and
- Chlorinated aromatic hydrocarbons.

The treatment of soil contaminated with bromine compounds has been successful on a laboratory-scale, but has not yet been tested on a full-scale.

Pollutant levels and removal efficiencies achievable by soil washing strongly depend on the distribution of the pollutants over the different fractions and the presence of soil particles other than sand (such as adsorbing carbon particles) which are difficult to wash. Where the amount of fine fractions < 63 µm is greater than 20 percent, the volume reduction of the contaminated soil will not be sufficient to warrant economical treatment. Where a combination of pollutants is present, a treatment recipe for the soil must be tailor-made. HWZ has also had some problems in extracting PNAs and oily material.

The rate-limiting step in HWZ's soil cleaning operation is the jet- or hydro-sizer, which can be slow at times and inaccurate, depending on the type of soil. HWZ is considering a larger unit to use in its place. Another unit which HWZ may add to improve the process is a crusher, which will crush the large rubble > 50 mm (currently done offsite), in addition to pulverizing the dense clumps of clay which can contain a high concentration of absorbed contaminants. The chemicals in the clay clumps cannot be reached by scrubbing, but if crushed, can be taken out in the sludge. Removal efficiencies for some contaminants are shown in Table G-1.

Table G-1. Typical Removal Efficiencies for the HWZ Soil Cleaning Technique

Contaminant	Input (ppm)	Output (ppm)
CN (complex)	100-250	5-15
Polynuclear aromatics	100-150	15-20
Chlorinated hydrocarbons	20-30	< 1
Heavy metals	300	75-125

Source: Written correspondence of H C.M Breek to J. Hyman, March 16, 1988.

Cost

The operating costs of HWZ are typical for soil washing, in the range of 100-150 Dfl/tonne ($55-82/ton). This price depends on a variety of factors including:

- Quantity of sludge < 63 µm;
- Chemical additives necessary; and
- Cleanability of the soil.

One can estimate 100 to 110 Dfl/tonne ($53/ton) for basic operations, with 5Dfl/tonne ($2.50/ton) for each percent of soil fraction < 63 µm. At the maximum of 20 percent the cost will, therefore, be 200 Dfl/tonne ($103/ton). HWZ pays at least 250 Dfl/tonne ($136/ton) to dispose of the contaminated fines abroad.

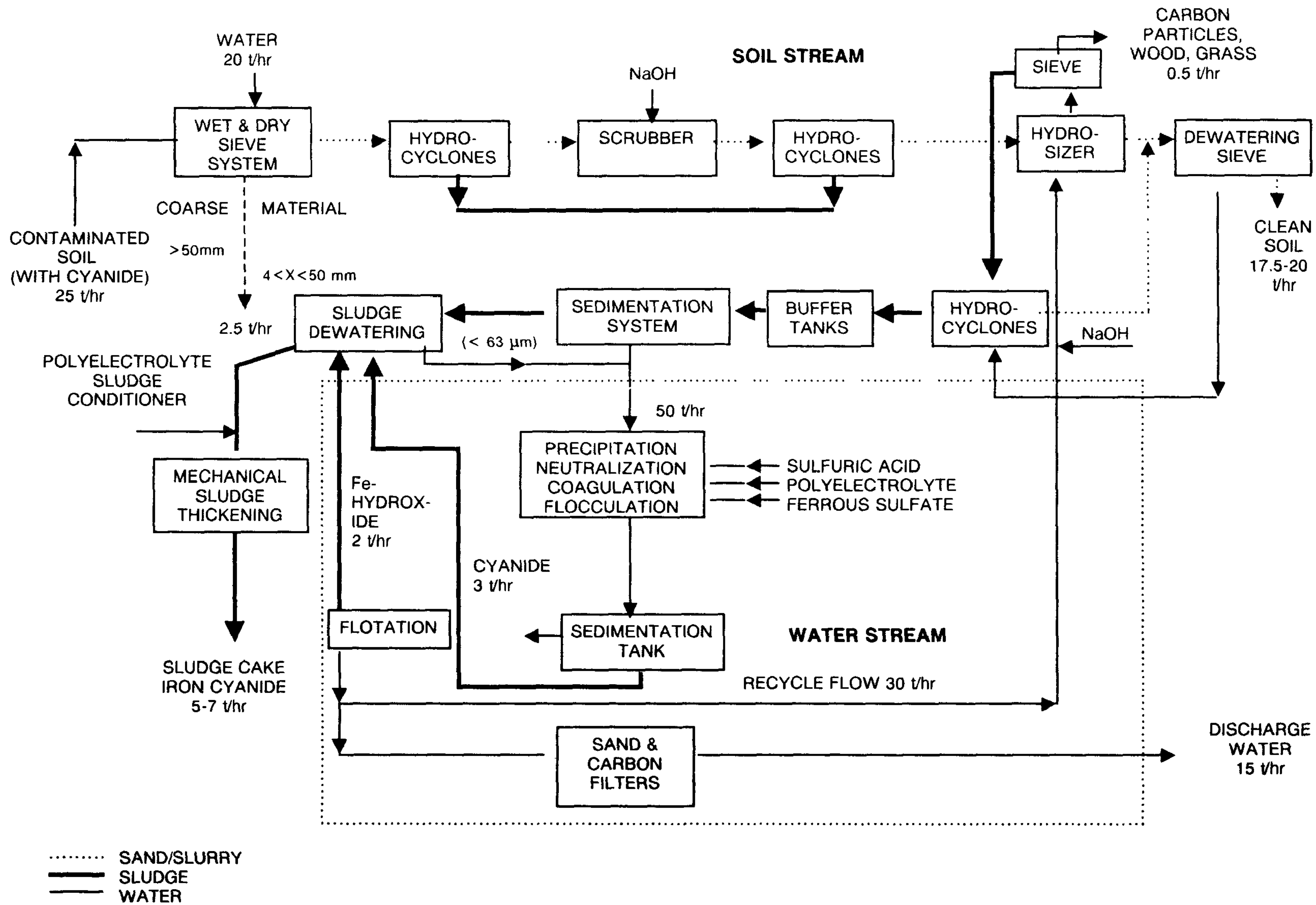
Maintenance costs can depend on such factors as the corrosivity of the contaminants treated and the age of the installation. The present maintenance costs vary between 50,000 Dfl and 100,000 Dfl/year ($28,000-56,000). Capital costs for such an operation are estimated to be 4-6 million Dfl ($2.2 to 3.4 million). The development costs and changes in a later stage are not included in this figure.

Process Status

HWZ built this unit in 1984 to be mobile, but the effort necessary to permit its transport in Holland is so great that it has become a fixed treatment facility. It is located on Nordzeeweg, in the western harbor area of Amsterdam. The unit is full-scale, with a typical throughput of 20 tonnes/hour (22 tons/hour), this figure depending on the quantity of fines present.

HWZ is owned by HBG, one of the largest operating groups in Holland, and is doing a comfortable amount of business. As a result, they have not needed to expand their business or technology outside of Holland. In addition, HWZ holds no United States' patents on their equipment, so they are not able to license their technology abroad. Most of the technology involved in this soil extraction facility HWZ was borrowed from the mining industry.

Figure G-1. HWZ soil treatment scheme.



Adapted from: Breek, H.C.M., written correspondence to J. Hyman of Alliance, March 16, 1988.

Appendix H
Heidemij Soil Washing Using Froth Flotation

Heidemij Uitvoering BV
afd. Milieutechniek
Veemarktkade 8 (5222 AE)
Postbus 2344
5202 CH 's-Hertogenbosch
The Netherlands

Ir. R. Haverkamp Begemann, Product Leader - Soil Cleaning
Ing. E.C. Mulder, Product Leader - Cum-Bac, Steam Stripping
Tel.: 011-31-73-21 50 50

Process Description

The froth flotation method of soil cleaning was developed out of mining technology and enlarged to a pilot-scale plant by Heidemij Uitvoering. The first step of the process is wet-screening out the coarse rubble fragments > 4 mm. The resulting slurry (one part earth, three parts water), is conditioned with cleaning agents before entering the froth flotation tanks. The slurry has a certain dwell time in the flotation cells, depending on the form of the pollutants. To allow for this flexibility, Heidemij has up to ten flotation cells which can be used in parallel. The contaminated float is skimmed off and the slurry is pumped to wet-scouring tanks where it receives its final washing in clean water. The cleaned slurry is dewatered by filtration and the soil is then usually returned to its original site.

The water in the system is completely recycled. The contaminated sludge is either incinerated or sent abroad for disposal. No special water treatment stream is necessary since it is cleaned during the froth flotation process.

Process Limitations/Performance Data

Heidemij's froth flotation process is applicable to soils contaminated by a number of materials by slightly adjusting the process and using the appropriate cleaning agents. These materials include:

- Oil products;
- Heavy metals;
- Inorganic compounds;
- Aromatic compounds;
- Polycyclic hydrocarbons;
- Chlorinated hydrocarbons; and
- Pesticides, herbicides, and fungicides.

The chemical additives used by Heidemij remain their "trade secret."

Heidemij does not treat soils with a fine fraction (< 50 µm) over 20 percent. It is not economically practical and the efficiency of the soil washing process is not good enough to reach accepted standards. Typically, the end volume of the cleaned soil is 85 to 90 percent of the starting volume. Results of laboratory and pilot-scale studies on a variety of contaminants is shown in Table H-1.

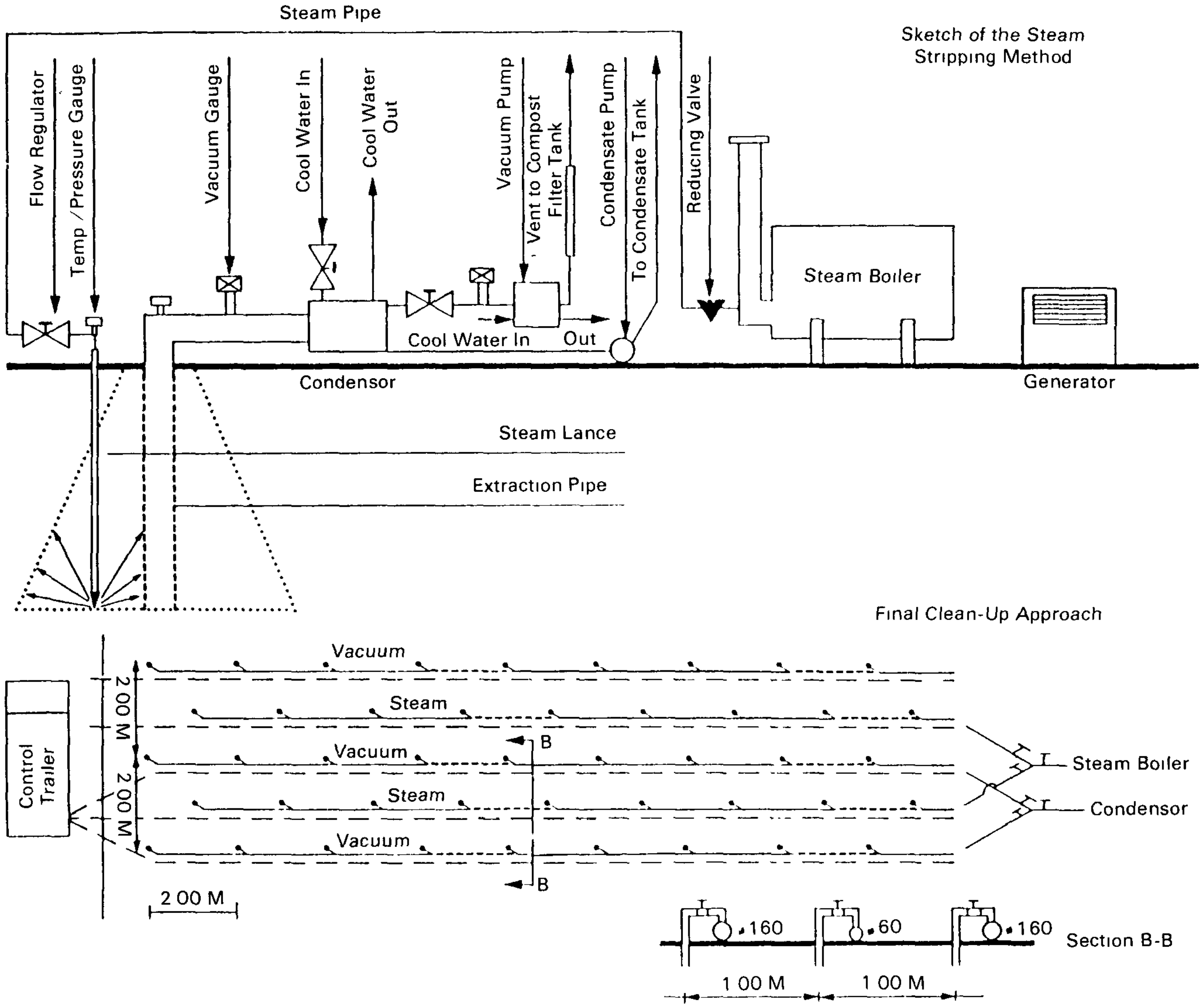
Table H-1. Results of Laboratory and Pilot-Scale Studies Using the Heidemij Froth Flotation Soil Cleaning Method

Contaminant	Before (ppm)	After (average ppm)
Cyanide	200-1,000	5
PCAs	19	0.34
Oils	> 1,000	65
Heavy metals: Pb	11,900	110
Zn	6,040	150
Hg	67	1.5
As	135	19
Chlorinated HCs: HCH	276	0.5
Extractable org-Cl compounds	5.3	0.4
Pesticides	650	14.4
Oil, Toluene, and benzene	3,000-18,000	20
Copper compounds	10,000-20,000	1,000
Lead compounds	500-1,000	90

Source: "Procestechnologie, heidemij Uitvoering," brochure, undated.

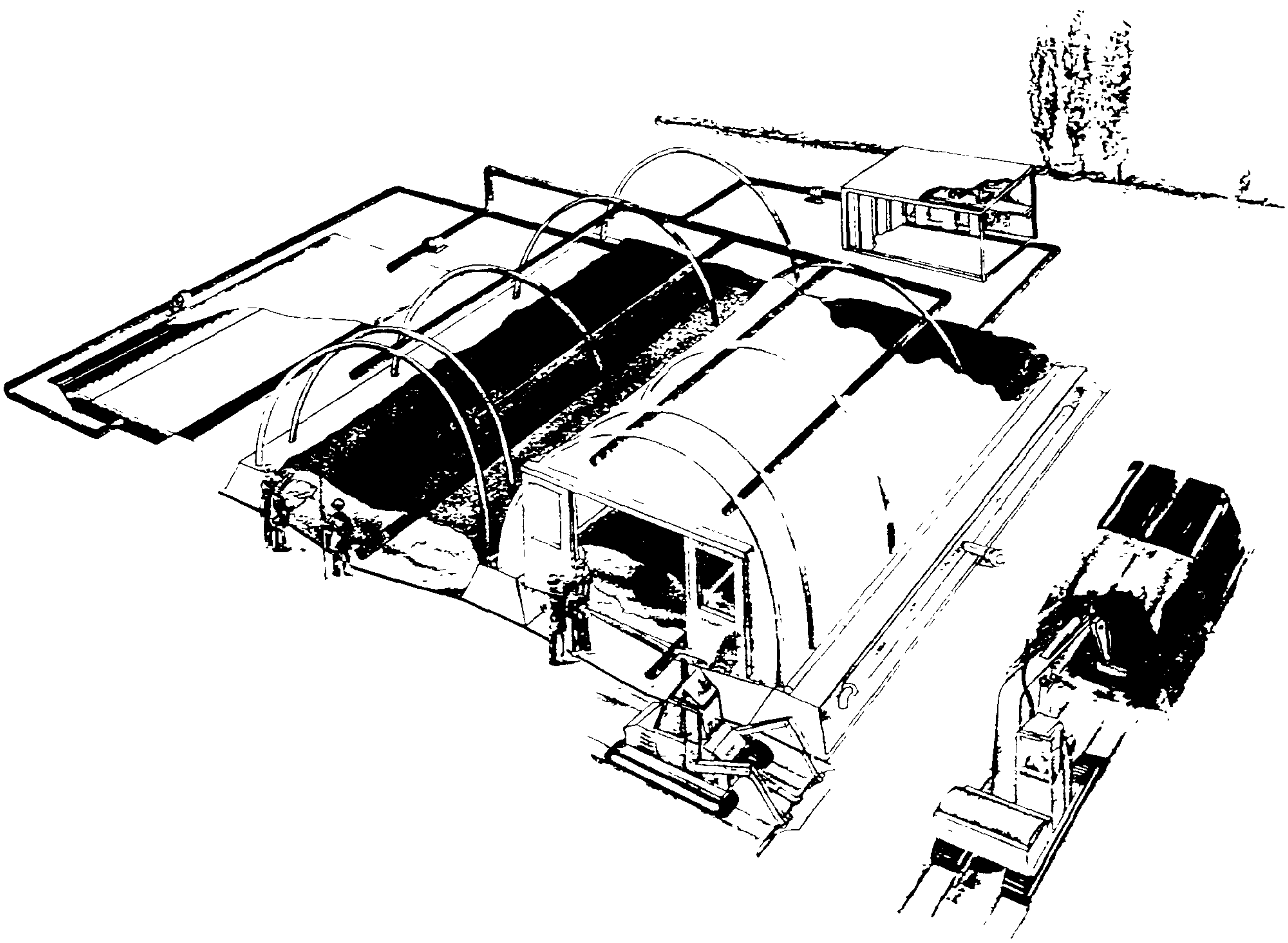
Heidemij has not had the opportunity to treat HCH (hexachlorocyclohexane - usually pesticides) with

Figure H-1. **Two diagrams showing the Heidemij method of in situ steam stripping.**



Source "Stoomstripper, Heidemij Uitvoering" brochure, undated

Figure H-2. An artist's rendering of a typical Cum-Bac[R] installation by Heidemij.



Source "Cum-Bac, Heidemij Uitvoering," brochure, undated

their full-scale system, however laboratory-scale treatment studies have been successful. Heavy metal-contaminated soil has only been treated on a pilot-scale by this system.

Cost

The processing cost varies from 145 Dfl to 250 Dfl/tonne ($90-155/ton), not including laboratory and pilot-plant investigations. Heidemij's full-scale mobile unit capital cost was 5-6 million Dfl ($2.8-3.4 million). Their break-even point, assuming 3 days for mobilization and demobilization of the plant, is 2,000 tonnes (2200 tons) of material per location. At least four different permits are necessary to treat on-site and the cost of disposing of the contaminated residue can be as high as 350 Dfl/tonne (about $182/ton). Heidemij is working on increasing the volume reduction of the contaminated fraction and decreasing the amount of chemical additives used in order to reduce costs.

Process Status

The Heidemij mobile soil washer consists of nine transportable skids, the heaviest one weighing 8 tonnes (9 tons). The plant occupies an area of 950 m^2 (1140 sq yds) and boasts a throughput of 27 tonnes/hour (30 tons/hour).

Since permitting a mobile unit for site remediation is so difficult in Holland, Heidemij hopes to permit their mobile plant at the site of their headquarters in 's-Hertogenbosch by the end of 1988.

Heidemij Steam Stripping and Composting

Heidemij Uitvoering has several other remediation techniques that they are beginning to market in

Holland. One technique that has been employed with success at several sites is in situ steam stripping. Although it takes a few months for the ground to be heated enough to initiate steam stripping of contaminants, cleanup only takes a few months more. Heidemij injects steam at 150-200°C (302-392°F) and extracts volatile organic contaminants under vacuum at a maximum of 0 mBar. Two diagrams of the process are shown in Figure H-1. Data on this technique were not available.

Heidemij is entering the biological decontamination market with a composting technique they call Cum-Bac®. A rendering of a typical Cum-Bac® installation is shown in Figure H-2. Operating details and data were not available on Cum-Bac® due to its novelty.

Heidemij Uitvoering does not currently have intentions for licensing or exporting their remediation technologies.

Appendix I
High-Temperature Slagging Incineration (HTSI)

SCK/CEN, Belgium Nuclear Research Center
Waste Treatment Department
Boeretang 2000
Mol B-2400 Belgium

Mr. Rik Vanbrabant, Project Leader
Tel.: 011-32 (14) 31 68 71

Process Description

High-Temperature Slagging Incineration (HTSI) is a volume reduction technique originally designed for low-level radioactive wastes, but may be applied to almost any waste type. HTSI thermally transforms waste into a mechanically strong and chemically stable basalt-like material in granules or bulk form. A schematic of the HTSI process is shown in Figure I-1.

The first stage of the HTSI process is waste pretreatment. Wastes are sorted, shredded to 7 cm, and then mixed in large bins to create a homogenous waste stream. Screw feeders convey the blended waste to the combustion chamber, the central unit of the HTSI.

In the combustion chamber, a burner powered by fuel and oxygen heats the top of the wastes into a layer of molten slag at about 1400°C (2550°F). Figure I-2 shows the progression of the molten slag film and waste feed. The underlying waste layer serves as a thermal barrier between the molten slag and the refractory lining. This lower layer pyrolyzes, and the upper molten layer undergoes oxidation. The molten slag acts as a liquid filter for the lower layers, absorbing most of the dust particles generated.

The slag droplets flow off the end of the refractory bell into the granulator where they are quenched and burst into granules. At the same time, the off-gases travel into the off-gas treatment section of the HTSI.

The first stage of off-gas treatment is post-combustion. In the post-combustion chamber, the off-gases and the water vapor produced in the granulator are completely oxidized and cooled to 900°C (1650°F). The post-combustion chamber can be fired by either oil or combustible liquid wastes. The off-gases are then vigorously purified by a string of cleaning units: teflon bag filters, followed by a scrubber unit, and ending with a series of HEPA filters. This redundant gas cleaning system results in a very low flue-gas organics and particulate content.

Process Limitations/Performance Data

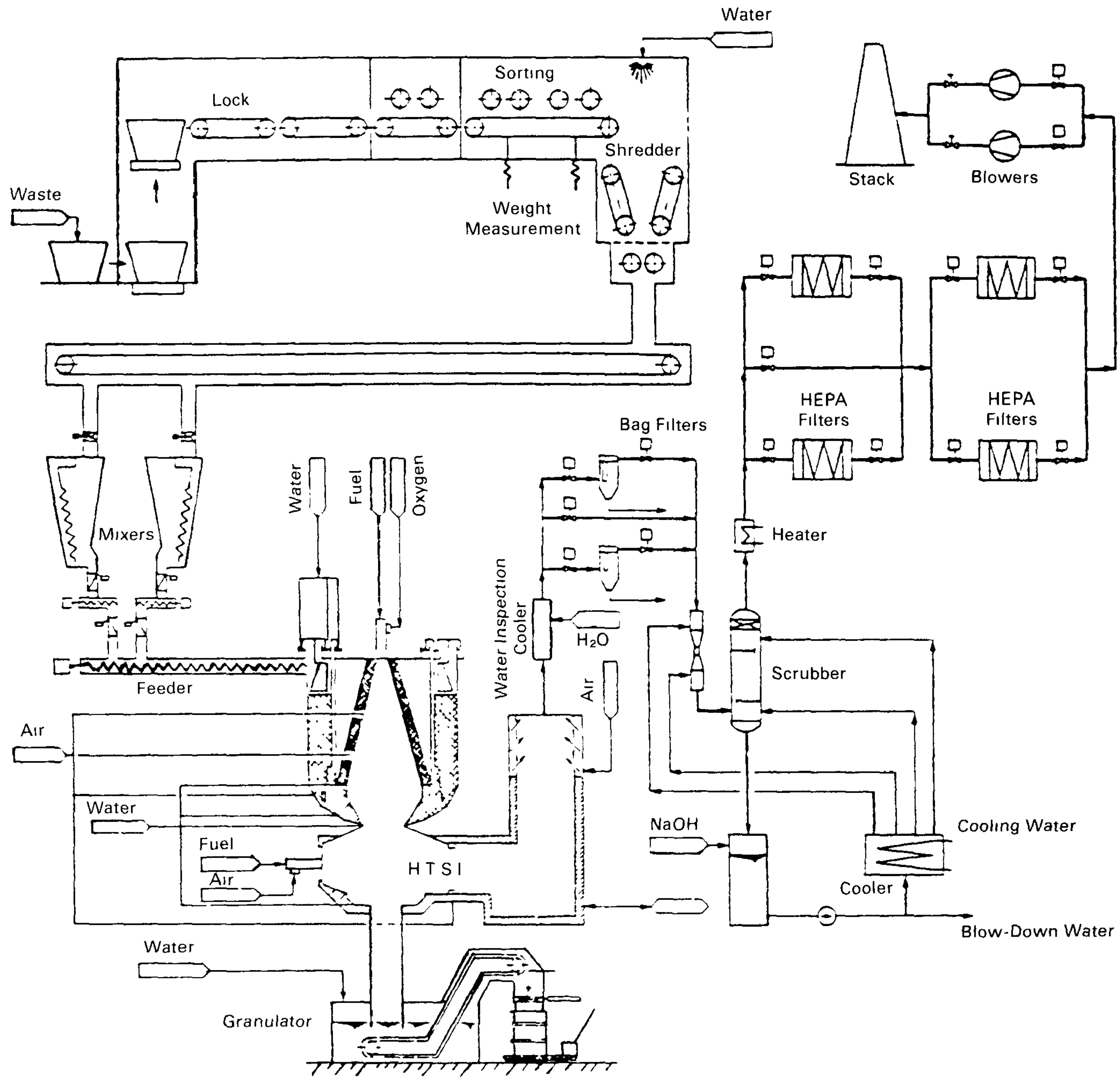
The Belgian HTSI has not been able to process regular quantities of hazardous waste due to its low capacity, but experimental test runs have been performed on the destruction of PCBs. Results of this study are shown in Table I-1. In the study, off-gas concentrations for PCDDs (tetra, penta, hexa, hepta, octa isomers) and for PCDFs (tetra, penta, hexa, hepta, and octa isomers) were all below detection limits. The data in the table shows a combustion efficiency of PCBs at 957°C (1755°F) to be 99.99977 percent. The DRE for PCB is expected to be much higher (> 99.9999 percent) because the decontamination factor of the complete off-gas system is between 10^4 and 10^6. However, this DRE has not been proven because in Belgium destruction efficiency and not removal efficiency has highest priority. When capacity permits, more test runs will be performed in the future.

Because of the high temperatures involved, HTSI can destroy even the most stable chlorinated aromatics. Its most severe limitation, however, is cost. Although most of the high cost of the Belgian unit can be attributed to safety measures to control and contain radioactivity, this technique would still be expensive if applied to hazardous wastes. As a result of its current high cost, it is likely that the HTSI technology would find applications limited to high hazard wastes such as dioxins and PCBs. Another likely application would be asbestos waste where concerns regarding fibrous emissions would be minimized both during incineration and from the solid residues.

Cost

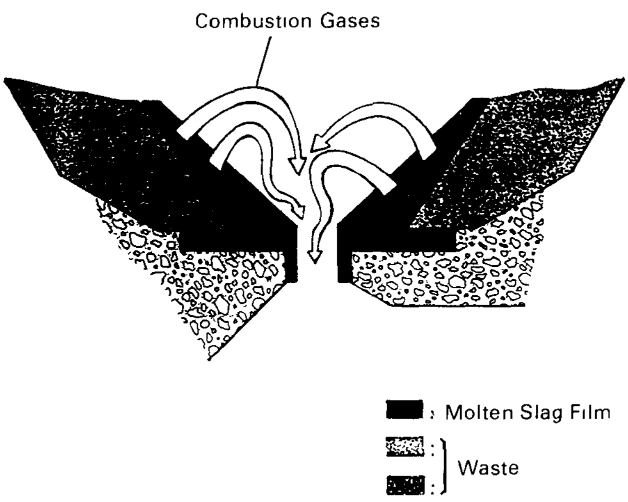
Annualized capital cost, assuming a 10-year life for the 60 kg/hr HTSI unit, is estimated at $600,000. The facility at SCK/CEN runs 24 hours/day for 5 days/week and has operating costs of $160,000, $13,000 and $16,000 a year for labor, energy and oxygen, respectively. Maintenance costs are also high, at $50,000 a year each for labor and materials.

Figure I-1 **Schematic of HTSI incineration process.**



Source Vanbrabant, R., and N. Van de Voorde "High Temperature Slagging Incineration of Hazardous Waste." 2nd International Conference on New Frontiers for Hazardous Waste Management Proceedings Pittsburgh, PA. p 42 September 27-30, 1987

Figure I-2. **Purification action of the molten film in the HTSI combustion chamber.**



Source. SCK/CEN "Hazardous Waste Incineration, HAWAI System, BWT, Belgian Wastes Technology," Brochure, p. 14. Undated.

Table I-1. Experimental Test Results of PCB Incineration in the HTSI

Mass flow rate of PCB	248 g/h
Air flow rate	1222 Nm^3/h
Off-gas flow rate	1272 Nm^3/h
% H_2O in off-gases	7.81%
% CO_2 in off-gases	8.47%
%N_2 in off-gases	75.91%
PCB mass flow rate in off-gases	0.55 mg/h
Residence	1.92 sec
Combustion temperature	957°C
Lambda air factor	1.635
Off-gas O_2 concentration	7.8%
Combustion efficiency	99.99977%

Source: Vanbrabant, R., and N. Van de Voorde. "High Temperature Slagging Incineration of Hazardous Waste." 2nd International Conference on New Frontiers for Hazardous Waste Management Procedings. Pittsburgh, PA. p. 40. September 27-30, 1987.

The price per year, therefore, adds up to $889,000. At a capacity of 60 kg/hr (133 lb/hr), treatment costs $3.50/kg ($1.60/lb).

Process Status

The SCK/CEN HTSI has been operating full-scale since 1981. A unit was sold to Japan in 1985 for treating low-level radioactive waste and another Japanese firm recently purchased a second plant to start up in September 1990, also for that purpose. In the United States, International Technologies of Torrance, CA is marketing the HTSI technology under the name Hazardous Waste Incineration system, or HAWAI system. The HAWAI system has a slightly modified geometry, the capabilites of using oxygen in both the primary and secondary combustion chambers, and a throughput of 400 kg/hr (883 lb/hr). The engineering details for this scaled-up system were worked out in 1987, but a unit has not yet been built. Currently, no HTSI facility exists for the purpose of treating hazardous wastes.

The HAWAI unit, with a higher throughput than the HTSI unit, would probably not meet the capacity demanded by hazardous waste treatment facilities in the United States. Costs would stay about the same as HTSI, but treatment would only be practiced for those wastes which cannot be effectively treated by rotary kilns such as PCBs, or wastes that need special handling such as pathological wastes.

Appendix J
In Situ Vacuum Extraction and Air Stripping of Volatile Organic Compounds

Hannover Umwelttechnik GmbH
Impexstrasse 5
6909 Waldorf
Federal Republic of Germany

Dr. Mathias Stein, Project Leader
Tel.: 011-49 (622) 79 052

Dr. Peter Wolff, Director
Tel.: 011-49 (511) 61 40 35

Process Description

Hannover Umwelttechnik (HUT) has developed an inexpensive and relatively effective in situ treatment technology for vacuum extraction of volatile organic compounds from soil vadose zones and ground water. A diagram of a typical HUT installation is shown in Figure J-1.

The equipment used by HUT is fairly simple and commonly available. PVC slotted piping, 2 inches in diameter with 0.5 mm wide slots, is placed into the ground where the contamination is the highest as an extraction well. A small pump, attached to the top of the pipe via flexible plastic tubing, draws the volatile contamination along with soil moisture through a condensation drum for water removal. The air stream is then passed through an activated carbon canister to remove the volatile organic compounds. One extraction well under ideal conditions will affect an area up to 100 m (90 yds) in diameter. As many pipes and pumps may be used as are necessary for the contamination at a given site.

When the ground water is contaminated, cleanup by air stripping is practiced in coordination with the vacuum extraction. Compressed air is pulsed into the aquifer through injection wells. The compressed air strips the contaminants in the ground water and they are then drawn to the extraction wells. A diagram of this technique is shown in Figure J-2. The compressed air is introduced in a pulsed manner, not continuously, to prevent channeling or short circuiting.

Process Limitations/Performance Data

The HUT vacuum extraction technology is most effective on sandy soils, typically reaching background levels of 200 ppb hydrocarbons in the soil gas. Where there is a large clay fraction, the slotted pipes may become clogged or filled with silt. To try to avoid these problems, HUT has devised a double pipe extraction well. A second, larger slotted pipe (3 inches in diameter, 1 mm slot width) is placed concentric to the typical 2-inch extraction well, with gravel pack in between, to act as filters to the silt and clay particles. This extraction well configuration has shown some success in the field.

The vacuum extraction and air stripping technologies are only effective on volatile contaminants. Contaminants not treated by this method include, for example, extractable organics and PCBs. Figure J-3 shows the range and effectiveness of one extraction well after 2 months of operation. Figure J-4 shows the effects of vacuum extraction on hydrocarbon concentration followed by extraction with in situ air stripping of the ground water.

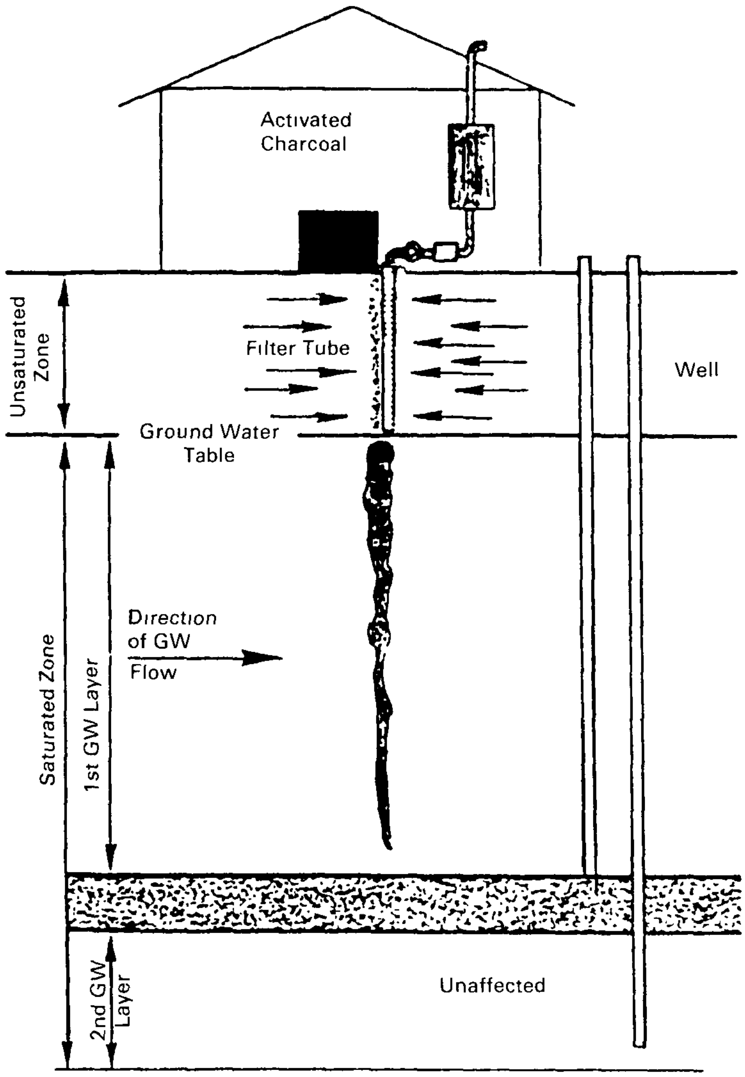
Cost

In carrying out a remediation project, HUT sells their equipment to the customer. After the treatment is completed, HUT may buy back the equipment at a depreciated price. Typical treatment costs by this method are < 10 DM/tonne (< $5 ton). The initial investigations for a typical installation cost about 2,500 DM ($1,500). The cost of a pumping installation is typically 2,500 DM ($1,500) also, bringing the total price of a treatment to 5,000 DM ($3,000). If the scale of the project is large, an automatic activated carbon filter and regenerator made by Prouter may be leased for 7,000 DM/month (about $4,000/month).

Process Status

A large insurance company developed HUT as a service arm to remediate dumped spills and storage tank leak problems at their clients' sites. The vacuum extraction equipment developed by HUT differs from

Figure J-1. Vacuum extraction of volatile organics in the vadose zone by HUT.



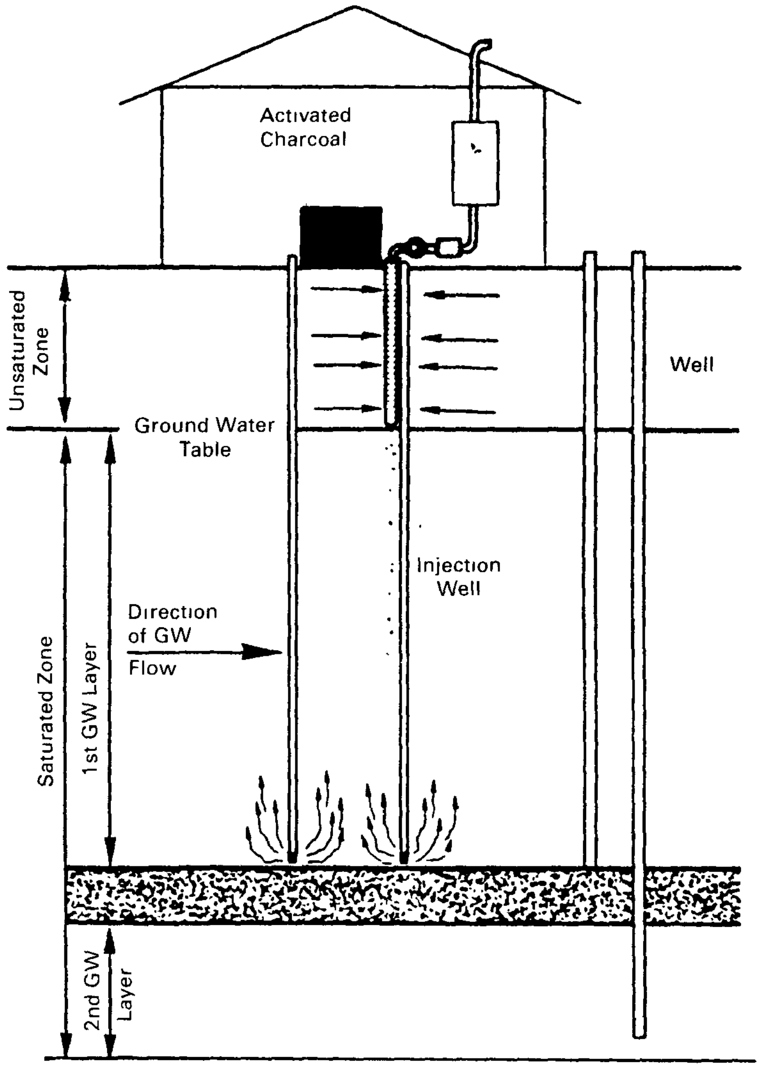
Source: Hannover Umwelttechnik GmbH brochure, "Ein Unternehmen Stellt Sich vor," p 11, October 1987

that found in the United States market by virtue of its simplicity and lower cost.

The key advantage to a vacuum extraction system is that it achieves cleanup of soils with minimal waste byproducts and is adaptable to contamination beneath buildings. When used in combination with on-site carbon regeneration, the by-product generation is minimized to an even greater extent.

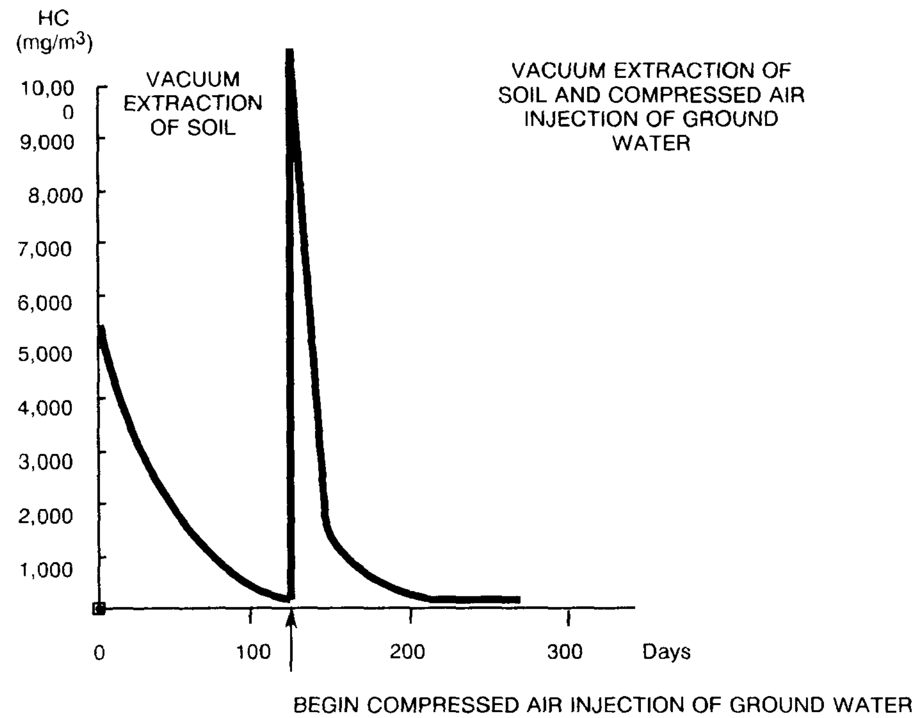
HUT has had over 300 vacuum extraction installations throughout Germany. Two research projects recently being carried out by HUT are an ozone-enhanced biological treatment study and the in situ use of a non-toxic surfactant to leach oils from the soil. HUT does not yet have serious intentions for licensing their technology abroad and they hold no patents. If they did become interested in transferring their technology to the United States' markets, they would probably start a U.S. affiliate and have the necessary equipment produced in the U.S.

Figure J-2. **Volatilization of organics in ground water by pulsing with compressed air.**



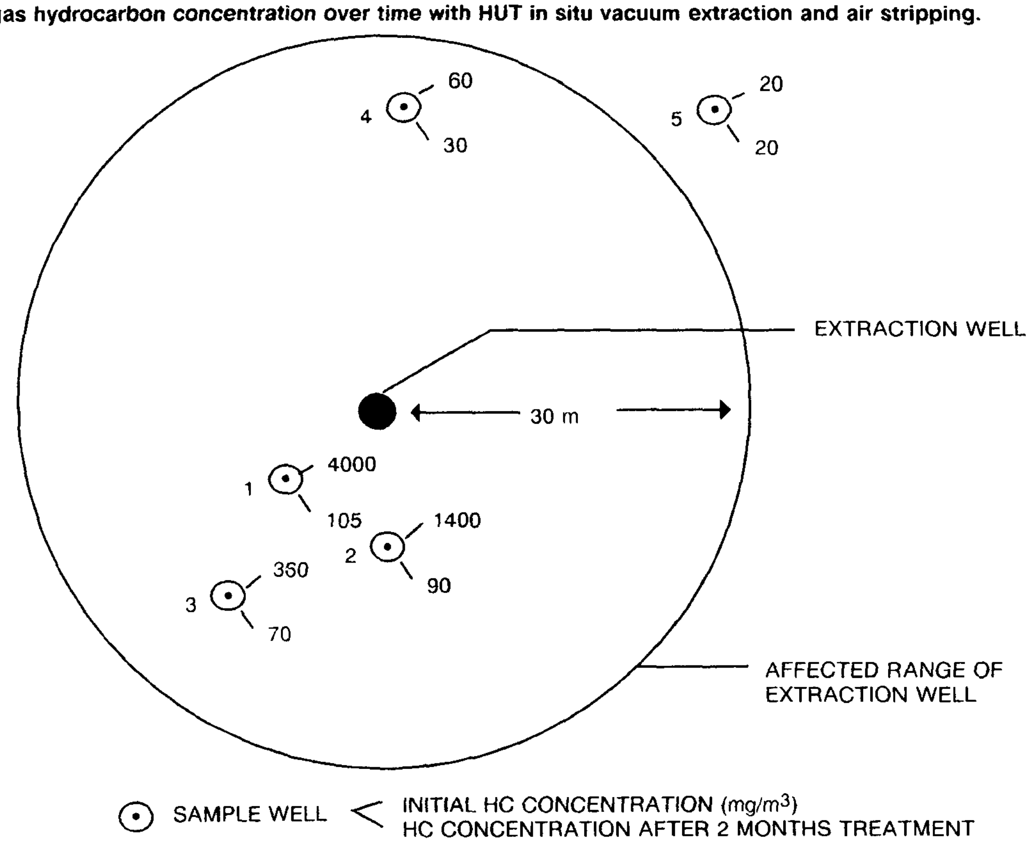
Source Hannover Umwelttechnik GmbH brochure, "Ein Unternehmen Stellt Sich vor," p. 9, October 1987.

Figure J-3. Performance and range of an HUT vacuum extraction installation.



Source: Hannover Umwelttechnik GmbH brochure, "Ein Unternehmen Stellt Sich vor," p. 18, October 1987.

Figure J-4. Soil gas hydrocarbon concentration over time with HUT in situ vacuum extraction and air stripping.



Source: Hannover Umwelttechnik GmbH brochure, "Ein Unternehmen Stellt Sich vor," p. 6, October 1987.

Appendix K
Harbauer Soil Washing Using Low Frequency Vibration

Harbauer GmbH & Company KG
Ingenieurbüro fur Umwelttechnik
Bismarckstrasse 10-12
1000 Berlin 12,
Federal Republic of Germany

Mr. Werner, Managing Director
Mr. Groschel, Engineer
Tel.: 011-49 (30) 341 19 12

Ms. Margaret Brown Nels, Consultant
Tel.: 011-49 (30) 404 17 96

Process Description

The Harbauer soil washing system is currently considered to be among the best soil washers developed in the FRG. The heart of the unit is a low frequency vibration step used to improve cleaning by mechanical action. The Harbauer unit, currently in operation at the Pintsch Oil site in Berlin, has high operating costs due to an extensive ground water/wastewater treatment system. A flow schematic of the Harbauer soil washing facility is shown in Figure K-1, with more detailed explanation that follows.

The first step in the Harbauer soil cleaning process is soil preparation. Particle sizes > 60 mm are separated out of the stream by a vibrating sieve. Gravel in the size range 10 mm < x < 60 mm is separated out and washed with a blade washer before the main soil stream, x < 10 mm enters the vibration unit.

Harbauer attributes the success of their soil cleaning plant primarily to the vibration unit. In this unit, the soil is subjected to oscillations using mechanical energy to dislodge the contaminated fines from the soil matrix. The soil is mixed with an extractant and passed through the vibration unit by a screw conveyor to which the vibrations are axially applied. Because the energy and residence time can be carefully controlled, the unit can handle a wide variety of pollutants and soil types. After passing through the vibration unit, the cleansed soil is then separated in stepwise fashion with removal of particle sizes from 10 mm down to 200 µm occurring in the first step by sedimentation; the second fraction is removed down to 20 µm by a series of hydrocyclones; and the last fraction is removed down to 15 µm by a flocculation step followed by a filter belt press. Dewatering of the sludge is done by belt press, to decrease the volume of residues which must be landfilled.

All the contaminated effluents from soil washing are pumped to the ground water treatment system on-site. The ground water treatment system has five main operations: dissolved air flotation (DAF), counter current stripping, air stripping, sand filtration, and adsorption (activated carbon and resin). Cleaned water is reused or discharged into a receiving stream.

Most of Harbauer's treatment experience has been with organic contaminations. The Harbauer facility has treated 10,000 tonnes (11,000 tons) of soil contaminated by organics. Heavy metals were treated with some success, but data are not yet available. In addition, data are being developed on gas works soil treatment, which is also in the testing stages.

Process Limitations/Performance Data

Although specific data is not available to support it, it seems that a combination of low frequency vibration and other washing techniques is effective at desorbing contaminants from the smaller particles, allowing Harbauer to separate out a larger proportion of reusable soil. Harbauer separates soil particles from 15 µm and greater for a recovery rate of 95 percent. Data on the efficiency of the Harbauer soil washing system on sandy and clayey soils polluted by various organics is provided in Tables K-1 and K-2. The data in Tables K-1 and K-2 show similar organics removal efficiencies for sandy and clayey soils. However, it is noted that higher residual volumes will be generated by the clay soil cleaning, adding to the treatment costs.

Limitations that Harbauer has encountered are typically associated with the treatment process they employ, such as the costly disposal of carbon containing PCBs and polyaromatics, or problems with the separation efficiency of hydrocyclones. As previously mentioned, Harbauer has had limited success in treating heavy metal contamination, but additional techniques are being examined for this purpose.

Figure K-1. A flow schematic of the Harbauer soil washing installation. Adapted from: Harbauer GmbH, "Harbauer soil cleaning process," undated.

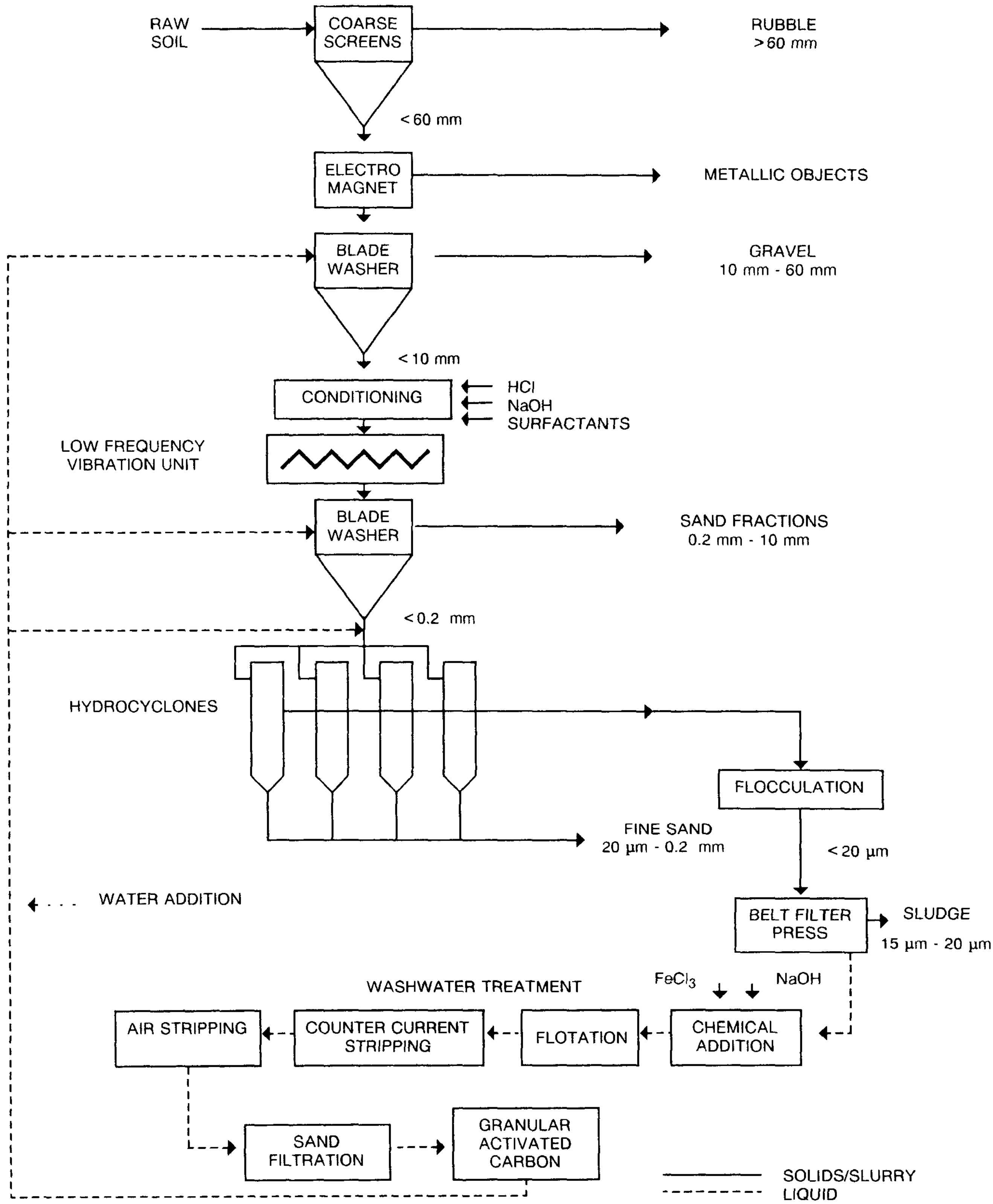


Table K-1. Performance of the Harbauer Soil Washing System on Sandy Soil

Pollutant	Input	Output	Removal Efficiency (%)
Total organics (mg/kg)	5403	201	96.3
Total phenol (mg/kg)	115	7	93.9
PAH (mg/kg)	728.4	97.5	86.6
Extractable org-Cl compounds (mg Cl-/kg)	90.3	n.d.	100
PCB (mg/kg)	3.2	0.5	84.1

Table K-2. Performance of the Harbauer Soil Washing System on Soils with High Clay Content

Pollutant	Input	Output	Removal Efficiency (%)
Total organics (mg/kg)	4440.5	159	96.4
Total phenol (mg/kg)	165	22.5	86.4
PAH (mg/kg)	947.8	91.4	90.4
Extractable org-Cl compounds (mg Cl-/kg)	33.5	n.d.	100
PCB (mg/kg)	11.3	1.3	88.3

Source for both tables:Harbauer GmbH, "Harbauer Soil Cleaning Process," undated.

Cost

Although the Harbauer system is considered semi-batch, because only some of the steps are run in batches, it has a throughput of 20 to 40 tonnes/hour (22 to 44 tons/hour). The unit cost is 250 DM/tonne of soil (about $136/ton, not including the cost of residue disposal). Capital costs for the same facility today would be in the range of 7 to 10 million DM ($4.3 to 6.1 million).

Process Status

The Harbauer soil washing facility was built in 1986 as a pilot-scale unit to remediate the Pintsch Oil site. With all the money and effort that went into building the facility on-site, Harbauer plans to keep the facility on the Berlin site as a fixed unit (the legality of this action is pending) and is already treating soil brought in from other sites. Three other units, which can be mobile or stationary, are currently in the planning stages.

The ground-water treatment facility is full-scale, treating 360 m^3/hr (1,584 gpm). Unique in its large capacity, it has been operating since 1984 and is a NATO/CCMS Pilot Study demonstration facility.

Harbauer is carrying out experiments to study the form and behavior of contaminants in order to increase the removal efficiencies and the percent of soil recovered by their soil washing operations. They plan to license and export the technology and are currently negotiating with several U.S. firms.

Appendix L
Soil Washing Using the Oil CREP System

TBSG Industrievertretungen GmbH
Langenstrasse 52/54
2800 Bremen 1, FRG

Fred K. Gunschera, Director
Tel.: 011-49 (421) 17 63 267

Process Description

The Oil CREP Soil Washer system is among the simplest operations seen in Europe. This system was developed mainly for remediation of hydrocarbon and oil contaminated sandy soils. The unit is typically fitted with add-on particle sizing to remove fine materials (< 100 µm) when used on well-graded materials.

Oil CREP (Cleaning Recycling Environmental Protection) is a proprietary combination of surfactants, solvents and aromatic hydrocarbons which cleans and extracts oil from various media while preserving the structure of the oil so that it may be recycled. The recently developed Oil CREP I is a slightly less efficient, biodegradable version of its predecessor. After the oil is separated from the water where Oil CREP I was used, the water is normally clean enough to be returned to a receiving stream.

The Oil CREP System SSC-20A is a mobile soil washer which occupies one 20-foot, 15-ton container. It was initially built to clean sandy beaches contaminated with oil products. A diagram of the Oil CREP system SSC-20A is shown in Figure L-1.

Oil-contaminated sand/gravel no larger than 50 mm is fed into the system via a hopper. Oil CREP I is injected into the sand as it is mixed in a screw mixer. The sand then travels to a rotating separation drum where the oil is floated off the sand using fresh or sea water, and spilled over into a collection tank. The cleaned sand is reused on-site and the contents of the oil collection tank, which includes the Oil CREP I, is transferred to a holding tank until it can be removed for refining or disposal.

Where necessary, TBSG often supplements their SSC-20A unit with other equipment. Hydrocyclones, for example, are added where a large fraction of contaminated fines < 100µm are present in the soil. Mixers, crushers and even flotation tanks have been added to the system. If contaminants other than oils are present, they will usually tend to form an emulsion when mixed with Oil CREP I. In this case a water treatment plant must be added.

Process Limitations/Performance Data

Although Oil CREP is meant for extracting oily compounds, TSBG is prepared to adapt their technology to any of a variety of situations. Where contaminations are complex and a large fraction of fines are present however, prices will rise and effectiveness will decrease.

This technique is applicable to gasoline, crude oil, mineral oil, and other oil products. The Oil CREP System was used successfully in Spring, 1986 on a site in Hansburg, FRG, to remove PCBs, PAHs, and various hydrocarbons. At this site, Oil CREP was not effective on fluoroanthene.

A diagram demonstrating the effectiveness of Oil CREP I with respect to the quantity added based on recent test trials is presented in Figure L-2.

Other data on the performance of the Oil CREP System SSC 20A is shown in Tables L-1 and L-2. It is recommended that Oil CREP I not be confused with Oil CREP, its toxic counterpart.

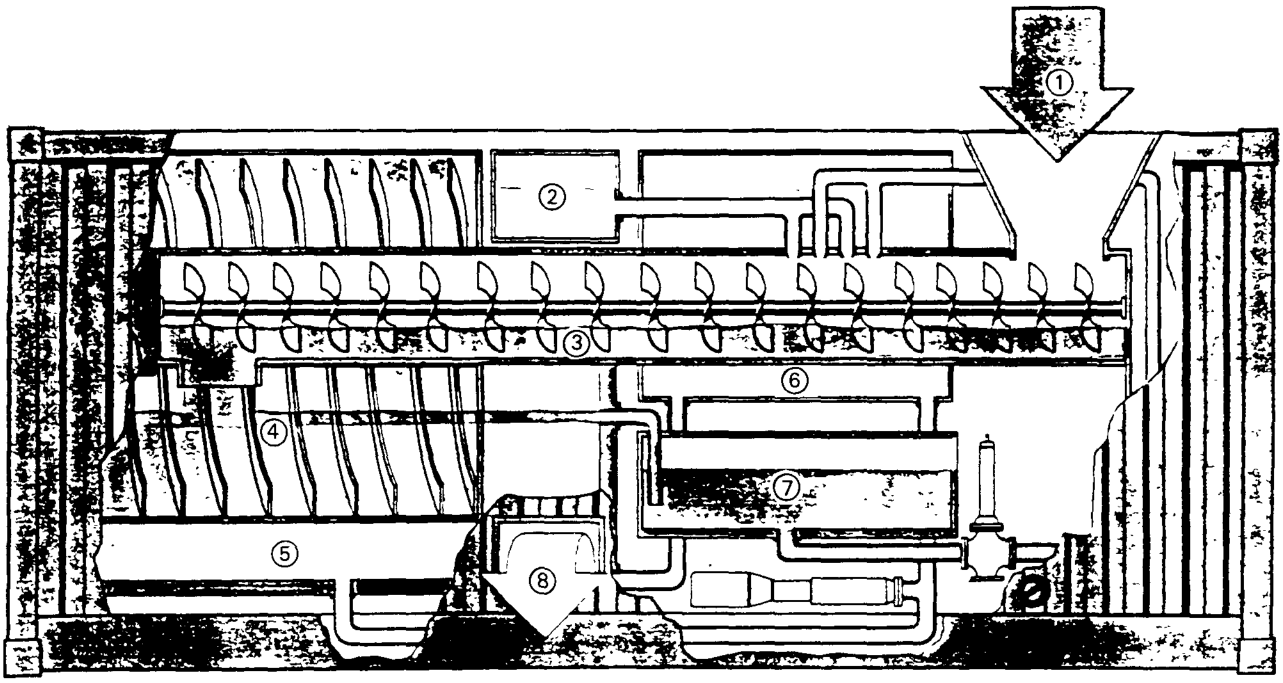
Cost

Including transport, but not including disposal of residues, cost of treatment using the Oil CREP System is 150-190 DM/tonne ($82-109/ton). Because of the set-up and break-down time involved, only sites with over 3,000 m^3 (3920 cu yds) of contaminated soil can be treated economically.

For a typical installation, costs run:

- 25-30,000 DM ($15-18,000) for mobilization and demobilization
- 10,000 DM ($6,000) for daily operations, and
- 10,000 DM ($6,000) for daily treatment of contaminants.

Figure L-1. The Oil CREP System SSC-20A.



1 Oil contaminated sand
2 Cleaning agent OIL—CREP I
3 Mixing unit
4 Separation drum
5 Washwater tub
6 Washwater reserve tank
7 Oil collection tank
8 Cleaned sand

Source Bremer Vulcan AG, et al, "Protection of the Environment, On-the-Spot Cleaning of Oil-Contaminated Sand and Soil, Oil CREP System SSC-20A," undated

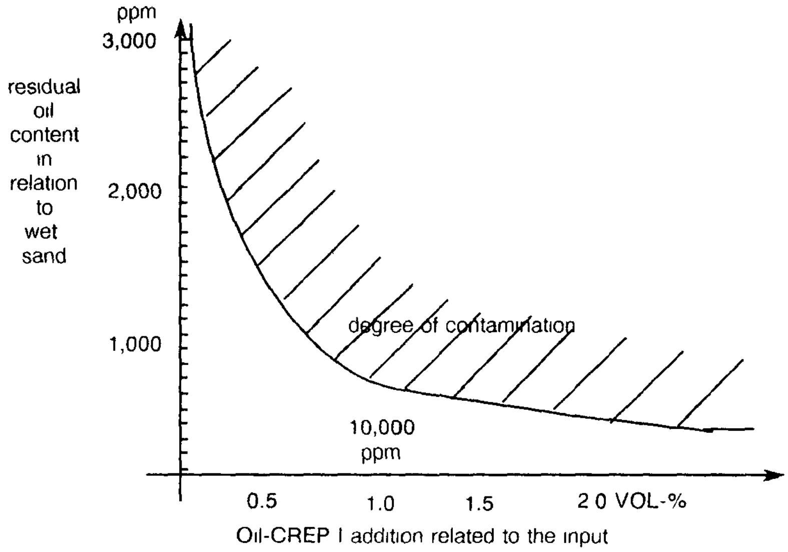
Process Status

TBSG, a shipping company, originally used Oil CREP to clean out the tarry oil residues in their oil tankers. Not only did Oil CREP dislodge the thick oil from the sides of the tanks in conjunction with spraying with high pressure water jets, but it changed its viscosity to allow it to be pumped out.

TBSG, Bremer Vulcan AG and AEG Marine and Offshore Systems Division, jointly developed the Oil CREP System SSC-20A in 1984 to clean sand contaminated by oil. It has a throughput of about 10 m^3/hr (44 gpm). A prototype unit, an updated version of the first, has an average throughput of 8 m^3/hr (35 gpm). A third full-scale unit is in planning stages, and is expected to have a throughput of 20 m^3/hr (88 gpm), supposedly the theoretically highest throughput achievable with this technique. A third washing compound, Oil CREP II, for use with soil types other than sand, is also being researched at this time.

TBSG is applying for licenses in Germany to sell their SSC-20A and in the future will seek European licenses. TBSG has not yet sought licenses in the U.S. The washing solutions Oil CREP and Oil CREP I are patented and can also be purchased separately from TBSG.

Figure L-2. An illustration of the residual oil contents related to Oil-CREP I injection in recent test trials.



Source: Bremer Vulcan AG, et al., "Protection of the Environment, On-the-Spot Cleaning of Oil-Contaminated Sand and Soil, Oil-CREP System SSC-20A", undated.

Table L-1. Performance of the Oil CREP System SSC-20A

Site #	1		2	
Volume in	$3.0\ m^3$		$5.0\ m^3$	
Volume out				
• Clean soil	$2.5\ m^3$		$4.0\ m^3$	
• Sludge	–		–	
• Centrifugate	$0.5\ m^3$		$1.0\ m^3$	
Contamination	Infl.	Effl.	Infl.	Effl.
Lead (Pb)	10	5.2	58.7	7.8
Nickel (Ni)	1.4	2.2	5.8	1.9
PCB	10.8	0.11	3.6	0.48
Aromatics	< 0.5	< 0.5	< 0 5	< 0.5
Hydrocarbons	1900	29	534	94
Extr. Halog.-org.	39	1.5	4.3	1.5
PAHs	1977	19	286	74
Acenapthylene	n.d.	1.5	n d.	8.5
Fluorene	7727	54	1158	132
Phenanthrene	3323	46	607	88
Anthracene	6863	2.9	961	14
Pyrene	803	27	269	49
Benzo(a)-anthracene	51	2	14	4.6
Chrysene	133	2.3	36	4.5
Benzo(b)-fluoranthene	13	0.83	13	19
Benzo(k)-fluoranthene	4.6	0.53	11	12
Benzo(b)-pyrene	n.d.	0.51	n.d.	11
Water content	13%	1%	15%	10%

Source: TBSG Industrievertretungen GmbH, Correspondence to J. Hyman, May 4, 1988.

Table L-2. Performance of the Oil CREP System SSC-20A on Four Different Samples

Sample Number		Water Content	Total Extractables (ppm)	HCs (ppm)
1	Infl.	3.7	4238	1410
	Effl.	10 8	56	19
2	Infl.	4.5	8686	2859
	Effl.	8.4	57	17
3	Infl.	5.7	3584	1603
	Effl.	8 5	81	27
4	Infl.	4.4	4017	1267
	Effl.	9.6	78	26

Source: TBSG Industrievertretungen GmbH, Correspondence to J. Hyman, May 4, 1988.

Appendix M
Biological Remediation of Soil Using the ECO-PLUS Biosystem

Umweltschutz Nord GmbH
Bergdorfer Strasse 49
2875 Ganderkesee 1
Federal Republic of Germany

Mr. Kurt Lissner, Board of Directors
Dr. Gustav Henke, Biologist

Process Description

Umweltschutz Nord has developed an on-site or ex situ composting technique called the ECO-PLUS Biosystem that is currently in use on a number of sites in Germany. They begin with a unique substrate made of pine bark, wood chips and straw that is composted on the site of their headquarters in Ganderkesee. Acclimated microorganisms that have an affinity for degrading hydrocarbons colonize in the substrate because of hydrocarbons that occur naturally in the pine bark.

Construction of the ECO-PLUS Biosystem begins with a PET-lined bed and leachate collection system. The contaminated soil is cleaned of all wood, plastics, stones and other large items. A large mixer called a "Mole" is trucked on site and used to homogenize the soil and combine the substrate with the contaminated soil at a ratio of about 1:9. The substrate/soil mixture is then put into the beds at 100 m^3/bed (131 cu yds/bed). Dimensions of the bed are approximately 20 m x 5 m x 1 m, and as many beds are used on-site as necessary. The leachate is collected and recirculated over the beds periodically depending on relative humidity and soil moisture conditions. Regular sampling is performed to check oxygen and nutrient levels, for example, so that high biodegradation rates can be maintained. When wind and rain are a problem, the beds are protected by planting grasses, ground covers, or clear greenhouse enclosures.

At times, the native population of microbes are not effective enough for timely degradation of pollutants. In this case, Umweltschutz Nord brings their mobile bioreactor on-site to develop supplemental biomass by combining leachate from the beds with heat, air, and nutrients. This enriched solution is then sprayed over the beds. Treatment of the soil typically requires about 12 months. Translucent bubbles can be placed over the beds, keeping them warmer (24-35°C, 75-95°F) and decreasing treatment time to 6 months. When employing a bubble system, a compost filter is often used for emissions control.

The ECO-PLUS Biosystem treats soils contaminated with hydrocarbons, primarily oils. PACs and some organics are also treatable. For each project, a special substrate is formulated depending on the contaminants in the site. When a site is heavily contaminated, the soil is separated into three sections: low, medium, and high concentrations. The low concentration soil is not treated; the medium concentration soil is treated in the normal manner, and the high concentration soil is washed prior to normal treatment.

Where the soil cannot be economically excavated, Umweltschutz Nord performs biorestoration in situ. In this case bioreactors are used on-site to cultivate the microorganisms in combination with nutrients. This solution is then pumped into the soil and recirculated. This technique is most effective on sandy soils. On very sandy soils, the microbe/nutrient solution is not applied by pumping, but placed on top of the contaminated area and let to seep. At the time of this writing, Umweltschutz Nord had five in situ installations operating in the Federal Republic of Germany.

Process Limitations/Performance Data

The ECO-PLUS Biosystem, being only effective on biodegradable contaminants such as hydrocarbons, is not effective on heavy metal- or PCB-polluted soils. Another limitation is the length of time required for treatment, relative to other remediation techniques such as soil washing or incineration.

To improve their process, Umweltschutz Nord has developed a type of mixer that will be used to mix and aerate the soil in the beds. The use of this mixer, in conjunction with a bubble, will decrease the treatment time from 6 to as low as 3 or 4 months.

There are a total of 43 ECO-PLUS Biosystem installations in West Germany at the time of writing. Results from two of such projects is provided in Tables M-1 and M-2. In these two situations, the high concentration soil was not washed, but diluted with the low concentration soil prior to treatment. The cleanup level set by the German government for these two projects was at most 1 g hydrocarbon/kg dry soil.

Table M-1. Results of an Eco-Plus Biosystem Open Bed Installation at a Mineral Oil-Contaminated Storage Tank Facility in Altlast. Concentrations Shown are the Average from 14 Beds.

Date of Sample	Average mg HC/kg Dry Soil
6/86	7,000
7/1/86	6,911
10/1/86	4,240
12/16/86	1,380
3/87	1,000
8/5/87	396
3/88	145

Source: DGMK (German Scientific Society for Oil, Gas and Coal), "Report on the Results of Biological *Ex situ* Rehabilitation of Oil-Contaminated Soil." DGMK Project No. 396-02, Hamburg, Federal Republic of Germany, January 1988, p. 30.

Table M-2. Results of an Eco-Plus Biosystem Open Bed Installation at the Diesel Oil-Contaminated Department Grounds in Wedel. Concentrations Shown are the Average from 16 Beds.

Date of Sample	Average mg HC/kg Dry Soil
6/10/86	13,300
12/18/86	9,430
7/3/87	5,987
9/22/87	4,820

Source: DGMK (German Scientific Society for Oil, Gas and Coal), "Report on the Results of Biological *Ex situ* Rehabilitation of Soil." DGMK Project No. 396-02, Hamburg, Federal Republic of Germany, January 1988, p. 42.

Umweltschutz Nord literature claims levels less than 500 mg HC/kg soil can be easily reached within several months, depending on conditions. The treated soil is commonly returned to its original place, but because of its high biological activity, could be useful for embankments or as landfill covers.

Cost

For the two projects previously mentioned, the costs were 144 and 187 DM/tonne, respectively ($76 and $99/ton). These costs exclude excavation and preparations. Umweltshutz Nord predicts total treatment costs for ex situ biorestoration to fall in the range 150 to 240 DM/tonne ($82 to $136/ton). In situ treatment will cost less.

Process Status

Umweltschutz Nord is the name of the company of scientists and engineers that performs the research and cleanups. IAT-Biosystems is the subsidiary that manufactures all the necessary equipment. They are both located together at Ganderkesee. Besides the ECO-PLUS Biosystem, Umweltschutz Nord has at their disposal a wide variety of mobile remediation processes including physical/chemical units such as flotation tanks, self-actuating and continuous oil-skimmers, and reed beds for ground-water bio-remediation.

Since there is a German law that remediation by recycling be selected over destructive technologies, Umweltschutz Nord has received a great deal of business. The company is hoping that a small partner in the United States can be found to help them out with contacts in the oil and environment industries. A small consulting branch has been established in Big Sandy, Texas for this purpose, called ENTEC, telephone number (214) 636-4376.

☆U.S. GOVERNMENT PRINTING OFFICE: 1988 - 548-158/87045