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Challenges of
Modern Society

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Demonstration of Remedial Action Technologies for Contaminated Land and Groundwater

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**COMMITTEE ON
THE CHALLENGES OF
MODERN SOCIETY
Number 190**

FINAL REPORT

Volume 2 Appendices

Part 1: Pages 1 through 662

Demonstration of Remedial Action Technologies for Contaminated Land and Groundwater

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Participating Countries

Canada	Germany
Denmark	The Netherlands
France	United States

Observer and Other Countries

Austria	Norway
Italy	Turkey
Japan	United Kingdom

1986 – 1991



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Keywords

Aerobic	Emissions, stack gas	Leach testing
Anaerobic	Encapsulation	Microbial treatment
Aqueous extractments	Extracting agents	Microorganisms
Aroclor(s)	Extraction	Oxidation
Binder screening	Fixation	PCB
Binders, generic	Fractured rock	Pesticides
Binders, Portland cement	Furan(s)	Pozzonanes
Biodegradation	Ground water, contaminated	Pyrolysis
Biological treatment	Ground water, contaminated, treatment	Remedial investigation/Feasibility study
Bioreactor	Hazardous waste	Remediation
Cement, Portland	Hazardous waste site	Remedy selection
Chemical treatment	High-pressure jet	Separation
Chloroform	Immobilization	Soil, contaminated
Composting	In-situ	Soil, contaminated, treatment
Dehalogenation	Incineration	Solidification
Dichlorobenzene	Indirect heating	Stabilization
Dioxin(s)	Infrared incineration	Stack gas emissions
Electro-osmosis	Kiln, rotary	Thermal desorption
Electro-phoresis	KPEG	Thermal destruction
Electro-reclamation	Landfarming	Trichloroethene

Foreword

The Council of the North Atlantic Treaty Organization (NATO) established the "Committee on the Challenges of Modern Society (CCMS) in 1969. The CCMS was charged with developing meaningful environmental and social programs that complement other international programs with leadership in solving specific problems of the human environment within the NATO sphere of influence; as well as transferring these solutions to other countries with similar challenges in environmental protection.

Ground water and soil contamination are among the most complex and challenging environmental problems faced by most countries today, and there is an ongoing need for more reliable, cost-effective cleanup technologies to address these problems. Many governmental and private organizations, in many countries, have committed resources to the development, test and evaluation and demonstration of technologies to meet this need. The ongoing challenge to these organizations is how to maximize the value of these technology advancements and effectively transfer the information to people responsible for making decisions and implementing remedial actions.

Consequently, a NATO Committee on the Challenges of Modern Society (NATO/CCMS) Pilot Study on the Demonstration of Remedial Action Technologies for Contaminated Land and Ground Water was conducted from 1986 through 1991. It was designed to identify and evaluate innovative, emerging, and alternative remediation technologies, and transfer technical performance and economic information on them to potential users. The Study was conducted under the joint leadership of the United States, Germany, and The Netherlands. In addition to these co-pilot countries, Canada, France, and Denmark actively participated throughout the five year study. Norway participated as an "observer" nation, and the United Kingdom, Department of the Environment was represented at conference and workshop meetings. Japan was represented at the initial International conference. Organizations from Hungary and Austria attended the Fifth International Meeting.

This is the detailed report of the findings, conclusions and recommendations produced by that Study. It is intended to serve as a reference to the state-of-the-technologies examined by the participants. It is not intended to be a manual on technology applications but as a guide to the potential application of different technologies to various types of soil and ground water contamination. The conclusions reached from this Study revealed both the strengths and weaknesses of current technologies as well as what efforts are needed to increase the effectiveness of remediation tools and their application.

There are several volumes to this report. Volume 1 is the report itself. Volume 2 is the Appendices, and comes in two parts. Part 1 contains overviews of national environmental regulations, and papers by NATO/CCMS Guest Speakers; it consists of pages 1 through 662. Part 2 contains the final reports of the NATO/CCMS Fellows, and reports of the individual projects; it consists of pages 663 through 1389.

A limited number of copies of this report are available at no charge from two sources: NATO Committee on Challenges to Modern Society, Brussels, Belgium; or U.S. Environmental Protection Agency, 26 West Martin Luther King Drive, Cincinnati, Ohio 45268, United States. When there are no more copies from these sources, additional copies can be purchased from the National Technical Information Service, Ravensworth Building, Springfield, Virginia 22161, United States.

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Abstract

This publication reports on the results of the NATO/CCMS Pilot Study "Demonstration of Remedial Action Technologies for Contaminated Land and Ground Water" which was conducted from 1986 through 1991. The Pilot Study was designed to identify and evaluate innovative, emerging and alternative remediation technologies and to transfer technical performance and economic information on them to potential users.

Twenty-nine remediation technology projects were examined which treat, recycle, separate or concentrate contaminants in soil, sludges, and ground water. The emphasis was on *in situ* and on-site technologies; however, in some cases, e.g., thermal treatment, fixed facilities off-site were also examined. Technologies included are: thermal, stabilization/solidification, soil vapor extraction, physical/chemical extraction, pump and treat ground water, chemical treatment of contaminated soils, and microbial treatment.

This report serves as a reference and guide to the potential application of technologies to various types of contamination; It is not a design manual. Unique to this study is the examination and reporting of "failures" as well as successes.

Acknowledgements

The Pilot and Co-Pilot Study Directors thank all who made significant contributions to the work of the Pilot Study:

Those representing their countries made a major contribution to the direction of the Study by recommending projects within their respective countries which would be of particular interest to this Study, and by discussing the regulatory and general environmental technology situations in their countries.

The various chapters were written by the respective authors after reviewing reports prepared on the Case Studies for the meetings of the Study Group.

Good use was made of the NATO/CCMS Fellowship Program to further enhance the value of the Study and a number of Fellows contributed directly to the preparation of this report. Robert Offenbittel of Battelle also served as the general editor for the report, supported by Virginia R. Hathaway of JACA Corp., editor.

Expert speakers, often supported by NATO/CCMS travel funds, participated in the workshops and conferences of the Pilot Study and contributed to the work of the Pilot Study Group.

Until his retirement, the NATO/CCMS International Staff was represented by the former CCMS Director, Mr. Terrence Moran. Dr. Deniz Beten replaced Mr. Moran and attended the Fifth International Meeting.

Ms. Naomi Barkley of the Office of Research and Development, Risk Reduction Environmental Laboratory, Superfund Technology Demonstration Division, U.S. Environmental Protection Agency served as Task Project Manager for this project.

The names and addresses of all participants in the Study Group are given in Volume Two.

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Appendix 1-A

NATO/CCMS Tour de Table

**National Regulations and Other Overview Topics (Given by
Countries and Institutions Involved in the NATO/CCMS Pilot Study)**

Canada's Tour de Table Presentation

Contaminated sites - An Update
of Canadian Activities
T.W. Foote, P. Eng.
Environment Canada

Presented at the Fifth Annual NATO, CCMS Conference of the Demonstration of Remedial
Action Technologies for Contaminated Land and Groundwater - November 18th - 22nd, 1991 -
Washington, D.C.

Contaminated Sites - A Canadian Perspective

1.0 Introduction

This paper provides an overview of programs and activities associated with the identification, assessment and remediation of contaminated land and groundwater in Canada.

2.0 Profile of Canadian Contaminated Site Problems

Table 1 provides a listing of those municipal and industrial activities that have contributed to the creation of contaminated sites in Canada.

Given the extent to which our countries' economy has been based on our vast natural resources, it is no surprise that mining, metallurgical and wood preservation facilities account for a large share of the contamination problems being encountered.

As well, with increasing frequency, urban redevelopment is unearthing contamination attributable to abandoned coal gasification plants, some of which have been out of operation since the turn of the century.

Other problems are a lot more recent, for example the contaminated sites that resulted last year from two enormous fires at automobile tire storage areas, one in Quebec and the other in Ontario.

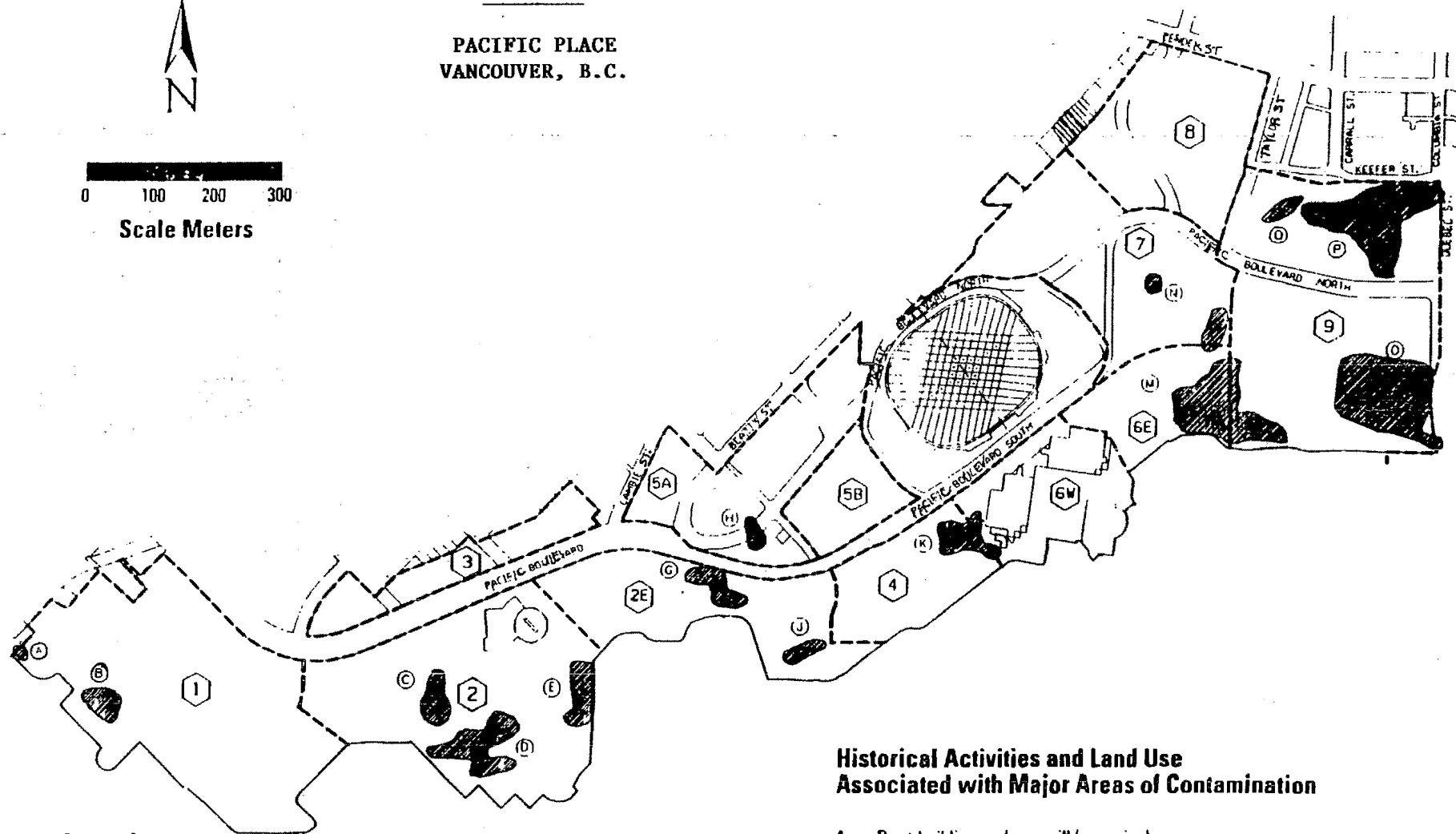
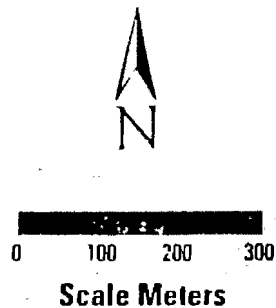
Scrap yards present an emerging and, because of their numbers, widespread problem in Canada. The fact that many of these facilities have a limited financial base also means that when contamination problems are encountered, governments are often likely to inherit them.

At some of our larger sites such as in downtown Vancouver, we are encountering contamination that covers the spectrum of industrial activities as shown in Figure 1.

Table 1
Profile of Contaminated Site
Problems in Canada

1. Treatment/Disposal of Wastes	Primary Concern
Municipal Sanitary Landfills (Dumps)	<ul style="list-style-type: none"> - Land settlement - Methane gas - Some toxic organics and inorganics
Industrial Waste Landfills (Dumps)	<ul style="list-style-type: none"> - Toxic organics and inorganics
Mine Tailings	<ul style="list-style-type: none"> - Toxic heavy metals, radionuclides - Acid mine drainage
2. Industrial/Commercial Activities	
Chemical and Petrochemical Facilities	<ul style="list-style-type: none"> - Toxic organics, inorganics
Metallurgical Facilities	<ul style="list-style-type: none"> - Heavy metals
Foundries/Steel Mills	<ul style="list-style-type: none"> - Heavy metals, hydrocarbons
Wood Preservation Facilities	<ul style="list-style-type: none"> - Chlorophenolics, toxic metals
Coal Gasification Facilities	<ul style="list-style-type: none"> - Polyaromatic hydrocarbons
Scrap yards/shipyards/rail yards	<ul style="list-style-type: none"> - Metals, solvents, hydrocarbons, asbestos - PCB's
Pesticide Storage Sites	<ul style="list-style-type: none"> - Pesticides
Waste Storage Sites	<ul style="list-style-type: none"> - PCB's, tires

FIGURE 1
PACIFIC PLACE
VANCOUVER, B.C.



Legend



Areas of Hazardous Waste

| 1 | Parcel Number

**Historical Activities and Land Use
Associated with Major Areas of Contamination**

- A - Boat building and sawmill (organics)
- B - Woodwaste fill from sawmill activities
- C - Shoreline dumping (lead)
- D - Pintsch Coal Gasification Plant (organics, metals)
- E - Shoreline dumping (metals)
- G - Shoreline dumping and fuel lines (metals, organics)
- H - Chlorophenol dip tank operation (chlorophenols)
- J - Deep woodwaste fill associated with sawmill activities (organics)
- K - Mixed lumber and industrial activities (organics, metals)
- M - Coal-tar dumping associated with BCER Coal Gasification Plant
- N - Industrial, lumber and warehouse operations (metals, organics)
- O,P - Coal-tar associated with BCER coal gasification plant

Note: The remaining portions of the site, including the areas represented by the letters F, I, and L missing from the list opposite, may include contamination below hazardous wastes levels. These will be remediated if and as required to meet provincial standards

3.0 Evolution of Legislative Initiatives

Protection of the environment in Canada is a shared responsibility between the federal and provincial levels of government.

While the federal and ten provincial governments each have comprehensive environmental legislation, federal regulatory activities have by in large been associated with controlling toxic chemicals in the market place (i.e. manufacture or importation) and in the development of minimum national effluent and or emission standards for specific industrial sectors such as petroleum refineries and pulp and paper mills.

The provinces have and continue to be responsible for issuing operating permits to specific industrial and commercial establishments located within their respective borders. The provinces also have assumed the lead for dealing with contaminated sites, except where such sites are located on federal crown land or associated with federal government activities (e.g. military bases and airports)

The evolution of environmental legislation in Canada mirrors that of the majority of industrial countries starting in the late 60's and early 70's focusing on conventional pollutants. In the late 70's and early 80's, a significant shift was made towards controlling toxic substances including more recently those being released to the environment from contaminated sites.

As we are all finding out, establishing a regulatory framework to deal with sources of pollution that were created years ago by companies which either don't exist or haven't got the money to carry out the necessary clean-up action presents a significant challenge.

Under the National Contaminated Sites Remediation Program, which will be dealt with in more detail later in this paper, considerable progress is being made in putting in place the necessary regulations at the provincial level to enforce the "polluter pays"

principle to the maximum extent possible when dealing with contaminated sites.

Within the past year, Ontario, Quebec, British Columbia and the Yukon Territories have all strengthened their legislation in this regard.

A new issue has recently come to the fore in Canada dealing with administration of bankruptcy cases. Specifically, the question being addressed by both regulators and the courts is whether environmental liability takes precedence over secured and non-secured creditors.

In a recent case in Alberta, a provincial court ruled that a bank was required to bring a bankrupt facility into compliance with a provincial clean-up order before any of the companies assets could be distributed. In another case, this time in British Columbia, no trustee could be found who was willing to administer the bankruptcy process because of the unknown extent of environmental liability associated with the property.

Government/industry consultations have been initiated in an attempt to identify the full scope of this problem and how best to resolve it in a way that recognizes both financial as well as environmental requirements.

4.0 National Contaminated Sites Program

4.1 Background

In recognition of the potential magnitude of the contaminated sites problem in Canada and the lack of a consistent national approach to deal with it, this issue was placed on the agenda of the Canadian Council of Ministers of the Environment (CCME) in 1988.

Subsequent problem definition and assessment by the federal, provincial and territorial governments culminated in October 1989 with the announcement by CCME to establish the National Contaminated Sites Remediation Program.

The program has three objectives:

- i) based on the polluter pays principle, to identify, assess, and remediate, in a nationally consistent manner, all contaminated sites that are adversely affecting, or have the potential to adversely affect, human health or the environment.
- ii) to provide the necessary government funds to remediate those high-risk contaminated sites (termed "orphan" sites) for which the owner or responsible party cannot be identified or is financially unable to carry out the necessary work, and
- iii) to stimulate the development and demonstration of new and innovative remediation technologies.

The NCSRP operates on a cost-shared, five-year, \$250 million budget based on matching funding by the federal government and the provincial/territorial governments. Of this total, \$200 million will be directed to the remediation of orphan high-risk contaminated sites, and the remaining \$50 million will be used to develop and demonstrate new remediation technologies.

The program is administered mainly through bilateral agreements between environment canada and the provinces and territories. These agreements define administrative procedures and the role and responsibilities that each party has in cleaning up orphan sites and in managing individual projects to develop and demonstrate technology.

To date, such agreements have been signed between the federal government and the governments of British Columbia, Alberta, Ontario, Quebec, New Brunswick, Nova Scotia and Newfoundland.

4.2 Specific "Orphan" Contaminated Site Activities

In the first year and a half that the program has been in effect, remediation projects have been completed, are underway or are in design-phase at 15 sites.

Alberta

Under the Alberta agreement, work has begun at three orphan high-risk sites -- Canada Creosote in Calgary, Peerless Wood Preservers in Cayley and Purity 99 in Hartell.

Initial work at the Canada Creosote initially involves on-site containment and free product recovery. Additional site assessment and the demonstration of a gravel washing technology are to be carried out before any further remedial action is planned.

At the Peerless site, pentachlorophenol contaminated soil will be excavated and sent for incineration to the Alberta Special Waste Management Facility in Swan Hills.

At Hartell, a former refinery site with widespread hydrocarbon contamination, on-site containment accompanied by groundwater recovery and treatment will be pursued.

Ontario

Two sites -- one in Hagersville, and the other in Smithville, are the first being addressed under the Canada/Ontario agreement.

Remediation at the Hagersville site, which is almost complete, involved the removal of contaminated soil, subsurface oil recovery and the treatment of contaminated surface and groundwater arising from a massive fire at this tire storage facility.

Remediation at the Smithville site, a former waste oil transfer site, is well underway using rotary kiln incinerator to destroy PCB liquids and PCB contaminated soils and sludges.

Quebec

Sites in Saint-Jean-Sur-Richelieu and Saint Amable are the first to be addressed under the Canada/Quebec agreement. Remediation at the Saint-Jean-Sur-Richelieu site, completed earlier this year, involved the excavation and secure landfilling of lead contaminated soil from residential properties located near a battery recycling facility formerly operated by Balmet Canada Inc.

Remediation at Saint-Amable has initially focused on the treatment of groundwater contaminated as a result of the fire at this tire storage site. Additional remedial action at the site is being considered.

Nova scotia

The first orphan high-risk contaminated site to undergo clean-up will be a scrap yard site located at Five Island Lake near Halifax. Excavation and secure storage of lead and PCB contaminated soils is underway. Additional assessment is being carried out to determine whether groundwater contamination at the site is a problem which must also be addressed.

New Brunswick

Remedial activity has been initiated at six sites under the Canada/New Brunswick agreement.

Remedial action at these sites, all of which involve petroleum contaminated soils and groundwater, employs enhanced bioremediation and groundwater recovery/treatment.

Newfoundland

Under the Canada/Newfoundland agreement, alternative technologies are being evaluated to remediate a PCB and heavy metal contaminated soils at a scrap yard site located in Makinsons.

4.3 Technology Development and Demonstration Projects

The principle objective of the DESRT (development and demonstration of site remediation technology) component of the program is to accelerate the development of new and innovative technologies having the potential to resolve problems which are critical to the environmental remediation of contaminated sites. It covers the areas of site characterization, assessment, remediation, and compliance monitoring.

The first priority is demonstration, over the medium term, of promising new technologies that have been developed to the pilot plant stage, but require on-site, field evaluation to verify performance and cost information. The second priority is to encourage the advancement of technologies that are in the laboratory stage of development, and offer alternative technologies for site remediation over the medium term.

The basic eligibility criteria for technology projects are as follows:

- The technology must be unique, or used uniquely, and must have the potential for wide application at contaminated sites across Canada, or relate to a serious problem identified in an area within Canada.
- The project must involve technological risk, and should be designed to lead, ultimately, to commercialization of the technology.
- DESRT funding must bring incremental value to the project; if it would otherwise proceed at the same level of effort without desrt assistance, the project is ineligible.

As this is a federal-provincial/territorial program, approval by both levels of government is required.

Technology development/demonstration projects that have to date been approved under the program are as follows:

British Columbia

The Pacific Place Site in Vancouver is a proposed residential, commercial, and open space development of 82.5 hectares of land on the north side of False Creek in Vancouver. The site is contaminated with PAHS, other organics, metals, wood waste, and PCP. DESRT is participating in treatability studies involving innovative technologies for stabilization of organics and inorganics, bioremediation, and thermal extraction. It is expected that these studies will be completed prior to the end of March, 1991.

Alberta

The Peerless Wood Preservers site in Cayley is polluted primarily with PCB. The R&D project under DESRT is to investigate the on-site land treatment of the contaminated soils, combined with in situ enhanced biodegradation in fractured till, and leachate capture in the underlying bedrock aquifer.

Located on the bank of the bow river in the centre of Calgary, the Canada Creosote site is polluted with creosote and PCP as a result of wood preserving activities. There is a dense, non-aqueous phase liquid (DNAPL) pool within the gravel overlying bedrock under the site; drilling in the riverbed gravels of the bow river showed DNAPL as well. Creosote can be seen on the river bed. Initial work under DESRT involves the development of technology for washing the riverbed gravel, allowing it to be replaced in the river.

New Brunswick

The Department of Transportation site in Saint John is contaminated with PCBs and heavy metals--mainly lead. The project under desrt involves the investigation of soil

washing/solvent extraction and bioslurry reactors for use in the treatment train. The study will be completed early in 1992.

4.4 Common Assessment and Remediation Guidelines

Since the program was announced in 1989, considerable effort has been directed towards the development of guidance documents to enhance national consistency in assessing and remediating contaminated sites.

In working towards this goal the CCME has benefited considerably from the evaluation of systems and criteria currently in use in various jurisdictions in Canada and in other countries. As well, consultations held between governments, industry and public interest groups in April and November of 1990 have contributed to ensuring that site evaluations and criteria proposals are both workable and responsive to the needs and expectations of various sectors and interests in Canadian society.

Due to be published in January 1991, the CCME National Classification System will be used to classify contaminated sites into three broad categories of concern, according to their level of risk. A site is designated high-risk when site contamination is such that it represents a real or imminent threat to human health or to the environment. In this case, immediate action is required to reduce the threat.

Another document which was released at the annual CCME meeting on November 7th in Halifax, is the Interim National Environmental Quality Criteria. These criteria establish numerical standards for the assessment and remediation of soil and water based on the safe use of agricultural, residential, commercial, industrial, and park lands. They are based on a review of existing criteria used in some jurisdictions, and incorporate the guidelines established by the CCME in 1987 on Canadian Water Quality, as well as Health and Welfare Guidelines established in 1989 on Canadian Drinking Water Quality.

Environmental quality criteria for contaminated sites are intended to provide general technical and scientific guidance to provincial, federal, territorial, and non-governmental agencies in the assessment and remediation of contaminated sites in Canada. They serve as benchmarks against which to assess the degree of contamination at specific sites. More importantly, they constitute a common scientific basis for the establishment of site specific remediation objectives. Variations in local conditions.

In the last decade, environmental concerns have become a major preoccupation. There is a recognition that preventable damage must be avoided and, where possible, the effects of past neglect attenuated. In the coming year, the National Contaminated Sites Remediation Program will continue to carry this basic principle forward, and to focus on consolidating its early gains.

Denmark's Tour de Table Presentation

**NATO/CCMS Pilot study on
Demonstration of Remedial Action Technologies
for Contaminated Land and Groundwater**

**Contribution to the Tour-de-Table
Neel Strøbæk, M.Sc.
Danish-EPA**

**5th International Conference
Washington D.C.
USA**

Contribution to the Tour-de-Table, Neel Strøbæk, M.Sc., Danish-EPA

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1. Legislation and financing
2. Status, site investigations and remedial actions
3. Reactions from society
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1. Legislation and financing.

The Danish Law on Waste Sites concerns mapping, investigations, remedial actions and monitoring on former landfills, industrial sites and oil/petrol storages. Regarding orphaned sites the activities are financed by the authorities, which means that the tax-payer is paying.

The decentralized structure of the Danish Society with 275 Municipalities within 14 Counties has made it possible to divide the work between the Counties and the State, represented by the Danish Environmental Protection Agency. In general, the Counties are responsible for the actual work, while the EPA sets up regulations and guidelines.

The total number of sites are not yet known, and the necessary funding are laid down for periods of 4 years. For the 1990-93 period a total amount of 540 mio. Dkr (app. \$ 80 mio U.S.) is of disposal for investigations, monitoring and remedial actions.

2. Status, site investigations and remedial actions

The inventory of September 1991 counts 2493 waste sites. The total number must be expected to be between 6.000 to 10.000.

On the 1st of January 1990, the investigations and risk assessments were terminated on 306 sites and 102 remedial actions had taken place. Further 21 remedial actions were on the planning stage. For the time being drafts have been made for 35 remedial actions. The drafts are evaluated by the EPA.

App. 40 waste site had been totally cleaned up, and no further actions will be needed.

3. Reactions from society

By the 1st of September 1990 a change in regulations stated, that a polluted site must be registered in the Land Registry, so that potential buyers, financial institutes etc. are able to get information of a pollution, if any. This caused a strong reaction in the real estate market, and owners of polluted sites was faced with the fact, that their houses suddenly became of no value. By that, the public interest on the waste site area have changed from an environmental focus to a question of private economy. This is especially the case of owners of orphaned sites.

The authorities are thereby met with a growing demand for an even stronger effort, especially for a larger number of remedial actions.

4. Remedial action technologies

Up to now remedial action technologies at sites are pump and treat solutions and removal of contaminated soil. In-situ technologies are very rarely chosen, primarily because of the very varied soil conditions in Denmark, and secondly because of the poor documentation of the methods. The latter must be seen in connection with the psychological aspects, which govern the "no value"-discussions.

5. Guidelines

Several guidelines within the field of site investigations and risk assessment are made or are in preparation. First of all a guideline on how to make an order of priority among drafts for

remedial actions on a National basis have been discussed. In Denmark, where app. 99 % of the drinking water comes from groundwater, the groundwater protection aspects are of very high priority. This explains the high number of "pump and treat" remedial actions. Another aspect of great concern is of course the risks of health concerning living on polluted soil.

The "how clean is clean" discussion in Denmark is now followed up by guidelines on soil quality criteria, and guidelines on the demands of the quality of microbiological treated soil, when the soil is reused.

6. Looking at the Future.

The Danish Government has stated, that there must be found a solution to the "no-value" problems. The innocent owners of polluted sites must in one way or the other be compensated. It can be foreseen, that the compensation will be in the form of cleanup activities and the regulations and necessary additional funding will be laid down around 1992/1993.

Investigation planning, sampling and analysis have been implemented. Uniform risk assessment methods are in function and in general it can be said, that the work done by the counties and their consultants are of very high quality.

There is, though, a lack of knowledge in understanding the behavior of chemicals in soil and groundwater. The on-going research, national and international, must be seen as a major input to the risk assessment.

Looking in "the light of the rear-view mirror" it can be underlined, that concerning remedial action technologies, there is a strong need for cost effective and documented technologies. In Denmark the needs are primarily focused on soil treatment technologies, on and off site.

International cooperation and discussion is highly needed, and the participation in the NATO/CCMS Pilot Study has broadened the view of the possibilities and limitations. The Danish EPA will recommend a continuation of the Study for the benefit of the environment in

the participating countries.

The Danish EPA would like to express its gratitude to all the participating scientist in this study, and wishes especially to thank the Pilot Study Director Mr. Donald E. Sanning and Mr. Robert F. Olfenbuttel for the very fine work done on the final report of this Pilot Study.

France's Tour de Table Presentation

NATO - CCMS INTERNATIONAL CONFERENCE WASHINGTON DC (NOV 18 - 22, 1991)

TOUR DE TABLE - FRENCH PRESENTATION

Considering the question of contaminated sites in France at the present time, we can mention two main aspects : legal and administrative on one side, technical and industrial on the other side.

I. - LEGAL AND ADMINISTRATIVE ASPECT

1.1. - On January 9, 1989, the Ministry of Environnement issued a directive for the local Authorities facing situations of impossibility to find responsible parties able to pay for investigations and/or rehabilitation of contaminated sites.

The main steps of the resulting procedure are as follows :

1. The local Authorities must carry out all the existing legal possibilities to find the polluter and make him realize and pay the rehabilitation project.
2. In the case of impossibility to find a reliable responsible party the local Authorities inform the central level and ask its agreement for the following step which is as follows : the prefect of the Department, acting as representative of the government, will designate the National Agency for Waste Recovery and Disposal (ANRED) to carry out the rehabilitation of the considered site.
3. In this situation, Anred will carry out the rehabilitation project financed by the government and after completion will engage lawsuits to find the responsible party of the contamination and try to get the repaying of the expenses.

At the present time 15 cases have occurred and the total amount of public money spent is about 22 millions francs. However, it has to be mentioned that :

These cases are very different in importance : from some drums of PCB waste or some hundred of kilograms of laboratory waste abandoned in the country to industrial derelict sites or dumps involving some millions francs for rehabilitation. Among the 15 considered sites, two cases are requiring additional works to treat contaminated soil and water.

- Up to now, the budget given to ANRED is about 10 millions francs/year which is not enough to take in charge important cases with much higher costs for rehabilitation (the main example is a very severely contaminated site located south of Paris Region, the cost of a first step of

rehabilitation being 20 millions, and much more for completion). A project of a tax on landfilling of waste has been proposed by the Minister of Environnement in the Frame of a Plan National pour l'Environnement (P. N. E.), the product of such tax should be partly reserved to finance such cases. However, up to now this project has been postponed because of the opposition of the Minister of Finances.

On the other hand, in application of the directive, ANRED has carried out lawsuits against potentially responsible parties in every case of intervention. Up to now, five judgments have been issued by the courts (in the first stage of the procedure), all of them are favorable for ANRED.

1. 2. - The ministry of Environnement is preparing :

- a project of regulation obliging vendors of industrial sites for redevelopment to carry out assessment studies of the state of contamination of the land before selling.

- a project of directive to the local authorities, giving technical guidelines to deal with problems of contaminated land :

- nature and characteristics of the investigations to be carried out to assess the state of contamination of industrial sites or waste disposal sites.

- nature and features of the techniques to be utilized for the rehabilitation of contaminated sites.

ANRED is deeply involved in these projects which would take in account the national and international experiences in connection with new research and development actions in two main directions :

- soil quality, assessment of contamination levels/decontamination goals, decision making procedures

- development of new treatment processes (or improvement of existing).

1. 3. - In connection with these efforts to improve the mastery of contaminated sites, the particular case of ancient gaswork sites has to be mentioned because the main industrial party concerned, Gaz de France, (National Gas Board) owner of most of the sites (about 600) where town gas plants were located has decided to develop an important action to face its responsibilities both on technical and economical point of view.

II - TECHNICAL AND INDUSTRIAL ASPECT

The main fact to be mentioned is the creation or the development of technical capacities to deal with the problems of investigations and rehabilitation of contaminated sites.

- For sites characterisation and evaluation this occurs generally by the way of developing specific departments in consulting firms dealing with geological/hydrogeological expertises. On national level at least 6 to 7 of such firms take part and for some of them with international partnership (Germany, U.S.A, Canada)

- For rehabilitation of sites the increase is even more important since the beginning of this year. At the present time it can be estimate that at least 14 firms intend to be present on a significant basis at the national level. Some of them are trying to develop their own capability (bioremediation and in situ soil venting are the more frequently proposed techniques) and more have engaged international partnership in-order to import and adapt existing proven technologies. Among the 14 mentioned enterprises 8 are developing such cooperation (3 American, 3 German, 1 Dutch, 1 Canadian).

Most of these french firms entering the market are subsidiarites of important companies specialized mainly in water and waste managment or in public works (construction, road building, dams...)

III - CONCLUSION

As a conclusion, it can be mentionned that there is a new significant progress in France to deal with the problem of contaminated sites. Not only because the Authorities are improving their capability to master these problems (limitation of action remains because of too limited financial resources) but mostly because of the fast growing technical capability for expertise and rehabilitation. Consequently, it can be estimated that the previously existing limitation resulting of the lack of rehabilitation techniques has deseappeared. In addition an other reason of technical progress with result of the application of new regulation on landfilling (now in preparation) that will imply very strong limitation of occeptance of untreated waste and contaminated soils.

Germany's Tour de Table Presentation

NATO/CCMS Pilot Study
Demonstration of Remedial Action Technologies for
Contaminated Land and Groundwater

Fifth International Conference
Washington, D.C.

18 - 22 November 1991

Recent Developments in National Programs: Federal Republic of Germany

1. Introduction

As a result of the unification of the two German states on 3 October 1990, the Federal Government's responsibility for environmental protection now also extends to the five new federal states. The expressed aim is to cancel out the differences in environmental conditions between the two parts of Germany, brought on by 40 years of a planned economy, within the next ten years. In accordance with Article 34 of the Unification Treaty, ecological remediation and development programmes are to be drawn up, with priority to be given to measures aimed at the prevention of hazards to the health of the population.

The "Eckwerte der ökologischen Sanierung und Entwicklung" (basic data on ecological remediation and development), submitted in November 1990 by the Federal Minister for the Environment, Nature Conservation and Nuclear Safety, form the overall conceptional framework for a set of measures in the new federal states, which are described in the following as they relate to abandoned contaminated sites.

2. Identification of abandoned contaminated sites

Deficits in the enforcement of environmentally acceptable management of household, commercial and industrial waste as well as negligence in handling substances posing a hazard to the environment have led to a large number of soil and groundwater contaminations due to abandoned waste disposal and industrial sites. The problem is aggravated by the fact that a large number of former lignite opencast mines and other pits hardly suitable geologically for the depositing of wastes were used as landfills without any containment measures. Furthermore, the improper and, in some cases, negligent handling of toxic substances at the sites of numerous industrial plants and commercial businesses has resulted in dramatic hazards to human beings and the environment.

In the preliminary survey of potential contaminated sites, a total of 27,877 sites were identified by November 1990. This figure comprises approx. 11,000 abandoned waste disposal sites, approx. 15,000 former industrial sites, approx. 700 abandoned munitions and explosives production sites, as well as approx. 1,000 widespread contaminations. This is estimated to cover not more than 60% of all potential contaminated sites. Of the total number of potential contaminated sites identified, 2,457 sites were classified as being contaminated, the cleanup of 196 of which is accorded high priority.

As of 1 October 1991, the number of potential contaminated sites identified in the new federal states rose to 47,023. When adding the sites identified as potentially contaminated in the original federal states, the status of identification stands at approx. 105,000 potential contaminated sites. When taking the results of a very detailed pilot survey conducted in Baden-Württemberg as a basis (one potential contaminated site per 300 inhabitants), projections of more than 200,000 potential contaminated sites are arrived at for the Federal Republic of Germany.

To supplement the afore-mentioned "basic data on ecological remediation and development", investigations over large areas have been performed for high-pollution areas. These areas comprise:

- Leipzig, Bitterfeld, Halle, Merseburg (chemical industry)
- Mansfelder Land (copper/ore mining and smelting)
- Lower Lusatia (mining and energy generation)
- Dresden and upper Elbe valley
- Wismut (uranium ore mining)
- coastal region of Mecklenburg (shipbuilding industry).

Parallel to these regional investigations, studies for environmental media related remediation are being performed. Altogether, the financing needed is gigantic. The cleanup of lignite opencast mines alone is estimated at DM 30 billion. The cleanup of contaminations caused by uranium ore mining is assumed to cost up to DM 15 billion. The measures taken in 1990 in more than 600 projects were supported with funds amounting to roughly DM 500 million. An additional DM 100 million were appropriated for pilot and demonstration projects.

3. Ecological rehabilitation

Based on the work hitherto performed, the Federal Minister for the Environment submitted, in February 1991, the action programme "ecological rehabilitation", which underlined the urgent need for action in the fields of water supply, waste water disposal, air pollution control, contaminated sites, and waste management. In addition to setting up an infrastructure for remediation, environmental-policy measures are to be taken immediately to create jobs over the short term. In continuation of the 1990 immediate action programme, another immediate action programme totalling DM 800 million has been initiated for the years 1991 and 1992. The funds are awarded to priority projects in coordination with the federal states. The aim is to create a

total of 280,000 positions (job creation measures) by the end of 1991, of which some 100,000 are earmarked for environmental cleanup.

The measures planned to be taken within the framework of ecological rehabilitation include the following:

- establishment of soil treatment centres;
- preliminary investigations and remedial actions in the uranium ore mining region;
- establishment of companies to perform remedial actions;
- identification, evaluation and remediation of abandoned munitions and explosives production sites;
- establishment of a world exhibition of remedial action technologies.

To finance the future cleanup of contaminated sites in the new federal states, a draft act providing for a charge to be levied on waste is currently being prepared at the Federal Ministry for the Environment. The planning so far envisages a charge to be levied on all types of waste. The revenue is estimated at DM 5 to 6 billion per year, an annual DM 2 billion of which is to be used for the cleanup of abandoned contaminated sites in the new federal states.

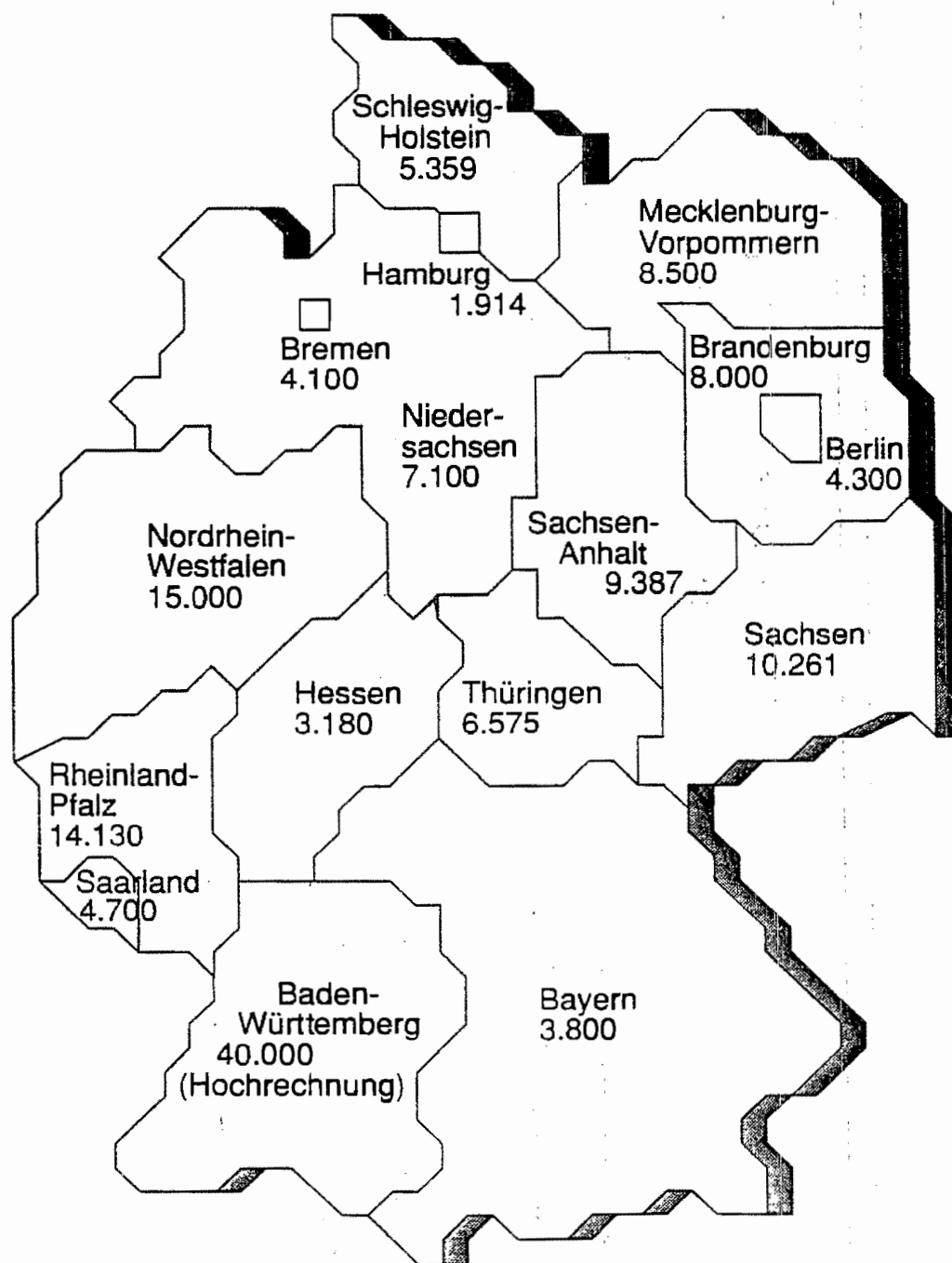


Figure 1: 105,000 identified potential contaminated sites in Germany (as of 1 October 1991
(projections: more than 180,000)

	Total number of sites	Potential contaminated sites
Westgroup of the Soviet Army in East-Germany	1,026	approx.700
Federal Armed Forces (Terri- torial Command East-Germany; former National People's Army)	3,300	?
Federal Armed Forces and NATO- real estate	3,500	500
U.S. Army in Germany	847	364 (confirmed)
Former Armament Production	2,800	?

Jahr	Quelle	Mrd. DM
1985	Franzius (UBA)	17,2
1966	SPD	50
1988	Brandt (Uni HH)	22-41
1988	Deutscher Städte- und Gemeindebund	70
1989	Kaiser Unternehmensberatung	29,1
1989	Ifo	17
1989	SRU	20
1989	TÜV-Rheinland	100
1990	DIW	54,6
1990	Reidenbach (DIFU)	52,7
1991	Ifo (neue Länder)	10,6
1991	THA	53
1991	Wicke (SenStadtUm)	50-200
1991	WMK	52-390

Table of estimated costs for clean-up
of contaminated sites in Germany
(Billions of DM)

Standort	Stand		Verfahrensstränge		
	geplant	realisiert oder im Bau	thermisch	chemisch- physikalisch	biologisch
Hamburg-Veddel		x		x	
Hamburg-Billbrook	x			x	x
Hamburg-Elmsbüttel		x		x	
Hamburg-Peute		x		x	
Itzehoe		x		x	
Ganderkesee		x			x
Bremen		x			x
Ahnsen		x			x
Hildesheim	x		x	x	x
Northeim-Göttingen		x			x
Berlin-Grünau		x			x
Berlin-Tiergarten		x	x		
Großkreuz	x			x	x
Münster	x				x
Hattingen	x			x	
Bochum	x				x
Duisburg	x		x		
Dresden	x			x	x
Gröbern (bei Meißen)	x			x	x
Schwarze Pumpe	x		x	x	x
Neunkirchen	x		x	x	x
Frankfurt	x		x	x	x

Planned or operational centers for treatment of contaminated soils (as of 1 October 1991)

The Netherlands' Tour de Table Presentation

TEN YEARS OF SOIL CLEANUP IN THE NETHERLANDS

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1. INTRODUCTION

In the early 1980s the Netherlands, like many other countries, was faced with the problem of contaminated soil. In 1981 the estimated number of sites under suspicion was 4,000. However, since then it has become clear that this number will be exceeded many times (Table 1).

Table 1. The estimated number of suspected and contaminated sites and cleanup costs, 1980-90

Year	Suspected sites (estimated)	Contaminated sites (estimated)	Estimated costs (Billions of Dutch guilders)	Cleaned up sites
1980	4,000	350	1	3
1983	4,300	1,000	2	25
1986	8,000	1,600	3	250
1990	600,000	110,000	50	> 1,000

To date, about 4,000 contaminated sites have been investigated and about 1,000 sites have been cleaned up under the jurisdiction of the Interim Soil Cleanup Act (IBS). The total expenditure for the investigation and the cleanup, financed by the government, is approximately 1.5 billion Dutch guilders (about 750 million US dollars). The supplementary cleanup circuit spent approximately 0.5 billion Dutch guilders on site cleanup.

2. CLEANUP POLICY

In 1983 the IBS came into force. According to this act the cleanup operation aimed at tackling the sites that were posing a "serious threat to public health or the environment" [1]. The examining framework for assessing this threat and for cleaning up contaminated sites is given in the Soil Cleanup Guideline [2]. In the coming years the government will continue to pursue the principle of restoring the multifunctionality of contaminated sites. Multifunctionality is interpreted as all concentrations at or below the A-values*. In the case of special (environmental, technical or financial) circumstances, which make such remediation practically impossible, the principle is relaxed. These circumstances have to be location-specific. In such a case the hazardous effects have to be controlled by isolation of the site under a well-defined criteria regimen (IBC: isolation, control and check).

The IBS will be incorporated in the new Soil Protection Act (WBB), which forms the framework for several additional regulations. The WBB focuses more on pollution prevention. Several regulations are in preparation or already operative within this framework, i.e. the regulations on building materials (see elsewhere in this report), waste disposal, treatment of manure and storage tanks. Target groups are encouraged to pursue good manufacturing practices that include environmental concern in their policies.

* Values are explained at the end of this report.

By incorporating the IBS into the WBB, the government will create a legal basis by which polluters and users will be forced to clean up polluted areas. The way of financing remediation will be different from the preceding years. The government will try to recover the remediation costs from the polluters or soil users. Only when this is not possible and in cases of "urgent and serious threats" will the government finance the remediation. Consequently, in order to tackle overall soil contamination, the supplementary cleanup circuit will be obliged to take a greater part [1]. The first step in this process has been made by setting up a Committee for Soil Remediation at Industrial Estates (BSB). The members of this committee, consisting of governmental and industrial representatives, have agreed to a voluntary cleanup of industrial estates and to the investigation within five years of 30,000 potentially polluted industrial estates.

It is expected that the government, in cooperation with trade and industry, will clean up the most urgent sites within 10 years. The total costs are estimated at 5 billion Dutch guilders. For the other polluted sites the goal is set at cleaning these within one generation (20-25 years) [3]; this means an average expenditure of approximately 2 billion Dutch guilders per year.

Reuse of soil that has no multifunctional application after treatment is regulated, together with the use of other bulk waste materials, in the Regulation on Building Materials. This regulation takes concentrations, as well as leaching characteristics, into account and defines several categories to which restriction regimens are linked.

Recently, the RIVM made a proposition for new C-values*. These new C-values will be defined on a risk-assessment-based approach, including human and ecotoxicological criteria. In this revision values for the organic and clay fractions of the soil will be taken into account.

3. SOIL CLEANUP OPERATION

In the period 1980-1990 about 5.5 million tons of soil were cleaned up through Dutch government funding. There is no known exact information on the supplementary cleanup circuit. Expenditure was estimated at 100-150 million Dutch guilders per year in 1988. The types of soil remediation techniques used for cleanup in the period 1980-1990 are indicated in Figure 1.

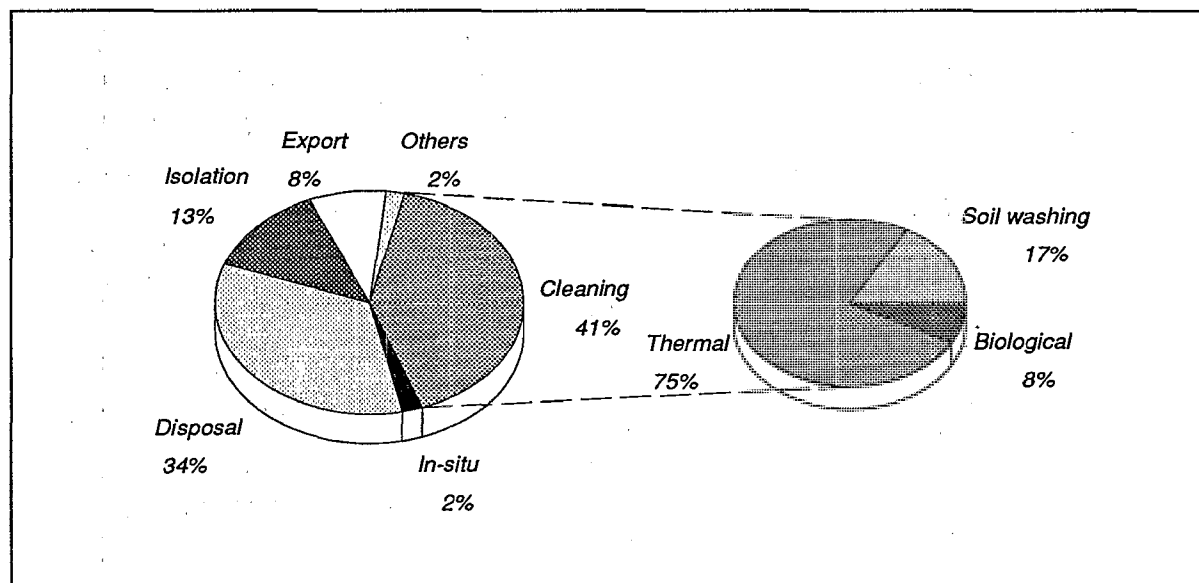


Figure 1. Types of soil remediation methods used for cleanup in the period 1980-1990.

For the coming four years an increase in the speed of soil remediation is expected to range from 2 million tons per year in 1991 to 3 million tons per year in 1994. The remediation method can be expected to change dramatically after 1993 because disposing cleanable soil will be prohibited. To meet the raised supply of excavated soil, the number of temporary disposal sites and the capacity of soil cleaning plants will have to be increased.

The Service Center for Soil Treatment (SCG), including local, provincial and national governments was founded in 1989. The main task of the SCG is the management and control of the treatment of excavated contaminated soil. Soil that has been excavated at IBS sites has to be reported to the SCG, where the decision is made to either clean or dispose of the soil. The SCG also monitors the quality of the cleaned soil. A generally accepted strategy for testing the level of residual concentrations of contaminants in the cleaned soil is of importance, both for the authorities as a justification of the remedial action and for the contractors as proof of the quality of their product. A standardized testing procedure has recently been developed by the RIVM, with controls both for the consumer's risk (unjustified approval on the basis of the samples of a batch with concentrations above the reference values) and the producer's risk (an unjustified rejection of a batch with concentrations below the reference values) [4].

4. SOIL TREATMENT TECHNIQUES

For about 10 years soil treatment techniques in the Netherlands have been in development and optimized on a continuous basis. At present, essentially three kinds of treatment methods are available: thermal, soil washing (including flotation) and biological (including landfarming and bioreactors). Variations of these treatment methods can be applied both after (ex-situ) and without (in-situ) excavation of the soil, after some modifications.

Thermal and soil washing plants have been operational for several years. Biological methods, except landfarming, are still in the development stage. Most of the in-situ techniques are in full-scale operation, however, they have to be improved and optimized to assure meeting the reference values for soil and groundwater quality. The available capacity of the operational ex-situ treatment techniques is about 600,000 tons per year. The application of these techniques is indicated in Table 2.

Table 2. Application and capacity of operational ex-situ soil treatment techniques in the Netherlands

Ex-situ technique	Costs (Dfl./ton)	Capacity (tons/year)	Type of soil ¹		Type of contaminant				
			Sandy soils	Clay/loam	Oil	PAHs	CN	CHCs	Heavy metals
Thermal	80-200	320,000	+	+	+	+	+	(+) ²	-
Soil washing	50-200	220,000	+	-	+	+	+	(+)	+
Landfarming	50-80	60,000	+	-	+	(+) ³	-	-	-
Bioreactors	-	-	(+)	(+)	(+)	(+)			

(+) Limited practical experience.

1) Treatment techniques are not available for peat soils.

2) See remarks on thermal treatment.

3) Lower PAHs only.

On the basis of a decade of experience in soil treatment, the following conclusions can be drawn [5]:

Thermal treatment on a regular basis is suitable for the removal and destruction of organic contaminants, such as oil compounds (alifatics and aromatics), PCAs and cyanides. The cleaning efficiency is high: in most cases 98-99.5 per cent. A demonstration project showed that it is also possible to clean soil that has been contaminated with chlorinated hydrocarbons (CHCs). However, the local authorities gave no permission to continue on a

regular basis because of unacceptable levels of dioxin emission. A new experiment has been performed to show if dioxin emissions can be kept at acceptable levels. The results still have to be analyzed. The costs of thermal treatment will vary between Dfl. 80 and Dfl. 200 per ton of soil, depending mainly on both the moisture content of the soil and the types of contaminants.

Soil washing techniques can be applied to a broader spectrum of contaminants but, generally, with a lower efficiency. By means of soil washing, about 95-99 per cent of contaminants such as oil, cyanides and PCAs can be removed from the soil. The cleaning efficiencies for heavy metals vary from 80-95 per cent. At present, soil washing is the most suitable technique for the removal of heavy metals. However, it provides no option for the treatment of clay or soil with high loam or peat content because of the large volume of waste sludge coming from the fine particle fraction. The amount of sludge varies from about 20 per cent for extraction/classification processes to about eight per cent for flotation techniques. The sludge that is produced in a soil washing process has to be considered as hazardous waste and most of the time it is dumped in controlled disposal sites. The costs of the treatment by means of soil washing vary between Dfl. 50 and Dfl. 200 per ton of soil (including dumping costs of the waste sludge), depending mainly on the quantity of small particles in the soil and the type of contaminants in the soil.

Landfarming is mainly used for the treatment of sandy soils contaminated with oil compounds. The final oil concentrations are in most cases between 400 and 1000 mg/kg dry matter, which is still above the reference value for good soil quality, but probably is a useful level in view of the Regulation on Building Materials. The treatment costs by means of landfarming are in the range of Dfl. 50 and Dfl. 80 per ton of soil.

For bioreactors, there is no experience beyond the pilot project level. It can be concluded from the available results that in bioreactors, a considerably higher biodegradation rate might be achieved when compared to conventional landfarming. After an average treatment time of 1-3 weeks the final concentration of, for example, oil remains the same as for landfarming.

In the last five years several kinds of in-situ techniques have been developed in the Netherlands. These techniques are applicable, especially for remediation of industrial estates, where the costs of excavation are high and immediate removal is not necessary. A few limitations prevent a large-scale application of in-situ techniques. A heterogeneous soil leads to high spatial variations in the soil cleanup. As a result high local residual concentrations of the pollutant may remain. The heterogeneity of the soil and the heterogeneous distribution of the contaminants result in difficulties with the monitoring of the remediation process, prediction of time needed for the cleanup, as well as the assessment of the final situation. Therefore, practical experience is limited mainly to the well-known "pump and treat" techniques. The application of other in-situ treatment techniques is indicated in Table 3.

Table 3. Application of in-situ treatment techniques

In-situ technique	Type of soil		Type of contaminant		
	Sandy soils	Clay/loam	Oil	VOCs	Heavy metals
Biorestauration	+	-	+	(+)	-
Extraction ¹	+	-	+	(+)	+
Steam stripping	+	-	-	+	-
Electroreclamation	-	+	-	-	+

(+) Limited practical experience.

1) Liquid and gas extraction.

5. RESEARCH DEVELOPMENTS

To stimulate the development and innovation of adequate methods for investigation and cleanup the Dutch government supports several research and development programs. Among these are the Regulation for the Advancement of Environmental Technology, the Netherlands Integrated Soil Research Program and the Innovation-Oriented Research Program (IOP) Biotechnology [6]. As a result of this policy and the effort of research workers at institutes and companies, a number of thermal, physicochemical and biological methods are operational at present. Detailed information about these soil treatment techniques has been collected in the *Handbook for Remedial Action Techniques* [7].

In a recent ranking of research topics connected with remedial action techniques it was agreed that the following would have priority:

- The characterization of soil and contaminants.
- The reduction in the volume and treatment of waste sludge from soil washing processes.
- The additional treatment of heavy metals in the case of thermal treatment.
- Process control and study of bio-availability for biological techniques.
- Close monitoring of cleaning processes.
- Optimization and development of in-situ techniques

The policy of sediment treatment in water courses is also expected to boost the development of soil cleaning techniques [8]. The sediment cleanup program aims to clean up at least 2 million m³ of sediments in 1995. The development program for treatment techniques has a budget of 30 million Dutch guilders to carry it up to 1994.

6. CONCLUSIONS AND PROSPECTIVES

In the early 1980s, the Netherlands came face to face with the soil pollution problem. Since the introduction of the Interim Soil Cleanup Act (1983) the government has spent about 1.5 billion Dutch guilders for the cleanup of the most urgent contaminated sites. At this time it was believed that the cleanup program would be short term. The Dutch government focused on developing procedures and technologies for an adequate execution of the cleanup operation. Considering that an increasing number of contaminated sites have been discovered, the government will be paying more attention to pollution prevention in the future. To support this strategy the Interim Soil Cleanup Act will be incorporated into the Soil Protection Act. In this connection the Soil Cleanup Guideline is being revised at the moment. Renamed the Guideline for Soil Protection it will include the revised C-values, new protocols for investigation of contaminated sites and guidelines for the selection of the most appropriate remedial action alternative. The Handbook for Remedial Action Technologies is also being revised at the moment. In this version special attention will be paid to defining the applicability of the different technologies (based on experiences in practice). The next time considerable progress can be expected in the cleanup operation. On the one hand, because of a higher budget, partly due to the "enforced first approach", and on the other, a better organization of the cleanup process (e.g. by the introduction of the SCG). This will promote the improvement of operational technologies (so-called "second generation") and the development of new alternatives. Due to the high number of contaminated (operational) industrial sites, the development of in-situ technologies is strongly supported. R&D programs of several ministries will continue and also support the development of environment-friendly remedial action technologies.

EXPLANATION:

- A-value: soil quality reference value
(indicates the acceptable risk limit or target value).
B-values assessment value
(indicates the need for further investigation).
C-values: intervention value
(indicates the maximum potential tolerable risk limit; cleanup is required).

The A, B and C-values indicate concentration levels within the assessment framework for soil pollutants. In the new Guideline for Soil Protection only A and C-values are maintained.

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United States' Tour de Table Presentation

INNOVATIVE REMEDIATION TECHNOLOGIES: IMPLEMENTATION SUCCESSES AND CHALLENGES

Walter W. Kovalick, Jr., Ph.D.
Director, Technology Innovation Office
U.S. Environmental Protection Agency

Introduction

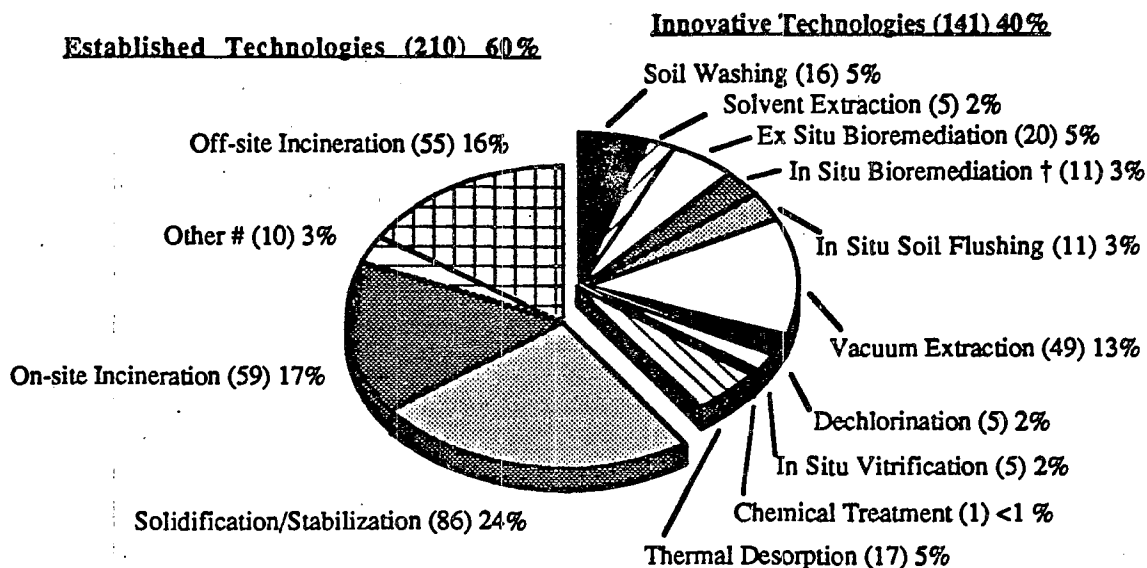
It is a privilege to be part of a Canadian dialogue about state-of-the-art technologies for contaminated hazardous waste sites. I would like to share two perspectives with you on our experience in the United States (U.S.). First, I'd like to ground my presentation graphically in the recent data we have compiled on the nature and use of newer technologies in remediating Superfund sites. Second, I'd like to briefly discuss our work to enable consulting engineers, Federal and State officials, and companies with contaminated sites to be more open and accepting of these new technologies as they design solutions in the future.

Defining Innovative Technologies

Our operating definition of innovative technologies for soils is those for which there are insufficient cost and performance data to support more routine engineering design. As shown in Figure 1, we consider incineration and stabilization/solidification as established technologies for site remediation, while the others shown are in the innovative category.

As you see, when treatment was selected over the last decade, innovative remedies made up about 40% of the selections. Most of these innovative treatments are used for source control, which is primarily the treatment of soil. This statistic is even more impressive when taken in the context of the dramatic increase in source control Records of Decision (RODs) since the passage of the Superfund Amendments and Reauthorization Act of 1986, shown in Figure 2. RODs are the documentation for the Agency's selection of a remediation approach for a site. As treatment technology use has grown as a way of dealing with soils, so has the use of innovative treatment methods, with except for a small drop last year (Figure 3).

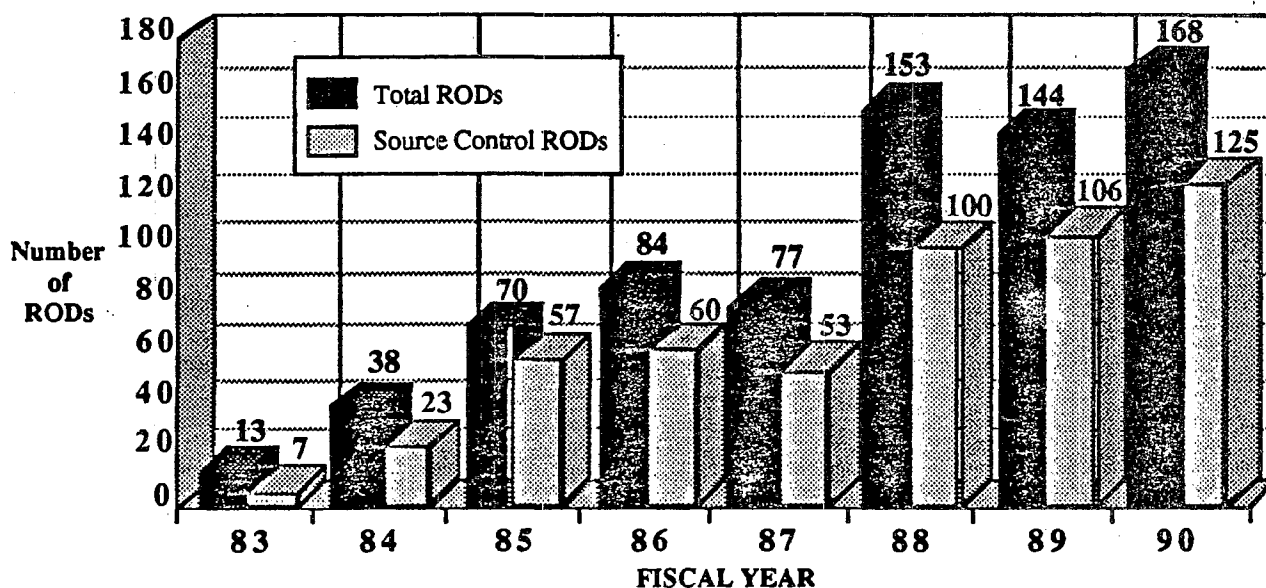
**FIGURE 1. REMEDIAL ACTIONS:
SUMMARY OF ALTERNATIVE TREATMENT TECHNOLOGIES THROUGH FY 90***



* Data are derived from 1982 - 1990 Records of Decision (RODs) and anticipated design and construction activities as of August 1991.
 () Number of times this technology was selected or used
 # "Other" technologies are soil aeration, in situ flaming, and chemical neutralization.
 † Includes in situ groundwater treatment.

FIGURE 2. REMEDIAL ACTIONS: RODS SIGNED BY FISCAL YEAR*

(Total = 751)



* 751 RODs corresponds to 435 NPL sites.
 Source: USEPA Office of Emergency and Remedial Response.

While these remedy selection trends are encouraging, a closer look at Figure 1 reveals how few actual projects have been selected in certain categories and how "new" these technologies are to the engineering community. Figure 4 further illustrates this point by showing how few of these technologies have moved to the completion phase--only 8%. This statistic gets to the heart of the nature of the problem of introducing these new technologies to the engineering profession. But, more on that issue later.

Trends in Technology Selection

Even with this modest number of project completions, we have begun to see the kinds and types of technologies that tend to be applied to certain characteristic sites and wastes. To give you a sense of the nature of the problems being confronted in the U.S. Superfund program, I am going to talk about the kind of site problems and the quantities being dealt with at these sites. This information results from an analysis we conducted of the potential market for innovative treatment in the Superfund program. The site characterization data are for about 750 Superfund sites for which EPA has made no cleanup decisions in RODs.

Figure 5 shows the primary industrial sources of Superfund wastes, and Figure 6 shows that, not surprisingly, soil and ground water are the most frequently contaminated media. A look at the types of contaminants found in soil shows that volatile organic compounds (VOCs) and heavy metals are by far the most frequent (Figure 7). Figure 8 gives an analysis of the quantities of soil being remediated: the vast majority (85%) of sites with RODs have less than 50,000 cubic yards (cy) of soil to be cleaned up; 10% have greater than 100,000 cy.

Given this context of site problems, the trends of innovative remedies we are seeing should be more meaningful. We see in Figure 9 that we are frequently selecting innovative treatment for the most common contaminant, VOCs. A wide variety of other methods are being used as well. However for heavy metals, which are almost as common as VOCs, Figure 10 shows that our use of innovative technology is far less. By contrast, polyaromatic hydrocarbons (PAHs) occur at relatively few sites, but we have selected innovative methods (primarily bioremediation) in almost 40 cases, as indicated in Figure 11.

We can also observe that there are clearly favorite innovative methods for some types of contamination: vacuum extraction for VOCs, soil washing for metals, and bioremediation for PAHs. But for polychlorinated biphenyls, as Figure 12 illustrates, no innovative technology is a clear winner.

Table 1 contains data on the quantity of material being treated by each innovative technology. Technologies are listed in order of average quantity of material addressed, but because there is a wide range of values for most technologies, the averages could be misleading. In general, however, batch processes, such as solvent extraction,

FIGURE 3. REMEDIAL ACTIONS: NUMBER OF ESTABLISHED VERSUS INNOVATIVE TREATMENT TECHNOLOGIES

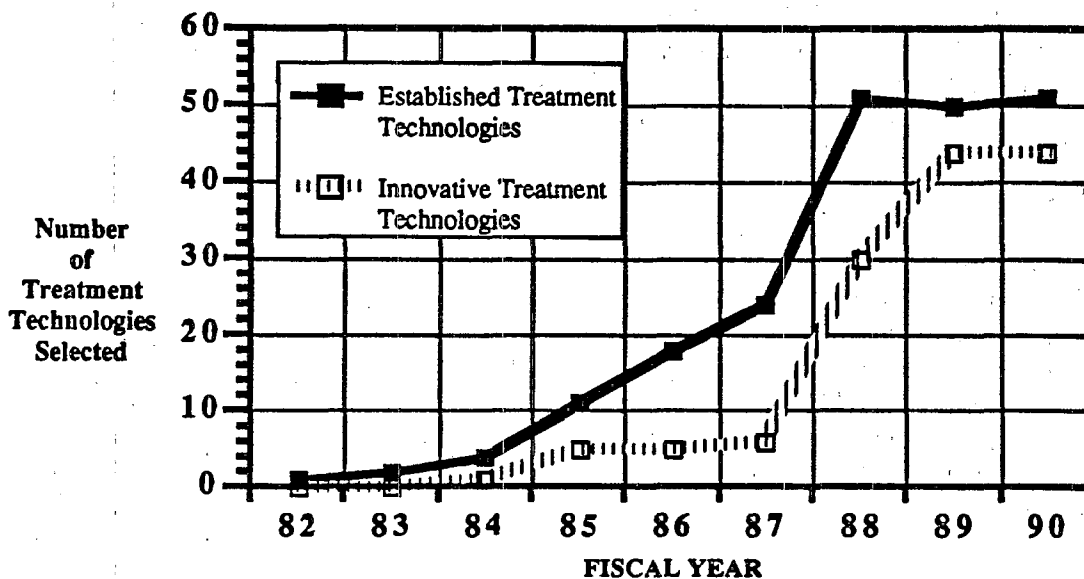
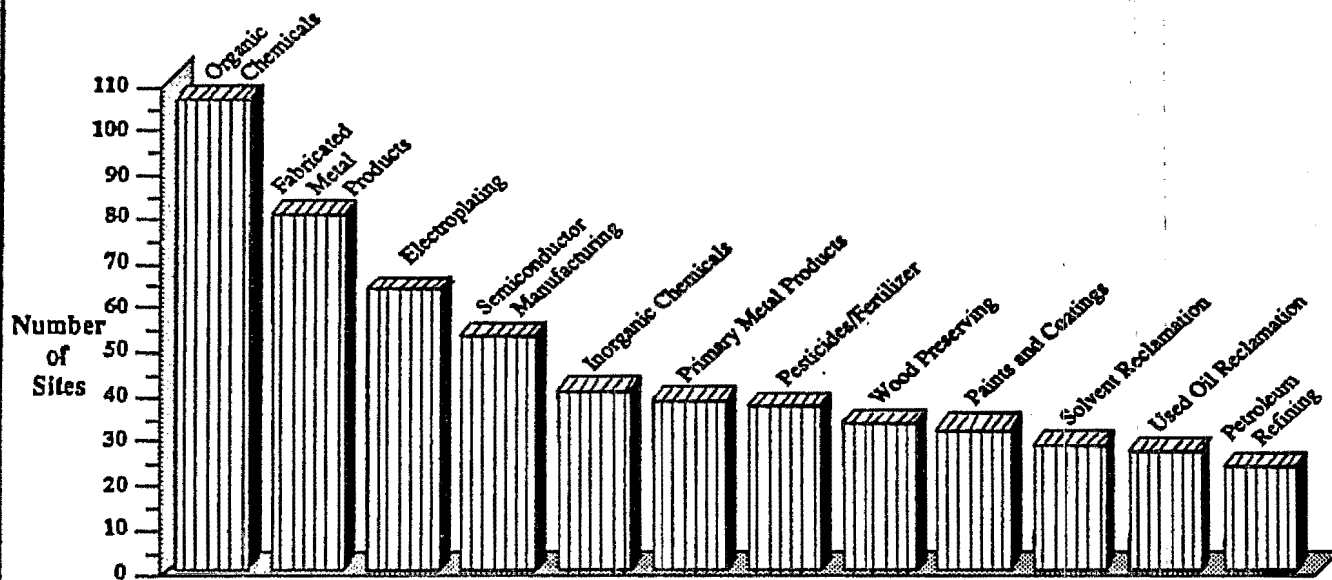


FIGURE 4. REMEDIAL ACTIONS: PROJECT STATUS OF INNOVATION TREATMENT TECHNOLOGIES AS OF AUGUST 1991

Technology	Predesign/ In Design	Design Complete/ Being Installed/ Operational	Project Completed	Total
Vacuum Extraction	36	12	1	49
Ex Situ Bioremediation	15	4	1	20
Thermal Desorption	14	0	3	17
Soil Washing	16	0	0	16
In Situ Bioremediation †	8	2	1	11
In Situ Flushing	9	2	0	11
In Situ Vitriification	5	0	0	5
Solvent Extraction	4	1	0	5
Dechlorination	3	1	1	5
Chemical Treatment	0	0	1	1
TOTAL	110 (78%)	22 (16%)	8 (6%)	140

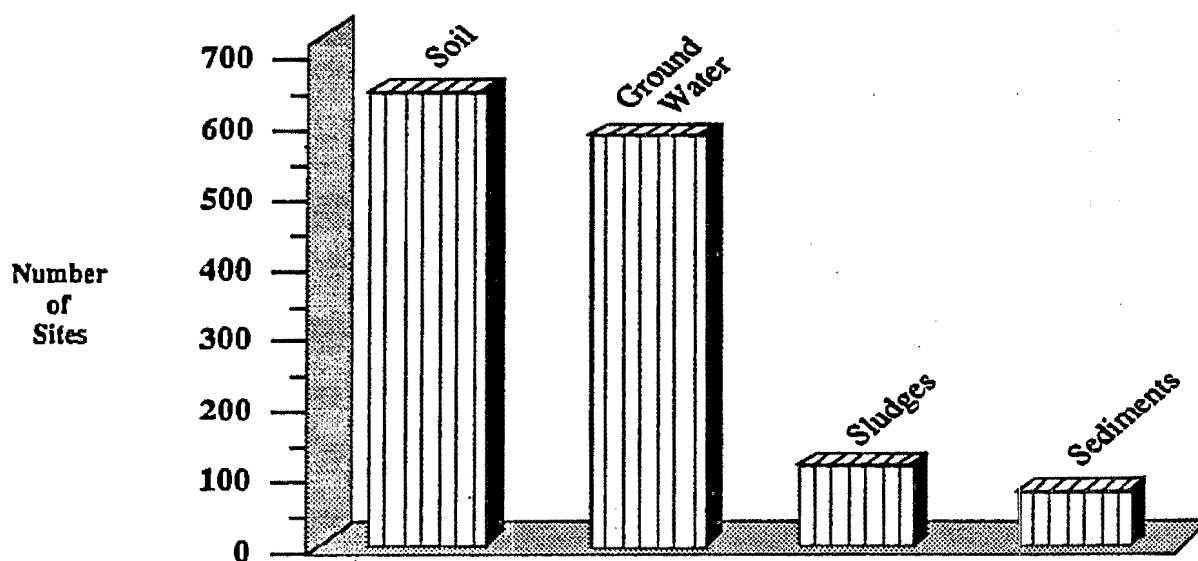
* Data derived from 1982 - 1990 Records of Decision (RODs) and anticipated design and construction activities.
† Includes in situ groundwater treatment.

FIGURE 5.
FREQUENCY OF INDUSTRIAL SOURCES AT SELECTED SUPERFUND SITES*



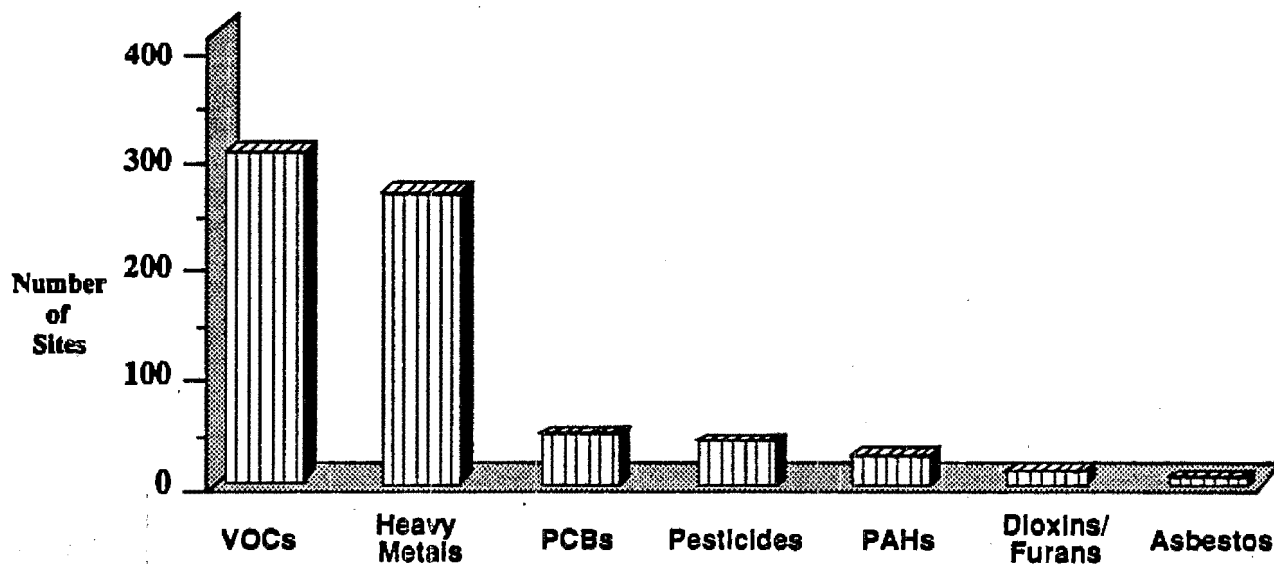
* May be more than one industrial source at each site.

FIGURE 6.
FREQUENCY OF CONTAMINATED WASTE/MEDIA AT SELECTED SUPERFUND SITES*



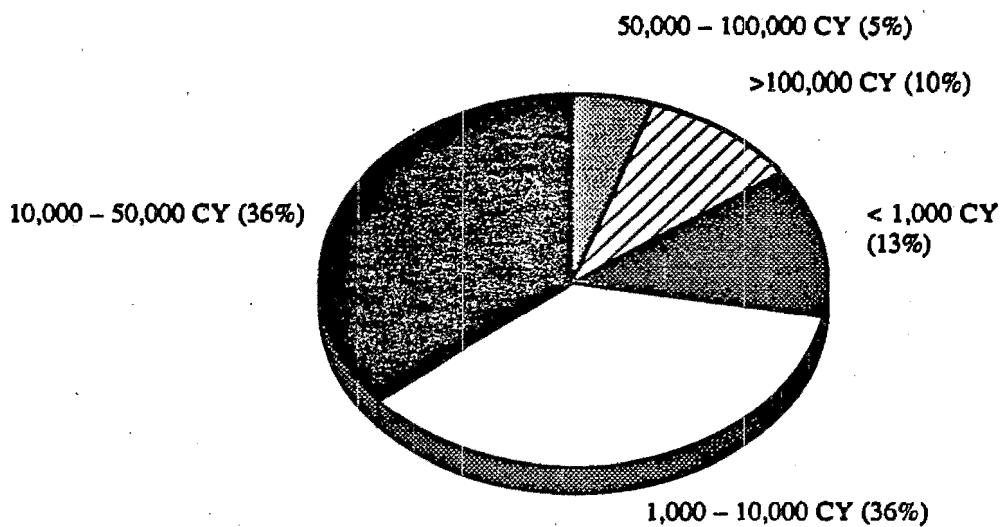
* More than one contaminant may be present at each site.

FIGURE 7. PRINCIPAL CONTAMINANT GROUPS PRESENT IN SOIL*



* More than one contaminant group may be present at each site.

**FIGURE 8.
QUANTITIES OF SOIL TO BE REMEDIATED BY PERCENT OF SITES**



Source: EPA's RODs Information Database

FIGURE 9. INNOVATIVE TREATMENT FOR SITES CONTAMINATED WITH VOCs

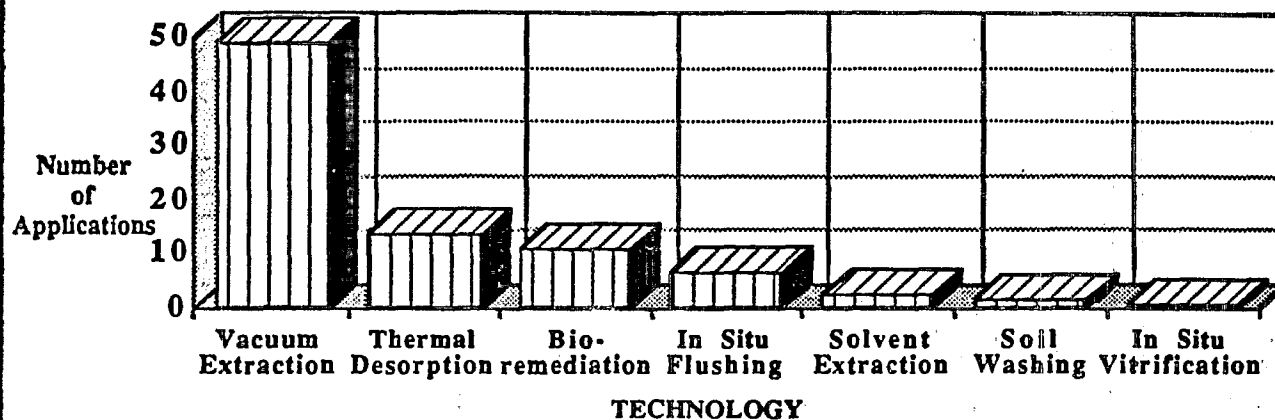


FIGURE 10. INNOVATIVE TREATMENT FOR SITES CONTAMINATED WITH HEAVY METALS

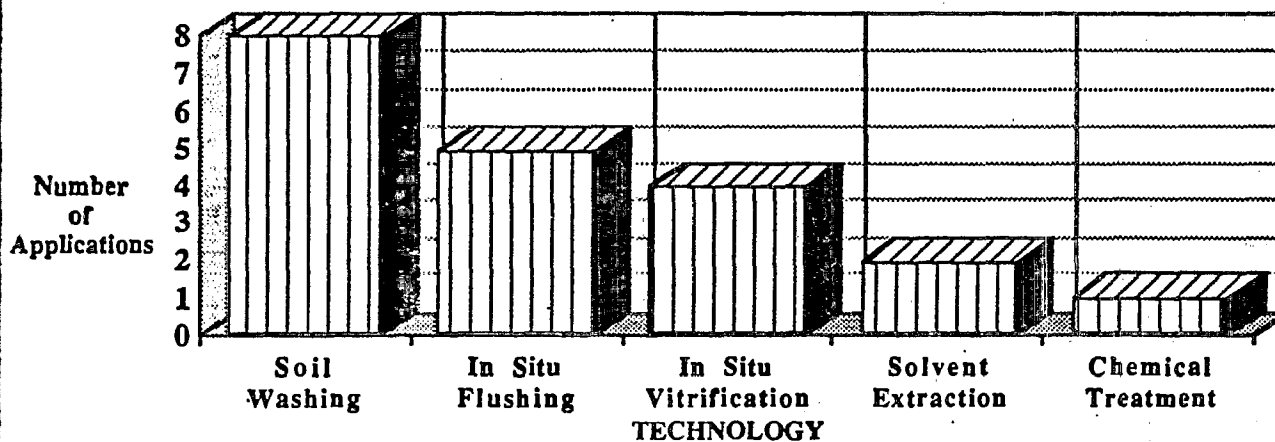


FIGURE 11. INNOVATIVE TREATMENT FOR SITES CONTAMINATED WITH PAHS

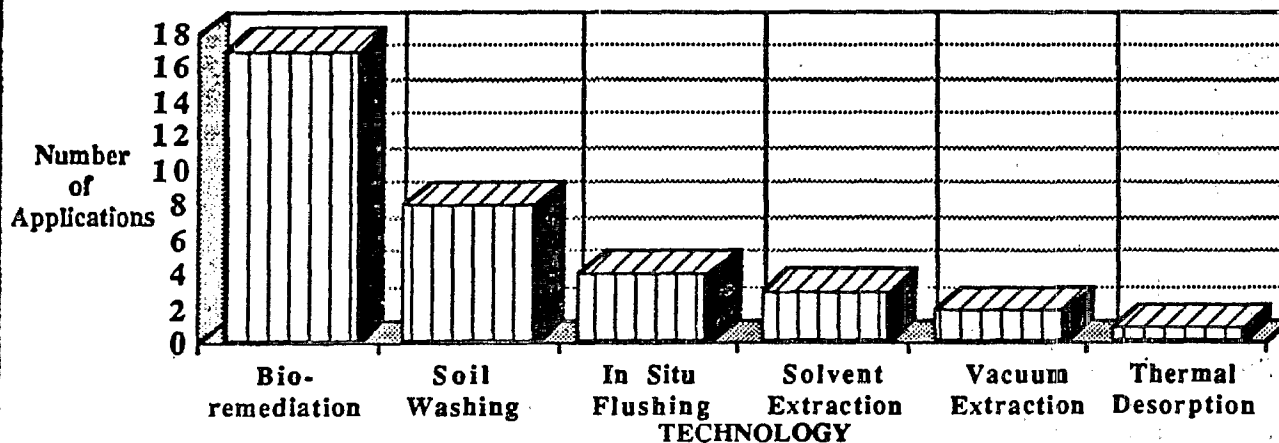


FIGURE 12.
INNOVATIVE TREATMENT FOR SITES CONTAMINATED WITH PCBS

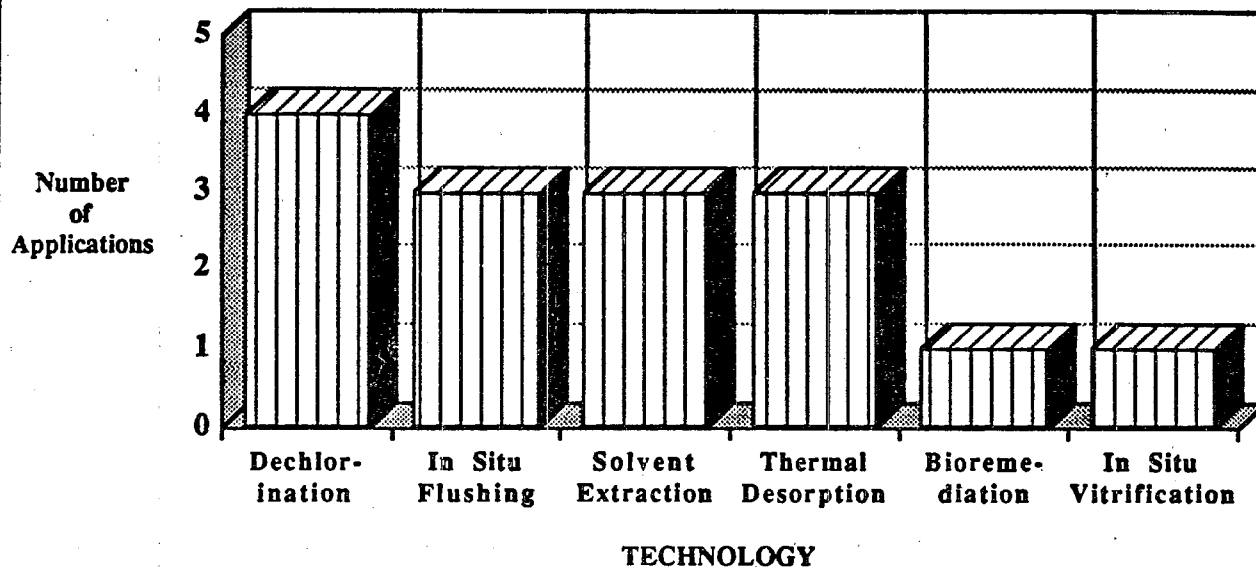


TABLE 1.
QUANTITIES OF SOIL TO BE TREATED BY INNOVATIVE TECHNOLOGIES

Technology	Number of Superfund Sites with Data	Quantity (Cubic Yards)	
		Range	Average
In Situ Soil Flushing	10	1,500 – 650,000	90,000
Vacuum Extraction	31	400 – 300,000	47,000
In Situ Bioremediation	5	5,000 – 10,000	47,000
Soil Washing	17	5,500 – 200,000	40,000
Ex Situ Bioremediation	18	5,200 – 120,000	33,000
Solvent Extraction	5	2,000 – 67,000	29,000
Dechlorination	4	800 – 50,000	20,000
In Situ Vitrification	5	4,000 – 38,000	14,000
Thermal Desorption	17	1,600 – 85,000	13,400

dechlorination, and thermal desorption, which require waste excavation and often pretreatment, tend to treat smaller amounts of material.

Technology Demonstration and Evaluation

Moving beyond our implementation data related to innovative technologies, let me turn to one other aspect of the Superfund program that is focused on technology development and demonstration. The 1986 law authorized the Superfund Innovative Technology Evaluation (SITE) with the goal of assisting developers of technologies to scale up and demonstrate these innovative technologies.

There are two components of the treatment technology program:

- o The Demonstration Program, entering its 7th year, focuses on technologies ready for field application. Vendors mobilize pilot or full-scale equipment to actual hazardous waste sites and pay for the cost of equipment operation. EPA pays for rigorous sampling and analysis of equipment performance. EPA prepares evaluation reports which provide performance and, to the extent possible, cost information.
- o The Emerging Technologies Program, entering its 5th year, focuses on developmental technologies. EPA provides up to \$150,000 per year for up to two years to assist in development of promising technologies. While the emerging program generally involves laboratory testing, it may include early pilot testing. Technologies which participate in the emerging program may "graduate" to the demonstration program.

Another component of the SITE program which focuses on innovative approaches to field monitoring and site characterization. Tables 2 and 3 summarize the kinds of technologies in the SITE Demonstration and Emerging programs, and the progress to date of each of the programs.

The SITE program stands as a unique national commitment to provide developers with the opportunity to authenticate their new technology claims for the marketplace.

Initiatives to Encourage Technology Use

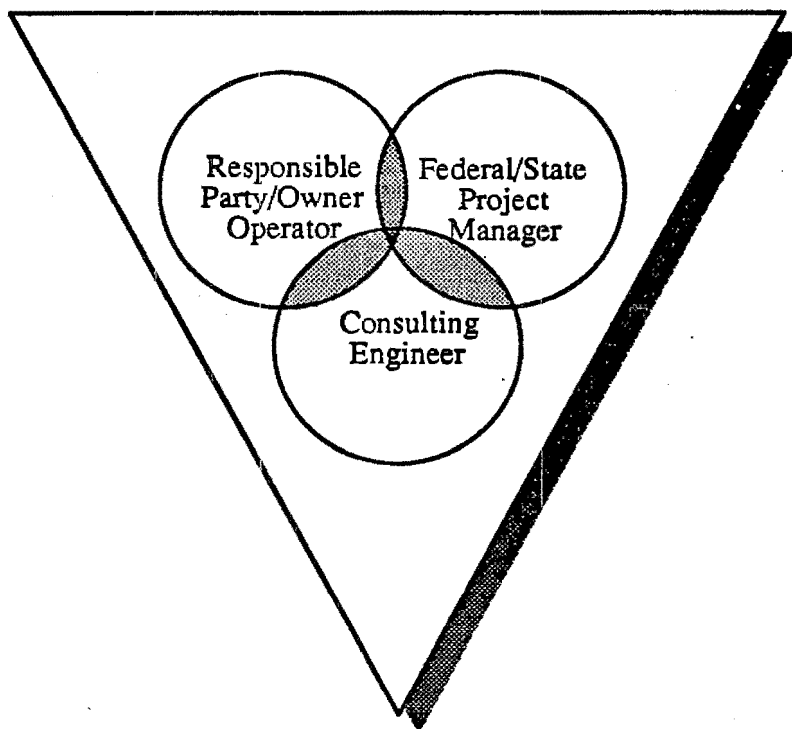
I would now like to discuss some of our work with practitioners to deal with changing the perceptions and reality of considering innovative technologies for site remediation. Figure 13 graphically portrays the critical decision-makers for cleaning up abandoned waste sites.

Either in the presence of or at the direction of a Federal or State project manager, consulting engineers are called upon to conduct studies and make recommendations for solutions at contaminated sites. More and more frequently in the U.S., the client who

TABLE 2. SITE DEMONSTRATION PROGRAM			
Technologies	Vendors Selected	Demon- strations Completed	Reports Available
Biological	16	3	1
Physical/ chemical	32	9	10
Thermal	13	6	6
Solidification/ stabilization	11	5	8
Radionuclides	2	--	--
Total	<u>74</u>	<u>21</u>	<u>25</u>

TABLE 3. SITE EMERGING TECHNOLOGIES PROGRAM			
Technologies	Vendors Selected	Tests Planned or In Progress	Reports Available
Biological	9	7	2
Physical/ chemical	21	16	5
Thermal	7	7	--
Solidification/ stabilization	2	2	--
Materials Handling & Mining	5	5	--
Total	<u>44</u>	<u>37</u>	<u>25</u>

**FIGURE 13.
TECHNOLOGY INNOVATION OFFICE:
MAKING INNOVATIVE REMEDIATION TECHNOLOGIES HAPPEN**



retains them is the potentially responsible party (a term from our Superfund program) or a hazardous waste facility owner/operator required to conduct corrective action under our hazardous waste law. Usually outside this decision triangle are the new technology developers who are attempting to "break into the club" of accepted technologies.

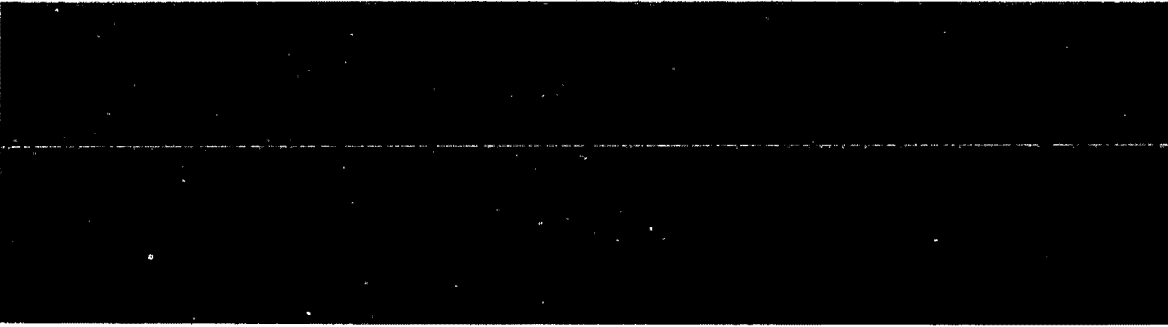
Given this scenario, my office has focused over the last 18 months on identifying and dealing with what's blocking each of these players from using innovative technologies. These barriers generally fall into three classes: informational, regulatory, and institutional/economic. We have met with each of these interested parties and developed "products" to serve these customers. While this is a unique role for a regulatory agency, it is proving fruitful. Below are a few of our initiatives to deal with these barriers:

- o *Innovative Hazardous Waste Treatment Technologies: A Developer's Guide to Support Services* (EPA/540/2-91/012) identifies programs and services that support technology development and commercialization. This includes Federal and State assistance programs, facilities that can provide services related to technology development and testing, and university-affiliated research centers. This information targets the technology developer who needs help validating or commercializing his technology, and in understanding permitting and other regulatory requirements.
- o *A Vendor Information System on Innovative Treatment Technologies (VISITT)* is a new database to provide screening level information on cost and performance from vendors and their clients. This information will provide a clearinghouse of innovative technology information for companies, consulting engineers, and state and federal project managers.
- o The *Bioremediation Field Initiative* is a joint effort between TIO and the Office of Research and Development. The program is designed to more fully document performance of full-scale applications of bioremediation, provide technical assistance for treatability studies and field pilot studies, and enhance cross-regional information transfer on bioremediation projects. Program progress and a list of sites using bioremediation are documented in a regular newsletter of the same name (EPA/540/2-91/018).
- o *Innovative Treatment Technologies: Semi-Annual Status Report* (EPA/540/2-91/001) documents the use of innovative treatment technologies at Superfund sites. The twice-yearly report contains overall statistics and site-specific information, including the technology selected or used, the waste to be treated, implementation status, and site contacts. This information can be used by site managers to identify others with similar sites and technology interests, and by technology vendors to evaluate to identify prospective customers.
- o *A Market Assessment Project* is underway to profile the remediation market retrospectively and over the next several years. The objective is to provide

developers and investors with information on the type and size of site problems so that development dollars can be channelled more productively. Information on specific sites may also help vendors market their technologies to site managers.

- o The *Federal Remediation Technologies Roundtable* serves as an information exchange network for and about Federal agencies conducting applied research and development on innovative remediation technologies. The Roundtable has recently published summary reports of federal demonstrations (EPA/540/8-91/009) and federal databases (EPA/540/8-91/008), and a bibliography of federal reports (EPA/540/8-91/007) concerning innovative treatment. Future efforts will focus on joint or collaborative demonstration projects.
- o *Identification and removal of regulatory impediments* is an ongoing function of TIO. The same regulatory framework which essentially establishes the market for remedial technologies unfortunately hampers the development and application of innovative technologies. Some of the impediments that TIO is addressing were identified in a 1990 EPA study of the strengths and weaknesses of the hazardous waste regulatory program. These include the cost and timing to get a research permit, unfamiliarity of permit writers with new technology, site-specific permitting for transportable units, and stringent cleanup levels under the Land Disposal Restrictions.
- o *Information dissemination* is one of TIO's major initiatives. TIO compiles a bibliography of all significant EPA publications on innovative technologies (EPA/540/8-91/006) and a periodic bulletin, *Tech Trends*, (EPA/540/M-91/004) which communicates experiences encountered in applying innovative technologies in the field.
- o TIO has sponsored three *Forums on Innovative Hazardous Waste Treatment Technologies: Domestic and International*. International and domestic vendors of innovative technologies present papers and posters with an emphasis on actual field applications. Abstracts are available (EPA/540/2-91/016) for the most recent of these conferences, which was held in Dallas in June 1991. Documentation is also available for the first forum in 1989 (EPA/540/2-89/055) and the second in 1990 (EPA/2-90/010).
- o Because one of the largest markets for remediation technologies may be the states, TIO has an *initiative to encourage states to promote innovation*. State regulatory requirements and remediation programs will have a major impact on the pace and extent of innovation. For various reasons, states have been slow to adopt EPA-promulgated innovation support and relief mechanisms such as research and development permits and the 1000 kg treatability exclusion. TIO is working with a number of interested states to explore opportunities to establish a regulatory environment which not only tolerates, but actively encourages innovation.

In addition to these projects, TIO is exploring avenues to more fully engage the nation's consulting engineers, responsible parties, and professional societies in collaborative information sharing, education, and remediation technology demonstration.



Increasing the Development and Use of Innovative Treatment Technologies for Site Cleanup

What are Innovative Technologies?

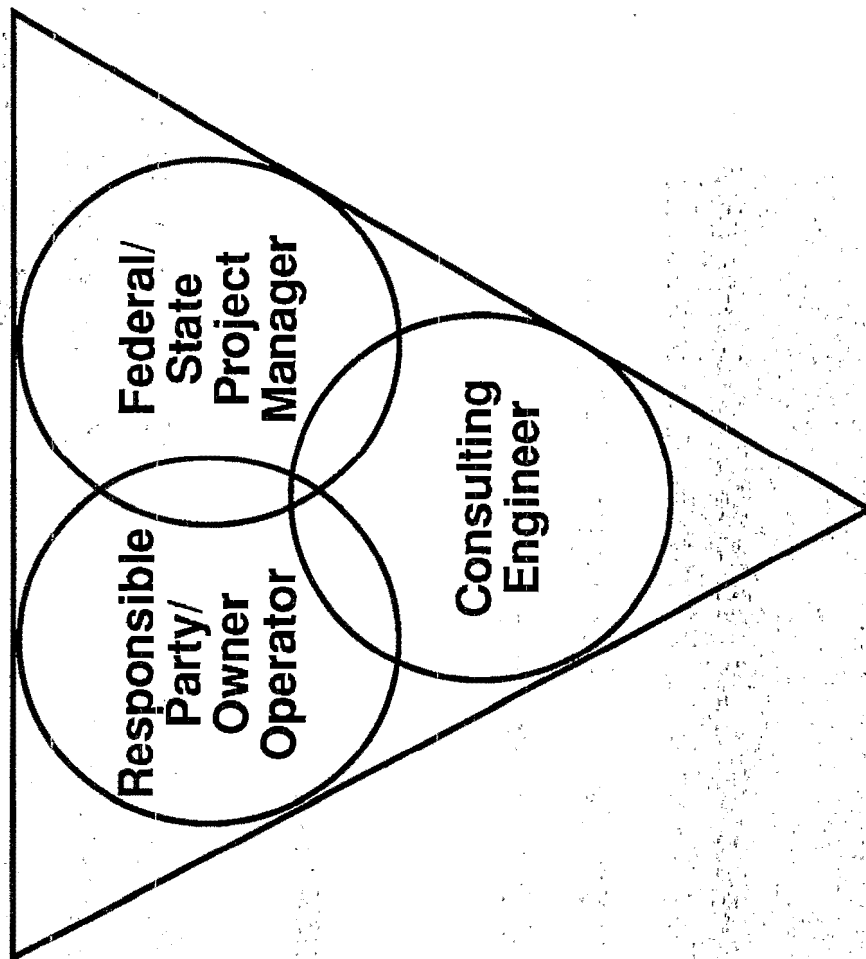
Methods for which performance or cost information is inadequate.

09 For source control:

- ❖ Thermal desorption
- ❖ Chemical treatment
- ❖ Solvent extraction
- ❖ *In situ* vitrification
- ❖ Vacuum extraction
- ❖ *In situ* flushing
- ❖ Soil washing
- ❖ Bioremediation

Who are Clients?

Technology Vendor



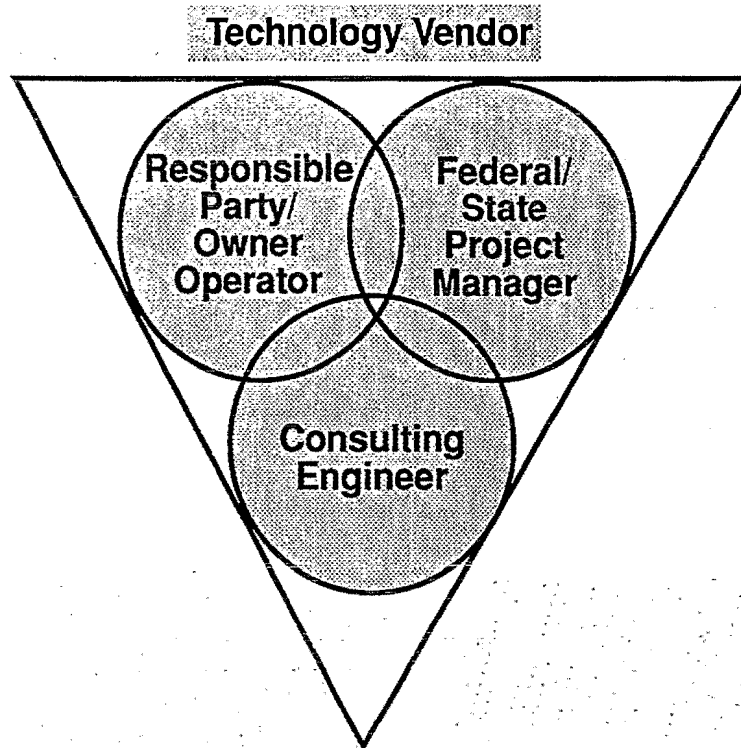
Technology Innovation Office

Interpret and Supply Information

ON-GOING PROJECTS

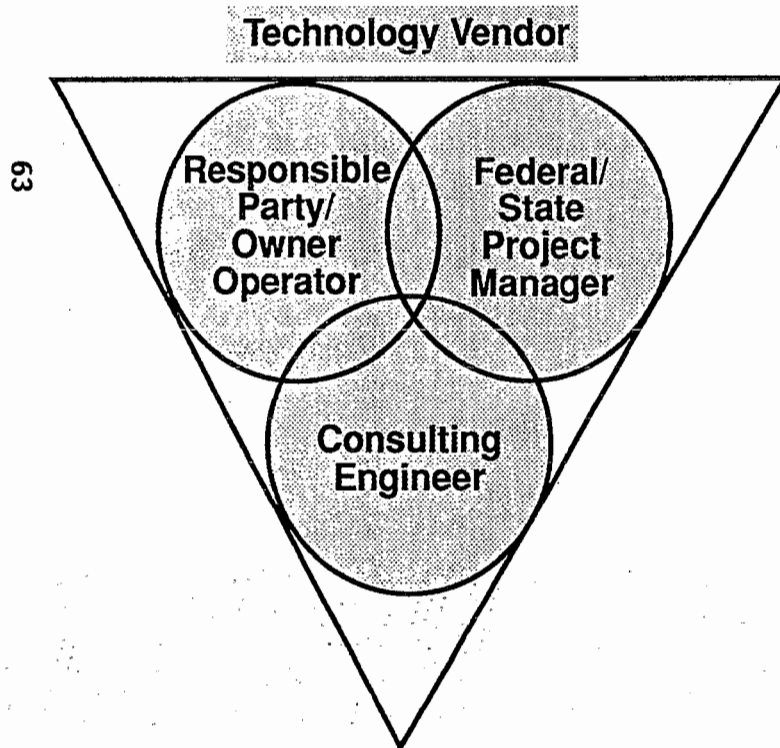
- ❖ Bibliographies/Newsletter (*Tech Trends*)
- ❖ Innovative Technologies Overview/Status Report
- ❖ *Bioremediation Bulletin* on OSWER/ORD field initiative
- ❖ Forum on Innovative Hazardous Waste Treatment Technologies: Domestic and International (3rd annual in June 1991)
- ❖ Joint work with ORD under NATO/CCMS and German Bilateral to obtain technology information
- ❖ Clean-Up Information (CLU-IN) Electronic Bulletin Board for exchange of information on hazardous waste site remediation (Now open to the public)

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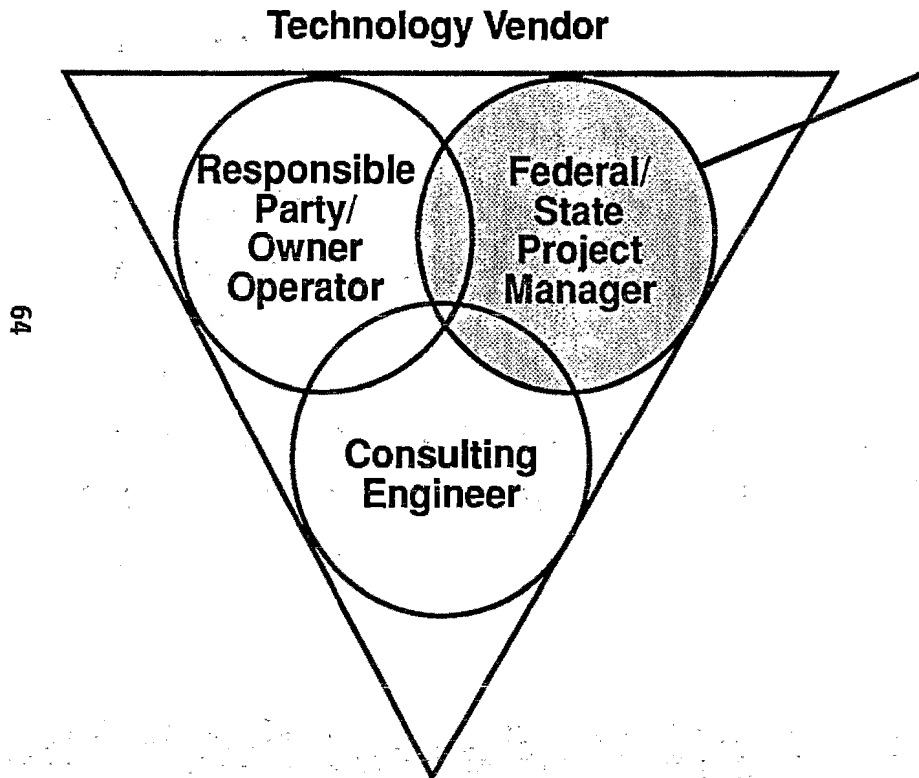
Interpret and Supply Information

NEW PRODUCTS



- ❖ AWMA and HWAC Satellite Seminar (1992)
- ❖ Federal Remediation Roundtable Publications (Summer 1991)
- ❖ Market Monograph (Fall 1991)
- ❖ Vendor Information System for Innovative Treatment Technologies (VISITT) (Early 1992)
- ❖ TIO "booth" and presentations at 8-12 technical professional meetings per year
- ❖ Lessons Learned during Technology Implementation
- ❖ Public Information Fact Sheets (Fall 1991)

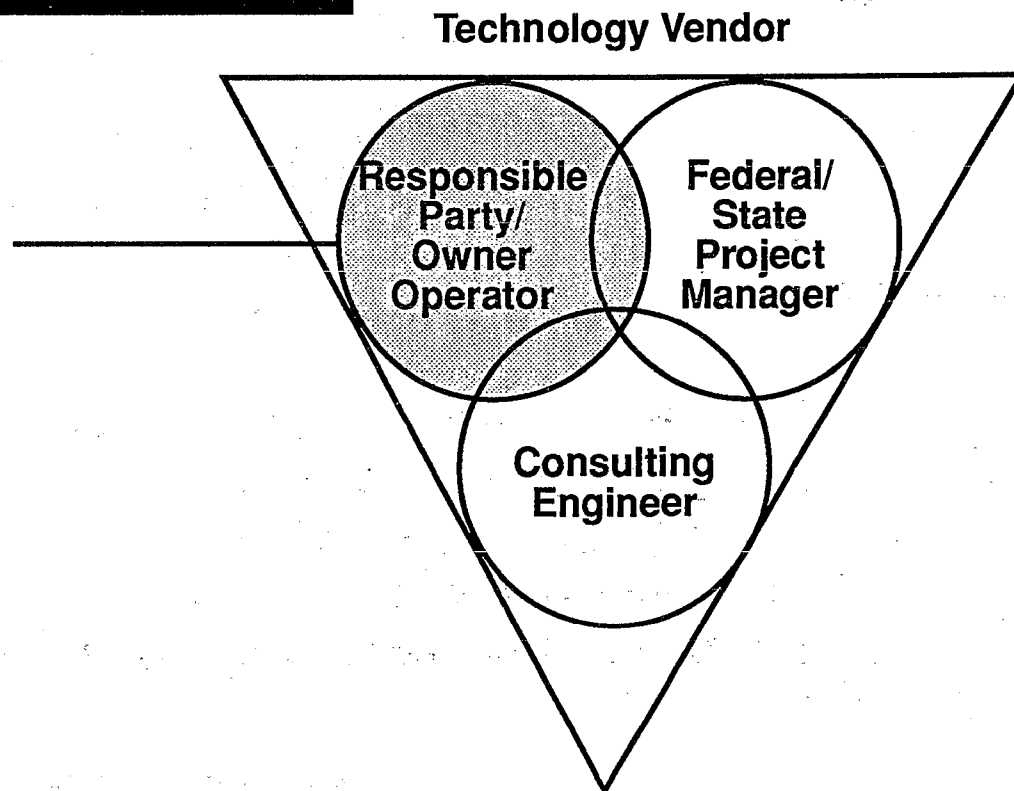
Increase the Demand for Trying the Innovative Approach



- ❖ OSWER policy directive (June 1991) with:
 - clear statement of intention
 - integrated SARA/RCRA/UST coverage
 - specific incentives to take risks
 - continued support systems
- ❖ Target training at Superfund Academy
- ❖ Impact RCRA corrective action and enforcement guidance and regulations
- ❖ “Cross market” with ORD (for SITE), OE (for Federal Facility Demos), OSW (for RCRA permits/variances), and OWPE (for RCRA orders)

Enable Collaborative Projects

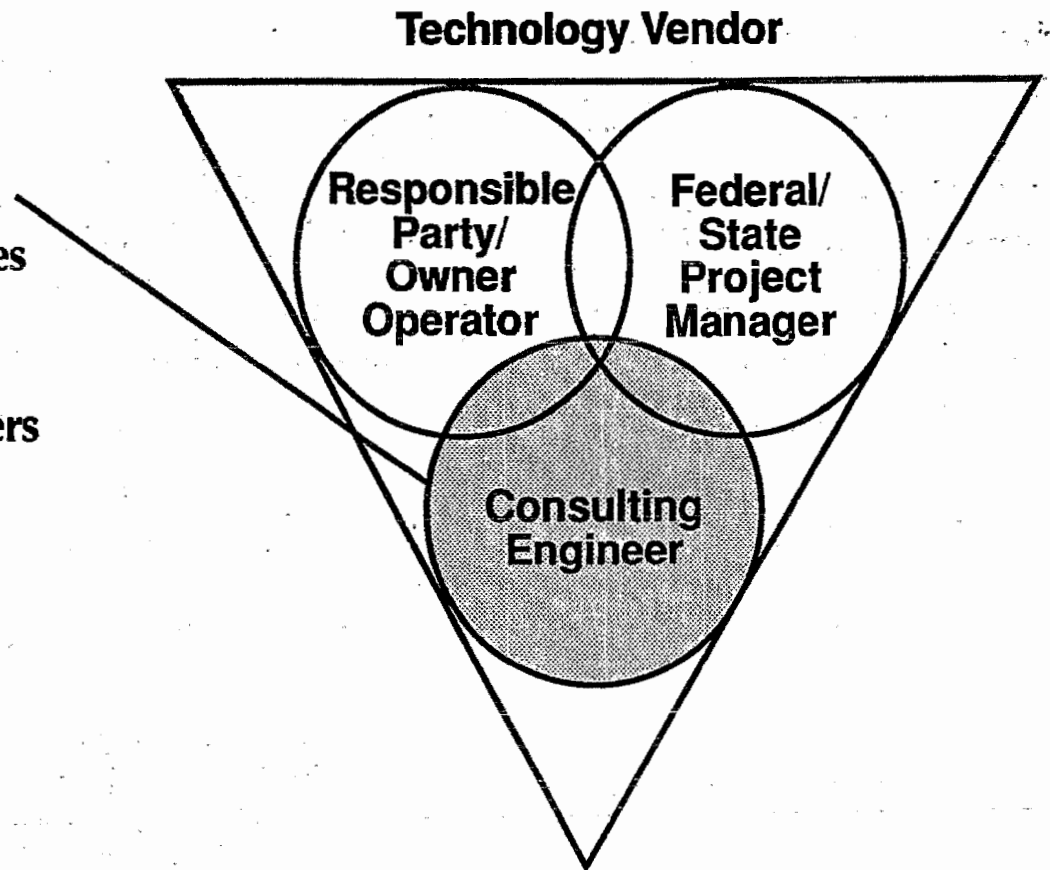
- ❖ Use Federal Remediation Roundtable to collaborate on demonstrations
- ❖ Create new industry/government technology forum
- ❖ Market Federal Technology Transfer Act to industry



continued...

Enable Collaborative Projects

- ❖ Support National Standards of Practice on Innovative Technologies
- ❖ Assist regular nationwide teleconferences for consulting engineers
- ❖ Follow-up on other work group recommendations with Hazardous Waste Action Coalition (ACEC)



What is Near-Term Agenda?

- ❖ Continue to supply updated information to targeted audiences
- ❖ Implement OSWER directive affecting Superfund and RCRA
- ❖ Begin National Technology Standards of Practice on technologies with 2-6 professional societies
- ❖ Create mechanism to collaborate with industry on their technology development agenda
- ❖ Support/announce 1-2 states as “Technology Meccas”

continued...

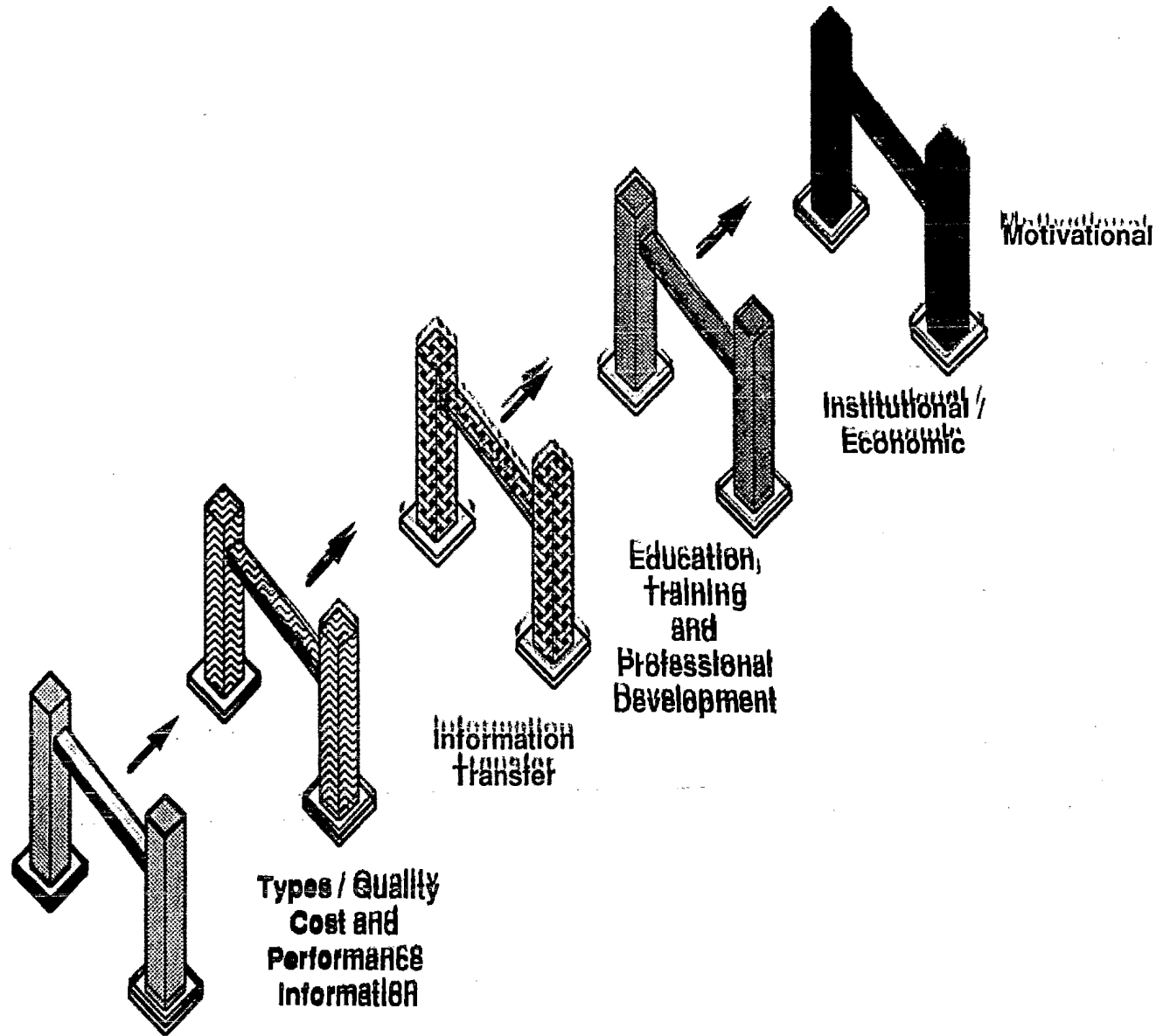
What is Near-Term Agenda?

- ❖ Fully embrace groundwater as well as source control technologies
- ❖ Issue VISITT Vendor Information System
- ❖ Continue and expand work on Federal Remediation Technologies Roundtable
- ❖ Aggressively market CLU-IN Bulletin Board
- ❖ Issue first Market Monograph

Hazardous Waste Site Clean-up Market

- o 1,200 - 2,000 Superfund sites
- o 4,700 RCRA facilities with 60,000 units may need corrective action
- o 28,000 State non-Superfund sites
- o 660,000 sites with 1.8 million underground storage tanks (90% of tanks contain petroleum)
- o 638 DOD installations with 7,400 sites
- o 76 DOE facilities with up to 1,500 contaminated areas per facility

Barriers To Implementing Innovative Technologies



Austria's Tour de Table Presentation

CONTAMINATED SITES - THE SITUATION IN AUSTRIA

Harald KASAMAS

(ÖKO-FONDS)

I. INTRODUCTION

Like the case of "Love Canal" in the US, Austria has also a popular contaminated site (named "Fischer Deponie"), which made the problem clear to the public.

It is a MSW-landfill site with approximately 4000 barrells of chemicals on its base. This site is one of the main contamination sources of Austria's largest aquifer. Approx. 500 000 people rely on this aquifer for drinking water purpose.

In 1987 the site was closed after conducting a groundwater-quality programm. As the debate about the next steps went on it became clear, that the legal situation was insufficient to deal with the problem and that the needed funds are not existent.

This acute case led to a prompt realization of a federal law, the "Altlastensanierungsgesetz".

II. "ALTLASTENSANIERUNGSGESETZ 1989 (ALSAG)" (or "Federal Law relating to Remedial Actions on Contaminated Sites")

The purpose of this federal law is to provide the basic structure for handling problems with contaminated sites in Austria, mainly to create the funds for financial support.

Altogether ALSAG regulates the following topics:

1. Registration and assessment of suspected sites
2. Organization and distribution of the necessary funds (Altlastenbeitrag)
3. Legislative authority to force necessary measures by expropriations, sufferance, and the related compensations
4. Important definitions about the topic

ALSAG was put into force on 1.7.1989.

ALTLASTENBEITRAG (or "How to create the needed money?")

The required finances are created by appropriated tax on landfilling and waste-export. This modell is funded on the fact that all waste-disposal in the soil needs controll and monitoring afterwards. Furthermore, the financial burden on landfilling and waste-export should give an impulse towards waste-minimization measures and should result in saving landfill-space.

The tax is collected from landfill-operators and waste-exporters by the revenue-offices. An advantage of this modell is the relatively small amount of contributories which should make the execution easier.

The extent of the taxation depends on the type of waste which is being handled. For hazardous waste it is approx. \$ 16.00 per metric ton, for non-hazardous waste it is approx. \$ 3.20 per metric ton.

The assessed valuation of the financial requirements for treating contaminated sites in Austria over the next 10 years ranges up to approx. \$ 800 million .

When "Altlastenbeitrag" was introduced in 1989, the expected annual revenue was approx. \$ 31 million. By collecting the tax over 20 years, 60 % of the estimated financial need would have come from these public funds. But the experience of the first year showed that only one third of the expected amount has been generated. The main reason why revenue has fallen short of expectations is that the taxes have not been sufficiently enforced. Furthermore, after enacting the "Guidelines for Financial Support" it was clear that the public has to take a greater overall-share than planned. Because of these reasons the tax will rise up soon.

But in spite of these experiences there are still no financial problems to support the first projects. ALSAG regulates that the Ministry of Finance is able to undertake liability up to \$ 1 billion in case of financial shortage. Nevertheless, the condition is that on the long-term all has to be covered by "Altlastenbeitrag".

Beside the generation of finances, ALSAG also defines the concerns for which the money has to be spent. These are as follows:

1. Detection and assessment of suspected sites, including additional investigations to define priority classes
2. Registration of suspected sites and assessed contaminated sites
3. Remedial measures on contaminated sites
4. Construction, expansion and improvements of waste disposal sites, as far as they are related to clean-up measures
5. Studies and projects, including development of treatment technologies

To fullfill points 1 and 2, 10 % of finances are transferred to the Ministry of Environment. The other 90 % of the funds are intended for ÖKOFONDS to support matters of points 3 to 5.

III. "FÖRDERUNGSRICHTLINIEN 1991" (or "Guidelines for Financial Support")

The guidelines have been enacted since 1.7.1991. They regulate the conditions for which ÖKOFONDS can give financial support for remedial actions on contaminated sites.

As a general principle of these guidelines the financial support should encourage responsible parties to clean up contaminated sites voluntarily. Those parties who offer to participate in remedial measures can apply for financial support by ÖKOFONDS.

Altogether the guidelines answer the following questions:

1. What kinds of measures can be sponsored and which can't?
2. Who is able to apply for sponsoring and what conditions have to be met?
3. To what extent is financial support possible and under which circumstances are deductions applied for responsible parties ("Fund matching")
4. How can funding be transferred? Which conditions should be implied in the contract? And what happens if these conditions are not held?

FUND MATCHING

The guidelines distinguish between three different cases:

1. No responsible party is available: For sites where nobody can be forced to conduct remedial actions the funding can reach up to 100 % of clean-up costs. Those sites can be e.g. contamination caused by World War II or cases, which the responsible party isn't known or not existent anymore.
2. Responsible party is available: In these cases which someone can be forced by regulations to set measures respectively when someone has an interest to clean-up voluntarily, deductions of funding are applied for some defined cases of responsibility.

These cases are:

- not met the "Guidelines for landfilling from 1977" by landfill-construction (minus 10 % deduction)
- not possessing the required administrative appropriations (minus 10 % deduction)
- violation of a law or administrative injunctions which finally caused the contamination (minus 10 % up to the exclusion of funding depending on the extent of offense).

3. **Landfill sites in operation:** If the construction of the landfill was not sufficient to avoid damage to the environment, funding for the needed measures are possible. The extent of the financial support is linked to the remaining volume of landfill-space. The funding is adjusted in such magnitude that the future costs for landfilling MSW won't exceed \$ 100 per metric ton. For hazardous waste the limit is set to 1,5-times the cost for a modern constructed site. This modell should prohibit financial support for cheap landfilling.

In general, ÖKOFONDS has to consider the following:

1. The funding has to be covered by the revenue of "Altlastenbeitrag" overall.
2. The individual states should get back approximately their share of "Altlastenbeitrag" over a period of 5 years.
3. The priority of a contaminated site.

IV. PROCEDURE OF APPLICATION FOR FUNDING AND THE CURRENT SITUATION

- MINISTRY OF ENVIRONMENT

The individual states search for their possibly contaminated sites. These data are reported to the Ministry of Environment. This Ministry is responsible for executing the regulations of ALSAG and the coordination of the needed steps.

- UMWELTBUNDESAMT (UBA)

The reported sites are transferred from the Ministry of Environment to UBA for further investigations concerning the registration and assessment of possibly contaminated sites in the country. For these reasons, UBA holds two registers. One for the suspected sites ("Verdachtsflächenkataster") and one for the actual contaminated sites after conducted assessment ("Altlastenatlas").

The site-assessment modell of UBA is highly related to the modell of the German province Baden-Württemberg. As a result of this assessment sites are evaluated in one of four possible priority groups. Priority I, for a site expresses greatly needed measures because of the high risk to human health. Priority IV, expresses a cleaned or safed site.

A completed site-assessment of UBA with evaluation to a priority-catagory is a basic requirement for financial support by ÖKOFONDS.

Current situation:

3300 possibly contaminated sites have been reported to UBA. At the moment 803 sites are being assessed. By September 1991 52 contaminated sites were recorded as "ALTLASTEN". 36 are evaluated in priority groups.

Around 90 % of reported suspected sites are MSW-landfills. That's because their registration is far advanced compared to industrial contaminated sites. For the latter a systematic survey is planned by UBA for the near future.

- ÖKOFONDS

Applications for financial support can be made to the Fonds before site assessment by UBA is completed. This procedure should save time, so greatly needed measures are not slowed by bureaucracy. In very urgent cases the technicians of the Fonds are informed from the beginning and can push ahead the assessment of the project. As soon as the application is turned in to ÖKOFONDS the measures can be started.

The application for funding has to include as a main part a technical project. It is first transferred from the applicant to the state-government. Their job is to check if everything needed is included and to complete the application with additional information and data about the site. Then it is referred to ÖKOFONDS.

The application is examined in detail by the technicians of ÖKOFONDS under technical, ecological and economical aspects.

Current situation:

Until now 37 applications with a total of approximately \$ 216 million have been made to ÖKOFONDS. 20 of these projects refer to measures on MSW-landfills, the rest of 17 projects relate to industrial sites (including contaminations caused by World War II).

- ALTLASTENKOMMISSION

After a positive judgement of the project the application is presented by ÖKOFONDS-technicians in a session of the "Altlastenkommission". This commission consists of representatives of state-governments, concerned ministries, political parties, the Union, industry and commerce. They get together about four times a year for discussions and voting about every application for funding. After a positive vote the application is recommended by the commission to the Minister of Environment who finally decides about the issue.

Current situation:

The minister has accepted 16 applications so far. Approx. \$ 47 million (around 70 %) of the originally applied \$ 68 million have been found relevant for financial support relating to ALSAG. After deduction of the "responsibility-share" according to the guidelines, approx. \$ 36 million (around 50 % of applied) were granted by the Minister of Environment. So far 10 contracts for funding have been signed.

V. SICHERUNGS- UND SANIERUNGSTECHNOLOGIEN (or "Clean-up Technologies")

From a technical viewpoint the 37 projects applied to ÖKOFONDS can be classified into the following technological categories:

- 13 landfill containments (walls and surface) combined with hydrological measures and degas-measures
- 6 excavations of landfill combined with measures to sort old waste and redeposit it on a modern-equipped landfill
- 2 only active degas-measures for landfills, which are no hazard to the groundwater
- 3 soil-air-venting systems,
- 2 pump-and-treat measures
- 1 on-site biological treatment
- 10 investigation-measures for additional information to make a project

In general some "Austrian specific" types of technology can be identified:

1. Containment with sealing-walls for landfills is usually performed by "Wiener Kammersystem" (or "Viennese Chambersystem"). This method allows control of the system, both after establishment and on a long-term basis.
2. Incineration is not possible due to political reasons at the moment. Therefore the future way seems to be excavation followed by sorting. It was performed the first time last spring in Vienna for a relatively old MSW-site and on a small scale. A new technology to overcome odour-problems was performed with "Bio-Puster System". Oxygen-impulses into the waste changed microbiological processes in the waste from anaerobic to aerobic conditions.

VI. CONCLUSION

The first steps have been made in Austria. With ALSAG the basis (financial, legal) has been provided to deal with the problem of contaminated sites. For ÖKOFONDS which administers the mainpart of created funds it is essential to support proper technology to be cost-effective and successful.

Therefore we are highly interested in international cooperation. And as the last examples show we are also initiative in Austria to bring in new ideas.

We hope we are able to be an helpful part in an exchange of experiences.

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Altlastensanierungsgesetz 1989
***(Federal Law relating to Remedial Actions
on Contaminated Sites)***

**Registration and assessment of
suspected sites**

**Organisation and distribution of funds
(Altlastenbeitrag)**

**Legislative authority for expropriations,
sufferance and compensations**

Important definitions

Distribution of Altlastenbeitrag

Ministry of Environment (10 %)

Dedection and assessment of suspected sites

Additional investigations for priority definition

**Registration of suspected sites and
assessed contaminated sites**

ÖKOFONDS (90 %)

Remedial measures on contaminated sites

**Construction, expansion and improvements
of waste disposal sites**

Studies and projects

UWWF '91

Förderungsrichtlinien 1991 ***(Guidelines for Financial Support)***

Application

types of measures
possible applicants
conditions for application

Fund matching

extent for subsidy
deductions for responsibility

Contract

transfer of funding
contractual terms

PROCEDURE OF ALSAG

STATE GOVERNMENT

- searching for suspected sites
- report to Ministry of Environment

MINISTRY OF ENVIRONMENT

- coordination of ALSAG

UMWELTBUNDESAMT (UBA)

- registration and assessment
- evaluation in priority classes

APPLICATION FOR FUNDING

STATE GOVERNMENT

- first check of application
- additional data

ÖKO-FONDS

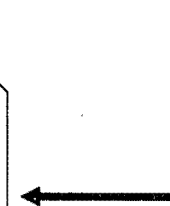
- examination of the application (technical, ecological and economical aspects)

ATLASTENKOMMISSION

- discussion and voting
- recommendation to the Minister

MINISTER OF ENVIRONMENT

- final decision



Norway's Tour de Table Presentation

NATO/CCMS Fifth International Conference

Demonstration of Remedial Action Technologies for
Contaminated Land and Groundwater
Washington D.C, United States

November 18 – 22, 1991.

Tour de Table

NORWAY

by

Per Antonsen

1. INTRODUCTION

The Storting (Norwegian Parliament) decided in 1989 that "the risk of serious pollution problems due to wrong management of hazardous waste in earlier years shall be reduced to a minimum by the year 2000". To follow up this decision, the State Pollution Control Authority (SFT) is preparing a Plan of Action to clean up hazardous waste. The measures include:

- * cleaning up hazardous waste abandoned earlier by enterprises no longer in operation
- * cleaning up pollution from mines no longer in operation
- * cleaning up abandoned industrial sites and environmentally hazardous waste previously buried at these sites
- * treatment of contaminated soil
- * cleaning up polluted sediments in fjords

2. NATIONWIDE SURVEY.

During the period 1988-1990 a nationwide survey of landfills and polluted ground was carried out. The objective of the survey was to establish the extent of the problem, and provide a basis for preparing a Plan of Action.

2.1 Method

The registration is based on available information. No soil surveys have been carried out, nor samples taken at the different sites.

The method involves reviewing the existing data. The greater part of the work has consisted of interviewing municipal officials and other persons with knowledge of waste management in their own municipality, and inspections and interviews at enterprises which generate or have generated hazardous waste. An attempt has been made to check the information with companies that collect and treat hazardous waste. Several methods have been used to inform the public and encourage them to "tip off" the authorities.

The registered sites have been ranked into five categories:

- Category 1. Sites requiring immediate investigations or measures.
- Category 2*. The case is being considered by SFT.
- Category 2. Need for investigation.
- Category 3. Need for investigations in the event of a change in land use.
- Category 4. No investigations needed.

Since the survey did not involve soil or ground water analysis,

the registration does not provide any basis for assessing the actual potential for pollution at the sites concerned. When ranked into categories, the information on hazardous waste is evaluated against the vulnerability of the recipients and the conflicts that possible pollution would cause in relation to land use, activities and animal life in the area.

2.2 A summary of the results of the survey

Table 1 shows the number of registered sites and the distribution between the different categories.

Table 1. National overview of registered sites

Site: type/ category	1	2*	2	3	4	Sum
Landfills:						
Municipal landfills	12	1	149	533	337	1032
Industrial landfills	20	11	124	205	132	492
Other landfills	6	6	48	181	241	482
Contaminated ground:						
Industrial ground	8	19	55	191	0	273
Other ground	3	1	19	47	0	70
Landfills and contaminated ground:	12	4	44	43	0	103
Sum	61	42	439	1200	710	2452

The most serious problems are connected to landfills polluted by heavy industry and chemical industry. Because much of the industry is located along the coast, many of the landfills are placed directly at the shore edge. Leaching of toxic pollutants from the landfills could contaminate Norwegian fjords for many years to come, and become relatively more important as other discharges are reduced.

It has also been registered that a large number of municipal landfills have received varying quantities of hazardous waste.

The survey shows that only very few sites give grounds to fear that the present form of land use involves a hazard to health. The sites are first and foremost a pollution risk to watercourses and fjords, and conflict with nature conservation interests and various forms of outdoor activities.

Pollution of groundwater is not a serious threat to drinking water in Norway at present, because groundwater is not used to any great extent for this purpose. However, pollution of groundwater reservoirs could destroy potential sources of drinking water.

3. THE GOALS FOR THE PLAN OF ACTION

The draft Plan of Action contains proposals for goals for the clean-up work, in the form of the level of environmental quality that one wishes to achieve from the clean-up. It has been decided to make a distinction between the different recipients, soil, groundwater and surface water (including fjords).

The proposals are intended as a basis for discussion, and as a help in formulating a final Plan of Action.

Pollution of watercourses and fjords has been a major concern of the pollution authorities in the past as well. This means that a number of goals and criteria for water quality have already been established. To the extent that landfills and contaminated ground contribute to the pollution of surface water it is natural to assess the measures in relation to the existing goals. Up to now, polluted soil and groundwater have not been given the same attention. Landfills and contaminated ground are primarily a source of these kinds of pollution, and it is in these areas that the Plan of Action raises new questions of principle in connection with the goals for environmental quality in Norway.

3.1 Proposed goals for groundwater quality

All large, exploitable sources of groundwater shall be protected against pollution. If already polluted, measures shall be taken, if technically feasible, to enable the groundwater to be used in future as a source of drinking water.

In essence, groundwater is well protected against pollution. However, groundwater is a vulnerable recipient in cases of large discharges or spillage of pollutants to the soil. The pollution can spread over large areas before being discovered, and can make the reservoir unsuitable as a source of drinking water in the foreseeable future, even if action is taken.

In Norway, very little use has been made as yet of groundwater resources. Only about 15-20% of our water consumption is covered by groundwater. It is an objective to increase this to 30% by the year 2000.

The proposed goal for groundwater also implies that polluted reservoirs that may be of interest as sources of drinking water shall be cleaned to drinking water quality; but experience from abroad shows that this can be difficult to achieve in practice.

3.2 Proposed goals for polluted soil

Pollution of soil shall be reduced to a level that does not conflict with the type of land use in the area.

How to define goals for soil quality depends on whether polluted soil is being regarded as a problem of land use, or as a damage to the environment which, in itself, requires that something be done.

In principle, if the soil pollution problem is to be solved independently of land use, the only proper measure is to clean the soil, either at the site or in special treatment plants. If, on the other hand, the problem is considered in relation to the use made of the land and resources in the area, a possible measure might be to dig up the soil and move the excavated material to a properly safeguarded landfill. Another possibility is to completely or partly isolate the polluted soil. The polluted area can then be used for purposes that are not affected to any degree by pollution, such as parking sites, roads or storage premises.

The above proposed goal implies that a requirement to clean polluted soil will be evaluated in connection with land use. The objective of the measure should be to remove any conflict between pollution in the ground and relevant or desired use of the land. Such conflicts might be connected, for example, to injuries to the health of persons who spend time in the area, or to risk of micropollutants being absorbed by plants cultivated in the area as agricultural products, etc. A conflict would also arise if knowledge of the pollution or of hazardous waste buried in the ground were to cause unpleasantness or anxiety, and therefore reduced well-being, for people living in or frequenting the area.

The proposed goal implies that, in some cases, it may be relevant to adjust the land use to an existing level of pollution, rather than clean the soil. The proposal takes into account that, in practice, it will often be impossible within a reasonable period of time to achieve a soil quality that is high enough after cleaning to permit the land to be used for every kind of purpose in future. The goal is also justified on the ground that there is a lot more to gain by preventive measures than by spending large amounts of time and money on cleaning polluted soil.

3.3 Proposed goal for pollution to watercourses and fjords

Pollution from landfills, contaminated ground and sediments shall be prevented or reduced to the level necessary to achieve the goals for water quality in the recipient.

What is implied by satisfactory water quality is expressed, for example, in the existing criteria for water quality and in the goals for the different recipients. Cost-efficiency criterias for weighing measures to clean up "old sins" against measures to combat other, active sources of pollution must take into account the long-term aspect of pollution from landfills and

contaminated ground. Leakage of toxic pollutants from these sites may continue for several hundred years to come. Measures which help to reduce the pollution load only slightly at the present point in time may have a large accumulative effect in the long term.

4. RATE OF IMPLEMENTATION AND COSTS.

So far, clean-up activities and monitoring have been initiated at about 60 sites and polluted areas. The measure are directed at the sites given highest priority, i.e. categories 1 and 2*.

To obtain control over all sites which involve risk of serious pollution or conflicts of land use, it would be necessary to initiate investigations and measures at about 400-500 sites by 1995. This work implies increasing the capacity of the regulatory offices which deal with these cases by about 20 man years in 1992-1993. At this rate of progress, a sum of approximately 450 million kroner would be needed for investigations and clean-up or safeguarding measures from 1991 to 1995.

With this capacity, the extent of investigations and measures initiated during the period from 1991 to the end of 1999 is expected to be:

Investigations at 800 sites	: NOK 400 mill.
Measures at 300 sites	: NOK 1000 mill.

Sum	: NOK 1400 mill.

It is emphasized that the cost estimates are preliminary, and very uncertain. Our experience from investigations and clean-up measures is still very limited, and the same applies to our knowledge about the extent of the pollution at the different sites.

A review of the ownership of the site in categories 1 and 2* (in all 103 sites) shows that, at almost 70% of the sites it is possible to find a financially solvent polluter or owner who can be made liable for the costs. A very large number of these sites are owned by large, national industrial companies. A smaller percentage, about 10%, are State-owned.

If the proposed clean-up rate is to be held, it will probably be necessary for the State to contribute with a larger amount of money than it is lieable to in the first place. The amount of money from the State to help achieve the goals will be decided by the Ministry of the Environment.

Turkey's Tour de Table Presentation

Round Table Discussions - TURKEY

Dr. Resat Apak

While discussing remedial actions, one needs to distinguish between (i) identification, (ii) assessment, (iii) remediation, (iv) financing.

There is no discovery program to identify polluted sites of land. The Ministry of the Environment and the municipal authorities take action for ground water pollution only if complaints from local people are reported. In that case, possible sources of discharges are located, and emissions restricted or stopped. Ground water contamination of a previously-polluted now-abandoned site has not been recorded. Therefore large-scale remediation programmes for the clean-up of such contaminated sites have not been undertaken.

Turkey's main concern at this stage is waste water treatment, surface water purification and pollution prevention, and prevention of hazardous waste dumping to water bodies (rivers, lakes, ponds etc.). The ground water resources may be considered to be clean, and no serious ground water contamination incidents have been reported. For soil remediation in industrial pollution sites, the responsible parties have to abandon the site in order that the applied measures gain effect on the interruption of further contamination. In some such sites, e.g., occupied by the leather-tanning industry which has dumped its alkaline Cr-containing wastes and slurries in nearby lagoons over the years, Istanbul Metropolitan Municipality offers new places to the industrialists on the condition that they completely abandon previous sites. However the current legislation based on prevention of hazardous waste discharges to lakes, rivers and the sea is inadequate in regard to prevention of land pollution and site remediation.

As for the legal aspects, the Prime Ministry Directorate of the Environment has become the responsible authority for environmental affairs between the years 1980 and 1991. This year (1991) in April, the Ministry of the Environment has taken independent legal action; there has emerged a much closer concern for the environment both in the public and government levels.

In the municipality level, state of the art (EPA) regulated industrial and municipal landfills are constructed in a heavy industrialized Bursa region. Istanbul Municipal Authority is preparing a Master Plan for the action and regulation of domestic and industrial pollution. In Istanbul where considerable pressure of urbanization and industrialization is perceived, the major industries that cause pollution are forced to move out of the Golden Horn Area by the Municipal Authority; investigations are underway to remediate this estuary (where water circulation is poor) and the surroundings. Two biological treatment plants for the handling of domestic wastes and sewage are being

constructed in Istanbul in addition to the primary (screening) treatment of sewage applied before.

To sum up, Turkey is at the start of the path, and he feels optimistic to have a better standing in land remediation and pollution prevention in the near future. The first consequences of these projects shall be discussed in the extended Pilot Study.

TURKEY'S RESEARCH PROJECTS

NATO/CCMS Pilot Study on "Remedial Action Technologies for Contaminated Land and Ground Water", International Conference, 18-22 Nov., 1991, Washington, D.C.

The abstracts of a number of research work and projects carried out in Turkey for the identification and assessment of ground water, surface water and land pollution are presented below for round-table discussions.

PHOSPHATE AND NITROGEN REMOVAL FROM WASTEWATER BY THE PLANT PASPALLUM PASPALODES

Omer SAYGIN and Ayse TOMRUK

Institute of Environmental Sciences, Bosphorus University
80815 Bebek, Istanbul, Turkey

Abstracts

An alternative and cheap way of nutrient (N,P) removal from wastewater is growing higher plants in it. Studies with Paspallum paspalodes show a zero order removal kinetics in both phosphate and ammonium ion concentration in the wastewater. A maximum rate of 50 mg/sqm h of PO_4^{3-} -P and 90 mg/sqm h of NH_4^+ -N was observed during the daytime. The daily average values for sunny days in August were 0.8 g/sqm d for P and 1.5 g/sqm d for N. The rate depends on the amount of biomass already present on unit area and on the light intensity. Fresh harvesting causes a considerable reduction in the P removal rates.

SOLAR DRYING OF RESTAURANT FOOD-WASTES AND REUSE AS ANIMAL FODDER

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Turkey

Abstract

A simple solar-boiler dryer, for restaurant food wastes, was constructed which has a surface area of 0.5 m² and works at 100 °C. Drying was achieved in two steps: first, boiling the wastes close to dryness, then further drying at ambient temperatures. By this way sterilization was achieved without over heating. The energy yield of the dryer at 100 °C was 0.85. The obtained product, in average, has a composition close to standards of chicken fodder. Chickens fed by this product mixed 1/1 with market fodder grow comparably well.

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Boron pollution in Simav River, Turkey and agricultural impacts

Süer Anaç

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Turkey*

ABSTRACT

Türkiye possesses approximately 60 % of the world's known boron reserves. The reserves of borate are located in the Susurluk basin. Simav river is the main source of water for irrigation schemes of the basin and the residues evolved during the mining process pollute the river. Boron concentration of river is in the range of 1-36 ppm.

In this study, results of several irrigation experiments which were conducted in the basin on rice, sunflower and bean are presented.

It was found that, the higher concentration of boron increased the accumulation in soil profile, consequently decreased the rice yields. For bean and sunflower, however boron contents were not reached to toxic levels, where winter rains provided effective leaching.

Nur Sözen, COMPUTER AIDED ENVIRONMENTAL DESIGN AND
REMOTE SENSING

The Department of Landscape Architecture
Faculty of Agriculture, Ankara University

The project work aiming to integrate a computer aided design network being carried out in the Department are as follows:

- Environmental Impact Analysis, Case Study: Sultan Sazlığı wetland and drainage works planned by the State Water Management Authority
- Impact of water reservoirs built on the river Euphrates on the environment (agricultural patterns, erosion, settlement, natural-cultural values).
- Determining environmental problems of İstanbul by computer support and remotely sensed data.

Ahmet Yüceer, Dept. of Civil Engineering, Faculty of
Architecture, Çukurova University, Adana, Turkey

70% Of the total pesticide consumption of Turkey occurs in Çukurova Region. Projects have been carried out on the ecological impacts and protection measures for Seyhan River and Barrage Lake, and on the pollution and protection of ground water resources in Adana. These works have been presented in the Environmental Pollut. Symp., Boğaziçi Univ., İstanbul on 21-22 May, 1991, and in Isparta on 3-5 June, 1991.

Determination of Ammonium-, Nitrite- and Nitrate-nitrogen by Molecular Emission Cavity Analysis Using a Cavity Containing an Entire Flame

Ali Çelik and Emur Henden

Department of Chemistry, Faculty of Science, University of Ege, Bornova, Izmir, Turkey

Ammonium-, nitrite- and nitrate-nitrogen were determined by molecular emission cavity analysis using a cavity containing an entire flame. Ammonium-nitrogen was converted to ammonia by injection on to solid sodium hydroxide. The calibration graph was linear for $5\text{--}100\text{ }\mu\text{g ml}^{-1}$ of nitrogen when the ammonia generated was swept directly into the cavity and for $0.05\text{--}1.0\text{ }\mu\text{g ml}^{-1}$ of nitrogen when it was collected in a liquid nitrogen cold-trap. Concentrations of 1.5 and $0.01\text{ }\mu\text{g ml}^{-1}$ of nitrogen could be detected using the direct and cold-trap methods, respectively. Nitrite was determined after conversion to nitrogen monoxide by iodide. Nitrate was reduced to nitrite using a copperised cadmium column and then determined as nitrite. The calibration graphs for both anions were linear up to $7\text{ }\mu\text{g ml}^{-1}$ of nitrogen and $0.1\text{ }\mu\text{g ml}^{-1}$ of nitrogen could be detected. The methods were applied successfully to the determination of nitrite and nitrate in meat products, and nitrate-nitrogen in drinking water samples.

Keywords: *Molecular emission cavity analysis; ammonium-nitrogen; nitrite-nitrogen; nitrate-nitrogen*

United Kingdom's Tour de Table Presentation

CONTAMINATED LAND: POLICY DEVELOPMENT IN THE UK

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ABSTRACT

In its response to the First Report on Contaminated Land from the House of Commons Select Committee on the Environment, the Government identified three key areas as part of the strategy for action on contaminated land. This paper sets out the progress on implementation of this strategy since the publication of the response. It provides an update of a paper presented at the IBC conference on contaminated land policy, regulation and technology in February this year and published in the Institute of Waste Management journal (1).

1 INTRODUCTION

1.1 Contaminated land is one of the many complex issues to be addressed by all those involved in ensuring protection of human health and the environment. It should be considered both in terms of its prevention and as part of the overall assessment of land for a variety of purposes and users. Dealing with contaminated land efficiently and effectively requires not only scientific and technical expertise, but also an understanding of legal, economic and social issues and the ways in which they interact.

1.2 This paper discusses the background to contaminated land and the developing policy in the UK, and in particular the proposals for registers of land which may be contaminated under s143 of the Environmental Protection Act 1990. It also outlines some of the practical issues which need to be taken into account in tackling contaminated sites.

2 DEFINITIONS AND ORIGINS OF CONTAMINATED LAND

2.1 Contaminated land has been defined by the NATO Committee on Challenges to Modern Society (CCMS) as "Land that contains substances which, when present in sufficient quantities or concentrations, are likely to cause harm, directly or indirectly,

to man, to the environment, or on occasion to other targets". This is in line with the Government's view that a precise, or quantitative, definition of contamination is not possible and that it should remain a general concept with the focus of attention on risks to human health or to the environment (2). The NATO/CCMS definition is also consistent with the idea that contamination is not necessarily synonymous with pollution, a distinction drawn by the Royal Commission on Environmental Pollution in its report (3).

2.2 Sources of contamination include a wide range of industrial processes and waste disposal practices, both current and historic, which use or give rise to substances which are harmful to human health or the environment.

2.3 Contamination usually results from:

- * storage and transport of raw materials, products and wastes
- * leaks and spillages
- * stack emissions
- * disposal of waste materials [on or adjacent to the site]
- * demolition of buildings or plant
- * application of sewage sludge or other materials to land

2.4 The definition above only covers man-made contamination. However, natural contamination cannot of course be ignored. Background levels of certain metals, radon and natural methane are all examples of natural contamination which need to be considered in terms of their impact on human health and development. The DoE has commissioned a study to review the sources and locations of natural contamination and consider their significance as part of the development of a consolidated strategy for tackling contamination.

Amount of Contaminated Land

2.5 There have been a number of estimates of the amount of contaminated land in England and Wales, but the figures vary widely. The most recent estimates suggest that 50 000 - 100 000 sites might be considered to be contaminated, affecting perhaps 50 000 hectares. Only a small proportion of these, however, are likely to pose an immediate threat to public health or the environment (4).

2.6 The geographical distribution of contaminated sites is of course related to the pattern of industrial development. The major industrial conurbations of the North, the Midlands and South Wales have large areas of land formerly used by industry

and now derelict or reclaimed for other uses. However, many other parts of the country are or were centres for industries or trades with the potential for leaving contamination, and the sites of former town gas works, scrap yards and waste disposal facilities are found throughout the country.

2.7 In its response to the Select Committee report on contaminated land, the Government recognised that more information was needed on the extent and location of contaminated sites. This is one of the objectives of the registers to be set up by local authorities under s143 of the Environmental Protection Act 1990, discussed later in the paper.

Types of Contaminants

2.8 The contaminants expected on a site are of course related to the activities on the site. Commonly encountered contaminants include: heavy metals, found at sites such as scrapyards, sewage works and tanneries; organic compounds, including chlorinated solvents from chemical industries; asbestos, from power stations and other industries; and combustible substances and flammable gases, for example from gasworks and former waste disposal sites.

2.9 Contaminants can have both short and long term effects on human health (directly or via other pathways such as crop uptake), the natural environment (including water resources or other ecosystems), or the built environment. These effects vary, depending on the particular substance and its availability and mobility.

3 UK POLICY

3.1 In their response to the House of Commons Select Committee on the Environment First Report on Contaminated Land, the Government identified three key areas for action: (i) information on the extent and location of contaminated sites; (ii) assessment criteria for the risks posed by the contamination found there; and (iii) technology and funding for clean-up. (4, 2)

4 INFORMATION ON LAND WHICH MAY BE CONTAMINATED

4.1 The best starting point for assessing contaminated land, and establishing what needs to be done about it, is to know how much there is and where it is. Such information is essential when there is concern over threats to public health and the environment, when land is bought and sold, when its use is to be changed, or when new development is proposed (5).

Environmental Protection Act 1990 - Section 143 Registers

4.2 To satisfy the need for this information, the Government introduced Section 143 of the Environmental Protection Act 1990. This places a duty on local authorities to compile and maintain registers of land which may be contaminated because of its previous or current use, in accordance with regulations. It is intended to have the regulations in force in April 1992 with registers open to the public in April 1993.

4.3 Consultation on the detailed proposals for the regulations and for guidance on compiling registers has now taken place (6) and responses have been received from a wide range of interested bodies covering landowners, financial institutions, planners, the legal profession, industries, environmental groups, local authorities, other government departments and professional bodies, including the Institute of Wastes Management. These comments and suggestions are now being considered both in the formulation of the regulations and guidance for registers, and more widely in the development of contaminated land policy.

4.4 Section 143 gives the Secretary of State powers to define the uses which may cause the land to be contaminated. Sites where these uses have been or are being carried out are to be included on the register. The consultation paper lists the uses which are being considered for inclusion in the regulations.

4.5 One important point to note is that sites which have been investigated or treated must not be removed from registers. Investigation and treatment of contamination do not change the facts about uses of the land. Instead, it is proposed that where it is known that a site has been investigated and/or treated for contamination, the register entry should state the date and nature of this work and refer to any report which may have been prepared.

4.6 The registers are to be compiled from desk studies of current and historic information, mainly map based. The sources to be used and the methodology for compiling the registers are all discussed in the consultation paper, and further guidance will be provided to authorities. Studies of this kind are the first step in conventional assessment of sites which may be contaminated.

Uses of registers

4.7 The main purpose of registers will be to alert local authorities, landowners and potential purchasers or developers

to the possibility of contamination, and to indicate the types of contamination to be expected. However, registers will also assist local authorities in carrying out many of their statutory functions, both in dealing with individual cases and in developing management strategies. Guidance on registers will also cover ways in which the information they hold can be combined with other environmental information or planning systems.

4.8 The registers will of course have their limitations. Firstly, no methodology can ensure that all land which may be contaminated will be identified. For example, it would be impossible to identify all sites of unauthorised dumping or accidental spillages of harmful material. However, registers will provide a record of a large proportion of land which may be contaminated.

4.9 Secondly, registers will only record sites which have been put to contaminative uses. They are not, in themselves, intended to pick up land affected by air- or water-borne contamination from activities elsewhere. They will however provide information which can be used with mathematical modelling or other techniques to trace the movement of contamination from its sources. Developments in site investigation techniques, in particular remote sensing, will also help to locate and identify contamination both on registered sites and elsewhere.

4.10 Registers will therefore have a key role in the collection of information on the uses of land and its condition, and will complement other information such as that on natural contamination. This coordinated information is all relevant to the development of an overall strategy for planning and assessing land use and ensuring environmental protection.

Blight

4.11 The Government recognises that the appearance of a site in the register may adversely affect the value or saleability of the site or of properties on or near it. This has implications for the property owner, the developer, the purchaser and all those involved in land use and land transactions. It should be recognised, however, that the information to be included on registers is likely to be required in any case by planners and/or purchasers, whenever a site is sold or a new use proposed. Awareness of the need for information on a site's history and possible contamination is constantly increasing.

4.12 The problem of blight has already arisen in a number of cases without the introduction of registers, particularly where properties have been built on closed landfill sites, and more cases can be expected as general awareness of environmental issues increases. The Government's view, however, is that in view of the increasing scientific knowledge and public awareness of the problems of contamination, in all but the short term it is best for all concerned to know the history of a site. They can then investigate, and if necessary deal with any problems, from a position of knowledge.

4.13 The introduction of registers will inevitably intensify the problem initially, but in the longer term it will provide a framework for dealing with blight on a systematic basis and preventing uninformed development or purchase of contaminated sites. The Department has commissioned a study of the problems of blight and how they can be dealt with. One important consideration is the question of communicating risks to the public and other interested parties, discussed later in this paper.

5 ASSESSMENT OF CONTAMINATION

Identification of the likely contamination

5.1 Once sites which may be contaminated have been identified, assessment is needed to establish whether they represent a problem. This requires a sound understanding of the specific contaminants which may be present as a result of the use of the site.

5.2 To help users of registers, the Government plans to publish a series of "profiles" on each of the contaminative uses defined in the Regulations. These will indicate the contaminants to be expected and will provide other information which will be useful in assessing the sites. Some 60 profiles are now in preparation by consultants who have drawn on a wide range of sources including trade associations. Preparation of the first batch of profiles for publication is now in hand. There will be a final peer review and further technical comments will be sought from relevant industries.

Risk assessment and quality criteria

5.3 At present the UK uses a range of "trigger values" for certain contaminants and end uses, together with other environmental criteria, to judge a site and the proposed remediation strategy. A study group has been set up to consider

the whole issue of risk assessment for contaminated land and is currently considering a draft report outlining a framework for the development of guidance on site assessment procedures and criteria. The report includes a review of approaches adopted in other countries.

5.4 Work is also in hand on the consolidation of trigger values. The general question of a soil protection strategy and soil quality objectives is also under consideration. However it is important to realise that the complexities of soils, hydrogeology, behaviour of contaminants and preventative measures mean that prescriptive formulae are not possible.

5.5 It is becoming generally agreed that clean up should not normally aim to restore the land for all possible future uses ("multi-functionality"). The cost of such an approach would far outweigh the benefits, and would in any case often merely shift the contamination elsewhere. The aim of restoration should be to ensure "fitness for purpose", balancing a number of local and national environmental, economic and social issues.

6 TECHNOLOGY AND FUNDING FOR CLEAN-UP

6.1 A fundamental problem in dealing with contaminated land is the availability and suitability of clean-up solutions. In its response to the Select Committee Report, the Government undertook to review its support for the development of clean-up technology.

6.2 An important research programme at Warren Spring Laboratory to investigate treatment techniques for contaminated land is now well under way. As well as the programme of laboratory and full scale work, technical appraisal reports are already available and others are in preparation, including a major report on clean up technologies. This report, which will be published shortly, will discuss in detail each category of process and the sub-categories in terms of process operation and limitations, as well as application and state of development. It will be based on a major literature survey as well as review of the NATO/CCMS study projects and other projects and commercial ventures. (7, 8, 9)

6.3 Clean-up technologies can be categorised on the basis of their general operating principles: biological, chemical, physical, solidification/stabilisation, and thermal. Clean-up techniques can be applied either in situ, where the material is not moved, or after excavation, ex situ, where the material is excavated prior to treatment. Ex situ processes can take place either on or off site, and cannot be fully distinguished from conventional waste treatment operations.

6.4 The Derelict Land Grant programme, which now places greater emphasis on reclamation schemes that will improve the environment or deal with serious contamination, continues to tackle contaminated sites which are derelict and can be reused. Financial assistance, in the form of supplementary credit approvals, is also available to local authorities for remedial measures on sites affected by landfill gas.

7 LEGISLATION

7.1 There are three main areas of legislation affecting contaminated land: prevention; powers to enforce clean up; and control of remedial treatment. The most common problems are usually related to the civil liability of the owner of the site to a third party, particularly in terms of recovery of clean-up costs, and to the question of retrospective liability.

7.2 It is almost impossible to give a definitive list of relevant legislation but the main statutory powers of particular relevance to contaminated land include those under:

- * Occupiers Liability Act 1957
- * Health and Safety at Work Act 1974
- * Water Act 1989
- * Environmental Protection Act 1990 (parts of which are carried forward from the Public Health Act 1936 etc and Control of Pollution Act 1974)
- * Town and Country Planning Acts
- * Building Regulations (see particularly Approved Document C)

7.3 The Water Act 1989 provides powers to the NRA and others to enforce emergency clean up of sites which represent a threat to controlled waters. Section 115 of the Water Act 1989 also provides for recovery of the costs of dealing with water pollution from the person who "caused or knowingly permitted" the pollution.

7.4 The Environmental Protection Act strengthens previous provisions under the Public Health Acts relating to "statutory nuisance". These powers have been used by local authorities in the past to require treatment of contaminated sites which are considered to represent a threat to public health or the environment. Section 80 empowers local authorities to enforce clean-up and recover the costs; it requires them in most cases to seek recovery first from the person responsible for the nuisance. Section 61 of the Environmental Protection Act 1990 empowers Waste Regulation Authorities to recover the costs of

of information to be obtained for further evaluation and cross checking.

8.5 The information from the site survey can then be combined with the historic records and information from other sources to arrive at a clear picture of the condition of the site. The requirements of the particular use of the site or other environmental protection measures can then be reviewed and options for management of any risk from the site identified and evaluated.

8.6 The most appropriate solution can be selected and will usually include an optimised combination of treatment methods appropriate to the particular types of contamination and other site conditions, since it is unlikely that one form of treatment method alone will be the most effective way to deal with all the contaminants and areas of the site, either technically or in terms of cost. Detailed proposals can then be developed and implemented, with continuous feedback as work progresses. Contingency plans and monitoring are essential components of a successful scheme.

8.7 Consideration should also be given to the possibility of use of additional treatment methods, not strictly required for the end use currently proposed, but which would, at a small extra cost, render the site permanently suitable for a wider variety of end uses. Such "polishing" treatments could go some way towards the ideal of multi-functionality without excessive cost.

8.8 A checklist for contaminated land assessment is given in Appendix A.

9 OTHER ISSUES

9.1 It is apparent in dealing with contaminated land that there are interactions with many other social and environmental issues.

Consultation

9.2 The wide range of interests associated with contaminated land can cause confusion and misunderstanding about statutory responsibilities. For example, different local authority departments have responsibility for planning, environmental health and building control. It is important to ensure that all parties who may have an interest are included in development of solutions to contaminated land problems.

Public Perception

dealing with pollution from old landfills from the landowner. The power is discretionary and WRAs are required to "have regard to any hardship which the recovery may cause".

7.5 Planning legislation also provides mechanisms to encourage or insist on clean up, particularly in relation to the return of contaminated land to beneficial use; contamination of land is a "material planning consideration" for development (3).

7.6 Liability to a third party can also be enforced as a civil action by a breach of duty (tort), such as trespass, negligence, nuisance, actions under the rule of Rylands v Fletcher and breaches of statutory duty.

8 PRACTICAL ASSESSMENT

8.1 Guidance on some of the problems of assessment and redevelopment of contaminated land is provided in a series of papers published by the Inter-Departmental Committee on the Redevelopment of Contaminated Land (ICRCL), which has representatives from a number of divisions in DOE and from other Government Departments. ICRCL publications are available from the DoE Publications Sales Unit, Building 1, Victoria Road, Ruislip HA4 0NZ.

8.2 As part of a programme of improving guidance for all those involved in the assessment and redevelopment of contaminated land, the Department is the major sponsor of an 18 month research programme through the Construction Industry Research and Information Association (CIRIA) on the provision of guidance on a wide range of practical issues relating to the assessment and treatment of contaminated land. CIRIA intend to publish guidance documents on specific issues as soon as they are available.

8.3 It is essential in tackling contaminated land to be clear about the issues to be addressed and the requirements for a solution. Good project management is one way of providing the framework within which problems are either avoided or overcome. Key factors are anticipation, flexibility, and communication.

8.4 The first step is to carry out a preliminary assessment of the site, which starts with the collection of information on the site history - such as that contained in Section 143 registers. This, together with a site walkover, reference to relevant ICRCL documents and a consideration of the broad environmental context of the development, should provide a good outline indication of the likely problems to be encountered. A detailed but cost effective survey can then be designed to provide the right level

9.3 Contaminated land can cause considerable alarm where people find that they are living on or near a contaminated site. This problem has already arisen in a number of places where housing has been built on closed landfill sites which are now generating methane. Section 143 registers of land which may be contaminated will heighten public awareness of contamination and, as noted above, there may be cases of alarm where property is found to be on the site of some long-forgotten contaminative activity. The Department's study of blight will consider how such concerns may be addressed.

10 CONCLUSIONS

10.1 It is clear that the contaminated land will assume increasing importance within the overall context of environmental issues. Expertise is available and a framework in place to tackle contamination effectively. There are many opportunities for exchange of knowledge and technology and interaction between many professional disciplines will be needed.

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**Tour de Table Presentation on United States/German
Bilateral Agreement on Abandoned Site Clean-up Projects**

**United States/German Bilateral Agreement
on Abandoned Site Clean-up Projects**

prepared for

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SUMMARY TABLE -- 1

U.S. Sites	Technology	Waste Matrices	<i>Applicable Waste</i>	
			Inorganic	Organic
Burlington- Northern (Minnesota)	Bio-Remediation	Soils		PAHs Phenols Oil and Grease
Parsons Chemical (Michigan)	GeoSafe In Situ Vitrification	Soil and Sludges	Mercury Arsenic Heavy Metals	DDT Chlordane
MacGillis & Gibbs (Minnesota)	Biotrol Aqueous Treatment System	Soil and Water		PCPs, Creosotes

SUMMARY TABLE - 2

U.S. Sites	Technology	Waste Matrices	<i>Applicable Waste</i>	
			Inorganic	Organic
Ott/Story/ Cordova (Michigan)	Solarchem UV Oxidation	Water		TCE VOCs Aniline
Lee Farm (Wisconsin)	Maecorp Stabilization/ Solidification	Soils	Lead	
Outboard Marine (Illinois)	Soil Tech Anaerobic Thermal Processor	Sediments		PCBs

SUMMARY TABLE - 3

German Sites	Technology	Waste Matrices	<i>Applicable Waste</i>	
			Inorganic	Organic
Gas-Works (Munich)	High Pressure Soil Washing	Soils Water	Lead Cyanide	PAH Hydrocarbons
Burbacher Hütte (Saarbrücken)	Thermal Treatment Soil Washing Bioremediation	Soils and Water	Sulfides Cyanides Lead Mercury	Phenols Benzol Toluol
Stadtallen- dorff (Hessen)	Soil Washing	Soils		Phenols PAH Hydrocarbons

SUMMARY TABLE - 4

German Sites	Technology	Waste Matrices	<i>Applicable Waste</i>	
			Inorganic	Organic
Kertess Chemicals (Hanover)	Soil Air Venting In Situ Soil Washing	Soils and Water		Halogenated and Petroleum Hydrocarbons
Varta Süd (Hanover)	High Pressure Soil Washing	Soils and Sludges	Antimony Arsenic Cadmium Lead	
Haynaüer Strasse 58 (Hessen)	High Pressure Soil Washing	Soils		PCB, PCDD, PCDF

Burlington-Northern (Minnesota) –Background

- **Creosote was used to preserve railroad ties from 1907 to the present.**
- **Creosote wastewater was discharged to unlined lagoons.**
- **Soils, groundwater and sludges were contaminated with PAHs, oils, and phenols.**
- **Site placed on EPA's National Priorities List in 1982.**

Burlington-Northern –Remedial Technology

- **Soil treatment focuses on aerobic biotreatment to transform and immobilize organics and inorganics in the soil.**
- **Biotreatment is not intended to completely degrade all waste constituents.**
- **Biotreatment transforms and immobilizes waste constituents, thus rendering them non-toxic and non-leachable.**

Burlington-Northern—Status

- Biotreatment degraded PAHs to lower level chemical rings and lower toxicity compounds.
- Soil treatment will be monitored every 4 months until all PAHs and phenols have decomposed or until no further reductions are evident.
- Remediation is expected to continue for several years.

Parsons Chemical (Michigan)—Background

- Operated as an agricultural chemicals manufacturing and packaging facility from 1945 to 1977.
- Soils were contaminated with pesticides, heavy metals, and dioxin from a leaking septic tank.
- Site placed on EPA's National Priorities List in 1989.

Parsons Chemical—Remedial Technology

- **In situ vitrification was developed by Battelle Memorial Institute and marketed by Geosafe Corporation.**
- **Technology uses electrodes to generate electric current that heats soil to its melting point.**
- **Soil melting destroys pesticides and dioxin and produces a glass crystal mass that immobilizes metals.**

Parsons Chemical—Status

- **EPA and Michigan Department of Natural Resources are conducting a remedial investigation and feasibility study.**
- **Soil treatment postponed 1 to 2 years for equipment restructuring; an off-gas hood is being redesigned with new inert materials.**

MacGillis & Gibbs (Minnesota) –Background

- **Operated as a wood preservation facility from 1920 to the present.**
- **Soils, surface water, and groundwater are contaminated with creosote, PCP, and chromated copper arsenate.**
- **Site placed on EPA's National Priorities List in 1984.**

MacGillis & Gibbs –Remedial Technology

- **Biotrol aqueous treatment system (BATS), a modification of aerobic biotreatment systems, uses *Flavobacterium* to degrade contaminants such as PCP in liquid wastes.**
- **In 1989, the technology was tested under the EPA SITE Program on groundwater containing a floating layer of PCP oils up to 2 meters thick.**

MacGillis & Gibbs—Status

- **In the SITE demonstration, BATS removed 96.4 to 99.8 percent of the PCP in the groundwater.**
- **Based on these results, BATS is being considered for large-scale remediation projects.**

Ott/Story/Cordova (Michigan) —Background

- **Operated as a manufacturer of synthetic organics and phogene-base intermediates from 1956 to 1977.**
- **Groundwater and soil were contaminated with volatile organic compounds (VOCs).**
- **Site placed on EPA's National Priorities List in 1982.**

Ott/Story/Cordova—Remedial Technology

- **UV oxidation technology applied at the site is manufactured by Solarchem International of Canada.**
- **UV radiation, combined with hydrogen peroxide or ozone, will detoxify halogenated and other VOCs in groundwater.**

Ott/Story/Cordova—Status

- **Pilot-scale treatability studies conducted from October 1990 to March 1991.**
- **Data from studies are being evaluated to finalize a site-specific treatment scheme.**
- **Remedial design and action are expected to follow after treatment scheme is finalized in 1992.**

Lee Farm (Wisconsin) –Background

- **Lead-contaminated battery casings were dumped at the site between 1971 and 1974.**
- **Soils were contaminated with lead and lead compounds.**
- **Emergency removal of lead-contaminated waste was completed in August 1991.**

Lee Farm –Remedial Technology

- **Soil solidification was accomplished in two phases:**
 - Phase 1 developed and completed by Maecorp. Proprietary powders and a Maepric solution solidified contaminated materials.**
 - Phase II completed by OHM. Portland cement and water solidified contaminated materials.**

Lee Farm—Status

- **Contaminated-soil solidification is complete.**
- **Solidified materials are buried on site.**
- **A clay cover has been installed to complete disposal area closure in accordance with Wisconsin Solid Waste Management Regulations.**

Outboard Marine (Illinois)—Background

- **Operated as a manufacturer of recreational marine products from 1961 to present.**
- **Operations produced PCB-contaminated wastes.**
- **Slip and harbor sediments, soil, and groundwater were contaminated with PCBs.**
- **Site was placed on EPA's National Priorities List in 1983.**

Outboard Marine—Remedial Technology

- **Soil Tech's anaerobic thermal processor (ATP)**
1) vaporizes PCBs and other contaminants in a rotary kiln, then 2) condenses and separates them into oil, water, gas, and treated solids.
- **Contaminated oil fraction disposed off site; contaminated water treated on site; gas fraction used as fuel for the rotary kiln burner; treated solids disposed of in an on-site containment cell.**

Outboard Marine—Status

- **Two containment cells were constructed to isolate PCB wastes.**
- **Contaminated soil has been excavated for treatment.**
- **Dredging of harbor sediment and dewatering of slip sediment will begin late 1991.**
- **Further soil treatment will begin early 1992.**

Gas-Works (Munich) –Background

- **From 1909 to 1975, the 81-acre site operated as a natural gas production facility.**
- **Soil and groundwater are contaminated with PAHs, lead, cyanides, and aliphatic hydrocarbons.**
- **Results from remediating a "hot spot" of contamination will focus the remedial design for the entire site.**

Gas-Works –Remedial Technology

- **Soil is washed in a "closed system" with mechanical crushers and high-pressure water jets.**
- **Soil clean-up criteria are expressed as numerical values while the groundwater clean-up target is qualitative—the upgradient shall be unaffected by the contaminated site.**

Gas-Works—Status

- **A mobile on-site soil washing plant was constructed and testing has started.**
- **Soils from the hot-spot have been excavated and placed in interim storage.**
- **A field test for microbiological treatment of PAH-contaminated soil is also planned.**

Burbacher Hütte (Saarbrücken) —Background

- **A 150-acre site operated from 1857 as a steel factory with a coking plant.**
- **Soils and groundwater are contaminated with cyanide, heavy metals, and aromatics.**
- **Unused production facilities will be demolished, but administrative buildings remain and new development is planned.**

Burbacher Hütte—Remedial Technology

- **Several on-site technology demonstrations are planned.**
- **Eight contractors will perform large-scale tests of bioremediation, soil washing, and thermal treatment processes.**
- **Soil extraction systems for in situ gas extraction will be implemented.**

Burbacher Hütte—Status

- **Old pipelines, utilities, and demolition debris must be removed before further work begins.**
- **Contracts for technology studies have been awarded.**
- **Contaminated debris will be stored; noncontaminated debris will be backfilled.**

Stadtallendorff (Hessen) --Background

- **From 1938 to 1945, two factories produced explosives and ammunition at the site.**
- **Factories were dismantled in 1949 and one area was converted to a residential area.**
- **Soil and groundwater are contaminated with explosives, prefabricates of explosives, phenols, and heavy metals.**

Stadtallendorff--Remedial Technology

- **Carbon adsorption and soil washing technology will be used in remediation because of their successful lab tests in 1991. Residuals will be incinerated.**
- **Research is being conducted to develop clean-up criteria and technology for explosive-related contaminants.**

Stadtallendorff—Status

- **A groundwater treatment extraction system is under construction and expected to be complete in 1993.**
- **A soil washing/thermal treatment plant is expected to begin operating in 1994.**
- **Treated groundwater is to be used as industrial process water; treated soil will be returned to excavated areas.**

Kertess Chemicals (Hanover)—Background

- **Site is located in an industrial area.**
- **From 1943 to 1985, the company transferred and stored detergents, acids, lyes and organic solvents.**
- **Groundwater flow leached the solvents and transported them off site.**

Kertess Chemicals--Remedial Technology

- **Several technologies are in use at this site:**
 - **Vertical barrier containment**
 - **Extraction and treatment of groundwater**
 - **Lowering the groundwater table**
 - **Contaminant extraction from soil by air venting**
 - **Vapor extraction and in situ soil washing**

Kertess Chemicals--Status

- **Groundwater treatment began in 1976 but did not meet cleanup objectives.**
- **Recently a new remedial plan was designed combining several technologies.**

Varta Süd (Hanover) –Background

- No residential areas exist near the site.
- Site was a military facility and prison from 1938 to 1945.
- Wastewater was discharged to a ditch from a nearby accumulator factory from 1945 to 1989.
- Soil and sediment contaminants include PCBs, PAHs, and lead.

Varta Süd –Remedial Technology

- Treatability studies were conducted using high pressure soil washing.
- Other technologies will be tested.

Varta Süd –Status

- Detailed information on contamination of different parts of the site will be collected.
- Sediment remediation and slag investigation are part of the clean-up effort sponsored by the BMFT.
- After remediation, parts of the site will be used as a "scientific park."

Haynauer Strasse 58 (Hessen) –Background

- A firm reconditioned chemical waste and waste oil on the site from 1952 to 1986.
- Surrounding land is residential and industrial.
- Oil and solvents from leaking storage tanks spilled on soil and into groundwater.
- Main contaminants are PHCs, AHCs, CHCs, along with PAHs and PCBs.

Haynauer Strasse 58—Remedial Technology

- **Remediation has five stages: 1) demolishing buildings; 2) decontaminating debris by thermal treatment; 3) extracting soil-gas; 4) excavating soil; and 5) decontaminating soil by high-pressure washing process.**
- **Because of space limitation, three soil decontamination processes must be completed off site.**

Haynauer Strasse 58—Status

- **Remediation began in 1990.**
- **All former buildings have been demolished and debris removed.**
- **Preparations are being made to begin soil excavation.**

NATO/CCMS Pilot Study
"Demonstration of Remedial Action Technologies for
Contaminated Land and Groundwater"

Washington 18 - 22 November, 1991

United States - German Bilateral Agreement
on Abandoned Site Clean-up Projects

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BMFT-Project Management:
Waste Management and Decon-
tamination of Abandoned
Sites, Germany

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2. Background and Goals of the Agreement

International cooperation is an integral part of the German Federal Government's environmental policy. In order to achieve success in the reduction of environmental overload, close cooperation is needed, both in terms of measures implemented and with respect to the research and development sector including the exchange of information and experience. Moreover, coordination and harmonization of environmental demands in the various countries helps to prevent barriers to trade and imbalances in competitiveness.

The United States of America and the Federal Republic of Germany have for many years cooperated in the exchange of information about the ongoing research and development projects as well as in the actual clean-up of contaminated sites. In order to intensify this cooperation the U.S. Environmental Protection Agency and the Federal Ministry of Research and Technology are working together under a United States / German Bilateral Agreement (April 1990).

The goals of this bilateral agreement are:

- * Facilitate understanding of each sides approach to the remediation of contaminated sites ("as-if-approach": as if the foreign project had taken place in the own country)
- * Demonstrate innovative remedial technologies
- * Compare quality assurance programs
- * Facilitate technology transfer

With respect to these topics it was agreed that a better understanding of each others efforts to develop and demonstrate remedial technologies could only be achieved if a demonstration of these technologies should not only follow the rules, regulations and other necessary guidelines of the country in which the remediation takes place but should take into consideration the respective rules of the other country.

Six sites on each side were selected for the cooperation. Detailed executive summary reports on each of the german sites are presently being prepared by the contractors working for the BMFT. These reports will be reviewed by designated U.S. EPA/RREL Technical Program Managers to determine what additional analytical-type Quality Assurance (QA) and Quality Control (QC) measures should be incorporated into the remedial action demonstration by the Germans to meet the U.S. EPA - SITE criteria for determining the effectiveness of the individual technologies being utilized at the sites.

The U.S. EPA Region V and U.S. EPA RREL have prepared similar reports for the U.S. sites. The BMFT will review these reports to determine what additional analytical QA / QC measures should be implemented into the remedial action demonstration to meet German criteria for determining the effectiveness of the individual technologies being utilized at the EPA sites.

3. Remedial Projects

In the course of the bilateral agreement, 12 remediation projects (6 in each country) will be subject to an intense study. The main characteristics of the projects are summarized in table 1 and 2 and additionally described in the subsequent chapter:

Table 1: German remediation projects

German Sites	Technologies	Type of Contamination
Gaswerke München	Soil-Washing + Volume Reduction of Residuals	PAH, Cyanides, Lead
Varta Süd, Hanover	Soil-Washing (+ Acid. Extraction)	Pb, Sb, As, Cd
Kertess, Hanover	Ground Water Pump + Treat, Soil Vapor Extraction, In-Situ Soil Washing	CHC + Degr. Products, CFC, HC, Monoaromatics
Haynauerstrasse 58, Berlin	Soil-Washing, Soil Vapor Extraction, Therm. Treatment of Residuals	CHC, CFC, HC, Monoaromatics, PAH, PCB, PCDD, PCDF
Saarbrücken-Burbach	Thermal Treatment, Soil-Washing, Microbiology	Sulfides, Cyanides, Pb, Hg, Phenols, HC, Monoaromatics
Stadtallendorf	Soil-Washing + Incineration	Munitions, TNT + Degradation Products

Table 2: U.S. remediation projects

U.S. Sites	Technologies	Type of Contamination
Burlington Northern	Bio-Remediation	PAH, Phenols, Oil & Grease
Waukegan Harbor (Outboard Marine)	Anaerobic Thermal Treatment On Site	PCB, Oil & Grease
McGillis&Gibbs	Ground Water Extraction and Biol. Treatment, Soil Washing	PCP, PAH
(Lee Farm)	Solidification/Stabilisation	
(Parsons Chemical)	In-Situ Vitrification	
(Ott/Story/Cordova)	UV Oxidation	

Brief description of the projects:

German Projects:

Gaswerke München

The remediation of a former coal-gasification and gas-distribution facility in Munich, Germany, is coordinated by an interdisciplinary working group comprised of the site-owner, the city and state authorities and various technical consultants. The entire site of the former gas-works is about 32.5 hectare (81.25 acres) in size and is located about 1 km northeast of the city center. Various site investigations since 1982 showed that both the soil and the ground water are contaminated with PAH's and the top most layer of soil is further contaminated by lead. Slightly elevated concentrations of aliphatic hydrocarbons and cyanides were found throughout the site, with some higher peaks in limited areas. One of the hot-spots of the contamination (the "C 1 area") was found to pose a substantial hazard to the ground water and shall be remediated in a first phase of the overall site remediation which is subsidized by the Bundesminister für Forschung und Technologie (BMFT).

Soil washing was selected as the appropriate remediation technology; 25,000 t of gravelly sediments will be treated on-site in a high pressure soil washing plant. At present (November 1991), the high pressure soil washing plant is under construction and will start the trial runs in this month. Parallel to the soil-washing, innovative treatment technologies for the soil-washing residuals shall be tested.

VARTA-Süd, Hannover

The goal of this project is the remediation of the "Varta-Süd" area which was contaminated by emissions from a battery factory nearby between 1938 and 1989. The remediation of the site owned by the City of Hanover is coordinated by a consultant with the support of the "Varta-Süd Assessment Group" consisting of independent scientists and engineers. The site is located northwest of Hanover and covers an area of 45 ha (approx. 110 acres).

From October 1989 to April 1991 the site investigation was performed showing lead, antimony and cadmium being the main contaminants in the soil. Major hot spots are sediments dredged from a creek ("Roßbruch-graben") which was used for waste water discharge by the battery factory. Furthermore slags from smelting and coal firing are distributed inhomogenously over the area, abandoned dumps are filled with rubble, slags and residues from the battery production. Besides the heavy metals, a PAH contamination of unknown origin was detected in the south-eastern part of the site. The ground water is not substantially contaminated with heavy metals but shows elevated concentrations of chloride and sulfate.

At present (November 1991), the remedial investigations and trial runs of different physical treatment technologies (physical extraction (high pressure soil washing), chemical extraction (acids), combination of both) are performed on a small scale base; concepts for the volume reduction of residuals are designed.

KERTESS, Hannover

The project involves the remediation of an industrial area which was used for the handling and storage of organic solvents and detergents, as well as aromatic and halogenated hydrocarbons from 1946 until 1985. The owner of the site is the Deutsche Bundesbahn (DB, German Railroad). The area is about 1 ha in size and is located in the southern part of the City of Hannover. Site investigations in 1975 detected a ground water contamination and in 1976 the first remediation measures (groundwater extraction and treatment) started. Caused by the lack of effectivity of these measures in 1990 consultants were hired to design a new remediation concept.

Major contaminants are chlorinated and aromatic solvents in the unsaturated zone and on the bottom of the aquifer (DNAPL).

The remediation technologies intended to be used are the extraction of the DNAPL by extraction wells, the excavation or in-situ soil-washing of contaminated soil from the saturated zone using vertical large diameter pipes, and the vapor extraction from the unsaturated zone with or without lowering the water table. Ground water will be pumped and treated after a cut-off wall (sheet piling) is installed.

At present (November 1991) ground water pumping and treating is performed, the design of the slurry wall is finished.

Haynauerstrasse 58, Berlin

This project involves the remediation of a former facility for the reconditioning of chemical wastes and waste oils in Berlin. The remediation of the site coordinated by an interdisciplinary working group comprised of the site-owner (Federal State of Berlin), local authorities and the project steering committee, which includes local authorities and various technical consultants.

The site has an overall size of 3,000 m² and is located in the south of Berlin, in the district of Steglitz. Various site investigations since 1986 have detected a contamination of soil and ground water.

The investigations show that both the soil and the ground water are contaminated with petroleum hydrocarbons, aromatic and volatile chlorinated hydrocarbons and PCBs. In addition the buildings contain dioxins and furanes. The highest concentration of petroleum hydrocarbons was found in the southern area of the site. Aromatic hydrocarbons are mainly concentrated in the northern area of the site and chlorinated hydrocarbons were found all over the site. Contamination caused by PCBs was only found occasionally.

The main objectives for the remediation of the site are the following:

- demolition and proper disposal of purified residues of the contaminated buildings
- extraction and treatment of contaminated soil vapor
- emission-free excavation, soil washing and thermal treatment of contaminated soil and reembedding
- remediation of contaminated ground water

In October 1991, soil washing treatability tests were performed and completed successfully. The soil washing plant has been constructed and been proved for different soils on a large scale base. At present single components are adjusted for the site specific situation. The thermal treatment plant will go into operation in the second half of 1992.

Burbacher Hütte, Saarbrücken

The objective of this project is the remediation and reutilization of the Burbach ironworks site from an ecological and economical point of view. The project is coordinated by the city of Saarbrücken who is the owner of the site, the KommunalSysteme GmbH who is responsible for the remediation, and the Gesellschaft für Innovation und Unternehmensförderung mbH responsible for the reutilization of the area.

The site covers 60 ha and is located adjacent to the river Saar in the western part of Saarbrücken, the capital of the federal state Saarland.

One third of the site used by the Burbacher Hütte is still in operation as a rod mill. Approximately 12 hectares are not contaminated and will be used as an industrial area without further treatment. On the northern part of the site, which is about 29 ha in size, soil and ground water contamination was detected during various site investigations since 1986.

According to the previous use of the area elevated concentrations of sulphides, cyanides, phenols, heavy metals (lead, mercury) were found in the soil and partly in the ground water particularly near the coking plant and gas

generation plant. In addition chemical analyses of soil and ground water showed high concentrations of aromatic compounds, particularly benzene and toluene.

At the moment heavy metals are immobilized to a large extent due to a slightly alkaline milieu. During the remedial action a release of vapors of aromatic compounds will require high safety measures.

Until November 1991 contaminated and non-contaminated buildings have been demolished. The future use of existing conduits on the site (coking gas pipes, electricity) are discussed.

The remedial technologies intended to be used include soil vapor extraction, bioremediation, soil washing and thermal treatment. Preliminary test runs were started in summer 1991.

Stadtallendorf, Hessen

The objective of this project is the remediation of soil and ground water contaminated with explosives like TNT and related chemicals. The Regierungspräsidium Gießen (district authority) is responsible for the project, supported by the Wasserwirtschaftsamt Marburg (local authority for water and waste). Two private consulting companies are in charge with the project management.

The city of Stadtallendorf is located 100 km north of Frankfurt and has approximately 20,000 inhabitants. Between 1938 and 1945 two German explosive and ammunition factories were operated by the DAG and WASAG, both covering areas of 420 ha with together 633 buildings, three waterworks and a large number of wells.

A total of 125,000 t TNT were produced. Both, the soil and the ground water, show a high rate of contamination with explosives like TNT and related chemicals, therefore presenting a hazard for humans and the environment.

The registration of possible contamination hot-spots was completed at the end of 1989. Analyses of the upper soil, inspection of closed sewer systems, exploration of former deposits, as well as preliminary explorations have been started. Final results of the investigation program (chemistry, toxicology, pedology and hydro-(geo)logy) will be available at the end of 1992.

The planning for the ground water remediation is under work. The system of wells, pipes and the adsorption treatment plant (activated carbon) will be completed at the beginning of 1993. A soil washing plant is expected to go into operation during the first quarter of 1994.

U.S. Projects

Burlington Northern Site, Brainerd, Minnesota

The Burlington Northern site in Brainerd, Minnesota, has been in operation since 1907, preserving railroad ties with creosote. Waste waters from the operation were discharged into two lagoon areas. Sludges in the lagoons, the soil under the lagoons and the ground water has been contaminated with PAH, oils, and phenolic compounds.

The soil and sludges were treated in a pilot-scale test to determine the effectiveness of biodegradation on the waste. Test plots containing various combinations of contaminated soil, sand, peat moss, and microbial seed were evaluated over time to determine contaminant removals and key operational factors that affect removals. Because the evaluation showed reduced concentrations for PAHs, benzene, extractables and phenols, on-site biological treatment of the contaminated soils and sludges was chosen for remediation of the site.

Five years of operational data (first application in 1986) show consistent degradation of benzene, extractable hydrocarbons and PAH compounds.

Outboard Marine Corporation (OMC), Waukegan, Illinois

The OMC site manufactures marine products for recreational use. From approximately 1961 to 1972, OMC used a hydraulic fluid containing polychlorinated biphenyls (PCBs), some of which escaped through floor drains. Studies have indicated that past releases of PCBs to on-site surface water bodies and an on-site harbor slip have contaminated the site. PCBs have also migrated off site into Waukegan Harbor.

The remedial actions for the OMC site will include excavating highly contaminated soil and sediment and treating it on site; containing less contaminated soil in on-site containment areas; containing contaminated sediment in-place in an on-site slip; and constructing a new slip.

Several treatment processes were evaluated to treat the highly contaminated soil and sediment. An innovative low-temperature thermal desorption process, the SoilTech Anaerobic Thermal Processor (ATP), will be the treatment process used to remove PCBs from the highly contaminated soil and sediment. Under its Superfund Innovative Technology Evaluation (SITE), EPA's Risk Reduction Laboratory (RREL) will collect performance data on the ATP process to determine whether or not the ATP process is capable of meeting the cleanup criteria for the site.

MacGillis & Gibbs/Bell Lumber & Pole (M&G), New Brighton, Minnesota

The MacGillis & Gibbs/Bell Lumber & Pole (M & G) site in New Brighton, Minnesota, is currently operating as a wood preservation facility in the Minneapolis-St. Paul metropolitan area. Preservation applied to wood include creosote, pentachlorophenol, and chromated copper arsenate (CCA). Components of all these chemicals have been found at the site, and are spreading through the ground water contained in the highly complex glacial deposits of the area.

The BioTrol Aqueous Treatment System (BATS) technology is a package plant variation of the aerobic biological treatment system used for sewage and other waste waters. BATS technology is modified to treat waters from hazardous waste sites. As a demonstration project under U.S. Environmental Protection Agency's (U.S.EPA) Superfund Innovative Technology Evaluation (SITE) program, pentachlorophenol-containing ground water from a portion of the site was pumped and treated with a biological growth including a bacterium known to degrade pentachlorophenol. After this demonstration, the BATS technology has been selected as an interim remediation measure for the site. A larger system will be installed to pump and treat contaminated water and the oil layer above it, preventing its spread. Meanwhile, the investigation that will lead to complete remediation continues.

Three additional projects in the U.S. are not yet chosen, nevertheless the preferred technologies are:

- solidification/stabilisation of heavy metals and/or organics
- in-situ vitrification by melting of contaminated soil
- UV-Oxidation of contaminated water

4. Working Plan

In the first step, the remediation projects are described in basic project reports to give comprehensive information on the project to the foreign partners. The case history, the remedial design and the planned technology are the focuses of interest. The intended measures concerning monitoring and efficiency-control (especially sampling and analyses) are described in detail.

In the second step, the partners design plans concerning monitoring and quality assurance especially regarding sampling and analyses procedures for the foreign projects, as if the project would be realized in their own country. After the exchange of the plans, differences and parallels are discussed. Monitoring measures additional to the usual measures are implemented in the clean-up procedures if necessary. These additional

measures, which can last a short period of time or can accompany the whole project are funded by the domestic partner of the bilateral agreement. Visits of the project managers are planned.

In the third step, the results are discussed focussing as well on the data as on the message of the results referring to the data quality and the treatment effectivity. The results of the bilateral agreement will be compiled in reports, intending to improve the bilateral understanding and discussion of the general approaches and to allow the evaluation and comparison of the foreign results and to facilitate the technology transfer.

5. Present Status and Schedule of the Project

In early August 1991, the representatives of the U.S. EPA visited the german sites to gain a first impression of the intended remediation activities and to discuss the clean-up concept.

Subsequently, in Germany two basic project reports (Gaswerke München; Haynauerstrasse, Berlin) were prepared with preference because of the different working progress of the particular projects. In the U.S. three brief reports were compiled, summarizing the information from the different detail-reports of the superfund projects. The detail-reports are part of the attachments.

In the late October 1991, the german representatives visited the U.S. sites and discussed the basic project reports with the U.S. EPA project managers. At present, the german partners are compiling the remaining basic project reports, whereas the U.S. representatives are choosing three additional sites.

Presently remediation experts are designing sampling and analyses plans and the quality assurance objectives for the first two german and the first three U.S. projects, as if these projects should be realized in their own country. Additional requirements will be identified and implented in early 1992 and conducted until 1993 if necessary.

The preparation of the remaining project reports will be carried out in early 1992, because the remedial design of the projects is not yet completed at the time.

Bilateral visits of the relevant project managers are scheduled in 1992 to assure the information exchange as comprehensive as possible. The schedule for the particular visits is depending on the progress of the remedial projects.

Appendix 1-B

Presentation by NATO/CCMS Guest Speakers

NATO/CCMS Guest Speaker:

Brett Ibbotson, Canada

AERIS, an Expert Computerized System to Aid in the
Establishment of Cleanup Guidelines

AERIS - AN EXPERT SYSTEM TO AID IN THE ESTABLISHMENT OF CLEAN-UP GUIDELINES

by

B.G. Ibbotson¹ and B.P. Powers²

1.0 INTRODUCTION

Wherever soil has become contaminated and the contamination poses a threat to people or the environment, a series of questions inevitably emerges: Does the site need to be cleaned? What types of remedial measures or actions should be taken? When will the site be safe to use? What level of residual contamination is acceptable? These and other concerns often are expressed by the simple phrase "how clean is clean?". Unfortunately, the answer is not so simply stated and at the present time few jurisdictions have established acceptable soil concentrations or clean-up guidelines.

The process of deciding whether to reduce or remove soil contaminants and render a site suitable for use is a complex issue. Many factors need to be considered including the type of industry that used the site, the contaminants that are present, the age of the plant, site-specific characteristics such as its geography, geology, hydrogeology, and climate, past waste management practices, and the proposed future use of the site. The extent and costs of clean-up activities are largely determined by the level of contamination which, from environmental and human health standpoints, can safely be left on-site.

To provide direction and guidance to decommissioning efforts across Canada, the Canadian Council of Environment and Resource Ministers (CCREM; subsequently renamed the Canadian Council of Ministers of the Environment or CCME) established the Decommissioning Steering Committee (DSC). Members of the DSC include Environment Canada, the environment ministries of Alberta, Ontario, and Quebec, and several industrial associations. In 1987, the DSC awarded a contract to a consortium of companies to investigate various aspects of decommissioning. SENES Consultants Limited took on the task of creating a computer program capable of deriving clean-up guidelines for industrial sites where redevelopment is being considered. The result of this effort is the AERIS program, an Aid for Evaluating the Redevelopment of Industrial Sites. The version of AERIS described in this paper currently is being reviewed by the Technical Working Group of the DSC and is expected to be finalized in 1989.

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- Presented at the Fourth Conference on Petroleum Contaminated Soils: Analysis, Fate, Environmental Effects, Remediation and Regulation, University of Massachusetts, 25 to 28 September 1989, Amherst, MA
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2.0 BASIC PROGRAM STRUCTURE

2.1 Underlying Premises and Constraints

While the broad objective of this study was to develop a model for establishing site-specific clean-up guidelines, the process of establishing guidelines is far more complex than can be represented by a mere computer model. As such, it was recognized from the beginning of the modelling effort that whatever program was developed, it should not be perceived or used as a sole arbiter in setting criteria. Accordingly, the acronym AERIS was chosen to help users remember its intended use, that of being an aid for evaluating the redevelopment of industrial sites. As an aid, AERIS can be used to identify the factors that are likely to be major contributors to potential exposures and concerns at sites and those aspects of a redevelopment scenario with the greatest need for better site-specific information.

The typical user originally was assumed to be an environmental scientist, but not necessarily an expert in understanding environmental fate, toxicology, computer programming, or the other disciplines that are represented in the model. It was also assumed that some users probably would use AERIS to study generic situations while others would be interested in specific scenarios. Those interested in specific scenarios might have some site-specific data but likely would be uncertain about some of the many factors that can be considered in such an evaluation.

The assumptions about the intended uses and users, together with the objectives and constraints noted above, influenced a series of decisions made at the outset of model development about basic model characteristics:

- AERIS would be structured so that each run evaluates one chemical for one receptor, one land use, and one environmental setting. This may require a user to run the model several times and base decisions on the collective outcomes of those runs. Accordingly, AERIS would be designed so that adjustments to input parameters could be made relatively easily.
- The user should be given the opportunity to select default values for various parameters or provide site-specific inputs so that the redevelopment scenario in the program can be made to resemble actual situations of interest. As a result, AERIS would include default values and various aids to help users select appropriate values.
- AERIS would consider only those exposures that are experienced on-site. Off-site exposures such as those that might be experienced by people whose drinking water supply is down gradient of a site or who consume commercially-sold produce raised at a former industrial site would not be calculated. Off-site populations would be considered indirectly by comparing concentrations in air, water, and produce with existing environmental criteria such as point-of-impingement criteria for air quality and drinking water objectives.
- AERIS would be designed to evaluate situations where the soil had been contaminated sufficiently long ago to establish equilibrium or near-equilibrium conditions between the various compartments of the environment. These conditions should apply to most sites that are being considered for redevelopment.
- It would be assumed that the concentration of the contaminant in soil is constant across the site and over the depth of soil that is contaminated. Furthermore, the concentration is assumed to remain constant over time (although there is the option to correct model results for degradation).

As such, AERIS is not suitable for evaluating recent spill sites or locations being considered as candidates for receiving wastes. Nor is it suitable for calculating changes in environmental concentrations or exposures over time due to ongoing contaminant contributions from a constant or sporadic source.

Based on many of these considerations, it was decided to design AERIS to run within an "expert system" programming environment. This facilitated the creation of a model in which the user has the option of entering either site-specific data or relying on default values. At each point where the user is asked for information, on-screen assistance can be invoked to help a user make decisions and understand how the choices can affect the outcome. The entire process has a relatively high degree of "friendliness" and provides some automatic error checking.

Because it runs within an "expert system" programming environment, AERIS consists of four basic elements - an "intelligent" preprocessor, a supporting data base, component modules, and a postprocessor.

2.2 The Preprocessor

The preprocessor takes the form of a series of questions that AERIS asks the user about the redevelopment scenario to be evaluated. These questions and answers collectively are referred to as the "Input Session". The answers are used to create a "context" file that describes the scenario of interest. Context files can be saved and recalled at the user's discretion.

The preprocessor is referred to as "intelligent" due to the utilization of expert system technology. The preprocessor uses a set of rules (collectively referred to as a "knowledge base") to establish a structure to the decision support offered; to aid the user in estimating unknown input parameters, and to control the flow of information between other program components. The preprocessor contains the "control modules" which are responsible for the user interface during the input and output sessions, the inference flow mechanism, the retrieval of information from the data base, and the management of information flow among the component modules.

The preprocessor uses rules to determine if and when goals are met. Many of the rules are in the form of If... Then... Else statements which represent the decision making that an expert would consider when evaluating this type of scenario. A rule may be predicated upon one or more subrules. The resulting branched arrangement formed by the rules is similar to that of a decision tree. If sufficient information is gathered during the Input Session, the preprocessor passes the data to the component modules. Only those modules deemed appropriate by the preprocessor are activated.

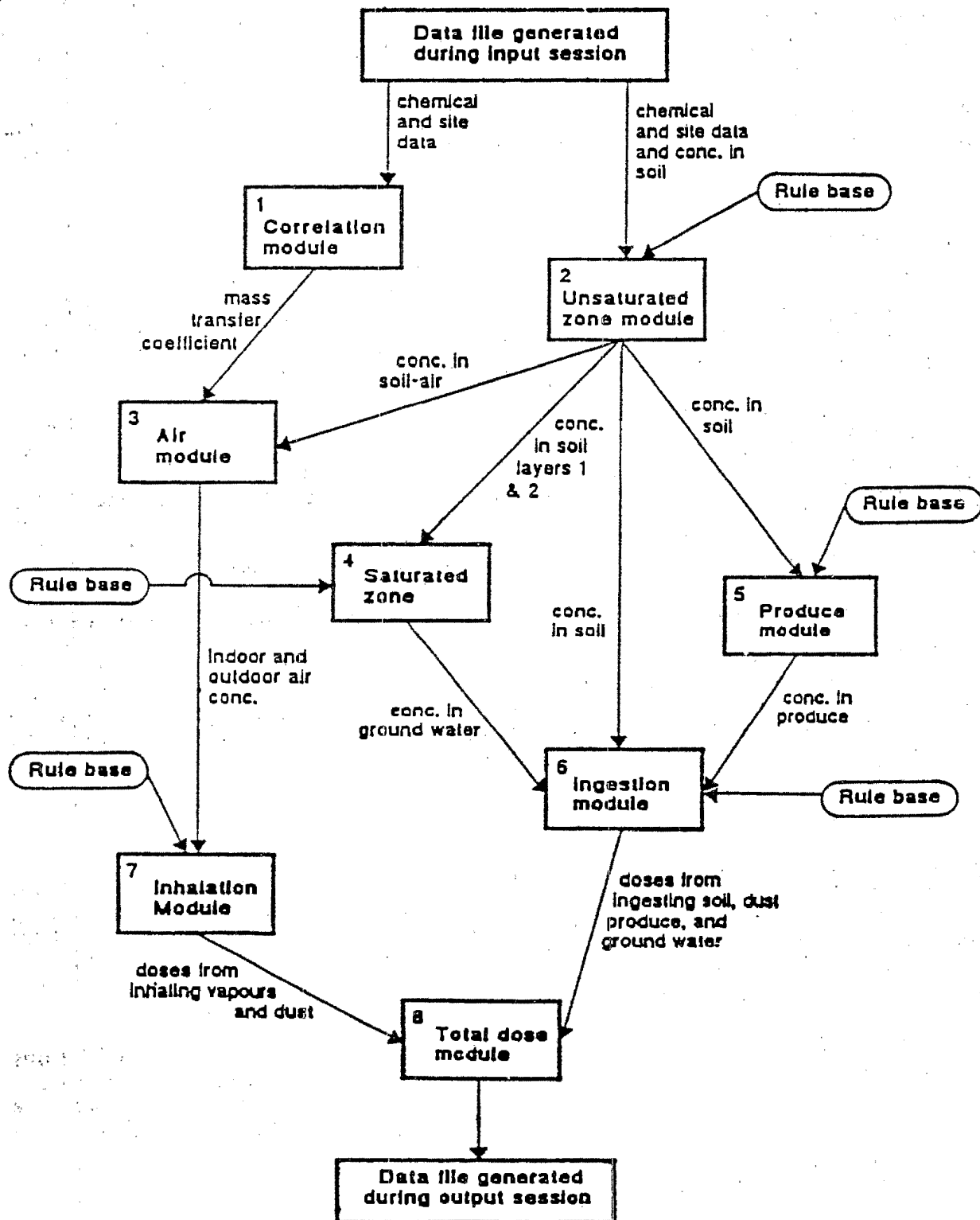
2.3 The Component Modules

The component modules contain algorithms that estimate contaminant concentrations in various compartments of the environment. The estimated concentrations serve as the basis for estimating exposures via various routes of exposure. Figure 1 indicates the sequence that the modules are used in AERIS and shows how they are interrelated by the information that flows between them. If concentrations of a contaminant have been measured in one or more compartments of a site, a user has the option to override the estimated concentrations with the site measurements.

The *Correlation Module* is used to predict mass transfer coefficients. The predictions subsequently are used in the *Air Module* which calculates the flux of chemical from the soil into outdoor air and into basements of buildings where it can be inhaled by a site user or visitor. The rate at which a chemical will be transported from soil into the outdoor air is influenced by

FIGURE 1

COMPONENT MODULES AND INFORMATION FLOW



properties of the soil, properties of the contaminant, and environmental conditions.

The *Unsaturated Zone Module* predicts concentrations in soil-water and soil-air in the soil above the water table. It assumes that there is a contaminated layer that starts at the surface and that the user can define the layer in terms of its typical or average depth and concentration of contaminant over that depth. If appropriate, there can be an underlying non-contaminated soil layer. The *Saturated Zone Module* predicts concentrations in ground water. Key factors it considers include the depth of contamination with respect to the depth to the local water table, and soil characteristics.

The *Produce Module* is used to estimate concentrations in produce grown on the site. The uptake of chemicals is assumed to be contributed by root uptake and foliar deposition of local soil particles. The extent of uptake is influenced by the type of produce, length of growing season, chemical properties of the chemicals, and soil characteristics.

In the *Ingestion Module*, the intakes of water, soil, and garden produce are estimated. The concentrations in the water, soil, and produce are determined in the Saturated Zone Module, Unsaturated Zone Module, and Produce Module, respectively. In the *Inhalation Module*, the amount of chemical inhaled by the receptor while outdoors and indoors are calculated. Both the inhalation of vapours and particulate matter are taken into account.

In the *Total Dose Module*, the doses via all pathways are combined. The total is then compared to the "acceptable" dose level. The user can decide whether all or some fraction of the "acceptable" level is to be used. While human health often will be the most stringent basis for setting clean-up guidelines, a user has the option of specifying a concentration in any one of several environmental compartments as the basis for calculating an "acceptable" soil concentration.

2.4 The Post Processor

The results calculated by the component modules are passed to the postprocessor, which offers the user various ways of displaying the results during the "Output Session". Each run of the model concludes with tables that display dose estimates for each route and the identification of an "acceptable" soil concentration. Three types of graphical summaries can be displayed: a plot of soil concentration versus dose; pie charts that show the relative contributions of each route to total exposure; and diagrams that compare the calculated "acceptable" concentrations to guidelines or criteria issued by regulatory agencies.

2.5 The Data Base

The AERIS data base can provide much of the information needed for the calculations. Information is retrieved as the user answers questions concerning the scenario to be evaluated. The types of information that can be retrieved include physico-chemical data, "acceptable" dose levels, bioavailability factors, concentrations associated with other types of adverse effects, guidelines or criteria from various jurisdictions, receptor characteristics, meteorological data, and physical characteristics of soils and underlying formations. The data base in AERIS has information for:

- two types of site users: an adult and a young child
- four future land uses: residential, commercial, recreational (park land), and agricultural
- more than 30 organic compounds and three inorganic substances
- the meteorology of six Canadian cities: St. John's, NFLD, Montreal, PQ, Toronto, ON, Winnipeg, MN, Edmonton, AL, and Vancouver, BC
- physical characteristics of nine soil types and 14 underlying formations.

The user has the opportunity to edit all of the information retrieved from the data base so that the redevelopment scenario can be made to resemble the actual situation of interest. AERIS also includes default values and various aids to help users select appropriate values.

2.6 Pathways Considered

Site users can be exposed to substances present in site soil through various pathways (routes of exposure). AERIS allows all or any of the following pathways to be considered: inhalation of vapours and particulate matter when indoors and outdoors; direct ingestion of local soil and indoor dust; ingestion of plants grown on-site; and ingestion of ground water (see Figure 2).

The extent to which a person is exposed to a substance by any of these pathways is influenced largely by the physical characteristics of the person and the way(s) that they use the site. The AERIS data base contains information for two types of individuals (an adult and a young child) and four types of future land use (residential, commercial, recreational, and agricultural). A program user has the option to use any or all of the default values or can replace default values with specific values at their discretion.

The characteristics associated with residential land use is directed towards estimating doses that result from the full-time use of the site. The receptor is assumed to live in a single-story house with a full basement located in the middle of the site. A garden on the property supplies fruits and vegetables.

Commercial land use is intended to estimate doses that result from spending a substantial portion of most days on a site inside a building. As such it is analogous to portraying an office worker or a child at a day-care centre. The building is assumed to have one story and no basement.

Recreational land use is intended to generate doses received by frequent visitors to a park or playground. While on-site, visitors are assumed to be engaged in vigorous activities.

The characteristics of agricultural land use are similar to those of residential except that larger amounts of time are spent outdoors and particulate matter levels are elevated for a portion of the year as they would be during plowing.

4.0 SAMPLE RESULTS

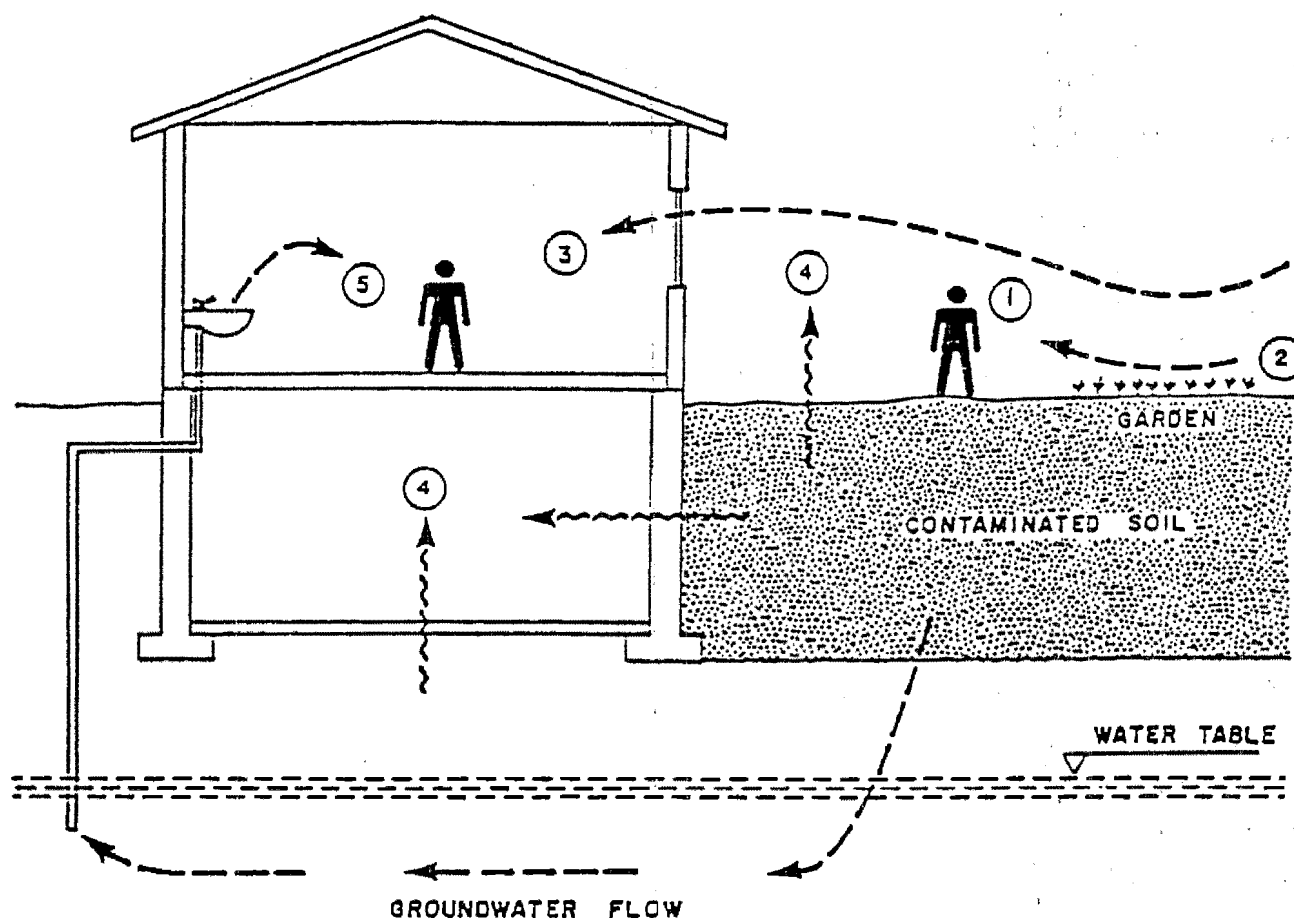
To illustrate various aspects of the AERIS program and its response to different sets of input parameters, two hypothetical redevelopment scenarios have been created. Scenario "A" has characteristics typical of those that might be encountered at a site in southern Ontario, while Scenario "B" is more representative of a site in central Alberta. Table 1 displays the information used to portray the two scenarios.

The AERIS program was used to identify "acceptable" soil guidelines for each scenario by considering two soil contaminants (benzene and lead), for all four of the land uses addressed in the data base, and using the young child as the receptor. Table 2 presents the results for both scenarios.

For benzene, the "acceptable" soil concentrations for Scenario "A" (0.08 to 0.6 mg/kg) are slightly higher than for Scenario "B" (0.04 to 0.6 mg/kg). The only guidelines in Canada include a value of 0.5 mg/kg recommended by the Province of Quebec as the threshold at which detailed site investigations may be needed. The lower concentrations in Scenario "B" stem from the

FIGURE 2

PATHWAYS CONSIDERED IN AERIS



POTENTIAL PATHWAYS :

- ① DIRECT INGESTION OF SOIL
INHALATION OF PARTICULATE MATTER
- ② INGESTION OF GARDEN PRODUCE
- ③ DIRECT INGESTION OF DUST
INHALATION OF PARTICULATE MATTER
- ④ INHALATION OF VAPOURS (BOTH OUTDOORS AND INDOORS)
- ⑤ INGESTION OF GROUNDWATER

lower organic carbon content in that site's soil and the subsequently higher concentrations of vapours in air (and higher doses via inhalation). The inhalation of vapours is a dominant pathway (50 to 84% of total exposure) for benzene in all land uses except recreational (in which all time on-site is spent outdoors). Associated with the "acceptable" soil concentrations are outdoor air concentrations well below the air quality criterion from Ontario but ground water concentrations above the guideline from Quebec. The associated soil values also are less than those reported to cause odours in air or phytotoxicological effects.

For lead, concentrations for Scenario "A" (8 to 500 mg/kg) are slightly higher than for Scenario "B" (5 to 15 mg/kg). Soil guidelines from several Canada provinces lie in the range of 200 to 1000 mg/kg. Ingestion of produce dominates the exposure in Scenario "A". AERIS makes no allowance for reductions of concentrations in produce that result during food preparation such as washing, peeling, or boiling. As a result, the estimated doses for eating produce likely exceed actual doses. This becomes an important consideration in interpreting the output for scenarios in which the consumption of produce is a major pathway.

The sandy soil in Scenario "B" results in higher concentrations of lead in ground water and therefore doses via that route are significantly greater than in Scenario "A". The dominating influence of ground water ingestion in Scenario "B" results in "acceptable" soil concentrations considerably lower than those being used or considered by some regulatory agencies. The inclusion of site ground water as a source of exposure is an unlikely condition especially in urban areas. If ground water had not been included as a pathway, the "acceptable" soil value for Scenario "B" would have been approximately 100 to 450 mg/kg. For both scenarios, the use of lead-specific bioavailability factors (rather than the default values) likely would significantly increase the "acceptable" soil concentrations.

5.0 CONCLUSIONS

AERIS has achieved many of the original objectives set for this project: it is highly user-friendly; it can be used even if various pieces of site data are missing; it is highly flexible in the types of contaminants and scenarios it can evaluate; and it generates site-specific clean-up guidelines. During the development of the model, it also was realized that with increasing ease of use also came the increasing possibility of misuse. While the original goal was to create a product that even a novice could use to develop guidelines, the developers have come to regard the model as being better suited to assisting experts to evaluate situations expeditiously and consistently. Rather than being used as a surrogate for expertise, its preferred role is as a tool to assist experts. That AERIS should not be perceived to be a substitute for expertise is evident in the cautionary notes that the developers suggest be applied to the interpretation of model results:

- The conservative, risk-based philosophy and default values that are used when health concerns are the basis for evaluating a site make it possible to generate "acceptable" soil concentrations lower than those that regulatory agencies may be using or considering. Conversely, relatively high "acceptable" soil concentrations can be identified when using AERIS if the scenario being evaluated generates very small dose estimates or the important exposure pathways are relevant for chemicals with certain physico-chemical properties or environmental behaviours.
- The algorithms used to estimate environmental fate and concentrations in environmental compartments as a function of the concentration in soil have been verified but not calibrated (that is, the predictions of the algorithms have not been compared to concentrations measured at actual industrial sites in various environments). An assessment of the model's worth may only be possible once it has been used to evaluate several real situations.

- Some of the algorithms represent processes that are not well understood (such as plant uptake) and the overall approach may require site complexities to be replaced with generalizations.
- "Acceptable" soil concentrations determined by AERIS should not be taken as absolutes but rather as being indicative of appropriate concentrations. Scenarios should be evaluated by running AERIS several times with key parameters adjusted between runs to develop an appreciation of the sensitivity of the output to input data or assumptions.

Table 1

PARAMETER INPUTS FOR CHARACTERISTICS OF SCENARIOS "A" AND "B"

	<u>Scenario "A"</u>	<u>Scenario "B"</u>
meteorology	Toronto	Edmonton
site length	1000 m	1000 m
soil type	stiff, glacial clay	uniform, dense sand
underlying formation	unweathered marine clay	silty sand
ground water table	1.5 m	3 m
soil pH	7.4	6.0
aquifer thickness	5 m	5 m
K_{di} for lead	$0.04 \text{ m}^3/\text{kg}$	$3.5 \text{ m}^3/\text{kg}$
depth of contamination	1 m	1 m
organic carbon content	2.5 %	1 %
hydraulic gradient	0.01	0.01

Other Assumptions for Both Scenarios

- dissolution dominates over desorption for lead
- all bioavailability factors set to default values

Table 2

"ACCEPTABLE" SOIL CONCENTRATIONS FOR SCENARIOS "A" AND "B"

<u>Chemical/ Land Use</u>	<u>Scenario "A"</u> (mg/kg)	<u>Scenario "B"</u> (mg/kg)
benzene		
residential	0.12	0.04
commercial	0.36	0.20
recreational	0.60	0.64
agricultural	0.12	0.04
lead		
residential	8	4.9
commercial	493	14.3
recreational	111	11.4
agricultural	8	4.9

NATO/CCMS Guest Speaker:

Colin Mayfield, Canada

Anaerobic Degradation

Anaerobic biodegradation

Aromatics - reviewed by Berry et al. (1987) - Microbiol. Rev. 51: 43-59.

Overview

Two basic pathways for ring reduction- hydrogenation and hydration

Hydration can occur using oxygen from water forming phenol from benzene and p-cresol from toluene (Vogel and Grbic-Galic, 1986 and 1987).

Five anaerobic processes that can degrade aromatics -

1. Photometabolism
2. Fermentation
3. Nitrate respiration (denitrification)
4. Sulfate reduction
5. Methanogenesis

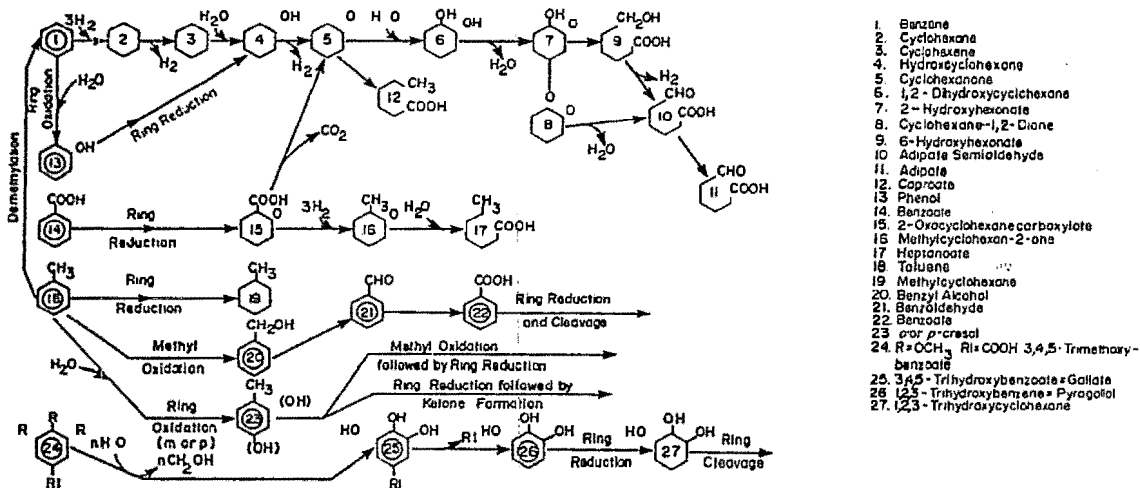


FIGURE 2

Generalized Anaerobic Degradation of Aromatic Compounds. (Modified from Berry *et al.*, 1987, Evans, 1977, and Kaiser and Hanselmann, 1982.)

Microorganisms in groundwater

- 1. Numbers - range from 1 to 10,000,00 per gram/dry weight using modern techniques.**
- 2. Activity - turnover times of naturally occurring compounds (amino acids and sugars) range from 50 to 2000 hours (Canadian sites at slower end of values !)**
- 3. Specific activity per cell varies less than numbers - probably the major difference between sites was in terms of percentage of active cells, not specific activity per cell.**
- 4. Bacteria tend to be adapted to low nutrient conditions - they are oligotrophic.**
- 5. The microorganisms in groundwater do not seem to be inhibited by "normal" (i.e. commonly found) levels of contaminants such as monoaromatics, PAHs, creosote and creosote by-products, phenols, halogenated aromatics and methanes, and heavy metals.**

Calculations of free energy changes:

Electron Donor	Electron Acceptor	kcal/electron equivalent
acetate	O ₂	-25.28
acetate	NO ₃ ⁻	-16.03
acetate	SO ₄ ²⁻	-1.52
acetate	CO ₂	-0.85
glucose	O ₂	-28.70
glucose	NO ₃ ⁻	-19.45
glucose	SO ₄ ²⁻	-4.94
glucose	CO ₂	-4.26
glucose	glucose (fermentation to ethanol)	-2.43

Metastable intermediates:

Glucose fermentation to methane: Stages in fermentation -	
1. Glucose + HCO_3^-	acetate + propionate + butyrate + hydrogen (kcal = -2.74 = 64.3% of overall total)
2. Acetate + H_2O	methane + HCO_3^- (kcal = -602 = 14.1% of overall total)
3. Butyrate + H_2O	methane + HCO_3^- (kcal = -0.075 = 1.8% of overall total)
4. Propionate + H_2O	methane + HCO_3^- (kcal = 0.093 = 2.2% of overall total)
5. H_2 + CO_2	methane + H_2O (kcal = .75 = 17.6% of overall total)

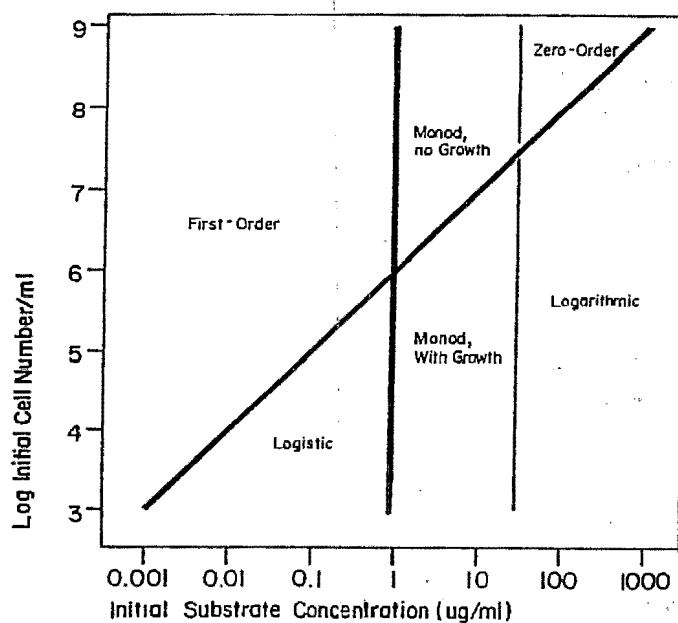
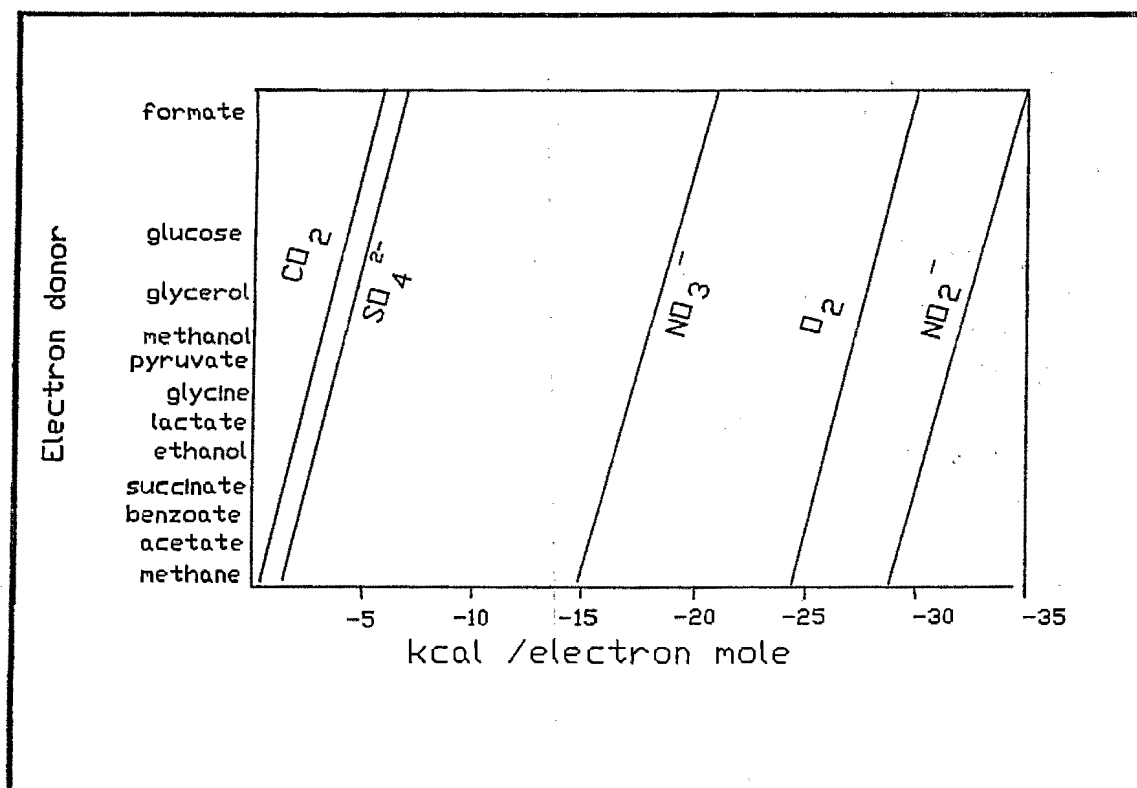


FIGURE 3a
Kinetic Models as a Function of Substrate
Concentration and Bacterial Cell Density (From
Alexander, 1985)

Fermentation

pyrogallol, gallic acid 2,4,6-hydroxybenzoate phloroglucinol syringic acid	CO ₂ & acetate	1982 (Schink & Pfennig)
o-methyl groups of aromatic acids	acetate & hydroxylated derivative of acid	1985 (Frazer & Young)

Denitrification

Compound metabolized	Product(s)	Date
p-hydroxybenzoate	hydroxybenzoate	1970 (Taylor)
benzoate	cyclohexanecarboxylate	1975 (Williams & Evans)
benzoate	adipate	1984 (Braun & Gibson)
3 and 4 hydroxybenzoate	-	
1-cyclohexenecarboxylate	-	
CCl ₄ brominated halomethanes	chloroform *	1983 (Bouwer & McCarty)
3-fluorophthalate	2 and 3-fluorobenzoate	1981 (Aftring et al.)
hydroxybenzoate	phenol	1989 (Kuhn et al.)
* may be chemical reaction (reduced iron ?)		

Sulfate Reduction

benzyl alcohol, p-cresol anthranilic acid	-	(1981) Balba
benzoate	CO ₂	(1983) Widdel et al.
isomers of cresol	-	(1979) Smolenski & Suflita

Methanogenesis

phenylacetate, hydrocinnamate, cinnamate, tyrosine, benzoate	-	1934 (Tarvin & Buswell)
benzoate	methane	1976 (Ferry & Wolf)
lignin ferulic acid	methane	1979 (Healey et al.)
3-chlorobenzoate		1984 (Shelton & Tiedje)
halogenated aromatics (many)	dehalogenated products	1982 (Suflita et al.) 1983 (Horowitz) 1985 (Suflita & Miller) 1986 (Wilson et al.) and others.

N.B. Most results involve "methanogenic consortia" of bacteria, not pure cultures.

Factors affecting bioremediation in groundwater -

- 1. Contaminants - are they amenable to aerobic and/or anaerobic biodegradation ?**
- 2. Concentration - are the concentrations present likely to support growth or be metabolized by co-metabolism or secondary substrate metabolism ?**
- 3. Concentration of nutrients, electron acceptors, dissolved oxygen, etc., in the groundwater.**
- 4. Hydrogeological conditions (site specific)**
 - porosity, flow pattern and velocity
 - DOC and TOC and their effects on adsorption and retardation
 - mixing zones, heterogeneity of porous media
 - historical data on contamination events
 - other sources of contamination or nutrients

- 5. Intermittent, controlled, alternating injections of low levels of oxygen and electron acceptors to modify groundwater in a localized area. Could set up alternating aerobic and anaerobic environments without excess biomass production. Could set up process leading to eventual methanogenic conditions (and consequent bioremediation activity), subsequent addition of oxygen could lead to methane-oxidizing activity. Addition of nutrients would then start process again.**

In all cases need to apply stoichiometry of reactions to calculate additions of nutrients, electron acceptors and oxygen.

Summary

- 1. Aerobic biodegradation and remediation is well-established in groundwater systems.**
- 2. Anaerobic bioremediation theory and technology is less well-understood; there are few well-documented field examples.**
- 3. Some non-aromatic organic compounds are obviously more amenable to anaerobic bioremediation.**
- 4. The hydrogeology of the site must be understood before using bioremediation technology. Even aerobic groundwaters can be "driven" anaerobic by biodegradation of contaminants .**
- 5. Anaerobic bioremediation has some advantages when it is applicable;**
 - The electron acceptors (NO_3^- , SO_4^{2-} , CO_2) are soluble and move rapidly in groundwater since they are not adsorbed.**
 - The contaminant plume can be "overtaken" by the treatment.**
 - Final contaminant concentrations could be very low.**
 - Can be cheaper and less obtrusive than other methods.**
 - Can be used in conjunction with other methods.**

NATO/CCMS Guest Speaker:

A. Stelzig, Canada

Cleanup Criteria in Canada

DECOMMISSIONING AND CLEANUP
CRITERIA OF INDUSTRIAL
FACILITIES IN CANADA

NATO/CCMS MEETING

NOV. 6-9 1989
MONTREAL

OVERVIEW OF NATIONAL PROGRAM

- OBJECTIVE
- C C M E
- HISTORY & BACKGROUND
- STATUS OF CURRENT PROGRAM

DECOMMISSIONING

OBJECTIVE:

Establish uniform approaches on decommissioning of industrial plants, storage facilities and waste disposal sites.

Canadian Council of Ministers of the Environment (CCME)

- WASTE MANAGEMENT COMMITTEE

- Responsible for the Hazardous
Waste Action Plan**

- Added decommissioning of
industrial sites to action
plan Sept/86.**

- Environment Canada and
Québec identified as lead
agencies.**

- Objective (established by
waste committee):**

- "Establish uniform approaches
on decommissioning of
Industrial plants, storage
facilities and waste disposal
sites."**

INDUSTRIAL DECOMMISSIONING TASKS

- DEVELOP CLEANUP CRITERIA
INCORPORATING SITE SPECIFIC
CONSIDERATIONS**
- DEVELOP NATIONAL GUIDELINES
FOR DECOMMISSIONING
INDUSTRIAL SITES**

HISTORY AND BACKGROUND

- Decommissioning guide
-consultants report 1985
- National workshops
and proceedings 1985
- recommendations
steering committee June 86
- Québec & Ontario
Regulatory Initiatives
- Inventory of cleanup
criteria and
methodology May 87

A: DECOMMISSIONING GUIDE

April 85 by Monenco Consultants Ltd.

- SCOPE AND PROBLEM DEFINITION
- GENERAL PRINCIPLES
 - Planning
 - Site Assessment
 - Site Investigation
 - Cleanup Criteria
 - Site Cleanup
 - Cleanup Confirmation
 - Long Term Monitoring
 - Regulatory Agency Involvement
 - Public Relations
 - Preventive Measures
- CASE HISTORIES
- CONCLUSIONS

B: WORKSHOPS

Calgary Nov. 85

Ottawa Dec. 85

STEERING COMMITTEE

- Industry/Gov't
- Define Objectives
- Manage Workshops

OBJECTIVES

Advance state of the art
level of understanding

- Exchange information
- Share expertise and
experience
 - Identify needs

CONCLUSIONS/RECOMMENDATIONS

APRIL 1986

- Cleanup criteria and guidelines
(Highest priority)
- Small facilities
- Field programs
- Treatment & Disposal
- Groundwater cleanup
- Long term monitoring
- Role of gov't and public

STEERING COMMITTEE

RECOMMENDATIONS

JUNE 1986

- Letter to Federal/Provincial ADM's and Industry Associated Presidents
- Workshop Recommendations
 - Highest priority
 - Criteria
 - Inventory
 - Cooperative effort
 - To follow up
 - Funding
- Response
 - Recognized need
 - Prepared to participate
 - Funding
 - Planning

ONTARIO & QUEBEC

INITIATIVES

- Development of policies and guidelines
- Québec action level
 - A, B, C
- Ontario decommissioning guideline

**INVENTORY OF CLEANUP CRITERIA
AND METHODS TO SELECT CRITERIA**

**REPORT COMPLETED
APRIL 1987**

- Canada, U.S., Europe
- Site specific examples

**REPORT TO WASTE COMMITTEE
MAY 1987**

REVIEW BY MARK RICHARDSON

**U.S. OFFICE OF TECHNOLOGY ASSESSMENT
Analysis of approaches to set cleanup goals**

Unacceptable

- ad hoc

**Technically and Economically
Impractical**

- restore to background/pristine
- best available technology

Potentially Feasible

- national standards
- risk assessment
- cost-benefit analysis

Preferred

- site classification based on
use combined with national
standards, risk assessment
and cost-benefit analysis

U.S. OFFICE OF TECHNOLOGY ASSESSMENT
NATIONAL, CONSISTENT APPROACH REQUIRED.

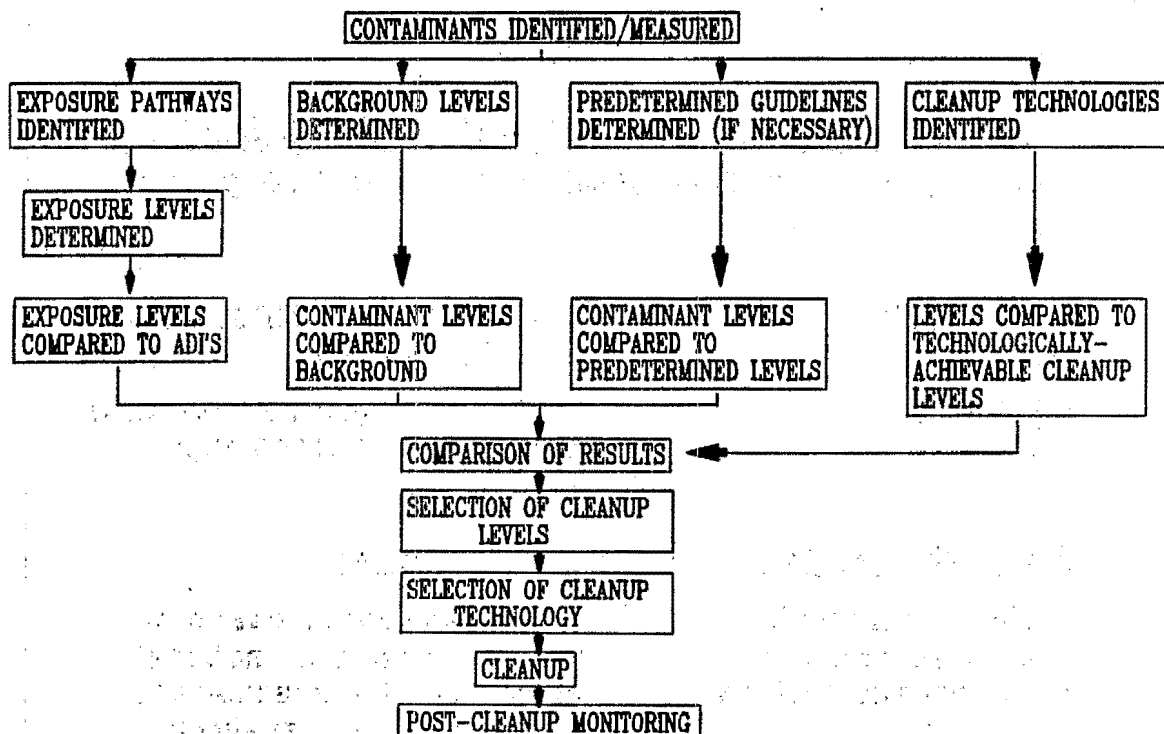
No consistent approach

No consistent levels of cleanup

Factors to be considered when selecting cleanup goals:

- Inherent hazard (potential to cause harm)
- site-specific considerations and exposure (pathways analysis)
- assessment of risks (hazard and exposure, probability of adverse effects)
- available technologies (detection, quantification, remediation)
- resource limitations (money, trained personnel, equipment)
- institutional constraints (laws & regulations, jurisdiction)

STEPS IN DECOMMISSIONING ON A SITE-SPECIFIC BASIS



STATUS OF CURRENT PROGRAM

- Project objective
- Components of project
- A.E.R.I.S.
(Aid in Evaluating the
Redevelopment of
Industrial Sites)
- National Guideline for
Decommissioning of
Industrial Sites

PROJECT OBJECTIVE

Development and validation
(critical components) of a
method for establishing site
specific cleanup criteria for
industrial sites.

COMPONENTS FOR PROJECT

- REVIEW AND EVALUATION
OF METHODS
- DEVELOPING OPTIMUM
APPROACH AND METHOD
- VALIDATING CRITICAL
COMPONENTS

PROJECT

BUDGET


\$1.1 MILLION

SPONSORS

-Federal Government — 50%
(Environment Canada
D.S.S.)

-U.S. EPA — 35%

-Alberta
-Québec
-Ontario
-CPA
-PACE
-CCPA



15%

Project initiation June 1987
completion feb. 1990

PROJECT TEAM

CONSULTANTS

Monenco Consultants Ltd.

Senes Consultants Ltd.

Cantox Inc.

Zenon Environmental Inc.

KRH Environmental Co. Ltd.

PROJECT ROLE

Management

Pathways

Toxicology

Analytical

Laboratory

PROJECT ORGANIZATION

CLIENT COORDINATING
COMMITTEE (11)

TECHNICAL WORKING GROUP (7)

EXPERT REVIEW COMMITTEE

PROJECT MANAGEMENT

M.J. Riddle
D.M. Gorber

METHOD REVIEW REPORT

A) Methods and strategies currently
used to develop cleanup criteria
for contaminated sites.
(completed January 1989)

- Reviewed by Technical
and Steering Committees.
- Submitted to C.C.R.E.M.
Waste Committee 12/01/89.
- Comprehensive Review
- Inventory Criteria Report
Precursor.

METHOD REVIEW

A-1) EVALUATION BASIS:

- Site specific data
- All environmental media
- All environmental contaminants
- Incorporate variety scientific
data
- Degrees of contaminants
exposure
- Routes of exposure
- Risk assessment
- Missing data
- Land use

METHOD REVIEW

A - 2) STRATEGIES:

- Site classification**
- Environmental standards**
- Risk assessment**
- Cost benefit**
- Technology**
- Background**

METHOD REVIEW

**A - 3) A combined approach
and methodology that
SYSTEMATICALLY considers
ALL of the strategies.**

A.E.R.I.S.

**(Aid in Evaluating the Redevelopment
of Industrial Sites)**

**Links exposure assessment (multi-
media pathway models) with toxicity
assessment as part of an overall
risk evaluation procedure.**

OBJECTIVES

- 1. Development of a risk assessment
method for selecting cleanup
criteria.**
 - user friendly computer model**
 - human exposure vs soil
concentration**
- 2. Selection of pollution transport
equations for model based on
evaluation in field study.**

**Model will aid in selection of
cleanup criteria for cases with
extensive contamination (conflict
between most economical and most
environmentally acceptable
approaches).**

MODEL DESCRIPTION

1. Input of site specific information

- user responds to questions
- approve or change default values
- ask for help, background information
- examples: soil, climate, pollutants
 - land use - residential
 - commercial
 - recreational
 - agricultural

2. Calculation of soil concentration that results in acceptable level of risk.

- Concentration in air, soil, water, plants; resulting human exposure
- Comparison of exposure with ADI
- Adjustment of soil concentration and recalculation of exposure

3. Graphic display of model output

- Recommended cleanup criteria;
background
existing guidelines (Canadian
water quality)
- Concentration in soil vs water
air
plants
- Importance of each pathway to
total exposure

NATIONAL GUIDELINE

A) GENERIC

- not industry sector specific

B) MAJOR COMPONENTS

- appropriate steps, information
needs, practices and considerations
- cleanup criteria and procedure

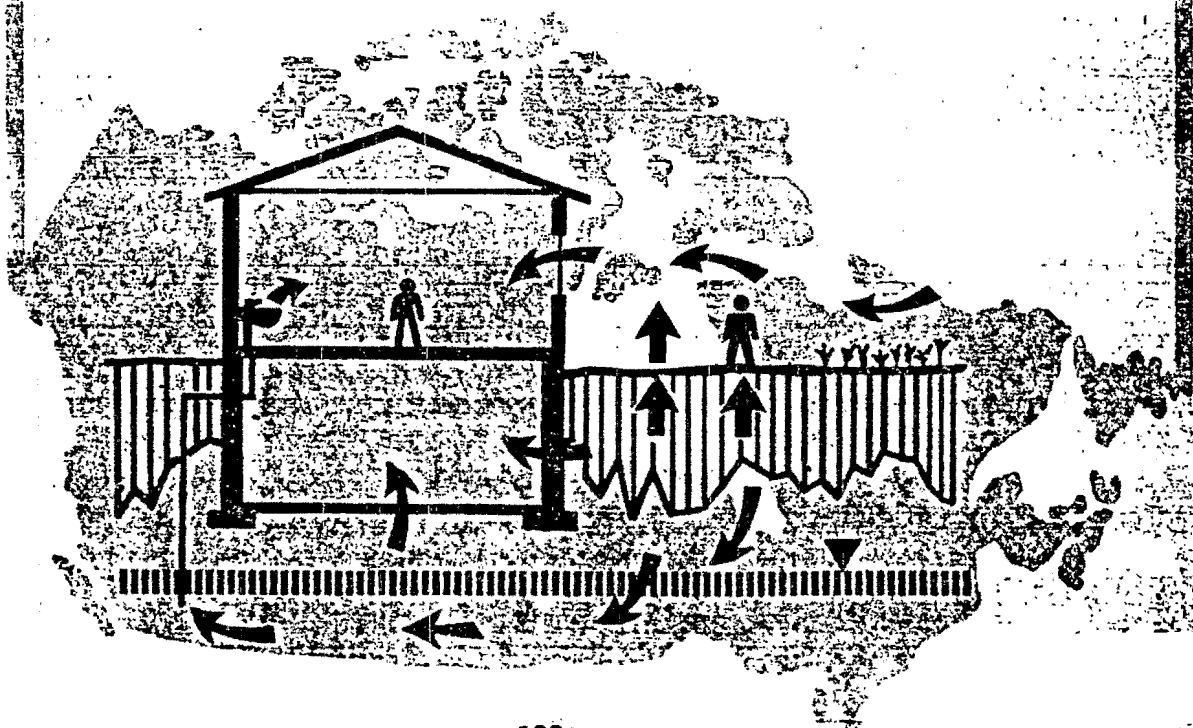
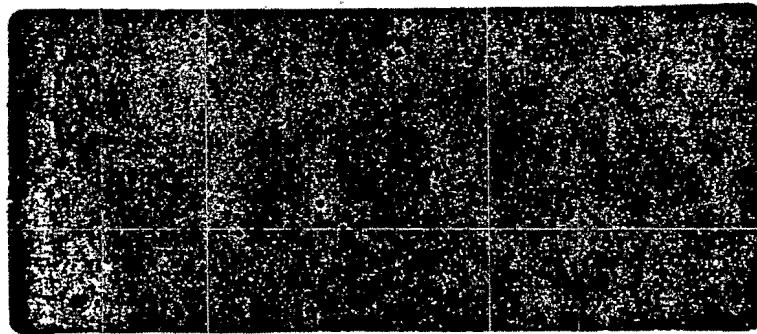
C) PRIMARY BACKGROUND AND REFERENCE DOCUMENTS

- guide
- draft Ont & Qué guidelines
- inventory criteria report
- workshop material
- current methodology study
- U.S. material
- other (i.e. water quality
guidelines)

PROPOSED DECOMMISSIONING GUIDELINES

- 1. Introduction**
- 2. Legislation**
- 3. Planning**
- 4. Site assessment**
- 5. Reconnaissance testing program**
- 6. Plant phasedown**
- 7. Development of cleanup criteria**
- 8. Detailed testing program**
- 9. Preparation of cleanup plan**
- 10. Implementation of cleanup plan**
- 11. Confirmation testing**
- 12. Long term monitoring**
- 13. Approval**
- 14. Land use control**
- 15. Liability**
- 16. Preventative measures**

THE DEVELOPMENT OF SOIL CLEANUP CRITERIA IN CANADA



CONTAMINATED SOIL CLEANUP
IN CANADA
VOLUME 1
METHODS AND STRATEGIES
CURRENTLY USED TO DEVELOP
CLEANUP CRITERIA FOR
CONTAMINATED SITES

prepared for the
Decommissioning Steering Committee

1988-09-16

ABSTRACT

A potential threat to human and environmental health is posed by the existence of toxic substances at closed industrial sites or inadequate waste disposal sites. It is generally acknowledged that this potential threat must be reduced to an "acceptable level" or eliminated completely. To deal with this problem (i.e. how clean is clean?) various governments and regulatory agencies in North America and Europe use a wide variety of strategies and approaches. These strategies can be divided into the absolute method, which is geared toward establishing a fixed concentration for a given contaminant in a specific medium, or the relative method, which derives a site-specific contaminant concentration to protect human health and the environment.

The Canadian Council of Resource and Environment Ministers (CCREM) have recognized the inconsistency of the various approaches used in Canada to develop cleanup criteria. CCREM has identified the need to establish a uniform approach for the development of cleanup criteria, which incorporates site-specific characteristics and is protective of both human health and the environment.

An evaluation of the various strategies used by governmental and agency jurisdictions in North America and Europe to develop cleanup criteria was made in terms of their capability to:

- o incorporate site-specific data;
- o address all environmental media;
- o address all environmental contaminants;
- o incorporate a wide variety of scientific data;
- o distinguish various degrees or periods of contaminant exposure;
- o deal with various routes of exposure;
- o deal with the effect of more than one contaminant exposure to a biological receptor;
- o differentiate between non-carcinogenic and carcinogenic contaminants;
- o incorporate risk assessment;
- o deal with missing data; and
- o incorporate the desired end land use.

Only the strategies adopted by the U.S. Environmental Protection Agency, the U.S. Army and the State of California had the aforementioned capabilities.

In view of the many strategies utilized for cleanup criteria development and the requirements for the development of a scientifically defensible, easily standardized, and "user-friendly" system, it is recommended that a combined approach be investigated. This combined approach would incorporate elements from strategies in both the absolute and relative methods categories for the purpose of providing the most cost-effective mechanisms to meet the diversity of sites requiring cleanup. This strategy would be consistent with the need identified by CCREM for a uniform approach to the development of cleanup criteria which incorporates site-specific characteristics and which is protective of both human health and the environment.

EXECUTIVE SUMMARY

A potential threat to human and environmental health is posed by the existence of toxic substances at closed industrial sites or inadequate waste disposal sites. It is generally acknowledged that this potential threat must be reduced to an "acceptable level" or eliminated completely. While this concept is admirable, the actual determination of what toxic substances should be eliminated and exactly how to define an "acceptable level" of a toxic substance can become very involved. To deal with this problem (i.e. how clean is clean?) various governments and regulatory agencies in North America and Europe use a wide variety of strategies and approaches. These strategies can be divided into two broad categories: absolute methods and relative methods.

The absolute methods generally focus on an established value (or fixed concentration) of a given contaminant in a specific medium (i.e. air, water or soil). Exactly how this established value was derived is usually less important than the fact that a specific regulatory agency or government use it to define:

- o contaminated versus uncontaminated;
- o an acceptable level of contamination; and/or
- o various levels of contamination requiring different responses.

The relative methods focus on the derivation of a site-specific value which will protect human health and the surrounding environment according to:

- o the physical-chemical properties of the contaminant;
- o the movement of the contaminant through environmental media at the site; and
- o the human interaction with those environmental media.

The Canadian Council of Resource and Environment Ministers (CCREM) have recognized the inconsistency of the various approaches used in Canada to develop cleanup criteria. CCREM has identified the need to establish a uniform approach for the development of cleanup criteria, which incorporates site-specific characteristics and is protective of both human health and the environment.

Specific alternatives or strategies for the development of cleanup criteria (as subsets of the general categories of absolute and relative methods) can be described as:

- o ad hoc practices;
- o site-specific risk assessment;
- o national goals for residual contamination;
- o restoration to background or "pristine" levels;
- o technology-based standards (best available technology or best engineering judgement);
- o cost-benefit approach; and
- o site classification and restoration relative to present and future land use.

After a review of these alternatives, the U.S. Office of Technology Assessment (1985) concluded that the ad hoc practices were no longer acceptable and cleanup criteria based on background or pristine levels did not make environmental, technical or economic sense. Although attractive, technology based standards did not offer human health and environmental protection comparable to the cost of implementation. The strategies of setting national goals, the cost-benefit approach and site specific risk assessment could be used, but each one poses considerable problems and has substantial limitations. Of all the strategies, cleanup criteria based on site classification (i.e. present and future use of a site and surrounding area) seemed the most beneficial approach. An even better approach might be obtained by utilizing a combination of some of

the strategies. Thus, a single strategy might include various components of site classification, risk assessment, cost-benefit analysis and existing, relevant environmental standards, as well as consideration of the available cleanup technologies.

Existing strategies used in North America and Europe according to governmental or agency jurisdiction are described below.

- o Alberta has no systematic approach to cleanup criteria selection. The province requires the responsible company or organization to identify site contaminants, contaminants of concern and cleanup levels for governmental approval.
- o Ontario is revising its guide for restoration and rehabilitation of industrial sites. This document provides details of the data and information required for governmental approval of any cleanup plan. Numerical guidelines are provided for some, mainly inorganic, contaminants.
- o Quebec uses an approach based on both the Dutch and French systems. This system uses specific numerical values (concentrations) of soil and groundwater contaminants to define background, moderate contamination and severe contamination, as a basis for the management of contaminated material.
- o The State of California utilizes a standardized, systematic and integrated set of individual tasks (the Site Mitigation Decision Tree) to set site-specific cleanup criteria for any media at any abandoned or uncontrolled waste site within the state.
- o The State of New Jersey derives site-specific, acceptable soil contaminant levels as the end-product of calculations describing human exposure to contaminated soil and groundwater (as a result of contact with contaminated soil). The system also

quantifies the exposure of aquatic organisms to contaminated surface water (as a result of contact with contaminated soil).

- o The State of Washington has a standardized, systematic, prioritized set of procedures for initial and long-term cleanup of contaminated sites. The system is based on the potential for contaminant migration through all environmental media to cause acute and chronic adverse human health effects.
- o The U.S. Army Preliminary Pollutant Limit Value approach was developed to predict the probable environmental limits for a soil contaminant to affect human health through a variety of pathways. Each pathway is described by a specific mathematical equation derived from the physical and chemical properties of the contaminant and the transporting media. Single pathways are combined to a total daily dose to a receptor organism. The contaminant concentration at the source would then be reduced until the total daily dose reaching the receptor is at an acceptable level.
- o The U.S. Environmental Protection Agency has a specific set of procedures (the Superfund Public Health Evaluation Manual) for the derivation of cleanup criteria to prevent adverse health effects in the exposed human population. The main features of this system are the quantification of the migration of contaminants among environmental media and a detailed human exposure assessment.
- o The Netherlands has established a list of contaminants (approximately 50 organic and inorganic chemicals and chemical mixtures) and associated concentrations in soil and groundwater. Three levels or categories of contamination defined by these concentrations are: 1) normal or background; 2) moderate

contamination; and 3) severe contamination. These concentration levels then form the basis for recommendations on the management of contaminated materials.

- o The United Kingdom has published a list of soil contaminant values ("trigger concentrations") below which a site could be regarded as uncontaminated. The trigger concentrations vary with the proposed future use of the site and have been adapted from existing guidelines developed for other purposes or were based on professional judgement.
- o France has published a list of values for four levels of contamination (i.e. threshold values) which once attained require a response. These four levels (responses) are: 1) background maximum (i.e. no response); 2) investigation threshold (i.e. further investigation required before disposition of contaminant is determined); 3) treatment threshold (i.e. soil must be treated to reduce contamination) and 4) emergency threshold (i.e. immediate and decisive action must be taken to remove contamination).

An evaluation of the various strategies used by governmental and agency jurisdictions in North America and Europe to develop cleanup criteria was made in terms of their capability to:

- o incorporate site-specific data;
- o address all environmental media;
- o address all environmental contaminants;
- o incorporate a wide variety of scientific data;
- o distinguish various degrees or periods of contaminant exposure;
- o deal with various routes of exposure;
- o deal with the effect of more than one contaminant exposure to a biological receptor;

- o differentiate between non-carcinogenic and carcinogenic contaminants;
- o incorporate risk assessment;
- o deal with missing data; and
- o incorporate the desired end land use.

Only the strategies adopted by the U.S. EPA, the U.S. Army and the State of California had the aforementioned capabilities. In view of the many strategies utilized for cleanup criteria development and the requirements for the development of a scientifically defensible, easily standardized, and "user-friendly" system, it is recommended that a combined approach be investigated. This combined approach would incorporate elements from strategies in both the absolute and relative methods categories for the purpose of providing the most cost-effective mechanisms to meet the diversity of sites requiring cleanup. This strategy would be consistent with the need identified by CCREM for a uniform approach to the development of cleanup criteria which incorporates site-specific characteristics and which is protective of both human health and the environment.

RÉSUMÉ

Les substances toxiques se trouvant dans des emplacements industriels désaffectés ou lieux d'élimination de déchets mal aménagés constituent une menace potentielle pour la qualité de l'environnement et la santé humaine. Il est généralement admis que cette menace potentielle doit être supprimée ou réduite à un niveau acceptable. Même si l'intention est louable, il peut être, de fait, très compliqué de déterminer quelles substances toxiques doivent être éliminées et de définir des concentrations acceptables pour chacune d'elles. Pour résoudre ce problème, les divers États et organismes responsables nord-américains et européens ont adopté une grande variété de stratégies et d'approches. Ces stratégies se répartissent dans deux grandes catégories: les méthodes absolues et les méthodes relatives.

Les méthodes absolues font généralement appel à des critères préétablis (ou concentration fixe) pur un contaminant donné dans un milieu particulier (l'air, l'eau ou le sol). La façon dont le critère a été élaboré importe habituellement moins que l'usage qu'un organisme de réglementation ou un état en fait, soit:

- . distinguer ce qui est contaminé de ce qui ne l'est pas;
- . établir un degré acceptable de contamination; et/ou
- . décider du type d'intervention en fonction du degré de contamination.

Les méthodes relatives s'appuient sur une grandeur qui est particulière à l'emplacement et qui dans ces fonctions particulières assurera la protection de la santé et du milieu environnant. Ce critère tiendra compte:

- . des propriétés physico-chimiques du contaminant;
- . du déplacement du contaminant à travers les divers milieux environnementaux;
- . de l'interaction de l'Homme avec ces milieux.

Le Conseil canadien des ministres des ressources et de l'environnement (CCMRE) a constaté l'incohérence des diverses méthodes adoptées au Canada pour élaborer des critères de décontamination. Le CCMRE s'est sensibilisé à la nécessité d'adopter une approche uniforme pour la mise en place des critères de décontamination, qui tient compte des caractéristiques propres aux emplacements et qui vise la protection de la santé ainsi que de l'environnement.

Pour l'élaboration des critères de décontamination, les solutions de rechange ou stratégies (sous-ensemble des critères généraux des méthodes absolues et relatives) peuvent être décrites comme suit:

- . les pratiques ad hoc;
- . l'évaluation du risque propre à un lieu;
- . les objectifs nationaux de contamination résiduelle;
- . la restauration au niveau du bruit de fond;
- . les normes basées sur les meilleures techniques disponibles ou sur les meilleures règles de l'art;

l'approche coûts/bénéfices;
le classement et la restauration des lieux en fonction de
leur utilisation actuelle ou future.

A la suite d'une évaluation de ces stratégies en 1985, le U.S. Office of Technology Assessment a conclu que les pratiques dites ad hoc n'étaient plus acceptables et que la restauration au niveau du bruit de fond était écologiquement, techniquement et économiquement inconcevable. Bien qu'attrayante, la décontamination basée sur les meilleures techniques disponibles n'offrait pas une protection de la santé et de l'environnement proportionnelle aux coûts de la mise en oeuvre. L'établissement d'objectifs nationaux, l'approche coûts/bénéfices et l'évaluation du risque spécifique à un lieu posent, malgré leurs qualités, des problèmes importants et ils sont considérablement limités. Seuls les critères de décontamination fondés sur le classement du lieu et de ses abords selon leur utilisation actuelle et éventuelle ont semblé le plus avantageux. Le mieux encore serait de combiner certaines de ces stratégies en une seule qui pourrait ainsi employer le classement du lieu, l'évaluation du risque, l'analyse du rapport coûts/bénéfices, les normes environnementales pertinentes, de même que la prise en considération des techniques de décontamination disponibles.

Les stratégies utilisées actuellement en Amérique du Nord et en Europe par les États et les organismes compétents sont décrites ci-dessous.

- o L'Alberta n'a pas de stratégie systématique lui permettant de sélectionner des critères de décontamination. Elle demande à la compagnie ou à l'organisme responsable d'identifier les contaminants se trouvant sur le lieu et ceux qui sont préoccupants et de proposer, pour approbation, les niveaux de décontamination suggérés.
- o L'Ontario révisé actuellement son guide de restauration et de réhabilitation des lieux industriels. Ce document précise quels sont les données et les renseignements requis pour obtenir l'approbation de plans de décontamination. Des critères sont indiqués pour certains contaminants, inorganiques pour la plupart.
- o Le Québec s'inspire des modèles néerlandais et français, c'est-à-dire qu'à partir de grandeurs particulières (concentrations affectant les contaminants des sols et des eaux souterraines) il définit trois niveaux de contamination (de base, modérée et grave) en vue de la gestion de la matière contaminée.
- o La Californie fait appel à un ensemble uniformisé, systématique et intégré de tâches unitaires (l'arbre de décisions pour la décontamination des décharges) afin d'établir des critères de décontamination propres à chaque lieu désaffecté ou sauvage dans l'État.

- o Le New Jersey obtient les concentrations acceptables de contaminants du sol en se basant sur des calculs tenant compte de l'exposition de l'Homme aux sols contaminés et aux eaux souterraines contaminées. Pour chaque site le système permet aussi de quantifier l'exposition des organismes aquatiques aux eaux de surface contaminées (par un sol contaminé).
- o L'État de Washington a mis sur pied un système uniforme systématique permettant un nettoyage préliminaire et à long terme des lieux contaminés. Le système est fonction de la probabilité que la migration éventuelle des contaminants dans les divers milieux exerce des effets nocifs, tant aigus que chroniques, sur la santé.
- o Le système "Preliminary Pollutant Limit Value" de l'Armée américaine a été élaboré pour déterminer les limites de probabilité qu'un contaminant se trouvant dans un sol affecte la santé par différents cheminements. Chaque cheminement est décrit à l'aide d'une équation mathématique découlant des propriétés physico-chimiques du contaminant et des milieux traversés. Les différents cheminements sont combinés pour obtenir une dose journalière cumulée pour un organisme récepteur. La concentration du contaminant à la source est alors réduite jusqu'à ce que la dose cumulée se retrouve à un niveau acceptable.
- o L'EPA recourt à un ensemble spécifique de modalités (Superfund Public Health Evaluation Manual) afin d'établir des niveaux de décontamination empêchant les contaminants d'avoir un effet nocif sur la santé de la population exposée. Les principales caractéristiques de ce système sont que la migration des contaminants dans les divers milieux est quantifiée et que l'exposition de l'être humain est évaluée dans le détail.
- o Les Pays-Bas ont dressé une liste des contaminants (environ 50 composés et mélanges organiques et inorganiques) et de leur concentration dans les sols et les eaux souterraines. Ces concentrations définissent trois degrés de contamination: (1) normale ou de base; (2) modérée; (3) grave, dont découleront les recommandations sur la gestion des matières contaminées.
- o Le Royaume-Uni a publié une liste des seuils sous lesquels on peut présumer la non-contamination du sol pour un contaminant donné. Ces seuils, qui varient selon l'utilisation projetée du lieu, ont été adaptés à partir de critères utilisés à d'autres fins ou se fondent sur une appréciation technique.
- o La France a publié une liste de critères, correspondant à quatre niveaux de contamination distincts, soit: (1) le seuil d'anomalie (aucune intervention); (2) le seuil d'investigation (enquête approfondie nécessaire avant de se prononcer sur la nécessité d'éliminer le contaminant); (3) le seuil de traitement (c'est-à-dire traitement du sol afin d'en réduire la contamination); (4) le seuil d'urgence (c'est-à-dire

intervention immédiate et décisive pour supprimer la contamination).

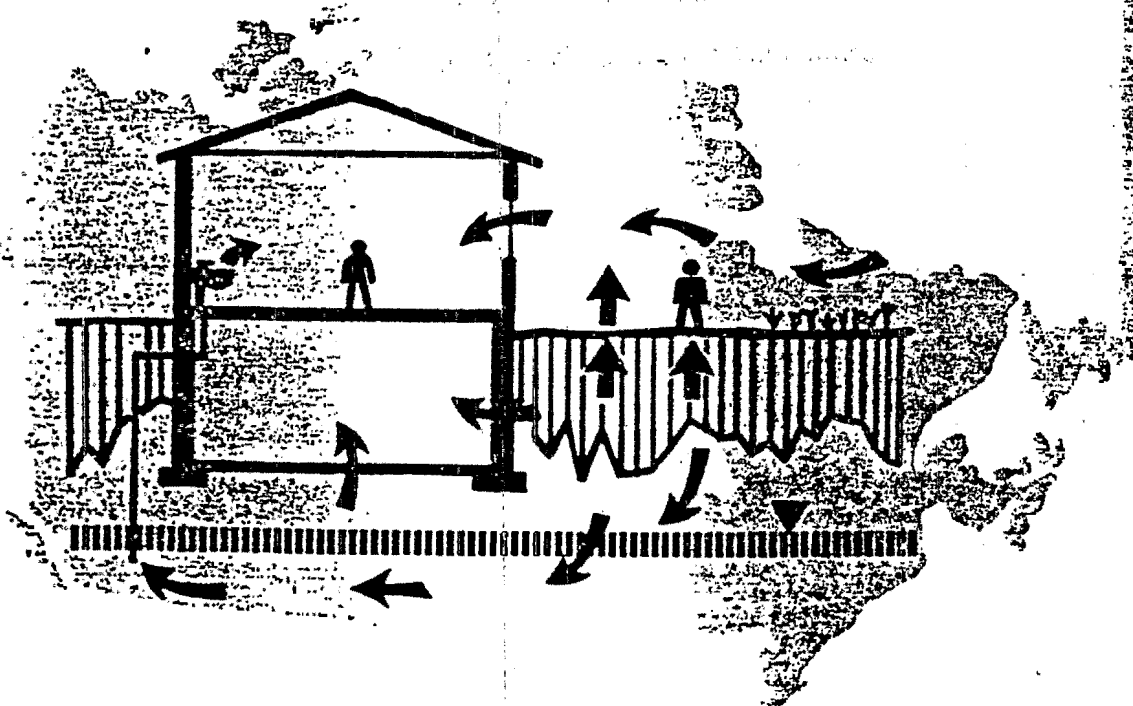
L'évaluation de chacune des stratégies utilisées pour élaborer des critères de décontamination s'est faite en tenant compte de leur capacité à:

- o inclure des données propres à chaque lieu;
- o tenir compte de tous les milieux;
- o tenir compte de tous les contaminants;
- o amalgamer une grande variété de données scientifiques;
- o distinguer entre les divers niveaux ou périodes d'exposition;
- o tenir compte de diverses voies d'exposition;
- o tenir compte de l'effet sur un récepteur biologique d'une exposition à plus d'un contaminant;
- o distinguer entre les contaminants cancérogènes et non cancérogènes;
- o évaluer le risque;
- o tirer le meilleur parti possible de données fragmentaires;
- o tenir compte de l'utilisation finale souhaitée du sol.

Seules les stratégies de l'EPA, de l'Armée américaine et de la Californie possédaient ces caractéristiques. En raison des nombreuses stratégies utilisées pour l'élaboration de critères de décontamination et de la nécessité d'élaborer un système scientifiquement défendable, facile à uniformiser et à utiliser, il est recommandé d'étudier la possibilité de développer un système combinant les méthodes absolues et relatives. Ce système combiné permettra un meilleur rendement coûts/bénéfices, tenant compte de la grande diversité des lieux pour lesquels un nettoyage est envisagé. Cette façon de procéder répondra au besoin, constaté par le CCMRE, d'uniformiser les critères de décontamination en tenant compte des caractéristiques particulières aux différents lieux et à la nécessité de protéger la santé et l'environnement.

THE DEVELOPMENT OF SOIL CLEANUP CRITERIA IN CANADA

CONTAMINATED SOIL CLEANUP
IN CANADA
VOLUME 2
INTERIM REPORT ON THE
"DEMONSTRATION" VERSION OF
THE AERIS MODEL
(AN AID FOR EVALUATING THE
REDEVELOPMENT OF INDUSTRIAL SITES)



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**prepared for the
Decommissioning Steering Committee**

1988-12-15

NOTICE OF WARRANTY

The organizations and individuals associated with the creation or development of AERIS make no representations or warranties of any kind with respect to its contents and disclaim any implied warranties of suitability for any particular purpose. Neither are they liable for any errors in the software or any damages resulting from its performance or use.

SUMMARY

Wherever industrial activities have caused on-site soils or ground water to become contaminated and redevelopment to another use is being considered, there is the potential for future site users or those located down gradient to be exposed to chemicals present in site soil through various pathways such as the inhalation of vapours, direct ingestion of soil, or the ingestion of local ground water.

At the present time, few jurisdictions have established acceptable soil concentrations. In June 1987, Environment Canada awarded a contract to a consortium of consultants headed by Monenco Consultants Limited. One of the goals of the consortium was to produce a computer model that can be used to derive clean-up guidelines for industrial sites where redevelopment is being considered or planned. The result is the "demonstration" version of the AERIS model. The acronym AERIS (Aid for Evaluating the Redevelopment of Industrial Sites) was chosen to help users remember its intended use, that of being an aid for evaluating industrial sites. As an aid, AERIS is suited to identifying the factors that are likely to be major contributors to potential exposures and concerns at sites, those aspects of a site redevelopment scenario with the greatest need for better information, or as an indicator of the extent to which remedial action may be needed at a site.

The AERIS model consists of four basic elements - an "intelligent" preprocessor, component modules, a postprocessor, and supporting data bases. The preprocessor takes the form of a series of questions that AERIS asks the user about the redevelopment scenario to be evaluated. The preprocessor is referred to as "intelligent" due to the utilization of "expert system" technology. It uses a set of rules (collectively referred to as a "knowledge base") to establish a structure to the decision support offered; to aid the user in estimating unknown input parameters, and to control the flow of information among the other program modules.

The preprocessor passes the information generated by the user's answers to the component modules which calculate environmental concentrations, doses experienced by the selected site user, and the resulting "acceptable" concentrations in soil. There are seven component modules in the "demonstration" version of AERIS.

The *Correlation Module* is used to predict mass transfer coefficients. The predictions subsequently are used in the *Air Module* which calculates the flux of chemical from the soil into the air and basements of buildings where it can be inhaled by a site user or visitor. The rate at which a chemical will be transported from soil into the outdoor air is influenced by properties of the soil, properties of the chemical, and environmental conditions.

The *Unsaturated Zone Module* predicts concentrations in soil-water and soil-air in the soil above the water table. It assumes that there is a contaminated layer that starts at the surface and that the user can define the layer in terms of its average or typical depth and contaminant concentration. If appropriate, there can be an underlying non-contaminated soil layer.

The *Saturated Zone Module* predicts concentrations in ground water. Key factors it considers include the depth of contamination with respect to the depth to the local water table, and the location of a well used for drinking water, if

appropriate.

The *Produce Module* is used to estimate concentrations in produce grown on the site. The uptake of chemicals is assumed to be contributed by root uptake and foliar deposition. The extent of uptake is influenced by the type of produce, length of growing season, chemical properties of the chemicals, and soil characteristics.

In the *Ingestion Module*, the intakes of water, soil, and garden produce are estimated. The concentrations in the water, soil, and produce are determined in the Saturated Zone Module, Unsaturated Zone Module, and Produce Module, respectively.

In the *Inhalation Module*, the amounts of chemical inhaled by the receptor while outdoors and indoors are calculated. Both the inhalation of vapours and particulate matter are taken into account.

In the *Total Dose Module*, the doses via all pathways are combined. The total is then compared to the "acceptable" dose level. The user can decide whether all or some fraction of the "acceptable" level is to be used.

The calculations of the component modules are passed to the postprocessor, which offers various tabular and graphical ways of displaying the results. Each run of the model concludes with tables that display dose estimates for each route, total dose estimates, and identification of an "acceptable" soil concentration. At the user's discretion, three types of graphical summaries can be displayed: a plot of soil concentrations versus dose; pie charts of the relative contributions of each route to total exposure; and diagrams that compare the calculated "acceptable" concentrations to guidelines or criteria issued by regulatory agencies.

AERIS data bases can provide much of the information needed for the calculations. Information is retrieved in response to the user's answers concerning the scenario to be evaluated. The types of information that can be retrieved include physico-chemical data, "acceptable" dose levels, bioavailability factors, concentrations associated with other types of adverse effects, and guidelines or criteria from various jurisdictions. The user has the opportunity to edit any of the information retrieved from the data bases so that the redevelopment scenario can be made to resemble actual situations of interest. AERIS also includes default values and various aids to help users select appropriate values. The data bases in the "demonstration" version of AERIS have information for:

- two types of site users: an adult and a young child
- four future land uses: residential, commercial, recreational (park land), and agricultural
- four organic compounds: benzene, methyl ethyl ketone, phenanthrene, and pyrene
- three inorganic substances: lead, selenium, and zinc
- the meteorology of six Canadian cities: St. Johns, NFLD, Montreal, PQ, Toronto, ON, Winnipeg, MN, Edmonton, AL, and Vancouver, BC
- physical characteristics of nine soil types and 14 underlying formations.

AERIS is structured so that each run evaluates one chemical for one receptor, one land use, and one environment. The user is encouraged to run the model

several times and base decisions on the collective outcomes of those runs. Accordingly, adjustments to input parameters can be made relatively easily.

AERIS is designed to evaluate situations where the soil had been contaminated sufficiently long ago to establish equilibrium or near-equilibrium conditions between the various compartments of the environment. These conditions should apply to most industrial sites that are being considered for redevelopment. As such, AERIS is not suitable for evaluating recent spill sites or locations being considered as candidates for receiving wastes. Nor is it suitable for calculating changes in environmental concentrations or exposures over time due to ongoing contaminant contributions from a constant or sporadic source.

To illustrate various aspects of the AERIS model and its response to different sets of input parameters, two hypothetical redevelopment scenarios were created. Scenario "A" was assigned characteristics typical of those that might be encountered at a site in southern Ontario, while Scenario "B" is more representative of a site in central Alberta.

The AERIS model was used to identify "acceptable" soil guidelines for each scenario by considering three soil contaminants (benzene, phenanthrene, and lead), for all four of the land uses addressed in the data base, and using the young child as the receptor.

For benzene, the "acceptable" soil concentrations for Scenario "A" (0.08 to 0.6 mg/kg) are slightly higher than for Scenario "B" (0.04 to 0.6 mg/kg). The only guidelines in Canada include a value of 0.5 mg/kg recommended by the Province of Quebec as the threshold at which detailed site investigations may be needed, and a concentration of 5 mg/kg which is recommended as the threshold at which immediate corrective actions may be necessary.

The lower concentrations in Scenario "B" stem from the lower organic carbon content in that site's soil and the subsequently higher concentrations of vapours in air (and higher receptor doses via inhalation). The inhalation of vapours is a dominant pathway (50 to 84%) for total exposure to benzene in all land uses except recreational (in which all time on-site is spent outdoors). Associated with the "acceptable" soil concentrations are outdoor air concentrations well below the air quality criterion from Ontario but ground water concentrations (at the site boundary) above the guideline from Quebec. The values also are less than those reported to cause odours or phytotoxicological effects.

For phenanthrene, the concentrations for Scenario "A" (3300 to 20400 mg/kg) are slightly lower than for Scenario "B" (3500 to 23300 mg/kg). Site soil conditions in Scenario "A" result in slightly higher ground water concentrations of phenanthrene, an important pathway that accounts for 24 to 64% of the total dose estimates. The only guidelines in Canada include a value of 5 ppm recommended by Quebec as the threshold at which detailed site investigations may be needed, and a concentration of 50 ppm which is recommended as the threshold at which immediate corrective actions may be necessary.

For lead, concentrations for Scenario "A" (8 to 500 mg/kg) are slightly higher than for Scenario "B" (5 to 15 mg/kg). Soil guidelines in Canada lie in the range of 200 to 1000 mg/kg. The dominating influence of produce ingestion in Scenario "A" stems from a relatively high plant uptake factor. The

"demonstration" version of AERIS makes no allowance for reductions of concentrations in produce that result during food preparation such as washing, peeling, or boiling. As a result, the estimated doses from eating produce are likely to exceed actual doses. This becomes an important consideration in interpreting the output for scenarios in which the consumption of produce is a major pathway.

The sandy soil in Scenario "B" results in higher concentrations of lead in ground water and therefore doses via that route are significantly greater than in Scenario "A". The dominating influence of ground water ingestion in Scenario "B" results in "acceptable" soil concentrations considerably lower than those being used or considered by some regulatory agencies. The inclusion of site ground water as a source of exposure is an unlikely condition especially in urban areas. If ground water had not been included as a pathway, the "acceptable" soil value for Scenario "B" would have been approximately 100 to 450 mg/kg. For both scenarios, the use of lead-specific bioavailability factors (rather than the default values) likely would significantly increase the "acceptable" soil concentrations.

Associated with the "acceptable" soil concentrations for lead are ground water concentrations (at the site boundary) below the drinking and ground water guidelines of several Canadian agencies. The values also are well below those reported to cause phytotoxicological effects.

The investigations of Scenarios "A" and "B" suggest that various aspects of AERIS are performing as intended. For example, the "acceptable" soil concentrations are inversely proportional to the relative level of toxicological concern posed by chemicals. As anticipated, future site use is an important consideration in setting "acceptable" concentrations. Residential and agricultural uses consistently generate lower "acceptable" concentrations than recreational and commercial uses. Comparisons of output for a compound in Scenario "A" with that for Scenario "B" show that site soil and meteorological conditions also can be important influences in determining "acceptable" soil concentrations.

Based on a review of the results for the two scenarios, it is apparent that "acceptable" soil concentrations for inorganic substances are strongly influenced by soil pH and the value of the distribution coefficient (K_{di}). Since default values for K_{di} are not provided by the model, a user who must "guessimate" at values for K_{di} may want to run the model several times to evaluate the overall sensitivity of the results to this parameter. For organic compounds that have physico-chemical characteristics in the data base, there is not a key parameter analogous to the K_{di} , but for compounds not in the data base, the veracity of the values used for aqueous solubility, vapour pressure and octanol-water partition coefficient should be key considerations in determining the level of confidence that can be placed in the results.

Because the development of the AERIS model has only reached the "demonstration" stage, the results that it produces always must be interpreted in the context of several cautionary notes:

- The "acceptable" soil concentrations that are identified are based solely on human health concerns. The conservative, risk-based philosophy and default values that appear throughout the model (examples include receptor behaviour characteristics, the bioavailability factors, the one-

in-a-million level of risk for VSD values, the general availability of contaminated site soil for exposure) make it possible to generate "acceptable" soil concentrations lower than those that regulatory agencies may be using or considering. Likely causes include the use of risk as a basis for setting concentrations and the inclusion in the model of pathways usually not considered. Conversely, relatively high "acceptable" soil concentrations can be identified when using AERIS, particularly if the scenario being evaluated generates very small dose estimates or the important exposure pathways are relevant for chemicals with certain physico-chemical properties or environmental behaviours. For example, this could occur in the evaluation of a non-volatile chemical that has a low level of toxicological concern in a commercial setting.

- The algorithms used to estimate environmental fate and concentrations in environmental compartments as a function of the concentration in soil have been verified but not calibrated (that is, the predictions of the algorithms have not been compared to concentrations measured at actual industrial sites in various environments).
- There likely are inadequacies in the algorithms in the "demonstration" version of AERIS. During model development, it was recognized that some aspects of the algorithms may be poorly suited to evaluating conditions where soil is extremely alkaline or acidic, plant uptake is not well understood, and the overall approach may require site complexities to be replaced with generalizations.
- The "acceptable" soil concentration values that are determined by AERIS should not be taken as absolutes but rather as being generally indicative of appropriate concentrations. To establish soil guidelines with greater confidence, it may be necessary to evaluate a scenario by running the model many times so that output variability and sensitivity can be assessed. It also may be necessary to examine each of the conservative assumptions used from a chemical-specific perspective and/or other non-health related issues may need to be considered.

NATO/CCMS Guest Speaker:

Troels Wenzel, Denmark

Membrane Filtering and Biodegradation

ON-SITE / IN-SITU RECLAMATION

MEMBRANE FILTERING AND BIODEGRADATION

by

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1. INTRODUCTION

Every year the number of known contaminated sites in Denmark increases. Today more than 2,000 sites are registered and the number has not culminated yet. Unofficially the number of contaminated sites is estimated to more than 15,000.

About 90% of the sites are contaminated with some kind of organic components, most of which can be biodegraded under aerobic conditions on-site as well as in-situ.

On that basis the three companies DDS-Filtration, Danish Geotechnical Institute and Højgaard & Schultz formed a joint venture with the purpose to develop and test new and more cost-effective methods for cleaning up organically contaminated soil and groundwater. The technique proposed was a combination of biological in-situ restoration and on-site membrane filtering followed by biological destruction of the contaminating agents.

2. ORIGINAL TREATMENT PLAN

The working group set up by the companies designed a treatment system based on the following main processes:

0. Recovering of contaminated groundwater
1. Pre-treatment of the pumped-up groundwater
2. Filtration of the groundwater by Reverse Osmosis (RO)
3. Biological purification of the concentrate from the RO unit
4. Recirculation of purified groundwater and oxidation
5. Biodegradation in soil and groundwater

The concept was planned to be tested and developed at a gasworks site near Copenhagen, Denmark, cf Figure 1.

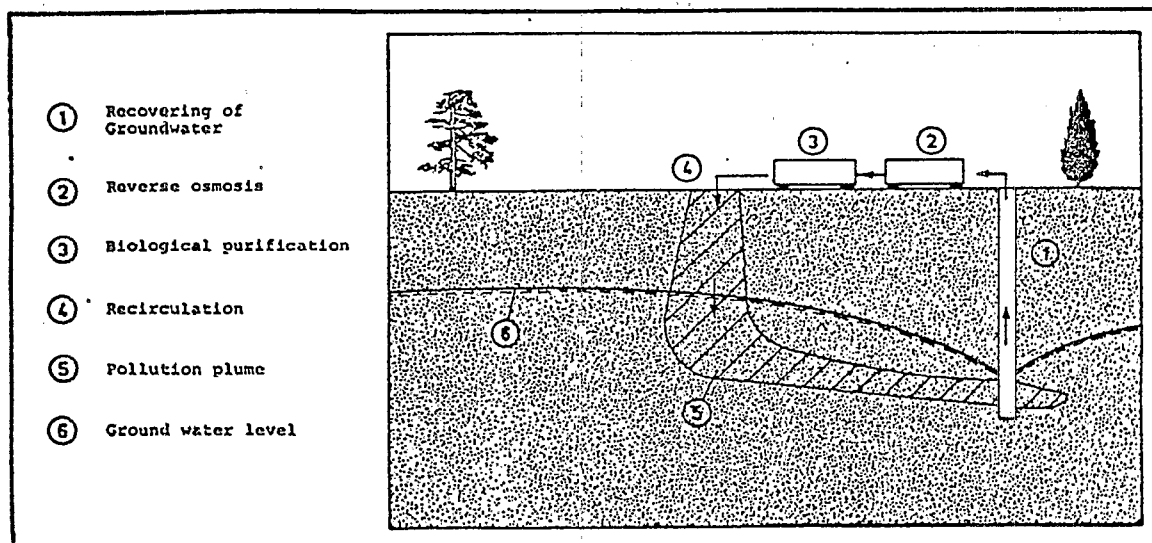


Figure 1. The main processes in the treatment system.

Previous environmental investigations had demonstrated that the soil and groundwater were polluted with tar components, cyanides and sulphur. The main results are shown in tables 1 and 2.

Coal tars	100 -	37000 mg/kg
Naphthalene	5 -	200 mg/kg
Cyanide (total)	100 -	3500 mg/kg
Sulphur	5000 -	40000 mg/kg

Table 1. Concentrations of pollutants in the soil.

Volatile aromatics	100 -	1600 µg/l
Phenols	10 -	2300 µg/l
Naphthalenes	300 -	18000 µg/l
Sulphur	30 -	1700 µg/l
Ammonium	20 -	200 µg/l
Cyanide (total)	0,01 -	1,9 mg/l
Iron	100 -	500 mg/l
Calcium	100 -	750 mg/l

Table 2. Concentrations of pollution components in the groundwater.

3. RESULTS, PROBLEMS ENCOUNTERED AND MODIFICATIONS

During the small-scale field experiments and laboratory tests, a series of operational problems were identified regarding the planned treatment.

3.1 Pre-treatment of the Pumped-up Groundwater

The testing of RO filtration is described in chapter 3.2. However, all RO membranes are very sensitive to the feedwater's contents of iron, calcium carbonate and particles in general so experiments were carried out with pre-treatment of the groundwater before entering the RO unit. Especially the extremely high contents of iron as Fe^{++} (300 ppm) caused problems in the early trials.

After the first long-time trial on the site, problems with clogging of the RO membrane by precipitated iron indicated that the proposed pre-treatment by simple sand filtration could not provide the water quality needed for the RO processing.

The modified pre-treatment system was optimized by running the system in batches. NaOH was added to the pumped-up groundwater and air was injected before entering the reaction tank. After a reaction period of approx. 15 min. the suspended particles were precipitated in a clarifier. The effluent was pumped to a sand filter and adjusted to pH 7 before entering the RO unit. The modified pre-treatment system is visualized in Figure 2.

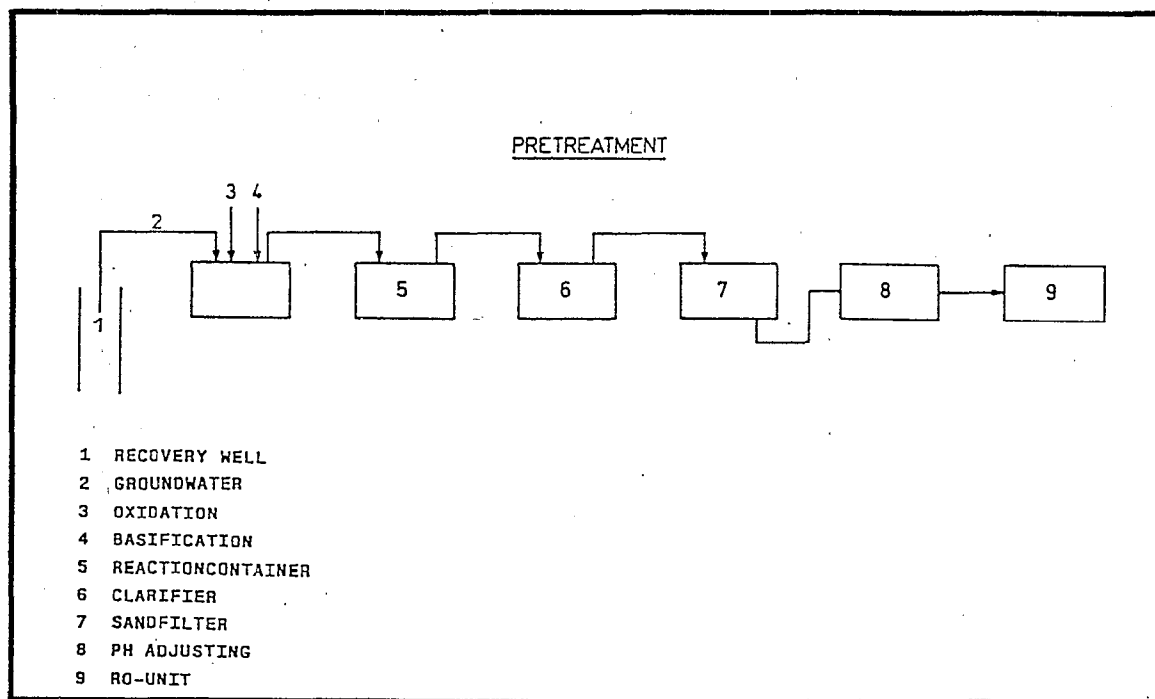


Figure 2. Modified pre-treatment system.

The sludge from the pre-treatment consisted mainly of ferri-hydroxide ($\text{Fe}(\text{OH})_3$) and smaller amounts of calcium carbonate (CaCO_3). Analyses of the sludge and feedwater entering the RO unit showed a substantial loss of organic components to the sludge during the precipitation of particles. The analyses also indicated that most of the volatile components had been stripped off into the atmosphere in the aerated reaction tank. The total loss of tar components before the water entered the RO unit was estimated to be 40-70 %.

The high content of tar components in the sludge made it heavily contaminated and therefore unfitted for deposit at an ordinary disposal site as planned.

3.2 Filtration of the Groundwater by Reverse Osmosis

Several types of filtering units and membranes have been tested for the purpose. The so-called Plate-and-Frame type was found to be the filtering system most unsensitive to clogging.

The RO unit used in the final tests was a DDS Plate-and-Frame system equipped with a HR thinfilm polyamide composit membrane.

The system consists of a specially moulded and perforated support plate which is flanked by two flat sheet membranes. These membrane-covered plates are staked and mounted in a stainless steel frame. When the plates are compressed, thin channels are formed between the membranes due to the plate ribs. This special flow pattern creates a high shear rate over the membranes.

The Plate-and-Frame unit used in the trials rejected the organic as well as the inorganic components successfully.

There was a tendency that the unit showed higher rejection rates for components with a relatively higher molecular weight.

Also the polarity of the molecules had an impact on the performance. The membrane chosen for the purpose had an approximately 10% higher rejection rate for unpolar components than for polar components. For example the rejection rate for BTEX's was almost 100% whereas phenols and cresols were separated from the permeate at a 90% level.

The rejection rates for metals and inorganic components were overall easily accomplished at a 97-99% level.

Component	Approx. rejection rate in %
Benzene	98 .
Toluene	98 .
Xylene	98 .
Phenol	89 .
O-cresol	88 .
M-cresol	95 .
P-cresol	97 .
Naphthalene	98 *
Cyanide	99 .
Chloride	99 .
Metal ions	98 .
* Estimated value	
. Measured value	

Table 3. Rejection rates for the RO unit under laboratory and on-site test operation.

3.3 Biological Purification of the Concentrate From the RO Unit

Comparing laboratory tests of activated sludge and Rotating Biological Contactor (RBC) demonstrated that the RBC was the more cost-effective and therefore the RBC was chosen as the reactor in which the destruction of the concentrate from the RO unit should take place.

The pilot scale reactor was started with groundwater recovered from the gasworks site and gradually fed with increasing volumes of concentrate from the RO unit.

The reactor performed well after an adaption period of 3-4 weeks, after which the components were destructed down to almost undetectable concentrations.

Xylenols created some problems and never reached values lower than 200-300 ppb in the effluent.

Odours from the bioreactor were foreseen but were expected to be reduced to acceptable levels by a reactor cover and an odour filter, a compost or an activated carbon filter.

3.4 Recirculation of Purified Groundwater and Oxidation

On-site testing of the possibility of percolating water through the soil showed that the infiltration rate was much lower than expected in the early phases of the project.

With hydraulic conductivities of 10^{-6} - 10^{-7} m/s the original intention to wash out mobile components of the soil by means of recirculation was considered as irrelevant at the site in question.

Under normal pressure and temperature conditions water saturated with atmospheric air is able to hold approximately 9 mg O_2 per litre. As a rule of thumb, 1 g of hydrocarbons requires 2-3 g of oxygen to be totally degraded, and only 10-30% of the oxygen reaching the contaminated area in the soil will be used for degradation of the contaminants. The rest is used for oxidation of a variety of other substances in the soil. The volume of water required for oxygen transport would therefore be enormous.

The use of other oxygen sources such as hydrogenperoxide could reduce the needed volume of water to some extent but the volume of water would still be very large which - in combination with the low permeabilities of the soil - made it impossible to sustain the biological degradation at a rate where the clean-up objectives would be reached within reasonable time.

The proposed solution to the problem of oxygen transport is to combine soil venting and water reinfiltration. In this solution atmospheric air is vented through the soil and water containing nutrients is infiltrated from the surface simultaneously. The infiltration rate is kept sufficiently low to avoid water saturation of the soil, thus enabling a constant oxygen supply to the microbes in the soil by means of diffusion of oxygen from the airfilled pores into the oxygen-depleted porewater.

An additional benefit of the soil venting is the stripping off of the volatile components.

3.5 Biodegradation in Soil and Groundwater

An additional research programme has been carried out with the object of studying the degradation rate of the tar components (polynuclear aromatic hydrocarbons, aromatic hydrocarbons and phenolic components).

The soil and groundwater used in the laboratory tests were collected from the gasworks site. All the experiments were carried out in bottles which were kept at 10 degrees Celsius in darkness in order to simulate the natural conditions in the best possible way. The groundwater discharge was simulated by rotating the bottles. The bottles were given different conditions by using nutrients, oxidation mediums (O_2 , KNO_3) and different concentration levels of contaminants.

The degradation rate was examined by means of chemical analyses using gaschromatography, microbiological tests such as DEFT and platecount, and tests with labelled components (liquid scintillation counting of carbon-14).

The data from the laboratory experiments have not been prepared for presentation yet. However, the results of some of the tests with labelled components and some of the microbiological tests are examined in the following figures and tables.

In table 4 some of the results from the platecount tests are listed. The data show an increasing number of colony forming bacteria in the first 19-58 days in both one litre bottles and in the small bottles. This could indicate that the reproduction of the bacteria principally takes place shortly after the start of the experiment.

Platecount data (colony-forming units pr. g)					
	0 day	19 days	58 days	176 days	197 days
One-litre bottle aerob, no nutrients	3×10^4	8×10^6			2×10^7
One-litre reference bottle (no biological activity)	$<10^3$	2×10^3			$<10^3$
300 ml bottle aerob, no nutrients	5×10^5		5×10^7	5×10^7	
300 ml reference bottle (no biological activity)	$<10^3$		$<10^3$	$<10^3$	

Table 4. The biological activity tested with platecount in one-litre bottles and in small bottles (300 ml).

The total decomposition of carbon-14-labelled anthracene was tested with liquid scintillation counting of the produced labelled carbondioxide. An example of the results is shown in figure 3. Figure 3 shows that about 2% of total decomposition in the test bottle has taken place and no degradation at all in the reference bottle. It should be noticed that the intermediates in the decomposition are not included in this kind of test.

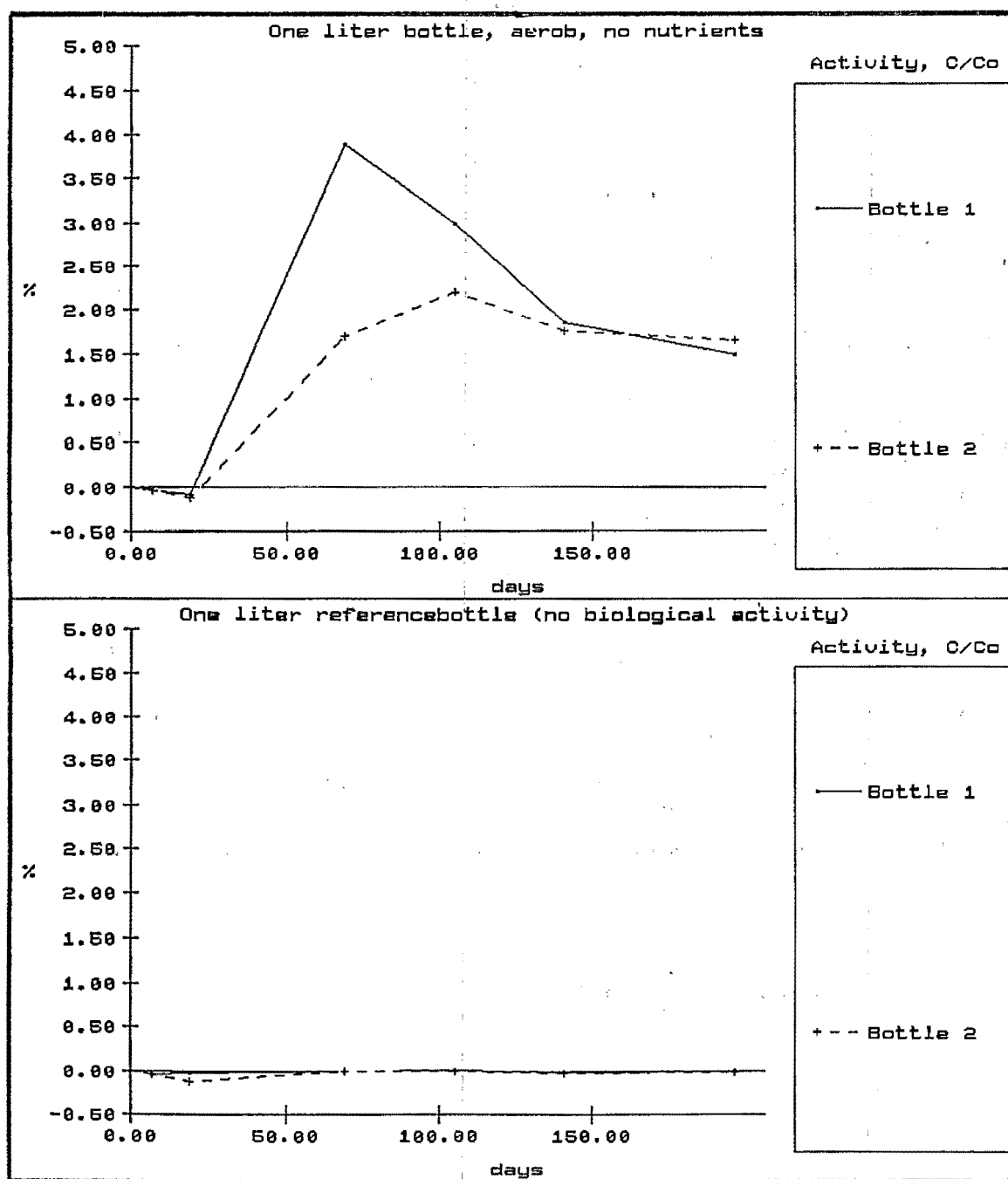


Figure 3. The total degradation tested with liquid scintillation in a test bottle system and in a reference bottle system. C : The actual concentration of the labelled carbon dioxide. C_0 : The highest possible concentration of the labelled carbon dioxide.

Figure 4 shows the decrease in the concentrations of some of the contaminants in the groundwater and aquifer materials. These data fit well together with the data shown in table 4 and figure 3 indicating decomposition of the tar components.

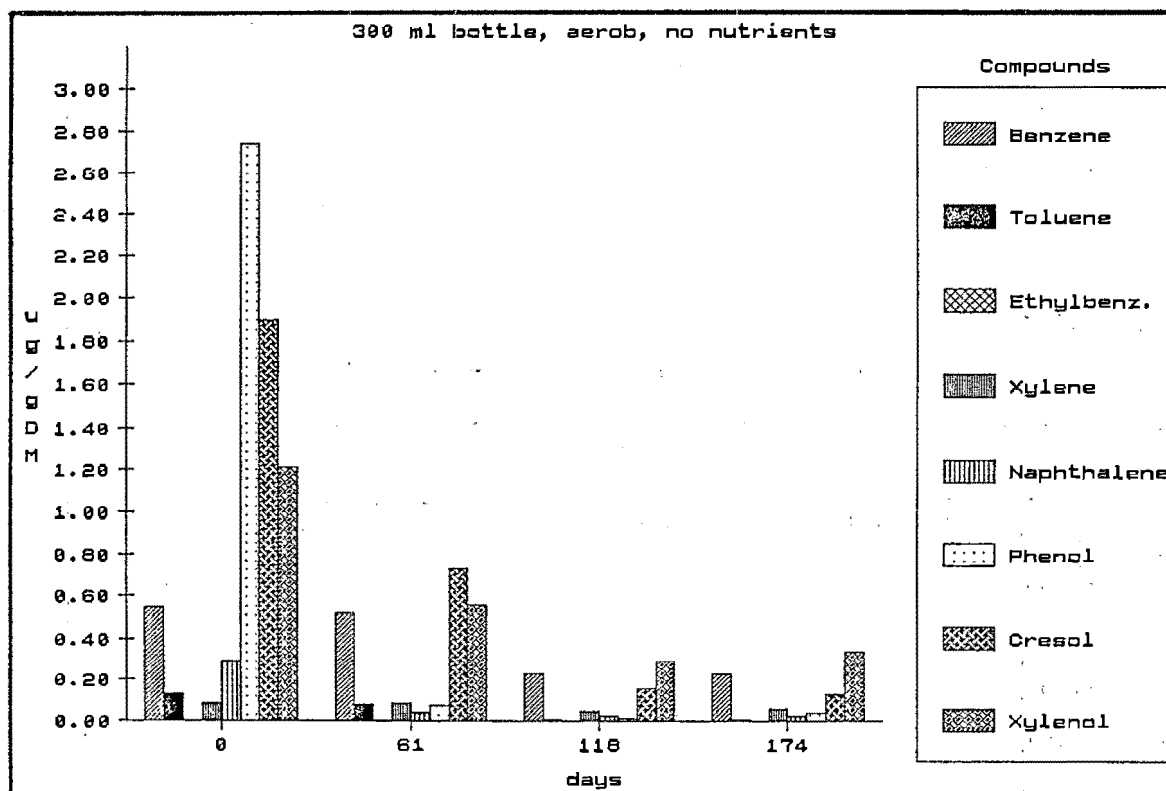


Figure 4. Decreasing concentrations of various components indicating biodegradation.

4. CONCLUSIONS AND FINAL REMARKS

On the basis of the results of the laboratory and small-scale on-site tests the following conclusions can be drawn:

- The RO system proved a high degree of purification regarding the organic components in the ground water. It also turned out to be very sensitive to some of the inorganic components. This required an extensive pre-treatment during which a great deal of the organic components were precipitated or stripped off. Thus, the RO unit which was a vital part of the purifying treatment ended up by being obsolete. Besides a sludge problem arose.
- In comparison with activated sludge the RBC was cheaper as well as more efficient and more sturdy towards the fluctuating concentrations of contaminating components. Laboratory testing of biological purification of the concentrate from the RO unit demonstrated a high degree of purification.
- Preliminary results from the laboratory analyses of the capacity of decomposition in the soil and groundwater samples from the trial site indicate decomposition of tar components under aerobic conditions.
- On-site tests of the percolation showed unexpectedly low permeability coefficients which in practice would make it impossible to wash out mobile components and to recirculate purified and oxidized groundwater enough to create and maintain aerobic conditions in the subsoil as originally planned.

For the above mentioned reasons the planned purification treatment was abandoned and the in-situ purification experiment on the former gasworks site was stopped.

NATO/CCMS Guest Speaker:

Herve Billard, France

Industrial Waste Management in France

**The NATO/CCMS Pilot Study
on Demonstration of Remedial Action
Technologies for Contaminated
Land and Groundwater**

Fourth International Conference

5 au 9 November 1990

ANGERS - FRANCE -

**INDUSTRIAL WASTE MANAGEMENT
IN FRANCE**

by
Hervé BILLARD

THE MANAGEMENT OF INDUSTRIAL WASTES

Industrial Wastes: A Few Figures

In France, industrial wastes are usually classified in three categories:

- 1) Inert wastes, comprised of earth, debris, inert materials produced by processing of minerals. These wastes are usually put in dumps. Estimated annual production: 100 million metric tonnes.
- 2) Commonplace wastes, similar to household refuse and able to be treated using the same methods. These wastes include wood, waste paper, cartons and cardboard, plastics, etc. Estimated annual production: 32 million metric tonnes.
- 3) Special wastes which are characteristic of industrial activity. These wastes contain harmful elements in concentrations of varying degree and therefore pose a higher risk to the environment. Disposal of the wastes must be carried out with special precautions. Estimated annual production: 18 million metric tonnes, of which 4 million metric tonnes are classified toxic or dangerous.

Special wastes may also be classified in three categories:

- a) Organic wastes (mainly hydrocarbon wastes, tar, solvents, etc.), usually able to be treated by incineration, although physico-chemical treatment processes are being developed for certain very specific wastes. The presence of chlorous molecules in a large part of these wastes requires special smoke purification.
- b) Liquid or semi-liquid mineral wastes (for example, treatment baths for metal surfaces, acids or bases) which are able to be treated physico-chemically (neutralization, separation of undesirable elements in a solid phase, oxydation, or reduction). The treatment processes aim at reducing the toxicity of the wastes.
- c) Solid mineral wastes (for example, moulding sand, cyanide hardening salts) which must be stored in dumps or deep storage facilities, depending on the toxicity of the constituent elements.

It must be noted that incineration and physico-chemical processing in turn produce new wastes (ash, dross, dust, sludge) which ultimately can only be eliminated by dumping.

1. The Role of the Industrial Waste Producer

When an industrial firm considers treating its own wastes, it is indispensable beforehand to carry out a study of its waste production. This study should be as precise as possible, detailing the physical and chemical characteristics of the wastes. In fact, wastes of various kinds are produced within the same firm and mixing these wastes could reduce their valorization potential and increase disposal costs.

A variety of waste treatment options may be open to the waste producer. The choice of a treatment system will be the result of a technical and economic evaluation of the

situation, which takes into account the characteristics of the wastes, technological limitations and the availability of external processing and collection systems. These options can be classified in the following manner:

- 1) Stopping the production of a waste product by changing the process or production (implementing "clean technology" in the strictest sense of term);
- 2) Recycling the waste product within the framework of the process that generated it;
- 3) Recovery and valorization of the waste for various uses within the firm;
- 4) Recovery and valorization of the waste for use outside the firm that produced the waste (This can be done either directly, firm to firm, or indirectly, through a professional waste recovery intermediary.);
- 5) On site disposal of wastes without valorization;
- 6) Disposal by waste disposal professionals outside the firm (treatment in a collective waste disposal centre).

Disposal options are often costly and it is obvious that an industrial firm has interest in seeking recycling or valorization options. (See Appendix 1)

The choice between on site treatment or processing outside the firm can be evaluated considering data which are inherent to each option and which may include the following:

- a) the profitability of an on site facility, linked to its critical size;
- b) the investing or subcontracting policy of the firm;
- c) the firm's energy needs in the case of an energy valorization treatment process.

At this point, it would be appropriate to bear in mind that under the Law of 15 July 1975, the producer or holder of waste is responsible for what becomes of the waste and must provide conditions amenable to the proper disposal thereof.

2. Wastes within the Firm

2.1 Separation of Wastes at the Source

Every precaution must be taken to succeed in not mixing the different types of wastes produced in a firm if these wastes are to undergo separate disposal or valorization processing or to undergo separate treatment processes. Separating wastes at the source often requires additional investment, but it offers certain advantages:

- a) Increased Valorization Potential. It is easier to valorize homogeneous waste products. For example, in surface treatments, the recovery of metallic salts in solution is profitable in concentrated baths; if these baths are mixed with diluted rinsing baths, recovery becomes less - if at all - profitable.
- b) Improved Work Conditions. Dangerous mixtures are avoided. Such mixtures can cause heat build-up, toxic fumes or they can be at the origin of fires and explosions. The unsupervised mixture of an acid and a base can cause a violent reaction that leads to a significant rise in temperature.
- c) Lower Treatment Costs. In the case of mixtures, the cost of treating the most difficult element will be applied to the entire mixture.

2.2 Appropriate Conditioning and Storage

Solid wastes must be stored on a reliable and environmentally sealed surface, in a holding tank, or - as a general rule - by any other means that avoid their being mixed with rainwater run-off or being scattered. Storage in portable containers facilitates subsequent collection and transport.

Liquid wastes must be stored in environmentally safe containers, generally hermetically sealed so as to prevent leaking or fumes escaping. The containers used may be cisterns, drums or tanks depending on the storage capacity needed and the nature of the wastes.

The choice of the conditioning equipment also depends on the duration of storage, handling and transport conditions and subsequent processing to be carried out on the wastes.

When waste collection can be carried out regularly and frequently, only reception and holding facilities are necessary at the waste production site. Thus the risk of accidents, which often occur during handling, is reduced.

3. The Means Available to Dispose of Special Wastes

In France, specialized centres are available to waste producing firms to process their wastes. They include:

- a) Incineration centres
- b) Physico-chemical treatment centres
- c) Specialized treatment centres
- d) Technical land-burial centres (controlled waste and disposal landfills)

Certain centres combine several of these activities.
(See Map, Appendix 2)

Certain "pretreatment" centres are specialized in mixing and sorting operations which make it possible to channel the waste, or each of its constituents, toward the most economically profitable destination.

3.1 Waste Acceptance Procedure

The disposal of industrial waste often can be carried out by several treatment centres. The firm's choice of a particular centre should be based on attaining the best processing at the lowest cost. It is therefore worthwhile for a firm to ask several centres for estimates and then to compare prices - taking transport costs into account - before selecting a disposal centre.

The procedure for waste acceptance followed by waste treatment centres is as follows:

- a) The centres, once contacted, will ask the firm for a sample of the waste for analysis in order to determine the nature of processing and the cost of disposal.
- b) Once the sample analysis is completed, the centre may then issue an Acceptance Certificate to the firm. Only then is the firm allowed to send a load of wastes to the centre for treatment.
- c) When the load arrives at the centre, it is tested to determine whether it corresponds to the sample previously analysed. If the load corresponds, it is accepted for treatment; if not, it is returned to the producer.
- d) Once the waste has been destroyed, the firm must receive a Certificate of Disposal, a document proving the waste was disposed of properly and in accordance to regulations.

3.2 Collective Incineration Centres

The waste acceptance criteria for incineration centres take the following factors into account:

- a) The calorific value of the wastes, which will determine the possible need for additional fuel in order to ensure combustion;
- b) Halogenated elements content, which determines a need for acceptance by centres specifically equipped for carrying out the necessary incineration techniques and treatment facilities for gasses;
- c) Metal content, because alkaline elements are responsible for damaging furnace refractories;
- d) The flash point, which will determine the need for special storage conditions.

Incineration centres accept solid, pasty or liquid wastes, in function with technical characteristics. Under current regulations, the centres must respect operating temperatures on the order of 750°C (simple organic wastes) to 1200°C (organochlorine wastes). Smoke undergoes dechlorination treatment, allowing the released smoke to attain the following characteristics: Chlorine (100 mg/nm³), dust (150 mg/nm³) and heavy metals (5 mg/nm³).

However, for plants currently under construction, public authorities require industry professionals to guarantee the following values :

Dust 30 mg/Nm³

Hcl 50 mg/Nm³

French centers usually succeed today in complying with these requirements, however they will shortly have to comply with new European directives which are currently under study.

When carried out properly, incineration is an effective means of disposing of a high proportion of toxic wastes, including organic wastes, phenolic waste water, hydrocarbons and chlorous wastes.

Current prices depend on the calorific value and amount of undesirable elements present, such as chlorine, metals and sulphur. Prices also depend on the conditioning, and conditioning in bulk is preferable to conditioning in drums.

Incineration in Cement Furnaces

Cement plants consume huge amounts of energy. Therefore cement plants have sought alternative fuels in order to lower their energy costs. The cement industry has now turned its attention towards wastes, and particularly wastes with high calorific value, such as hydrocarbon mixtures or certain non-regenerable solvents. The current trend is toward producing mixtures attaining - on average - the following characteristics:

- a) Minimum Calorific Value of 4000 kgc_{al}/kg
- b) Percentage of Cl < 0.5 %
- c) Percentage of H₂O < 40 %

Moreover, environmentally speaking, the technical conditions of furnace operation guarantee minimum pollution because of the burning temperature of clinker and because of the long contact time between the combustion products and the matter to be burnt. (The contact time of gasses in the area which is hotter than 1200°C is more than six minutes.)

Although clinker has complexing properties towards certain toxic elements (such as sulphur, chlorine and metals), too large a presence of these elements can become poison for cement (and particularly chlorine) and thus these elements must be limited in their usage. (The rate of chlorine can not exceed 2%; sulphur is limited to 4%).

The injection of wastes can occur at three different points:

- a) mixed with the paste before being put into the furnace;
- b) as fuel on the lepol grate or the precalcinator;
- c) as alternative fuel in the burner.

Thus, liquid wastes are most often burnt.

Certain heating stations and certain household refuse incineration units also accept special wastes for incineration.

The disposal capacity of collective incineration centres is nearly 800 000 metric tonnes a year (1989).

Incineration at Sea

The destruction of halogenated wastes can be carried out in facilities installed on ships working in the North Sea. Waste producers must contact either an intermediary storage centre or a collector, who will then subcontract with the firm managing the incinerator ship for the subsequent destruction of the wastes. A European directive will place legal limits on recourse to this method of disposal. The quantity incinerated in 1988 was 15 000 metric tonnes and is in constant reduction.

3.3 Physico-Chemical Processing Centres

Physico-chemical treatment centres mainly perform the following treatment processes: oxydation-reduction, neutralization, dehydration, fixation, and emulsion-breaking.

Wastes accepted by these centres are:

- a) liquid wastes containing cyanide. Solid cyanide hardening salts are not detoxified at these centres; rather, they are conditioned for land-burial storage in salt mines. At present, they are shipped to West Germany.
- b) Wastes containing hexavalent chromium. These wastes are first reduced and then precipitated into an insoluble form. When the solutions are highly concentrated, the possibility of valorization can be considered.
- c) Waste acids and bases. These wastes are neutralized.
- d) Solutions containing metals. They are precipitated.

- e) Pasty wastes containing toxic elements. These wastes can be treated by fixation or hydraulic bonding, thereby reducing the level of humidity and limiting leaching of toxic elements.
- f) Ion exchangers. They are regenerated.

The capacity of collective detoxification centres is nearly 360 000 metric tonnes a year (1988) (See Appendix 4).

3.4 Specialized Treatment Centres

Certain firms have specialized in the treatment of particular kinds of wastes:

Fluids Produced in Metalworking

The fluids can be grouped into two categories: solvents and emulsions. They contain approximately 5% oils and various sterilizing agents, bactericides etc...

Various processing techniques are available. Acid-breaking and ultrafiltration apply only to emulsions, whereas incineration can be used in the treatment of all such fluids.

The capacity of collective waste treatment centres is approximately 265 000 metric tonnes a year

Solvents

The regeneration of solvents can take three forms:

- a) Internal regeneration of solvents by the firm
- b) The firms supplies waste solvents for regeneration outside the firm and will subsequently use the regenerated solvents.
- c) Waste solvents are sold for regeneration outside the firm.

The choice of one of these three alternatives will depend upon the quality of the waste solvents produced, the market value of the solvent, the potential for re-use of regenerated solvents within the firm, etc...

The following regeneration techniques are available:

- 1) steam distillation
- 2) fractional distillation
- 3) separation in a fine layer

The first technique produces a solvent which is largely free of its impurities, but heavily saturated with water. This technique is often used for sales (see "c" above) of solvents with low market values, particularly with chlorous solvents.

The second technique is often used with solvents of higher market value when the firm supplies the waste solvents for regeneration to specialists in solvents refining (see "b" above).

Transfer Centres

Collective waste treatment centres are generally established in areas of the country with high concentrations of industries, thus satisfying a large part of treatment demand in terms of industrial waste tonnage produced. In some regions of the nation, the level of industrial activity is too low to justify the establishment of an industrial waste treatment centre. And yet, wastes produced by industries in those regions must be properly processed. This explains why it has been necessary to develop the technical means to store area wastes temporarily at centralized points, before transferring them to existing waste treatment centres in other regions.

Recently, such regional temporary storage centres for wastes were created. Although they are at present few in number, they allow a better channeling of wastes and even

earmark certain wastes for subsequent valorization, instead of disposal.

These centres are equipped for reconditioning wastes (separating them into homogeneous batches for easier disposal). The wastes are then shipped to the appropriate collective waste treatment centre. The transfer centre groups wastes in quantities generally between 50 and 100 litres in drums and 1 to 10 metric tonnes for bulk wastes.

3.6 Technical Land-Burial Centres

Not all special wastes require incineration or detoxification and for many of these wastes (particularly those containing the lowest concentrations of toxic elements) storage in landfill or dump facilities is a necessary and technologically accepted disposal solution, provided certain specifications are respected.

Technical land-burial centres can be established only in geologically favourable areas (with a permeability coefficient lower than 10^{-7} /s).

The circulars of 22 January 1980 and 16 October 1981 specify the conditions necessary for opening and operating such waste storage sites. They define three major types of sites:

- a) Impermeable sites, which ensure suitable confinement of wastes and leachable wastes. They are able to store certain special wastes.
- b) Semi-permeable sites, which ensure slow migration of leachable waste through a non-saturated zone of sufficient thickness. They can store mainly those industrial wastes comparable to household refuse.
- c) Permeable sites, which allow rapid migration of leachable waste. Only inert wastes should be stored in such sites.

Managing water at the site is one of the major problems when operating a landfill of this kind.

When the ground is impermeable, all the water penetrating into the site accumulates at the bottom of the pores. It is therefore important to restrict the amount of water coming onto the site. Water contained at a site can come from several sources:

- a) rainfall at the site;
- b) diversion of surface water or leachates, surfacing of groundwater or return seepage;
- c) water from pasty wastes or sludges.

The first source listed is not easily controlled. The only means of limiting this factor is through the selection of special sites or the reduction of the exposed surface-area.

The second source is controllable: one simply has to seal the site environmentally, both the sides and the base, and to build channels permitting water to run off beyond the site without coming into contact with the contents of the site.

The third source can be controlled by limiting the humidity of the waste accepted. Several techniques are available: dehydration of sludge through a filter press or a band filter, perhaps after flocculation; use of solidification techniques for dehydration; confinement of pollutants in a cement structure.

When the site is not totally impermeable, water passing through the site could filter into groundwater, presenting a risk of polluting this water. However, soil does have a certain retaining power, in particular in the case of heavy metals.

The principal criteria for acceptance of a waste product by a landfill are:

- 1) dryness
- 2) The nature of the soluble fraction obtained from leaching of the waste.

The table below presents a list of acceptance criteria:

- 1) Concerning the raw waste
 - a) Dryness> 40 %
 - b) Soluble fraction.....< 10 %
 - c) Hydrocarbon content: total hydrocarbons.....< 10 %
- 2) Concerning the leachable matter:
 - a) pH.....6 < pH <8
 - b) Metallic elements
 - 1) Cr VI, AS 3+, Organic Hg and Pb, CH.....< 10 mg/kg of waste
 - 2) Ag, Cd, Se, Th, Hg, Pb++.....< 100 mg/kg of waste
 - 3) Ba, Va, Sn, Cu, F-, S 2-, mineral Pb, Al, Mn, Ni, Zn, As5+, Cr3+.....< 1g/kg of waste
 - c) Organic substances
 - 1) Substances extractable from chloroform.....< 120 g/kg of waste
 - 2) phenols.....< 200mg/kg of waste
 - 3) DCO.....< 20 g/kg of waste
 - 4) DGO S.....< 7 g/kg of waste
 - 5) Nitrogen measured by Kjeldahl method (expressed in NH4+).....< 2.5 g/kg of waste
 - d) Ecotoxicity.....< 1 equitox/m³

Most technical land-burial centres receive both industrial and household wastes. Considering the current difficulty in opening new Class 1 sites, it would be preferable to restrict their use for wastes which could be treated in Class 2 sites.

The eleven (11) Class 1 technical land-burial centres received nearly 500 000 metric tonnes of special industrial wastes in 1988. Today, the major problem with this type of facility is obtaining their acceptance by people living nearby. Consequently, no new site has been opened for five years.

Conclusion

Industrial wastes management long consisted in skimming off a few wastes with a known market value (such as scrap iron, non-ferrous metals, waste paper and cardboard, etc.) while summarily - and frankly, even recklessly - disposing of all the other wastes.

The concern for better protection of the environment and for a better control of raw materials and energy has led to more rational and more effective management of industrial wastes.

Better knowledge of wastes' characteristics, better sorting of wastes at the source, and appropriate conditioning are prerequisites if one desires the best possible disposal (and, if possible, valorization) of wastes.

The proper management of wastes produced by firms rests on several principles:

- 1) The organization of waste storage must take environmental and security constraints into account, but it must also respect the limitations imposed by subsequent treatment of the wastes, in order to reduce costs.
- 2) The choice among waste treatment by the firm itself or by collective treatment facilities depends on the amount of wastes to be treated and on the firm's possibilities of using the products (or energy) obtained from valorization.
- 3) The choice between various waste treatment services depends on the total waste treatment costs (including transport costs); clean technology and valorization should be given preference because of the economic advantages they often present in comparison to disposal.

At a national level, for more than ten years, public authorities have actively supported the establishment of a national network of collective disposal centres for industrial wastes. This support has been translated principally into a

more demanding legal and regulatory framework (for example, the Law of 15 July 1975 on waste disposal and the Law of 19 July 1976 on facilities classified as being for the protection of the environment), the establishment of incentives (financial aid for investments) and unflagging support of research seeking to improve treatment techniques.

This combined effort from the public and private sectors toward the same goal - the effective treatment of industrial wastes - has led to providing France with a dense, if not yet totally sufficient, network of collective treatment centres for industrial wastes. This network is insufficient in that certain regions severely lack technical land-burial centres and that, nationally, France has yet to solve the problems of disposing of certain categories of wastes which, at the current state of technology, require deep storage.

The steady, regular progression of treating toxic and hazardous industrial wastes in collective centres (500 000 metric tonnes in 1982 ; nearly 1 030 000 metric tonnes in 1988 in addition to constantly improving effectiveness of treatment techniques is a sign of a certain level of success in this sector and also sign of a real need on the part of industrial waste producers. Even if, at a local level, technical landburial centres are less and less easily accepted by the population, the environment has everything to gain from an effective network of collective industrial waste treatment centres.

INDUSTRIAL WASTE PRODUCTION IN FRANCE

TOTAL AMOUNT
150 MILLION TONS

INERT
WASTES

100 M t

COMMERCIAL
WASTES

32 M t

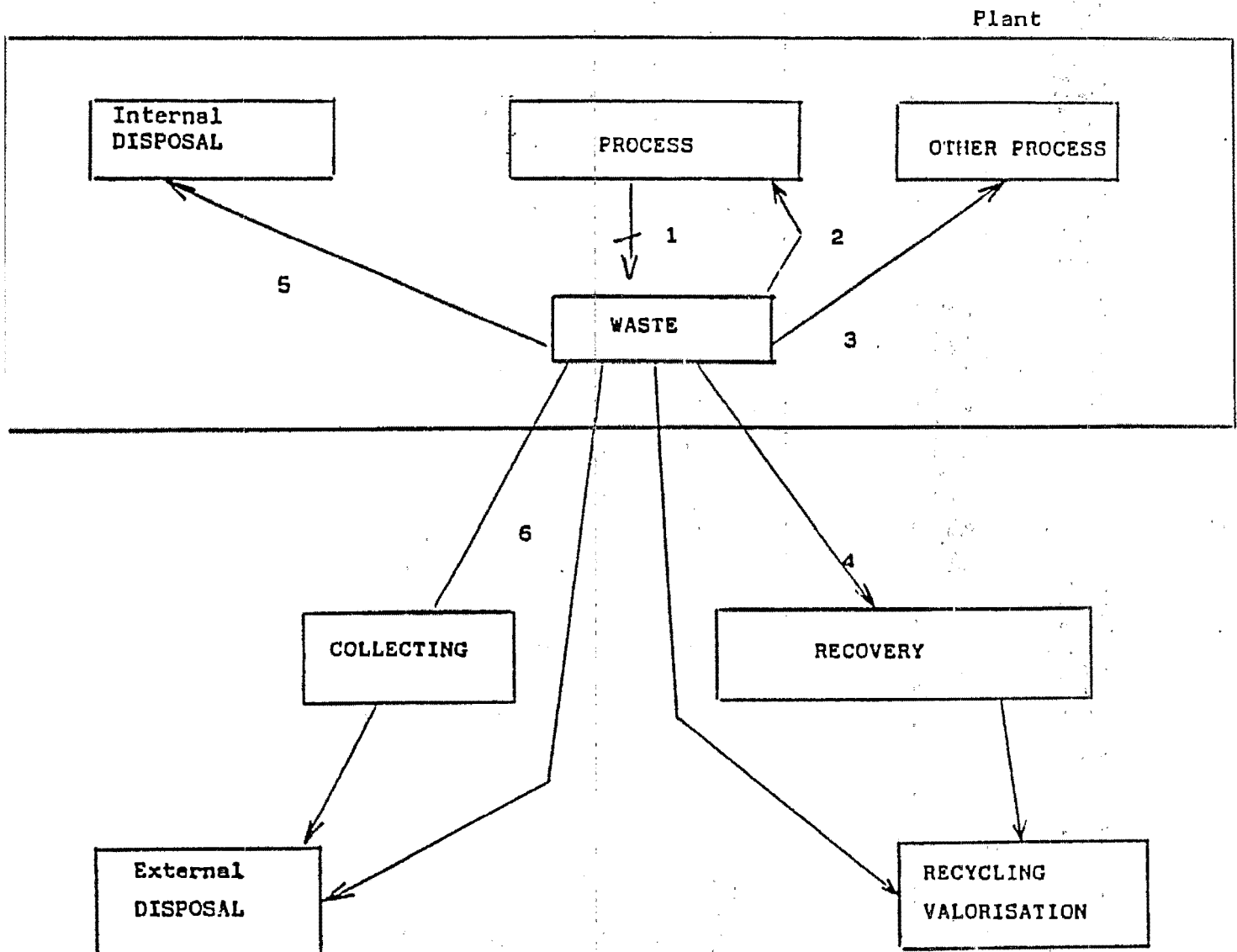
SPECIAL
WASTES

18 M t

HAZARDOUS
WASTE

4 M t

ANNEXE 1
INDUSTRIAL WASTES MANAGEMENT



HAZARDOUS WASTE TREATMENT FACILITIES

INCINERATION

SPECIFIC INCINERATOR

CEMENT KILNS

POWER STATION

MUNICIPAL WASTE
INCINERATOR

PHYSICO-CHEMICAL TREATMENT

OXYDATION REDUCTION

DESHYDRATATION

FIXATION

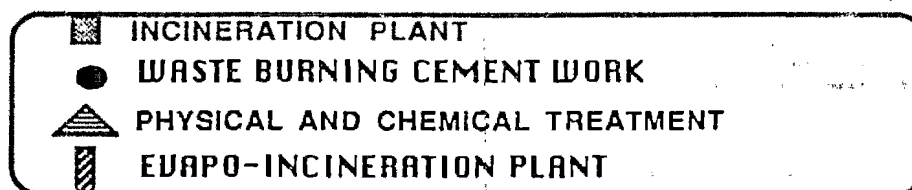
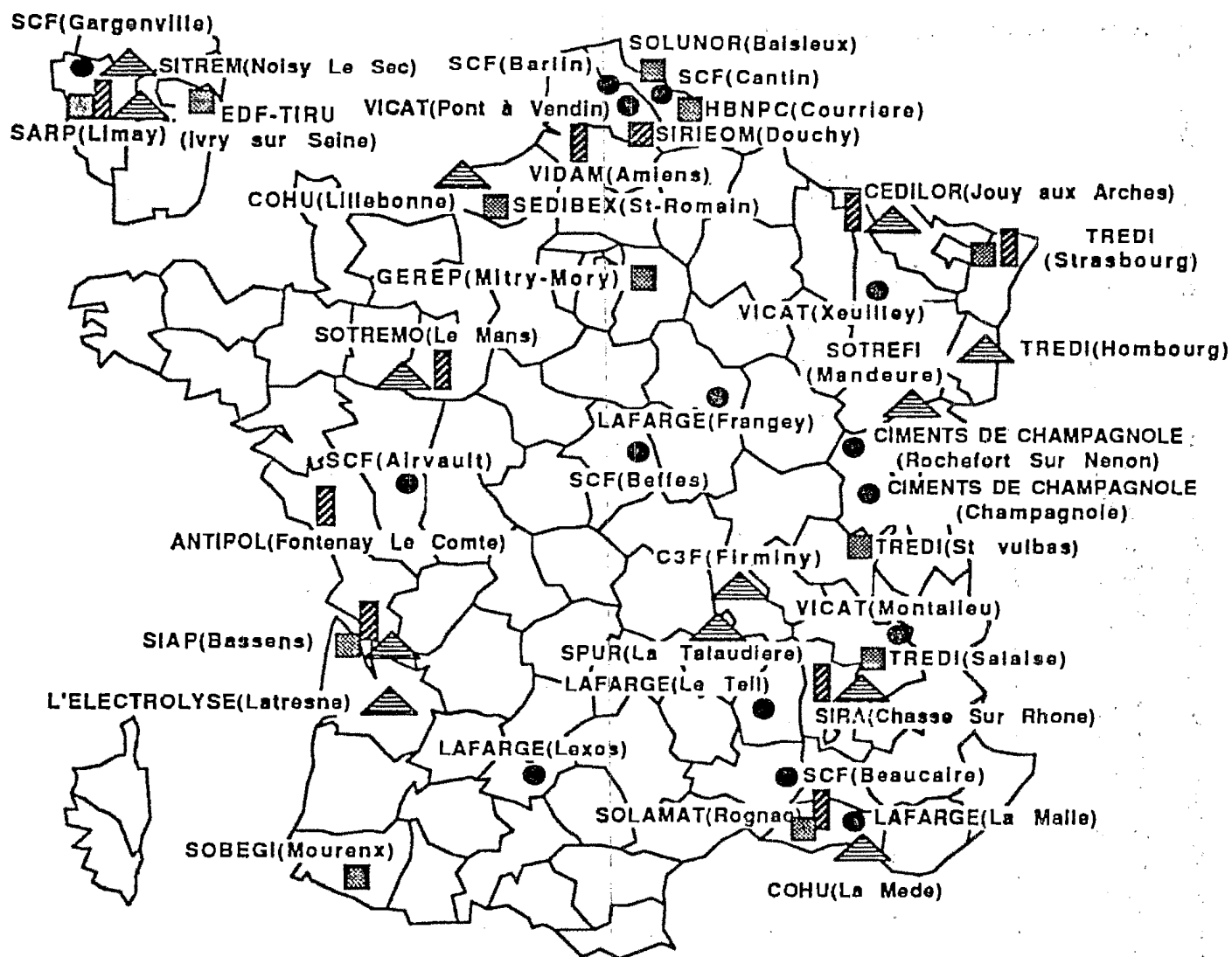
EMULSION BREAKING

LAND BURIAL

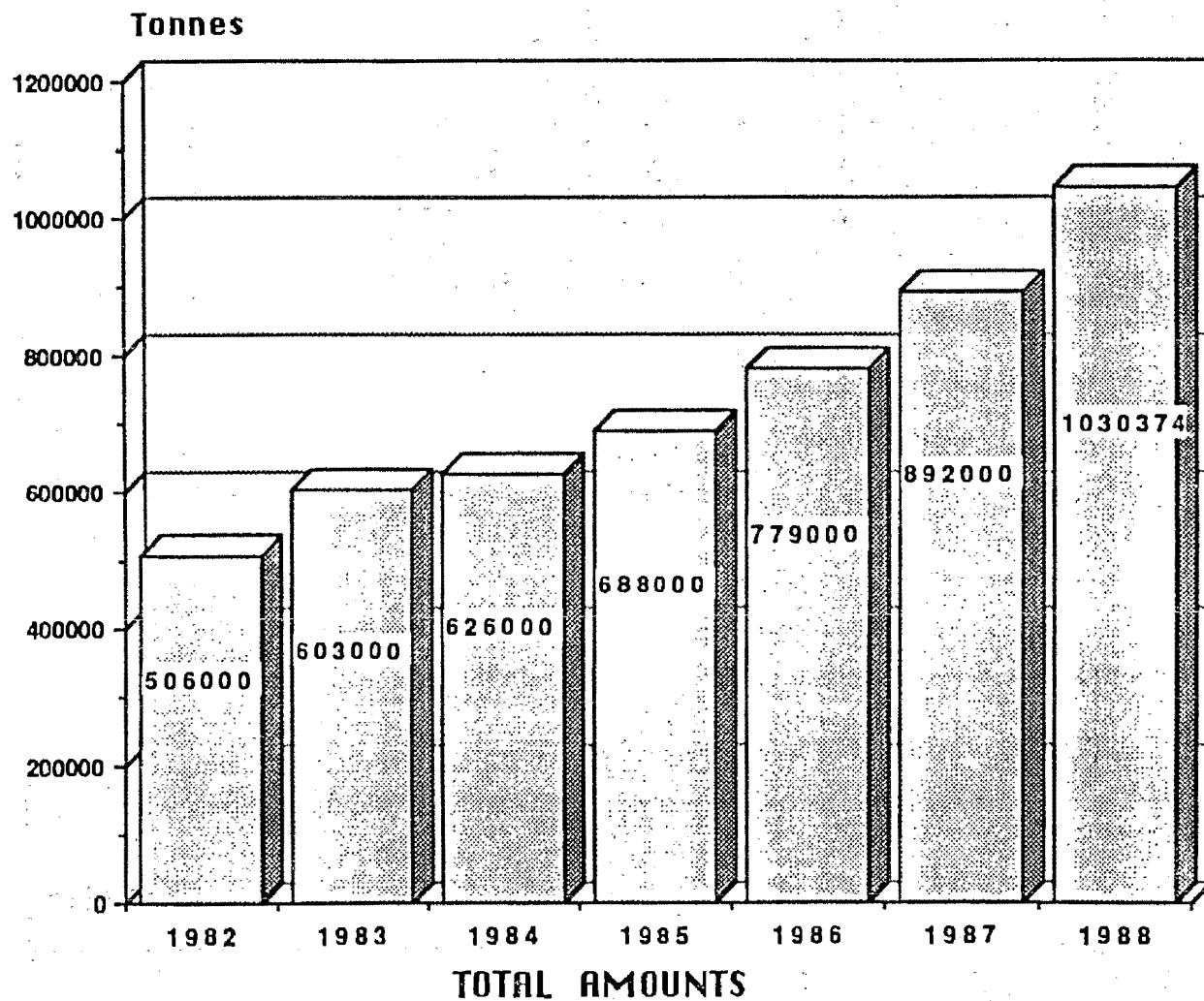
SECURE LANDFILLS

SALT MINE
BURIAL

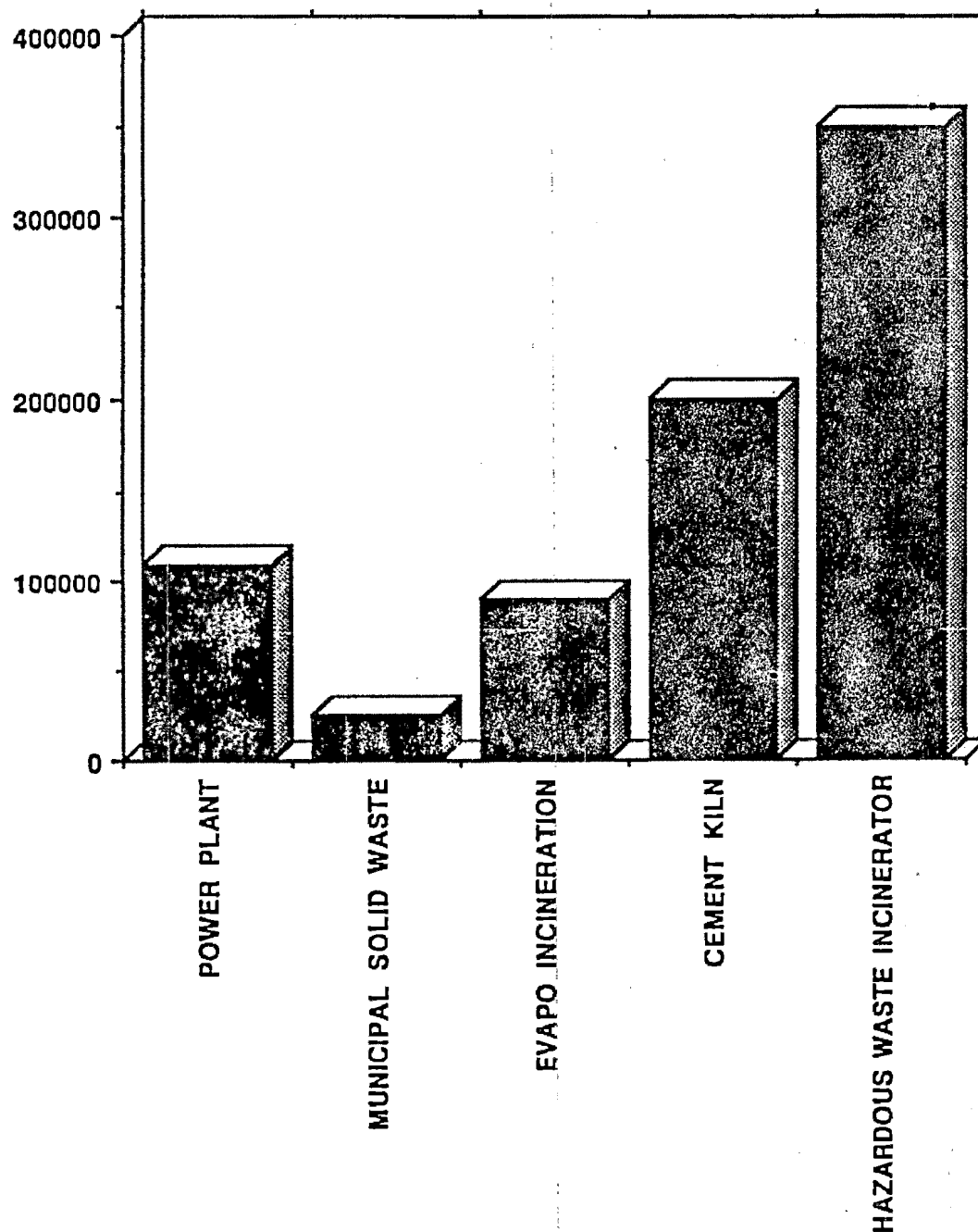
INDUSTRIAL WASTE TREATMENT PLANTS IN FRANCE (1990)



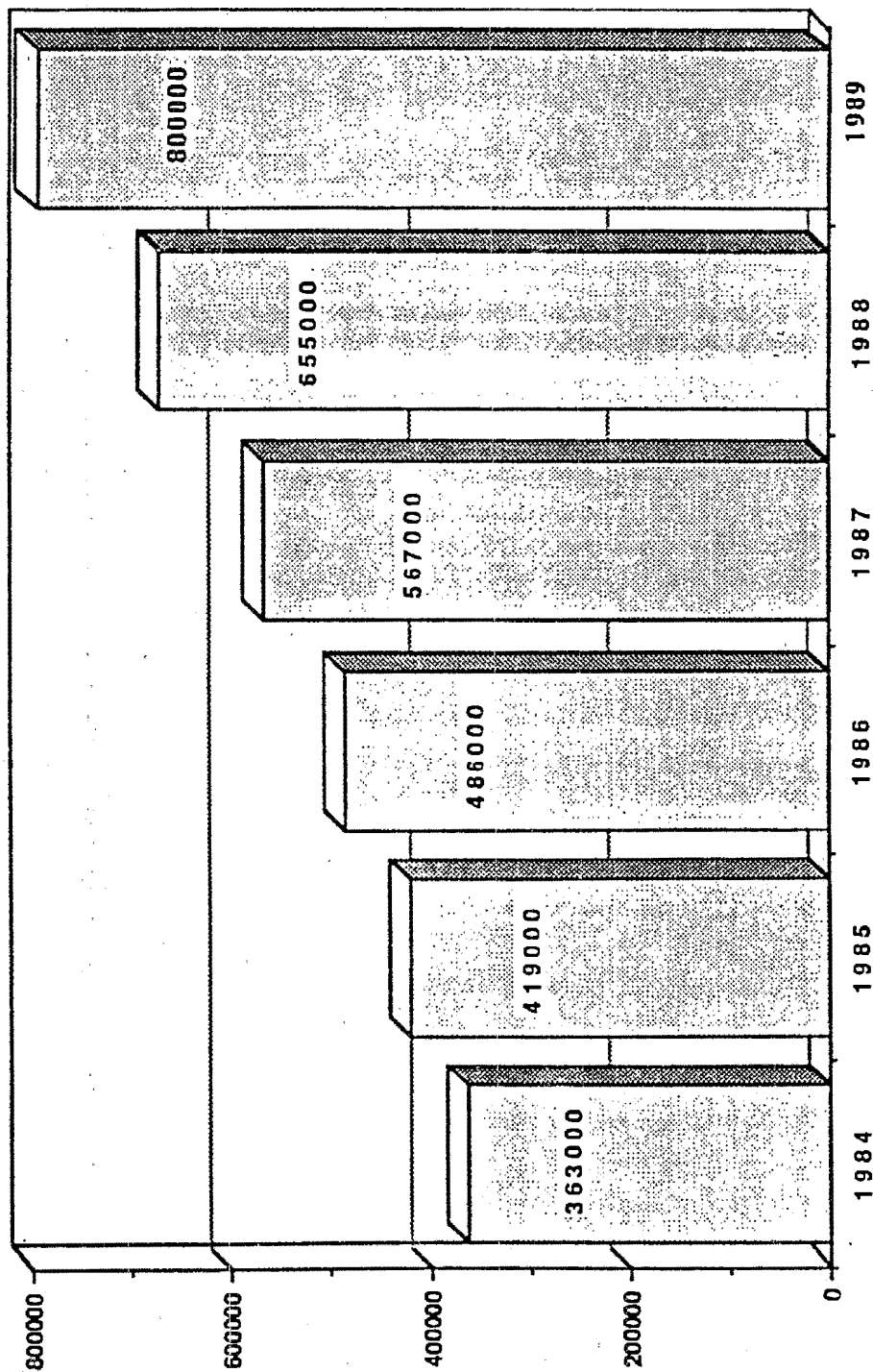
AMOUNTS OF WASTES DISPOSED OF IN COLLECTIVE TREATMENT UNITS



INCINERATION PROCESSES IN FRANCE IN 1989

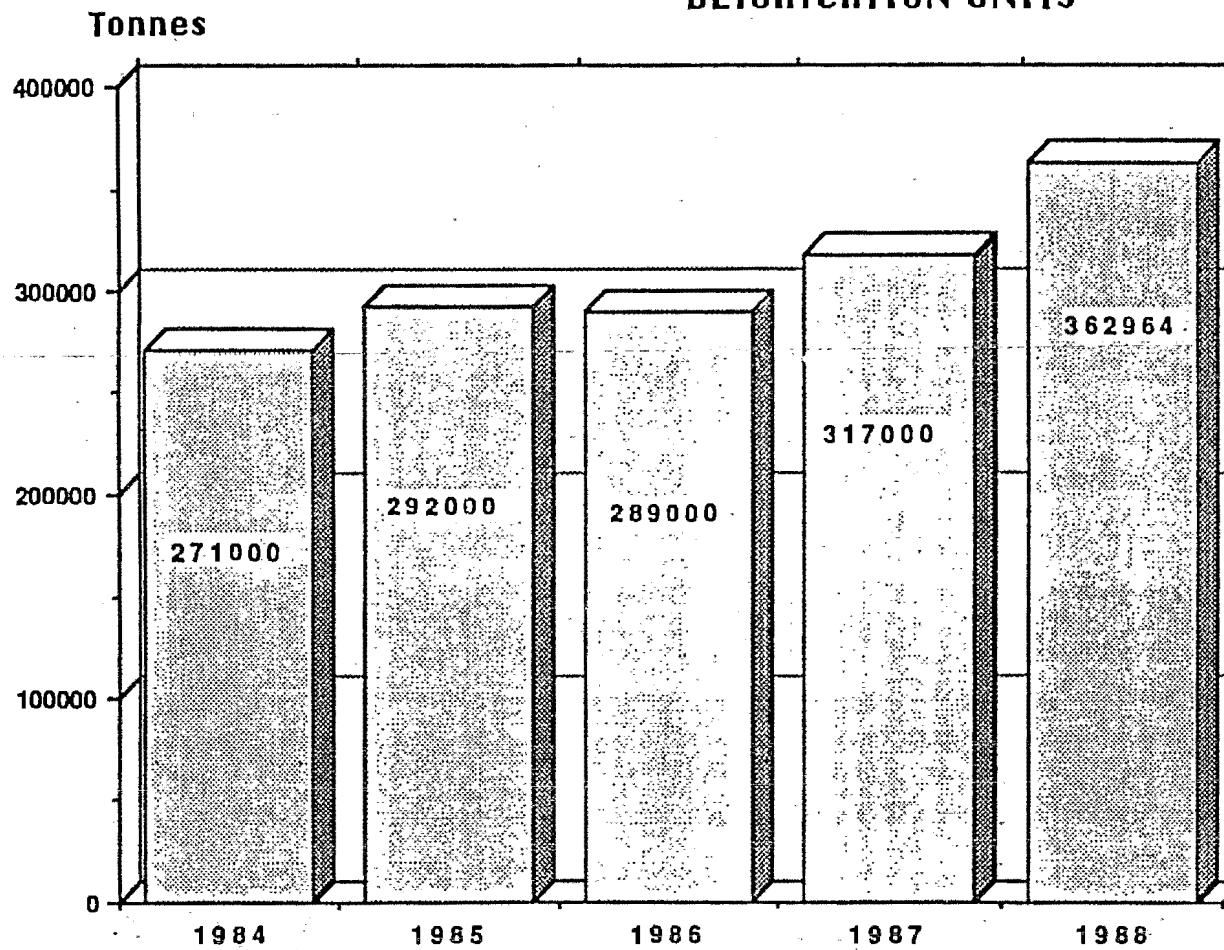


INDUSTRIAL WASTE INCINERATION

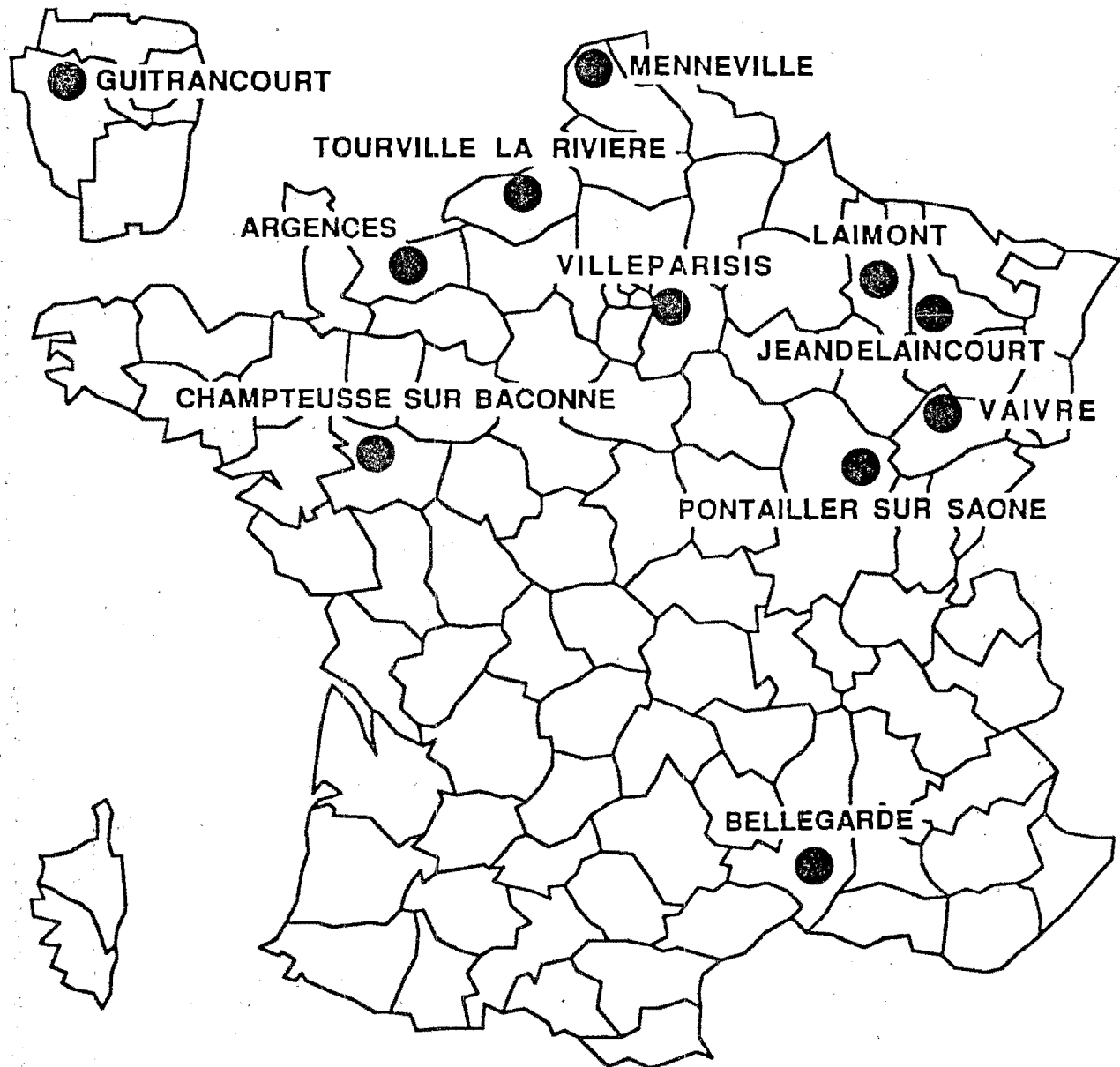


AMOUNTS OF WASTES DISPOSED OF IN COLLECTIVE TREATMENT UNITS

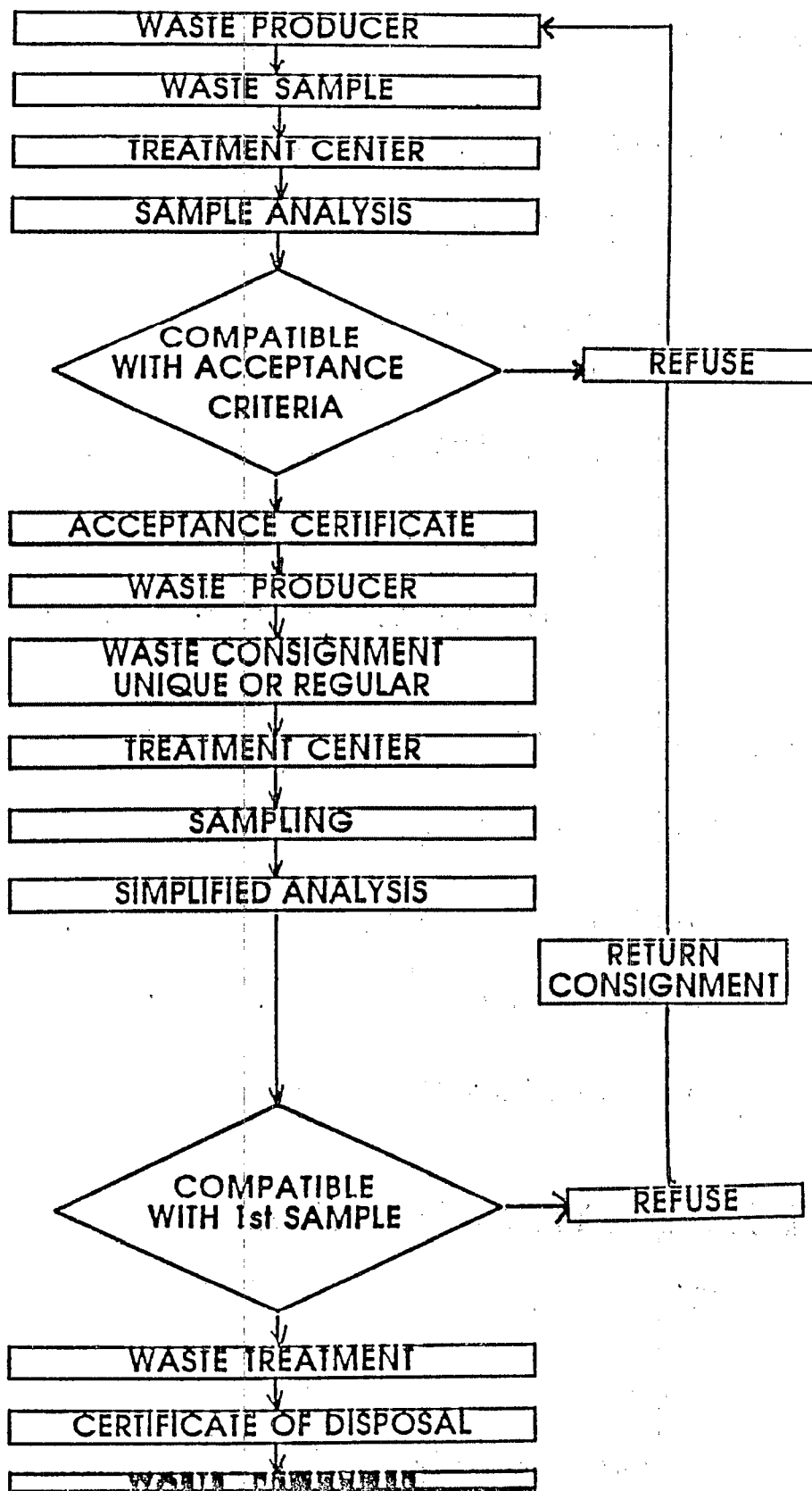
DETOXICATION UNITS



TECHNICAL LAND-BURIAL CENTRES (SECURE- LANDFILLS)



WASTE ACCEPTANCE PROCEDURE



TECHNICAL DATA FOR INCINERATION CENTERS

ACCEPTANCE CRITERIA

- Calorific value (combustion control)
- Halogen content (need for specific centre)
- Metal content (alkaline elements)
- Flash point (security)
- Physical aspect (liquid, solid or pasty)

COMBUSTION

From 750° C (simple organic wastes)

To 1 200° C (organo-halogenated wastes)

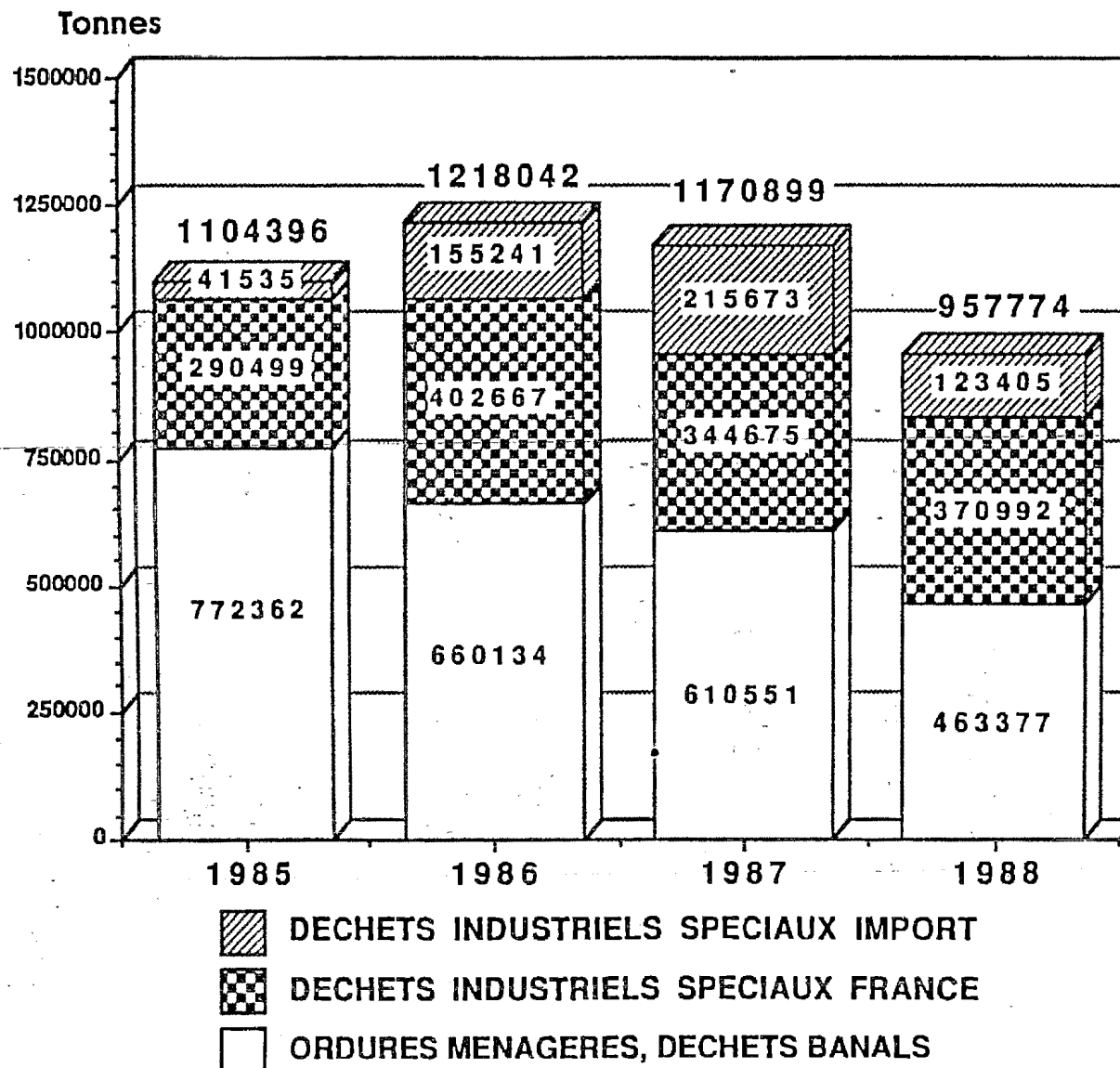
Time : 2 sec

Post-combustion necessary

FLUE GASES MAIN PARAMETERS

Cl	< 100	mg/N.m ³
Dust	< 150	mg/N.m ³
Heavy metals	< 5	mg/N.m ³

AMOUNTS OF WASTES DISPOSED OF IN TECHNICAL LAND-BURIAL CENTRES



TECHNICAL LAND-BURIAL CENTRES

SITE QUALIFICATION

Impermeable site : permeability $< 10^{-9}$ m/s
substratum > 5 m

**Water protection (surface and underground)
isolation from surroundings**

ACCEPTANCE CRITERIA

- Water content
- Physical aspect (solid ou pasty)
- Nature of soluble fraction (leachate test)
- Prohibited substances (PCB, cyanides, explosives,...)

NATO/CCMS Guest Speaker:

Christian Bocard, France

**New Developments in Remediation of Oil Contaminated
Sites and Ground Water**

**NEW DEVELOPMENTS IN
REMEDICATION
OF OIL CONTAMINATED SITES
AND UNDERGROUND WATERS**

**Christian BOCARD
INSTITUT FRANCAIS DU PETROLE**

and

**Jean DUCREUX, Claude GATELLIER (IFP)
Jean-François BERAUD (BURGEAP)**

REMEDIAL ACTIONS : WHY AND TO WHICH EXTENT ?

● BASIC DATA ON THE TRANSFER OF SOLUBLE HYDROCARBONS FROM RESIDUAL OIL TO GROUNDWATER

- . In the saturated zone (Figure 1)
- . In the unsaturated zone : more knowledge needed

● A FIELD EXPERIENCE

The construction of a subsurface railway across a contaminated area :

necessity of mitigating short-term and long-term risks towards the works

Actions undertaken :

- . Hydraulic pumping
- . Experimental in situ aqueous surfactant flushing (Figures 2 to 9)

THE USE OF SURFACTANTS TO IMPROVE IN SITU WASHING AND BIODEGRADATION

BASIC CONSIDERATIONS

- **EFFECTIVENESS OF SURFACTANTS**

- . Optimum oil recovery in column tests (Figures 10-11)
- . Enhanced biodegradation (Figure 12)

- **HYDRAULIC PARAMETERS TO OPTIMIZE**

- . Flowrate of surfactant solution
- . Arrangement of injection and pumping wells

in order to :

- . Sweep the whole contaminated area, taking account of water permeability and relative permeability
- . Avoid surfactant passing through the water table

Studies carried out in laboratory models and field pilot tests (Figures 13 -14)

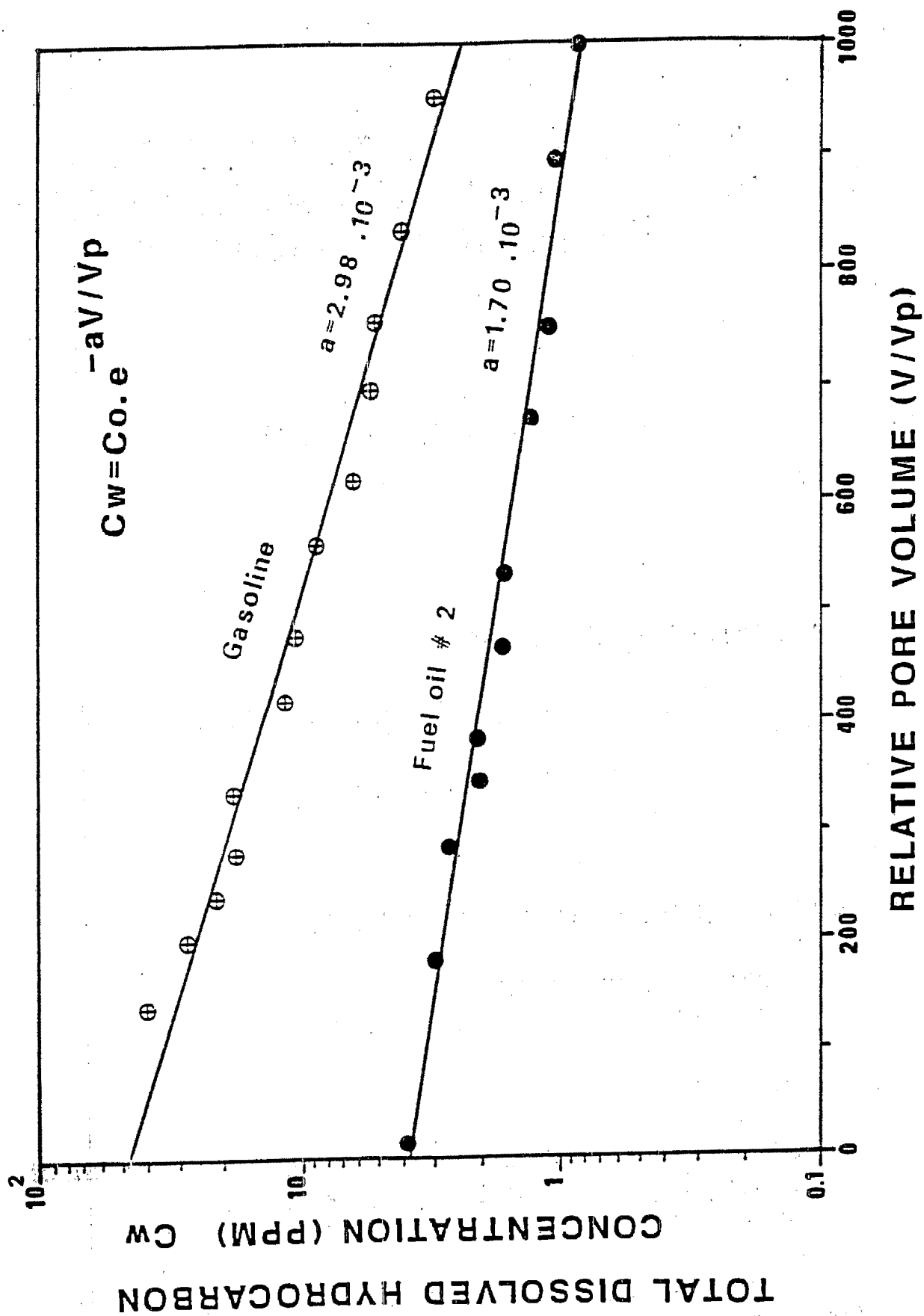


FIGURE 1 Solubilization of hydrocarbons

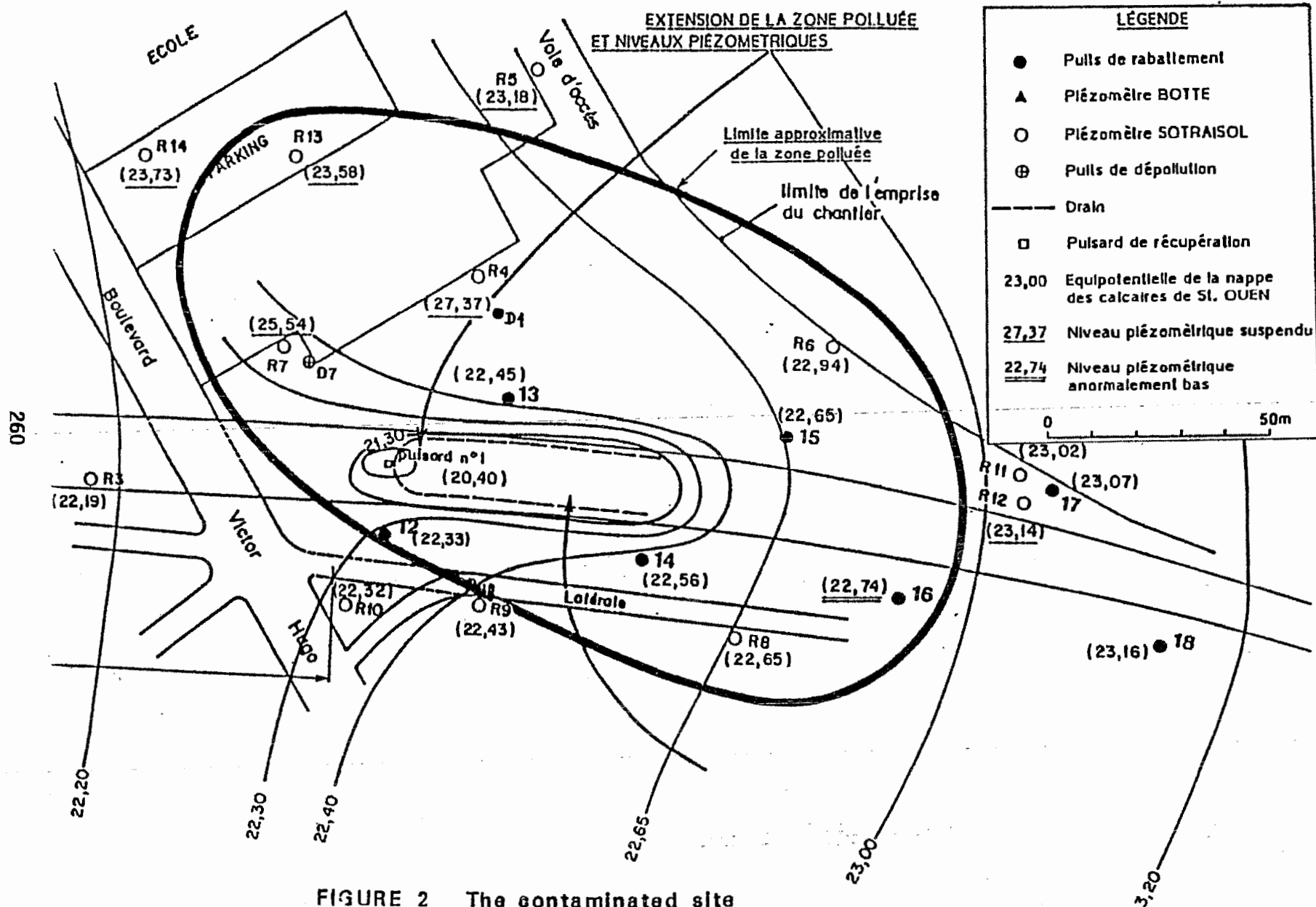
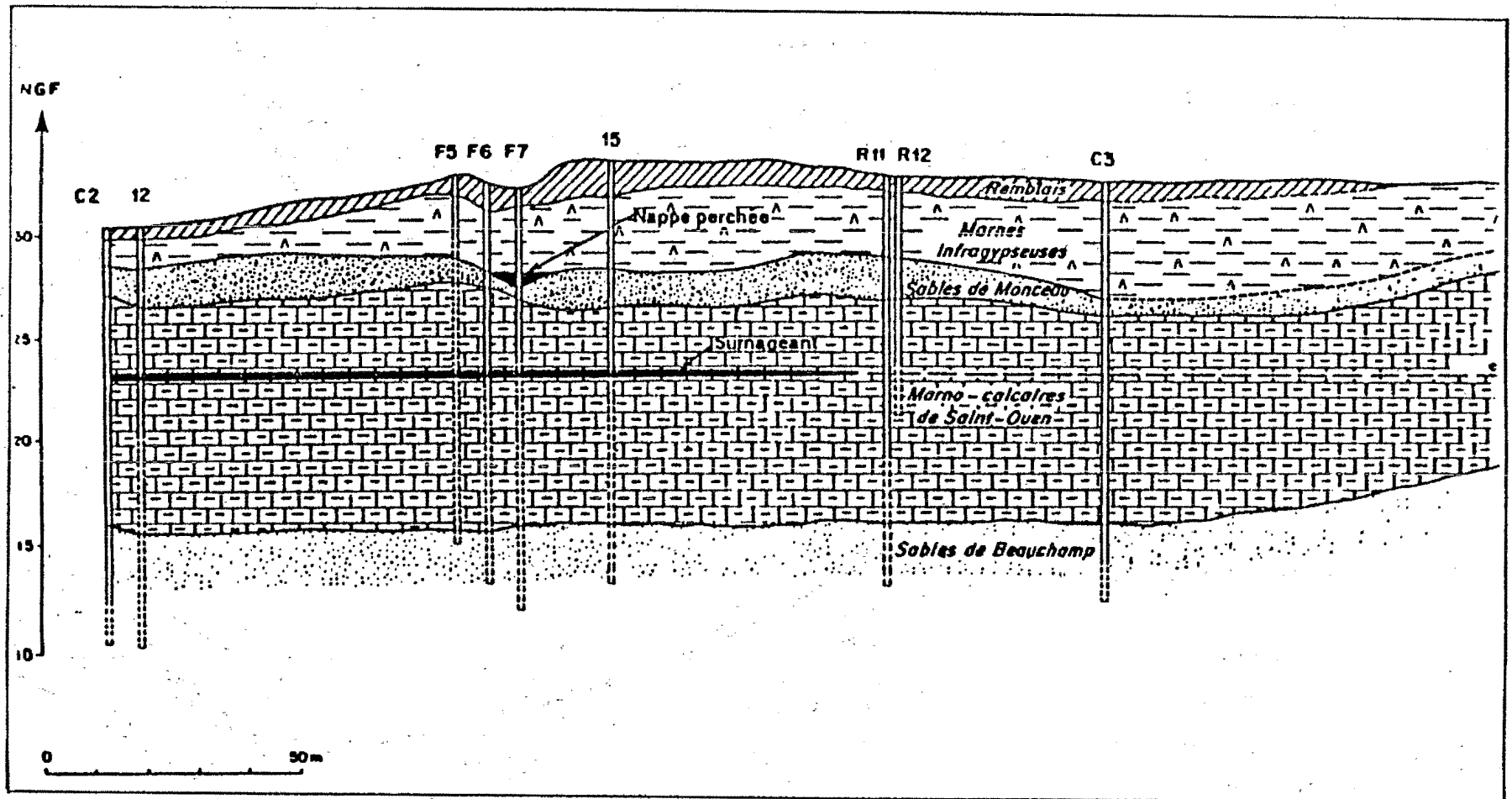
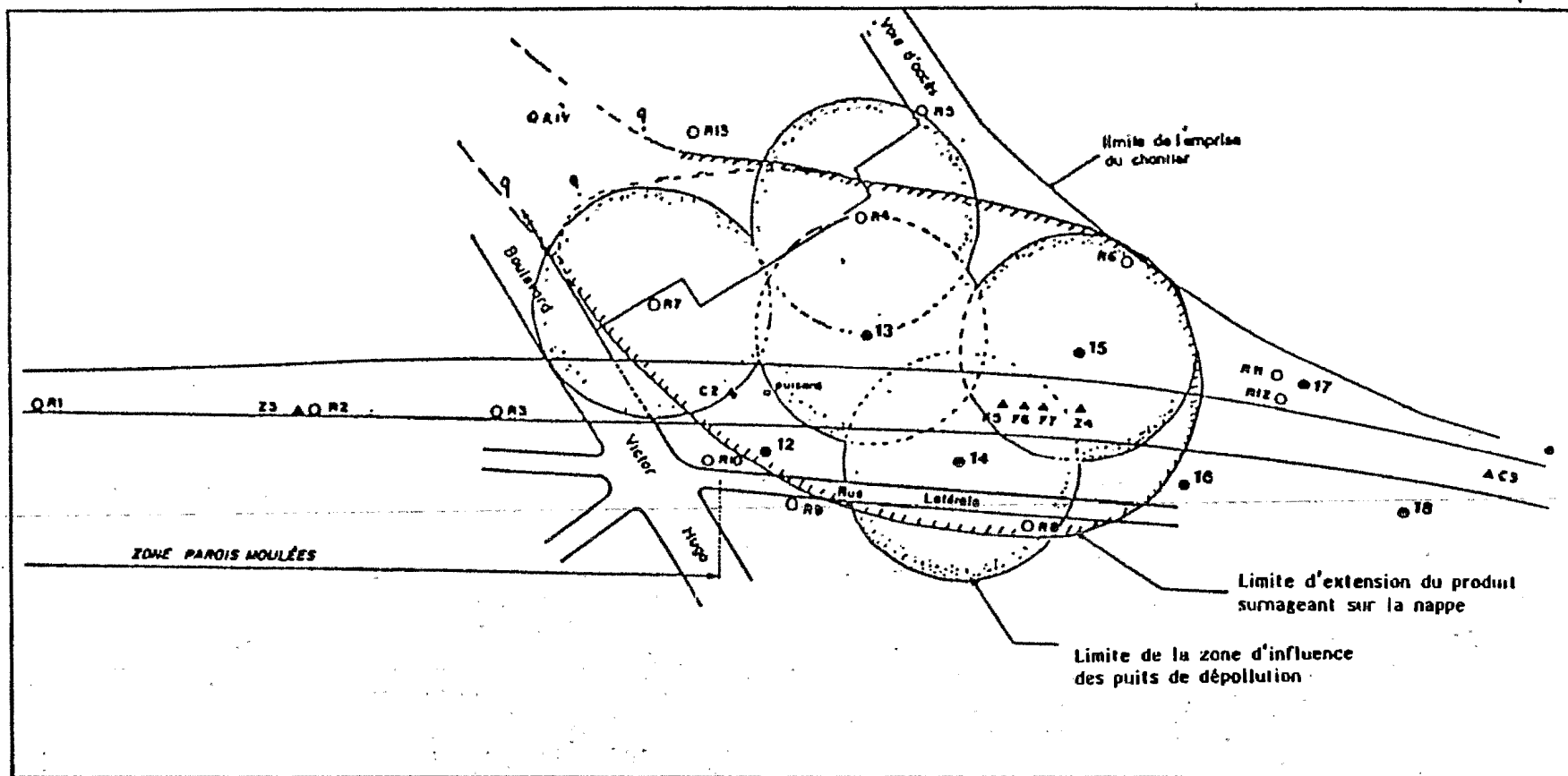


FIGURE 3

COUPE GÉOLOGIQUE PASSANT PAR L'AXE DE LA TRANCÉE





LIMITE D'ACTION DE LA PREMIERE PHASE DE DEPOLLUTION

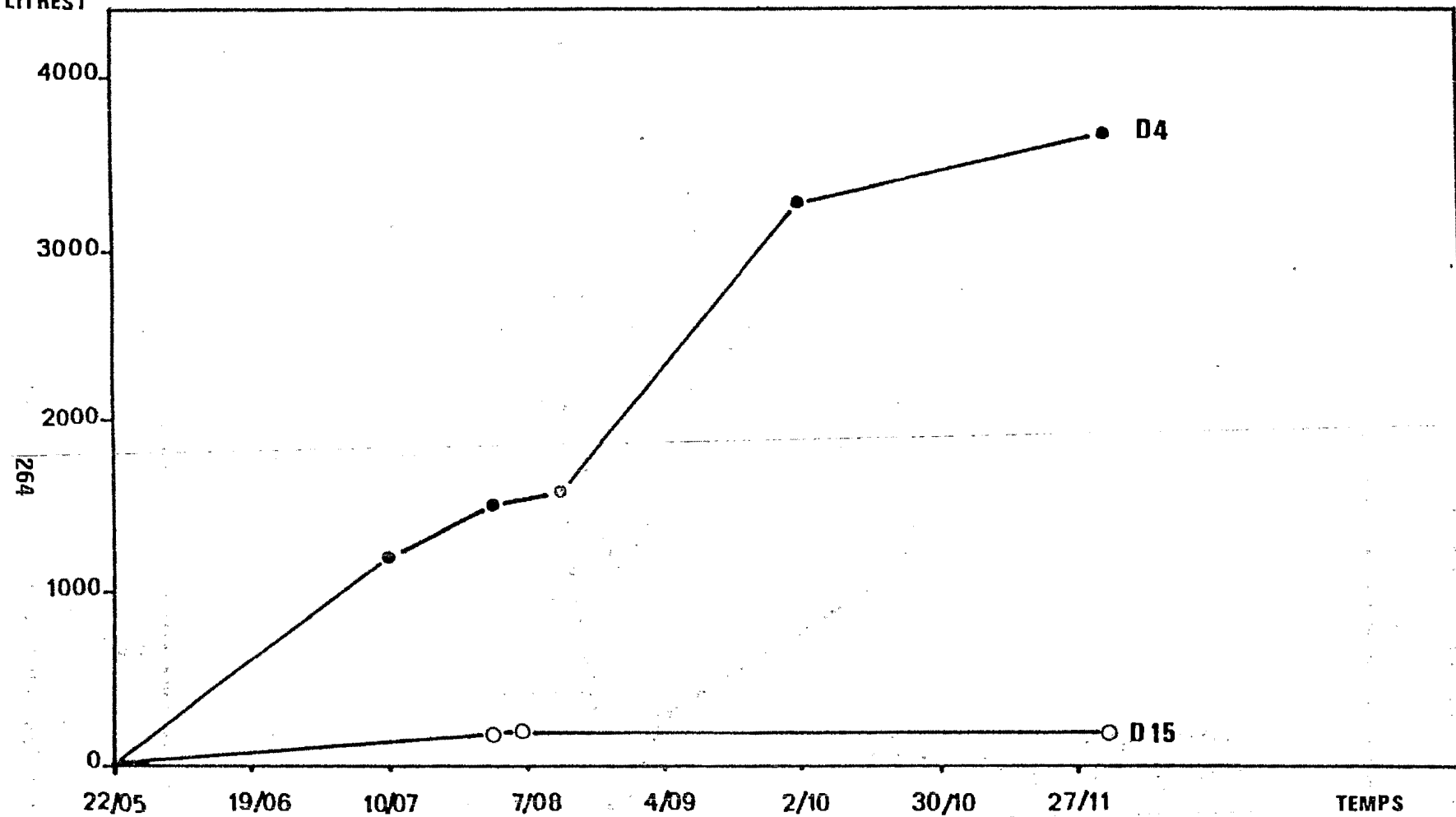
Après 10 à 30 jours de pompage

FIGURE 4 First hydraulic depollution phase

Après 20 à 70 jours de pompage

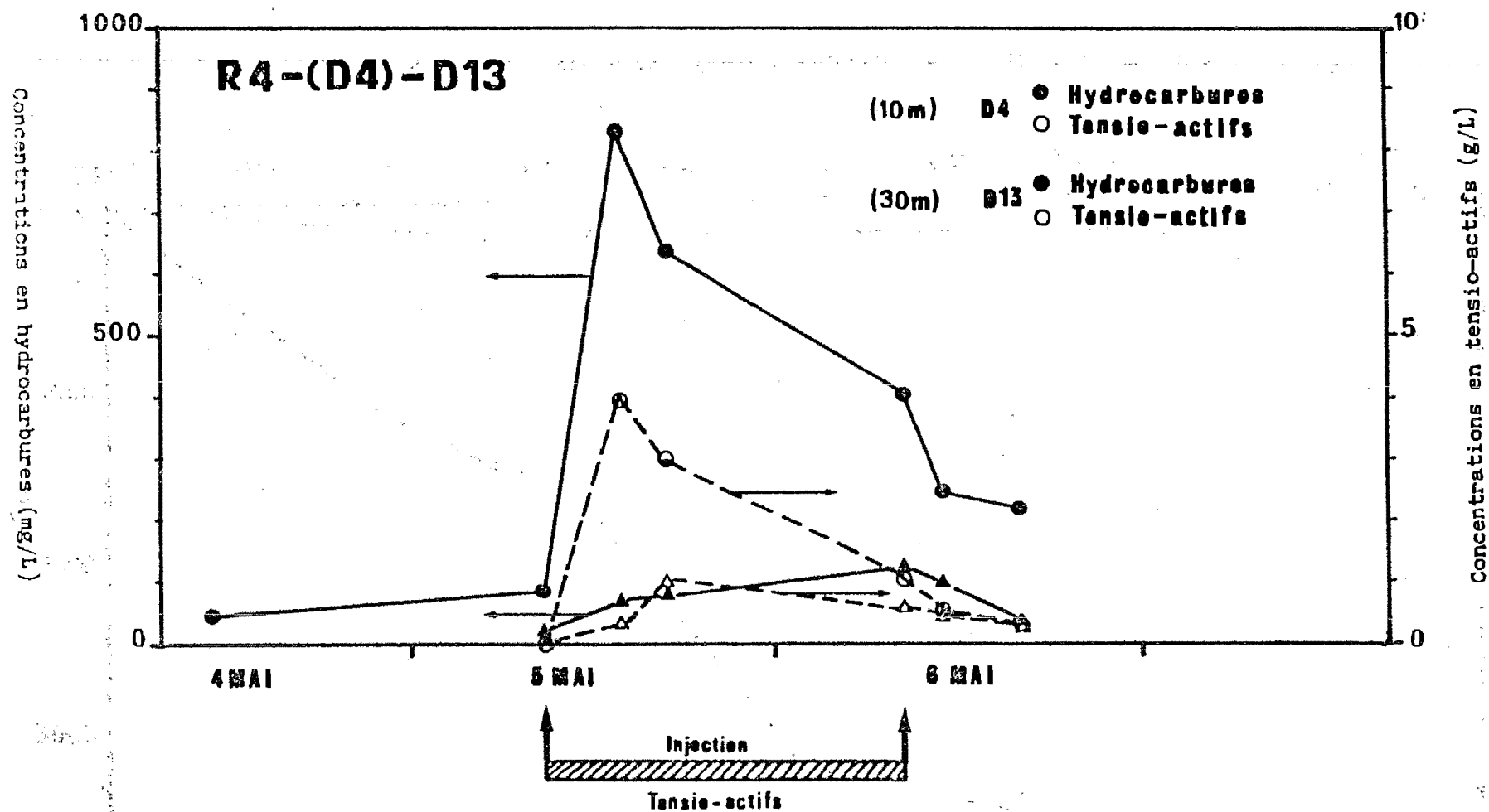
FIGURE 5 Second hydraulic depollution phase

VOLUME
RÉCUPÉRÉ
(LITRES)



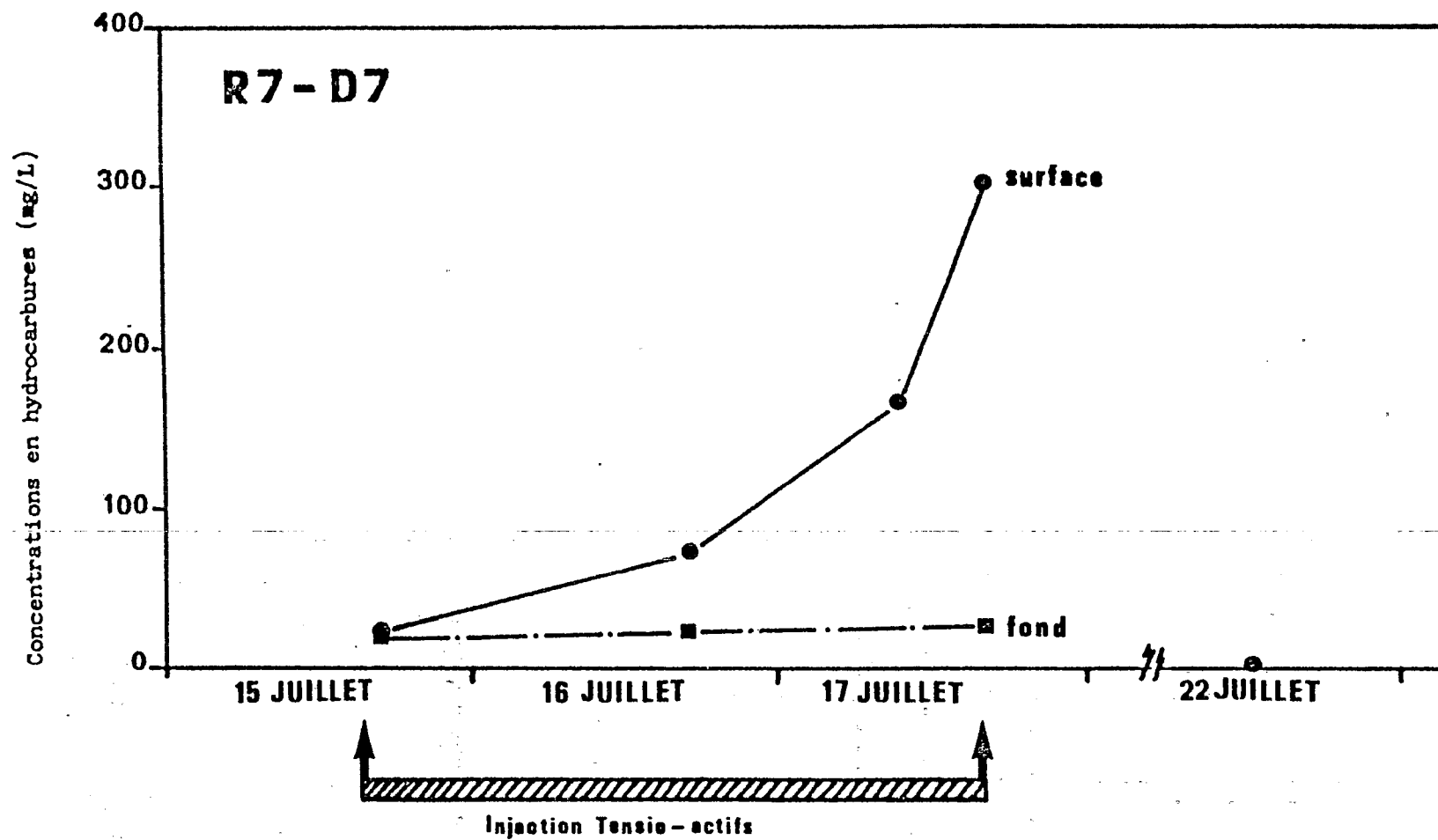
Quantité de produit récupéré sur les puits de dépollution D4 et D15

FIGURE 6 Cumulated volume of recovered oil



Evolution des concentrations en hydrocarbures et en tensio-actifs de l'eau des puits D4 et D13 lors des traitements : influence de l'éloignement des puits de dépollution

FIGURE 7 Surfactant flushing : concentration of emulsified oil



Evolution des teneurs en hydrocarbures à la surface et au fond du puits D7 lors du traitement aux tensio-actifs

FIGURE 8 Surfactant flushing : concentration of emulsified oil

	HYDROCARBON CONCENTRATION IN WATER (mg/l)			
	D4	D7	D13	D15
Before treatment				
1	63	15	19	6
2	22	0.6	13	27
After treatment				
3	5	0.3	7	5

TOTAL OIL RECOVERY WITH SURFACTANT FLUSHING : 250 litres

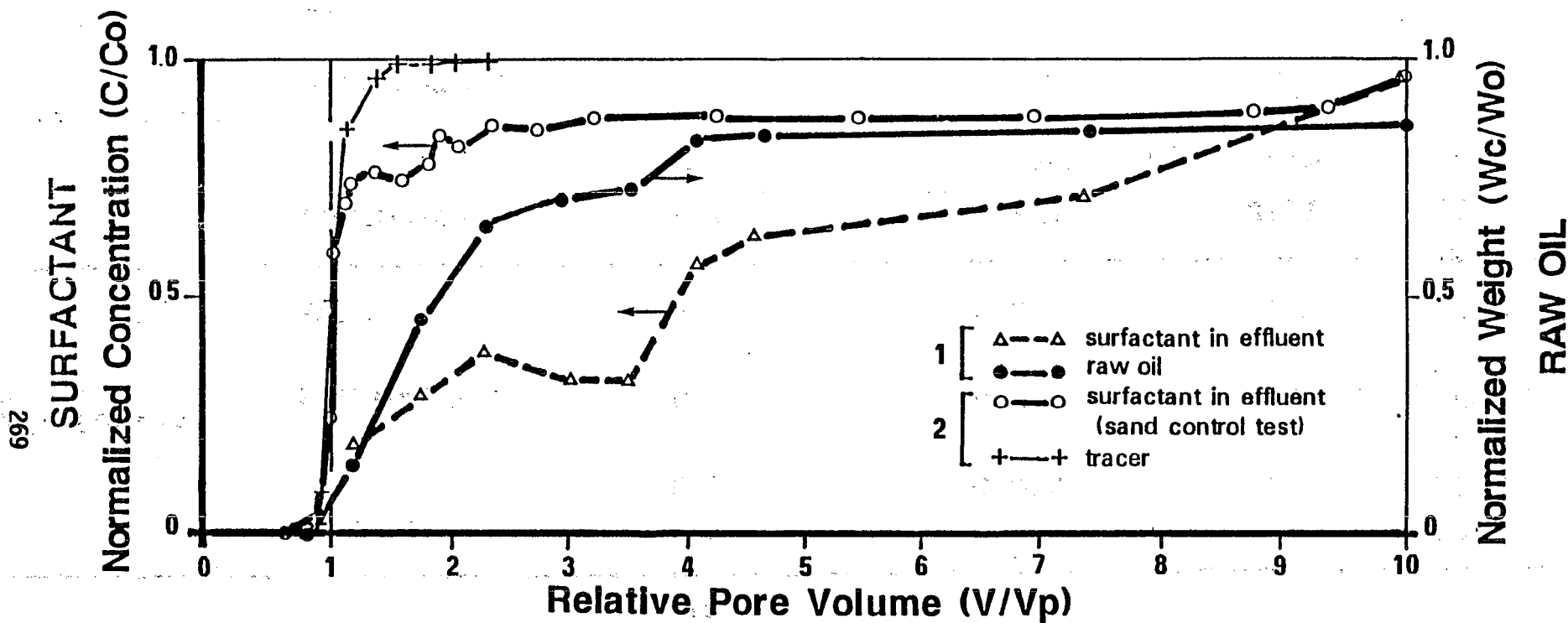
FIGURE 9 Results of surfactant flushing

Interfacial tensions and oil recovery efficiencies
of some commercially surfactant in experiments with
gasoline and fuel oil # 2 (tests in saturated column)

Oil	Surfactant type	Active Surfactant Concentration (%)	Interfacial Tension (mN.m-1)	Recovery Efficiency (%)	SO — (* EO
268 GASOLINE	SULFONATE 2	0.5	0.015	41.3	11.4
		0.1	0.025	13.3	15.8
	SULFONATE 3	0.5	0.358	4.9	0
	APPE1	0.5	0.091	14.5	3.1
FUEL OIL # 2	SULFONATE 2	0.5	0.085	83.1	13.6
		0.1	0.100	7.8	6.2
	SULFONATE 3	0.5	0.745	4.4	3.8
	APPE 1	0.5	0.130	8.8	5.3

* : SO/EO : ratio of separated oil to emulsified oil.

FIGURE 10

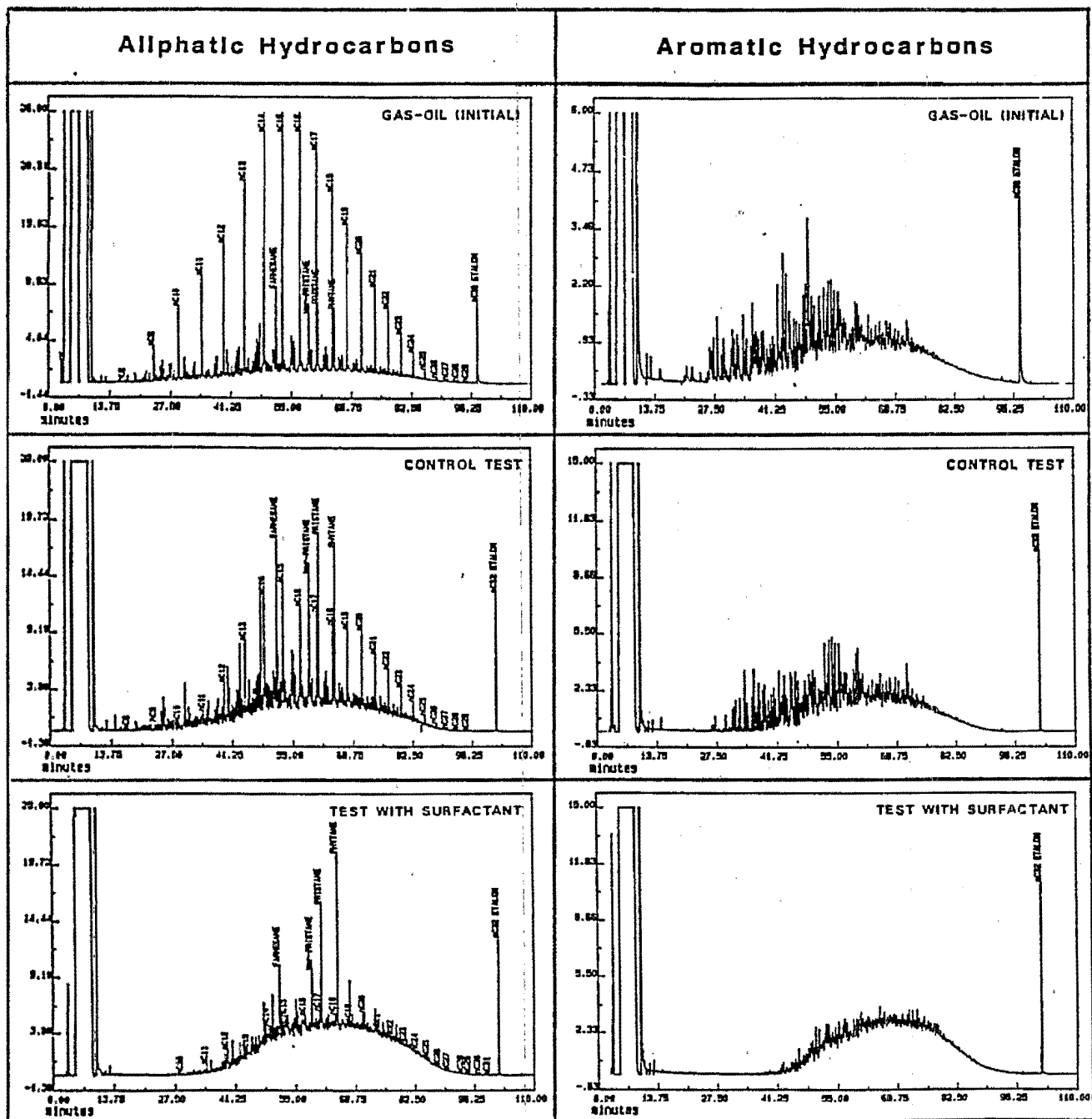


Surfactant effectiveness on the gas-oil recovery

Effect of the surfactant partition between water and oil.

1: Sand column 2: Control test (no oil) saturated column

FIGURE 11

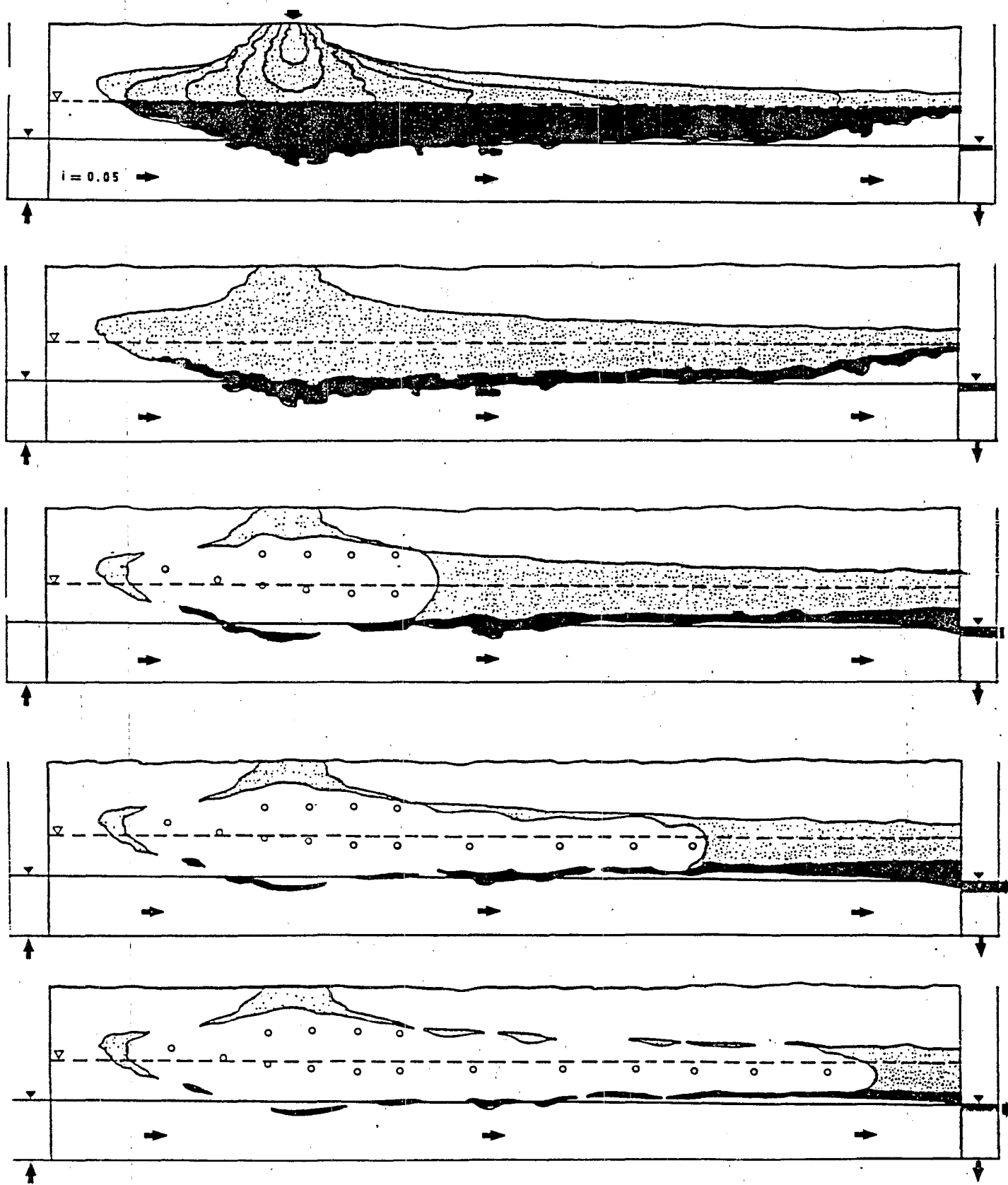


Aerobic biodegradation enhanced with surfactant

Oil eliminated after 50 days in column test, : control test : 53%

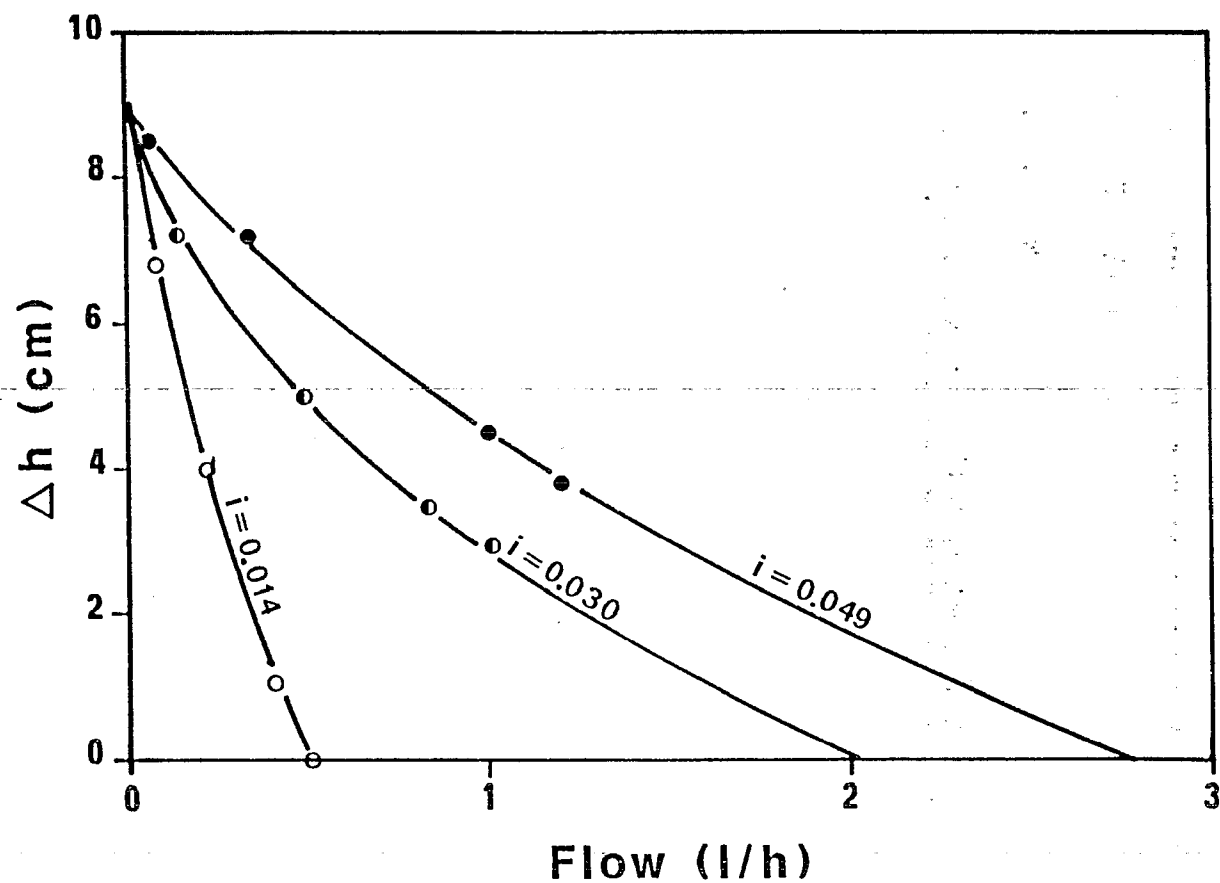
surfactant test : 98%

FIGURE 12



Surfactant flushing in laboratory model $2.5\text{m} \times 0.5\text{m} \times 0.12\text{m}$

FIGURE 14
272



Capillary fringe penetration by surfactant
vs injection flowrate and hydraulic gradient

NATO/CCMS Guest Speaker:

Jean Marc Rieger, France

Incineration in Cement Kilns and Sanitary Landfilling

N A T O C C M S

**PILOT STUDY DEMONSTRATION OF REMEDIAL ACTION
TECHNOLOGIES FOR CONTAMINATED LAND AND GROUNDWATER**

SESSION OF NOV. 8TH 1990 IN ANGERS :

INCINERATION IN CEMENT KILNS AND SANITARY LANDFILLING

**By Jean-Marc RIEGER
SCORI
10/24/1990**

SCORI is an outgrowth of the Environment Department of SERI RENAULT Engineering (Car Manufacturer).

The first projects date from 1972 and consisted of studies and surveys on industrial wastes on behalf of the French Government.

From 1976, SERI has collaborated with the company FRANCE DECHETS on the development of a network of controlled, special waste landfills in France. The cooperation between our company and FRANCE DECHETS is still running and will be described later on.

As early as 1977, the company had made contact with CEMENTS FRANCAIS for the development of waste incineration in cement kilns.

The company SCORI was created in 1979 and provides services in the field of sanitary landfilling of special (hazardous) waste and cement kiln incineration.

During the early 1980's, SCORI progressively expanded and strengthened its waste treatment activities and became one of the major French waste management firms.

In the continuation of its development, SCORI became a subsidiary of the principal cement companies in 1985, namely CEMENTS FRANCAIS, CEMENTS LAFARGE and VICAT.

Since then, SCORI has continued its internal and external growth.

Treating more than 700.000 tons of special waste in 1988, and almost 900.000 tons in 1989, SCORI has a consolidated turnover of FFr 180 millions.

SCORI employs over 160 personnel specialized in the recycling and disposal of industrial waste in its seven business offices and its five subsidiaries.

SCORI's principal activities are in the following areas :

- . Class 1 and 2 Controlled Waste Landfilling

Waste landfilling centres are the first in a line of SCORI services. At the 8 centres in France run by FRANCE DECHETS and its subsidiaries, SCORI receives a large spectrum of special industrial wastes in perfect conformance with existing legislation.

500.000 tons are treated annually on these Class 1 sites (permeability of the underlying earth less than 10^{-9} m/s).

The total number of Class 1 sites in France is 11.

- . Cement Kiln Incineration

Destruction in cement kilns combines environmentally safe waste incineration (up to 2000°C) and energy recovery. Fifteen kilns are today licensed for waste incineration in France. SCORI is involved in 14 of them. 250.000 tons are incinerated annually in these kilns.

- . Combustible Waste Preparation Centres

Certain types of waste cannot be directly incinerated at a cement plant because of their physical characteristics.

SCORI and its stockholders have developed a technique for producing a stable combustible suspension called "COMBSU", starting with liquid, solid or pasty waste.

Two centres are producing this combustible, treating approximately 50.000 tons/year altogether.

- . Pretreatment and Treatment of Waste by Physical-Chemical Techniques

Various centres are specialized in the stocking, grouping and pretreatment of industrial waste. SCORI is involved in 6 of them, where more than 150.000 tons of materials have been selected, prepared and distributed for appropriate treatment.

- . Co-Incineration with Household Wastes

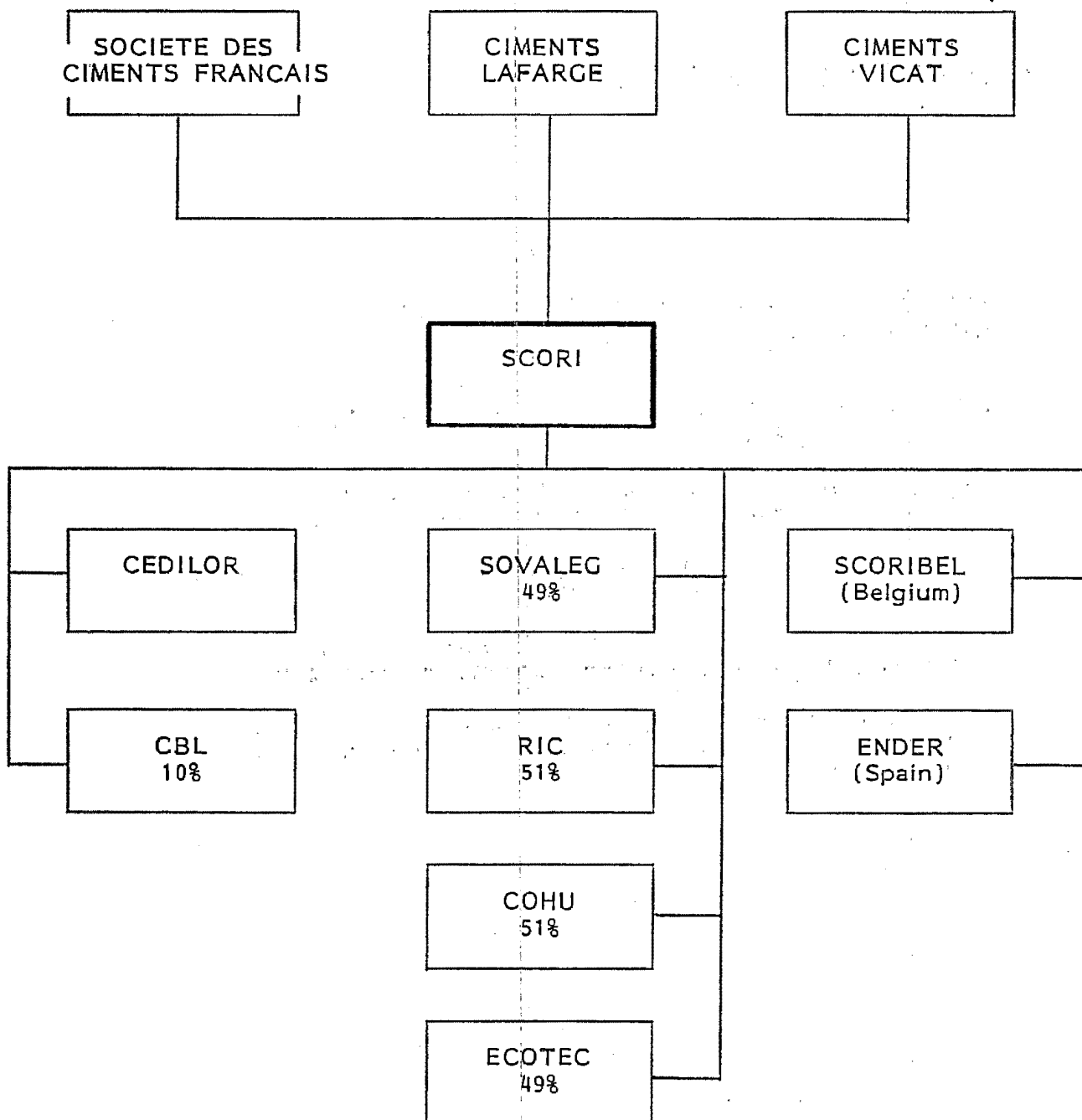
20.000 tons are treated annually by SCORI by co-incineration in one out of the two existing household waste incinerators licensed for hazardous waste treatment in France.

- . Waste Recovery and Plant Dismantling

SCORI provides sorting and disassembly services as well as a resale network. Close to 25.000 tons of different raw materials are handled realizing important savings for its customers (e.g. RENAULT).

A fast growing plant dismantling activity has been added to this department, mostly concerned by material recycling hit working together with our haz-waste specialists when cleaning or decontamination is required.

In addition, SCORI's policy of European expansion has led to the creation of two new foreign subsidiaries in Belgium and Spain.

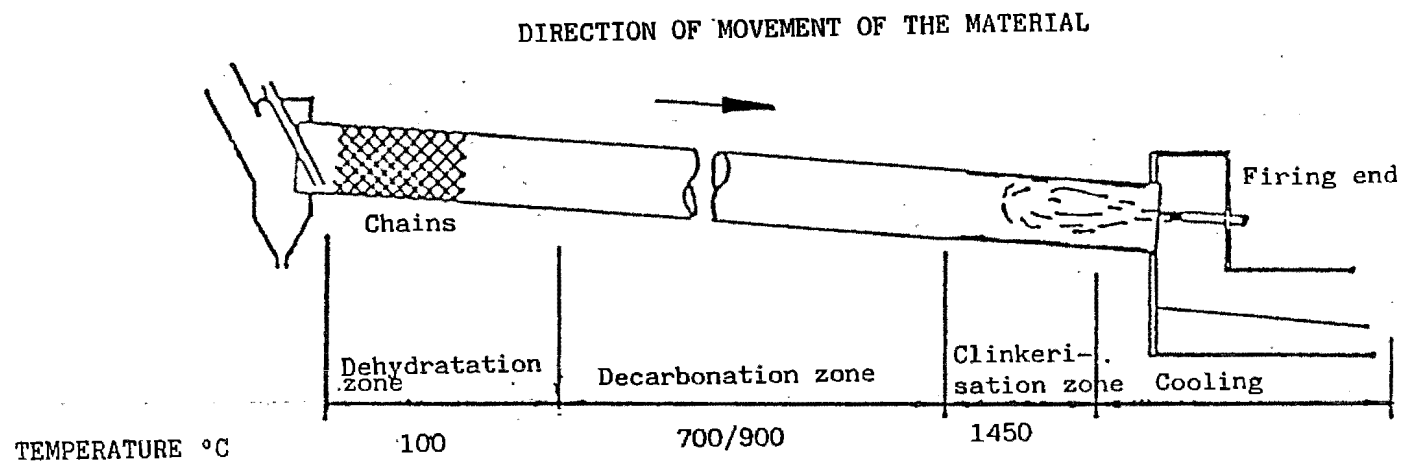


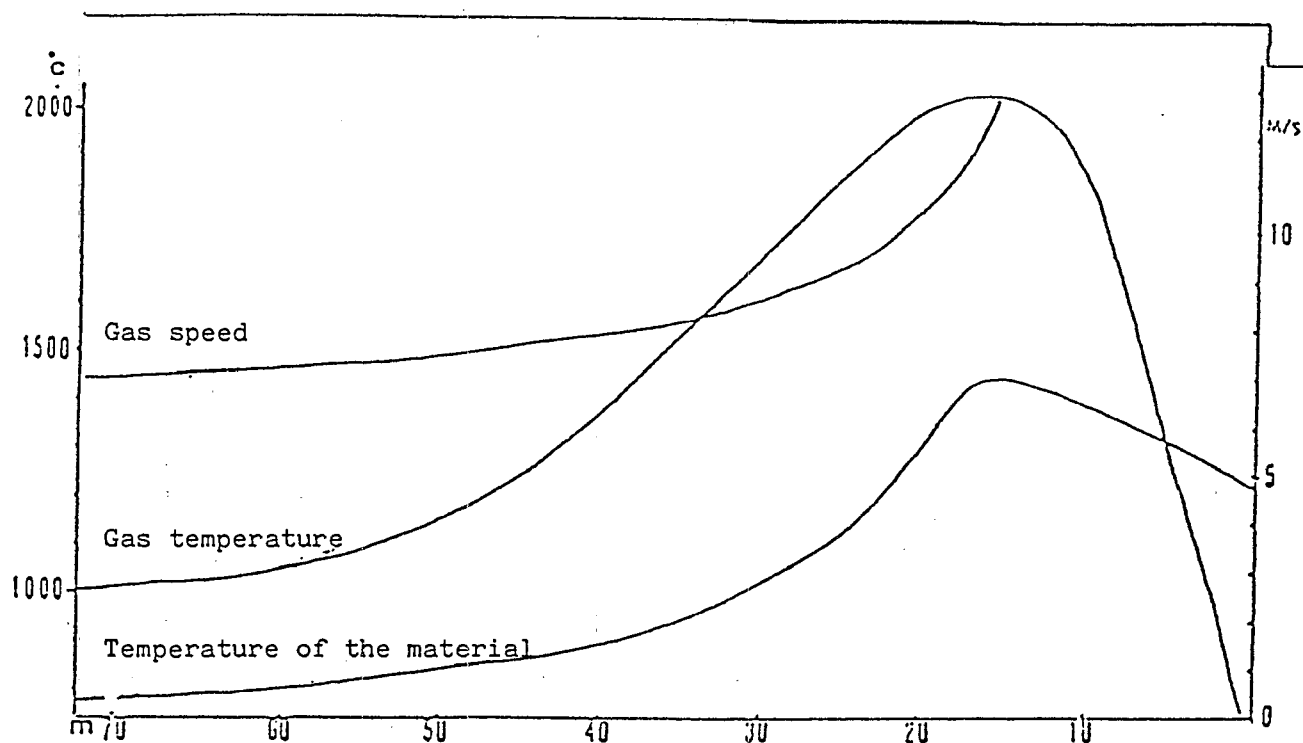
INCINERATION IN CEMENT KILNS

The cement kiln is a particularly effective tool for the incineration of special wastes :

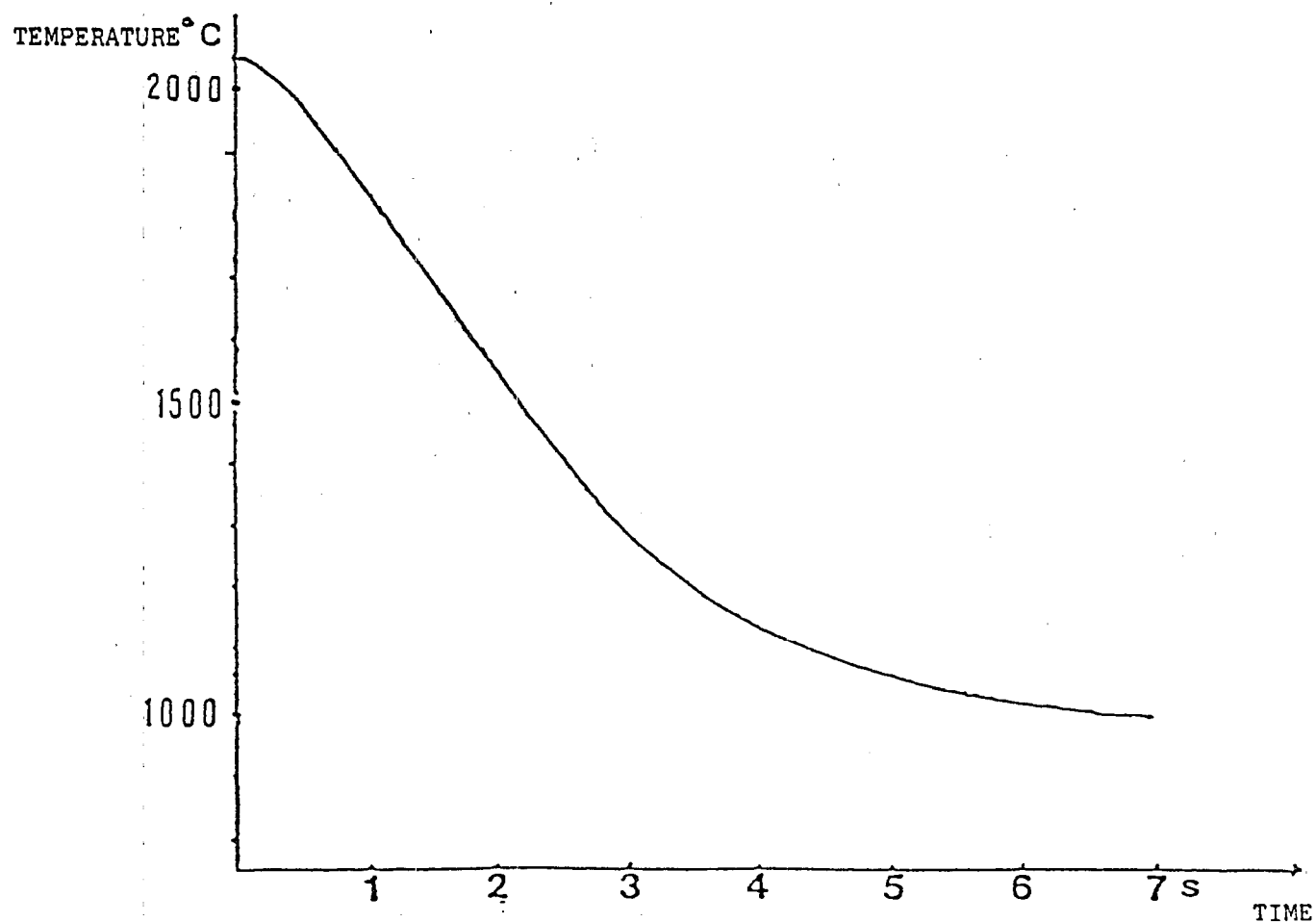
- . high temperatures and long gas residences times (more than 5 seconds at more than 1200°C),
- . efficient gas cleaning : the cement process offers a very high capture capacity for halogens (close to 100%) and for metals (greater than 95%),
- . the cinders remaining from waste incineration are incorporated in their inert form into the cement clinker,
- . the quality and the reliability of destruction are related to the necessity of closely following the clinker fabrication parameters,
- . the depth of response from the cement manufacturing profession which has oriented its significant technical potential towards the quality of incineration.

WET PROCESS





TEMPERATURE OF A MOLECULE INTRODUCED AT THE BURNER AS A FUNCTION OF TIME



SCORI'S WASTE ACCEPTANCE PROCEDURE

SCORI initiated and developed the procedure for acceptance of polluting wastes in treatment plants.

1st step : Waste characterization

Waste characterization is based on a sound knowledge of origins of the waste and on sampling and laboratory analysis.

For incineration, analysis of water content, calorific value, chlorine, heavy metals, PCB, sulfur etc... are performed.

In the case of landfilling, leaching tests are used to simulate the behavior of wastes in the presence of water and to identify the risk associated with the dissolution of polluting substances.

These analyses are performed by external laboratories, or by the laboratories of the treatment centres.

Waste acceptance

The results of waste characterization (physical state, levels of polluting substances in relation to admission thresholds, etc...), permit the evaluation of the acceptability of a waste in treatment facility.

When a waste is found acceptable, notification is made to the waste holder who can then arrange the delivery of his waste to the centre. An "Acceptance Certificate" is sent to the holder.

Waste admittance on the site

At site reception, and after checking the Acceptance Certificate, verification is made to ensure that the waste delivered conforms with the sample held by the onsite laboratory.

Following this admittance procedure, the weighing and unloading are performed, and a certificate of transfer of control is then given to the carrier and waste holder.

This procedure is rigorously followed and contributes to an efficient selection of wastes which merit specific disposal.

NATO/CCMS Guest Speaker:

Bruno Verlon, France

Contaminated Sites - Situation in France

CONTAMINATED SITES - SITUATION IN FRANCE

SUMMARY

In France, although the problem of contaminated sites has not reached until now the level of a first priority like in the USA or in some European Countries it is considered with seriousness by the National and Local Authorities.

Action has been and is presently carried out for the three main steps of these problems :

- Identification of potential problems - contaminated sites registration
- Evaluation of site contamination - risk assessment
- Treatment of contaminated sites - land recovery

Cleanup costs are most of the time supported by the waste producer or disposer according to the "polluter must pay" principle. In some cases, public funds have been granted, because of lack of responsible party. At the present time treatment techniques range from site control up to complete cleaning involving hazardous material extraction and off site elimination with some significant cases of waste encapsulation and more numerous examples of restoration by solidification-stabilization.

This last technique excepted, there have been, up to now, few french technologies developed specially for the rehabilitation of contaminated sites and soils. This situation can be explained by the relatively limited number of hazardous sites registered and by the existence of a rather well developed system for the treatment and disposal of industrial waste which can be used for the off site treatment of contaminated materials and soils. However this situation may change in the near future because of the increasing number of sites to restore and in this view we have decided to play an active role to promote the development of new french or imported techniques for the treatment of contaminated soils.

1 - IDENTIFICATION OF POTENTIAL PROBLEMS - CONTAMINATED SITES INVENTORIES

The first step of french action in the field of hazardous dumps sites and contaminated land consisted in two inventories carried out in 1978 on national level :

- the first one realized through inquiries of the Ministry of Environment among the local Inspections of Classified Installations responsible for control of polluting industries -including disposal installations-. By this mean, about 120 questionable sites were identified of which 62 were recognized as serious and therefore requiring priority corrective action
- the second one, consisted in a study made by the Bureau de Recherches Géologiques et Minières (B.R.G.M) for the account of the newly created ANRED. This study was carried out with the aim to discover hazardous sites by the collection of information available in the Regional Representations of the B.R.G.M, taking advantage of the particularly good knowledge these local agencies had of the environmental situation -assuming the fact that most of the time pollution occurring from contaminated sites affects groundwater-.

These investigations produced a total of 453 sites among which 82 were recognized as serious.

At the end of 1985, the official evaluation of the Ministry of Environment mentioned 107 cases which corresponded to a more important number of sites. This figure, compared with

the initial number of 62 hazardous sites shows that the first inventories carried out in 1978 were far from exhaustive. In addition two additional facts have emphasized the necessity of a new registration of unknown contaminated sites.

- The first is the extent of estimations to thousands of contaminated sites in countries where active environmental protection policy has been carried out on this subject : USA, Netherlands, Federal Republic of Germany.
- The second is the incidental discovery of abandoned hazardous sites that created certain pressure upon the local and national Authorities.

Consequently, the Minister of Environment has decided, at the beginning of 1985 to reactive new sites inventories. At the present time these actions are carried out through two main ways :

- 1/ Directives given to local Authorities responsible for the control of Classified Installation for the Environmental Protection (including industrial and municipal landfills) requiring reactivation of contaminated sites inventories.
- 2/ Mission given to the Agence Nationale pour la Récupération et l'Élimination des Déchets to develop new inventories actions at national and/or regional levels.

The main of these actions consisted in an inquiry of the municipalities by the mean of a mailed questionnaire. A great number of answer was obtained (more than 18000). However the number of questionable answers was only about 500 which are now being evaluted. This evaluation is not completed now but according to the main existing results it can be estimated that less than 10 percent of the mentioned cases would be really hazardous.

At the present time, according to a report published by the Secretary of State for Environment in july 1989, all these actions of inventory have produced a new list of about 100 officially registered hazardous sites that the government has planned to restore within the next five years. However this list is already not exhaustive : some existing important cases are not mentioned and the action of inventory is still going on.

II - ADMINISTRATIVE AND LEGAL ASPECTS

In France, the normal way to finance the studies and rehabilitation of contaminated sites is the application of "polluter must pay" principle. This is made possible by the implementation of two basic laws : the law of july 19, 1976 on Classified Industrial Establishments for the Purpose of Environment Protection and the Law of july 15, 1975 on the management of wastes.

These laws make the generators or holders of contaminated sites responsible for the pollution and pay for the investigations and rehabilitations. They have been successfully applied by Local Authorities under the supervision of the Ministry of Environment for most of the cases of rehabilitation carried out in France.

However, it appeared that in a significant number of cases it was not possible to find a responsible party able to pay for the depollution and some of these cases remained unsolved until the issue, on january 9, 1989 of a new directive for the Local Authorities facing such situations.

The main steps of the procedure described in this directive are the following :

- 1/ The local Authorities must carry out all the existing legal possibilities to find the polluter and make him realize and pay the rehabilitation project

2/ In the case of impossibility to find a reliable responsible party the Local Authorities inform the central level and ask its agreement for the following step which is as follows : the Prefect of the Department, acting as representative of the government, designate the National Agency for Waste Recovery and Disposal (ANRED) to carry out the rehabilitation of the considered site.

3/ In this situation, the ANRED carry out the rehabilitation project, financed by the government and after completion, engage lawsuits to find the responsible of the contamination and try to get the repaying of the expenses.

Up to now the implementation of this directive has given the possibility to solve about ten cases of middle importance.

III - TECHNICAL ASPECTS

III.1 - Introduction

In France, up to now, although there is a national policy on the subject of hazardous dumps and contaminated sites and some significant examples of land recovery there are no national or regional technical guidelines or standards applicable to the technical and economical management of the restoration of contaminated sites.

After the first inventories carried on in 1978, hazardous sites were ranked according to their estimated level of risk with colored point (black, red...). However this classification was roughly approximative with no really measurable parameters. In fact, risks assessment and decontamination projects have been carried out on pragmatic basis, according to variable estimations of the characteristics of the sites and of the vulnerability of the environment, allowing the Local Authorities to appreciate the seriousness of the problems and the manner to deal with them. Although this situation may be understood as a consequence of a necessary adaptation of a site restoration requirements to the local technical conditions it induces the risk of inadequate solutions and of inequality between polluters facing similar problems.

Therefore ANRED, working in many cases as a national expert has developed a special effort to rationalize the technical approach of these problems. The following paragraphs will reflect this point of view, based on our national and international experience.

III.2 - Evaluation and management of decontamination problems

The first step of a project for the rehabilitation of a potentially contaminated site consists in the definition of the problem : characteristics of the contamination, nature and importance of the risks, and further of the way to deal with it. In this view the assessment of the significance of the contamination, set up of cleanup goals and choice of rehabilitation techniques are of the utmost importance.

A first way to deal with these questions is to refer, when it is possible, to existing regulation not specific to contaminated sites, for example :

- In the case of the rehabilitation of a site by the isolation of hazardous material and contaminated soils reference should be made to existing regulations applicable to special industrial wastes controlled landfills : for example, requested maximum permeability of 10^{-9} m/s and necessity of efficient collection and treatment of liquid and gaseous effluents :

- In the case of treatment implying release of effluents (i.e leachates occurring after isolation or solidification-stabilization treatment) reference should be made to existing regulations :

- . applicable to drinking water supply in the case of the release of effluents in groundwater resources used for the population
- . applicable to the discharge of domestic and industrial effluents in the case of the release of effluents in surface water
- . applicable to gaseous emissions in the case of release of contaminants in the air.

More generally we think that the definition of the contamination and the set up of clean up goals should be based on site specific evaluation taking in account :

- The nature of the contaminants, their quantities, their chemical form and physical characteristics (toxicity and mobility) and the physical and chemical soils properties

- The characteristics of the migration pathways (environmental vulnerability) :

- . groundwater
- . surface water
- . soil
- . air
- . direct contact

- The present and future use of the soil and of the groundwater.

However it is also generally interesting to make reference to a comprehensive list of predetermined criteria of contamination levels of soil and groundwater to get an initial characterisation of the contamination and to set up preliminary cleanup goals. In addition the background level of pollutants naturally presents in the environment (metals, arsenic,...) has to be considered. As it has been mentioned before such specific criteria don't exist now in France and instead we can generally refer to the well known Dutch criteria.

III.3 - Techniques of rehabilitation

Up to now the main rehabilitation techniques which have been used in France are :

- extraction and off site treatment
- isolation of the contaminated area
- on site (or in situ) stabilization/solidification
- pump and treatment of contaminate water

At the present time projects are going on which implies the use of in situ soil vapor extraction and treatment, and thermal and biological processes are in development. However, considering the present existing contaminated sites it appears that there is a lack of techniques to solve many cases in satisfactory technical and economical conditions. In fact, the rehabilitations by extraction and off site treatment of wastes, contaminated soils and materials which has been performed in many cases by the use of the existing industrial hazardous waste treatment plants appears to be strongly limited in many cases of soils and contaminated materials not technically and/or economically adapted to such treatments. In this view the case of landfills for industrial waste has also to be specially mentioned because such installations have had up to now the possibility to accept a wide range of residues and polluted soils and materials

extracted in contaminated sites at rather low costs and this possibility will probably be strongly limited in the near future by more stringent regulations and increased costs.

In the perspective of this development of specific processes to restore contaminated sites we have studied on the national and international levels the different techniques which are already available or in development the following tables summarize their characteristics and their opportunities and limits of application.

III.3.1 - Techniques already available

TECHNIQUE	CONSISTS IN	APPLICABILITY	PARTICULARITIES LIMITS
Isolation	capping and lateral isolation	various kinds of solid waste materials and soils	-need a site suitable for isolation -relatively limited cost but require future control and maintenance -can be used as temporary solution
Extraction and off site treatment	Extraction, transport and treatment in industrial waste treatment plants	many kinds of hazardous waste and contaminated material	-characteristics of the wastes materials and soils has to be technically and economically adapted to the treatment -need transport -often costly
Solidification Stabilization	mixing with reactive agent, on site or in situ	sludges, liquids, soils. Mainly inorganic contaminants - in some cases non volatile organics	-limited efficiency (fixation not perfect) specially for organics and for amphoteric metals
Thermal treatment (soils)	Many kind of thermal treatment are available : the most usual include heating in rotary kiln + gas afterburner	Organics contaminants in contaminated soils and materials cyanides	-The temperature of the final incineration has to be adapted to the nature of contaminants -need special care for volatile metals

TECHNIQUE	CONSISTS IN	APPLICABILITY	PARTICULARITIES LIMITS
Extraction/ Soil washing	Many processes available : -some using pure water and mechanical energy to extract the contaminants. -other using various solutions or specific solvents.	Mainly inorganics (heavy metals) but also organics (PCB hydrocarbons)	- Usually efficiency limited by the size of particles - produces residues which have to be disposed with efficiency.
In situ vacuum extraction	-Creation of air depression in the unsaturated zone and treatment of the collected air -Possibility of improvement by air injection (in the saturated zone), by thermal desorption (heating)	Volatile organics	- efficiency influenced by impermeability, heterogeneity and water content of the soils.

In addition to these techniques it has to be mentioned the use of groundwater treatment. These treatments are carried out either alone in a continuous and long term decontamination process or in combination with other kind of treatment of a site. Different water treatment processes are utilized, either physicochemical or biological or combination of both. In many cases activated carbon is used in the final stage of the treatment to adsorb the micropollutants.

III.3.2 - Techniques in development

Many other kind of techniques are in development and for some of them are at the demonstration or commercialisation stage. We mention there after those of these processes we consider relatively promising :

- other kinds of thermal treatment : infrared, oxygen-enhanced, pyrolysis
- glycolate dechlorination (PCB)
- in situ vitrification
- wet air oxydation - supercritical oxydation
- electro reclamation

Biotechnologies appear also promising but have to be specially considered :

- they are developed in many countries by research institutions, universities, private enterprises and consultants, and a great number of research and development works are on going, based either on on site (on the field or in reactors) or on in situ processes, involving most of the time aerobic degradation and in many cases various ways to masterize and improve the degradation (i.e : enhanced oxydation). In many cases, it appears difficult to evaluate with accuracy the efficiency of treatment specially for complex molecules (halogenated organics) where the degradation implies stages of intermediate metabolites.
- up to now, few processes are available with proven efficiency on a commercial basis.

René GOUBIER
Texte présente à EUROFORUM
ALTLASTEN SAARBRUCKEN (R.F.A)
11-13 juin 1990

NATO/CCMS Guest Speaker:

Fritz Holzwarth, Germany

Cleanup of Allied Military Bases in the Federal
Republic of Germany

No text available.

1. The first part of the document discusses the importance of maintaining accurate records of all transactions and the role of the accounting department in ensuring the integrity of the financial statements. It also highlights the need for transparency and accountability in the reporting process.

2. The second part of the document outlines the various methods used to collect and analyze data, including surveys, interviews, and focus groups. It emphasizes the importance of using a mix of qualitative and quantitative techniques to gain a comprehensive understanding of the research topic.

3. The third part of the document presents the results of the study, which show a significant correlation between the variables being investigated. The findings suggest that the proposed intervention could have a positive impact on the outcome being measured.

4. The fourth part of the document discusses the limitations of the study and the need for further research. It also provides recommendations for future studies and suggests ways to improve the reliability and validity of the research.

5. The fifth part of the document concludes the study and summarizes the key findings. It emphasizes the importance of the research and the potential for future applications of the findings.

NATO/CCMS Guest Speaker:

James Berg, Norway

**Cold-Climate Bioremediation: Composting and Groundwater
Treatment Near the Arctic Circle at a Coke Works**

Cold-Climate Bioremediation: Composting and Groundwater Treatment Near the Arctic Circle at a Coke Works

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ABSTRACT

Bioremediation was evaluated as an alternative treatment method for a coke works site in northern Norway near the Arctic circle, which was characterized in 1989 as having significant contamination by polycyclic aromatic hydrocarbons (PAH), arsenic and cyanide. About 20,000 tons of soil containing PAH's (ca. 500 mg/kg) were excavated. Groundwater at the site contained ca. 2-3 mg/l and 0.4-1.6 mg/l naphthalene and benzol. A pilot study was conducted in 1990, in which 1,000 m³ of soil were treated in an enhanced composting system and 7000 l groundwater was treated in a biofilm reactor.

The variables tested in the composting study were: N and P, bark matrix and dispersant addition, temperature (4°-16°C), moisture (10-35 %), and aeration by blowers, H₂O₂ addition or pile turning. The treatment objective was ≤ 10 mg/kg Total PAH. Results showed that the PAH-content was reduced to below the objective within 8 weeks at 12-16°C. Treatment efficiency ranged from 96-99 % dependent on test variables. Optimal results were obtained by 1) addition of tree bark as a matrix, 2) supplemental forced aeration, 3) soil moisture maintained at 25-30 % for this soil type, 4) N and P additives, and 5) dispersant additives. Groundwater was pumped from a pilot well and treated in a rotating biological contactor (RBC), covered to control emissions of volatile compounds. The early migration of arsenic into the area also necessitated development of a two-stage pre-precipitation process using lime and ferric chloride in series to remove arsenic. Nitrogen was added after pre-treatment. Once the biofilms were acclimated to the water, chemical oxygen demand, Σ PAH, and toxicity (Microtox ®) were reduced 97, >99, and 93 %, respectively.

INTRODUCTION

The Norsk Koksverk coke works was located in Mo i Rana in the northern part of Norway. The plant processed approximately 440 000 tons of coal per year, beginning in 1964. The plant annually produced 55-60 000 tons NH₃, approx. 15000 tons tar and 5000 tons benzene. These products were sold without further processing at the plant. The plant was closed down in the fall of 1988 for economic reasons. Site characterization and clean-up was required by the pollution control authorities (SFT) before any further development of the area would be permitted.

Owing to the acute contamination of two areas, approx. 20,000 tons of soil was excavated and placed in lined and covered depositories on the site. This was designated as the "PAH-Soil" for the composting study and contained ca. 500 mg/kg PAH. Groundwater contained ca. 14 mg/l PAH originally, and later ca. 200 mg/l arsenic.

The remediation of a contaminated coke works site (Norsk Koksverk) i Northern Norway was initiated in 1989. It was unique in that it was Norway's first major cleanup in which several technologies had to be considered for the contaminants, including polycyclic aromatic hydrocarbons (PAH), arsenic, cyanide, and copper. The subject of this paper concerns the treatment of the PAH-contaminated soil and groundwater, in which biological processes were chosen for the pilot study. Biological treatment of soils contaminated with organics is a preferred technology in many cases because of its simplicity, lack of residuals (e.g. sludges) requiring further treatment, and relatively low cost (1-4). Coke or gas works sites are typically contaminated by PAH's (5) which can be biologically degraded (6-8). Bioremediation processes especially designed for aromatics have also recently been described (11-13).

PILOT STUDY REMEDIATION PLAN

General

As stated above, there were several types of contamination, requiring different remediation processes. Three separate pilot treatability studies were

conducted:

- (1) Composting of excavated PAH-soil.
- (2) Physical-Chemical-Biological Pump-and-Treat of As-PAH groundwater.
- (3) Stabilization of excavated As-soil.

The first two studies are reported herein.

Soil Composting Study

PAH-contaminated soil (Avg. concentration = 500 mg/kg total PAH) from "Dep. 4" was sorted, crushed, and mixed to form as homogeneous a material as possible.

The soil was then placed in 9 separate piles of ca. 10 m³, 2 m x 3 m x 1.5 m (W x L x H), on geomembranes. Seven piles were placed in an unused industrial building, while two were placed in an abandoned local mine. The latter was chosen since the mine is a candidate full-scale treatment facility with excellent capacity for final, secure deposition of treated soil (Volume of storage space is 1 million m³ with excellent ventilation and controlled drainage). Table 1 shows the variables tested in the study, which are described below.

Table 1. Experimental variables in the pilot study. FA = Forced aeration, T = pile turning, N & P = Nitrogen and phosphorous.

File	Treatment				
	Bark	N&P	Aeration	Temp (°C)	Other
1.	-	-	T	10 - 16	-
2.	+	-	T	10 - 16	-
3.	+	+	T	10 - 16	-
4.	+	++	T	10 - 16	-
5.	+	+	FA	10 - 16	-
6.	+	+	H ₂ O ₂	10 - 16	Recirc H ₂ O + dispersant
7.	+	+	T	25 - 35	-
8.	+	+	-	4	-
9.	+	+	T	4	-

Pine bark was added to all piles except No. 1 (control with no amendments) in a ratio of bark: soil equal to 1:1 on a volume basis. The soil was sandy and had very little capacity to retain moisture. Nitrogen and phosphorous were added to six of the piles in two different doses at the start of the study and after 8 weeks. The piles were oxygenated by either turning the piles every three weeks, by forced aeration, or by peroxide addition via a water recirculation system. Peroxide was replenished three times per week. Ambient temperature ranged from 4-16°C for six of the piles in the industrial building. One pile was artificially heated by electric cables under the geomembrane base. The two remaining placed piles in the mine remained at a constant 4°C throughout the study. The piles were watered initially, and after weeks 6 and 8. Pile 6 also had regular periodic recirculation of water throughout the study. Dispersant, peroxide, and nutrients were added to the water.

The piles were sampled twice weekly from 3 random locations at ca. 80 cm depth. Composite samples were prepared and placed in acid-washed brown glass jars and either analyzed immediately or frozen at -18°C. Temperature and soil gas measurements were taken at three locations at ca. 80 cm depth twice weekly also.

Analyses were conducted on site if possible. However, contract laboratories performed all PAH analyses. Analyses consisted of:

- Moisture
- pH
- Tot N
- Tot P
- Total PAH (+ all components by GC/MS)
- Soil gas (O₂ and CO₂)

Composting Study Results

The results of the study for the most predominant PAH's are shown in Figures 1 and 2. In all cases, biphasic reduction in PAH's occurs over the 14 week study period. It is largely the duration of the lag phase or initial reduction rate that is influenced by the various amendments. Notably, the control pile shows the slowest rate of PAH reduction in all cases. The proposed treatment goal, the Dutch "B" level of 20 mg/kg PAH is achieved in 6-8 weeks under optimal conditions. The individual PAH's, as typified by Figure 2 for fluorene and acenaphthene, also follow the same behaviour. Forced aeration and nutrient additions both contributed to a much more effective process. Other lab experiments (data not shown) indicate that increased volatilization of the 2-5 ring PAH's by forced aeration was not significant, suggesting that it was primarily biological activity that explains the reduction in PAH's.

Also, it is interesting to note that even at 4°C, there was effective removal of PAH's (See Figure 2, Files 8 and 9 for fluorene and acenaphthene) suggesting that the naturally occurring populations had been well adapted to the low temperature environment. Owing to problems with regulating the temperature in the pile with heating cables, no reliable data were obtained for greater than ambient temperature which ranged from 4°-16°C during most of the study.

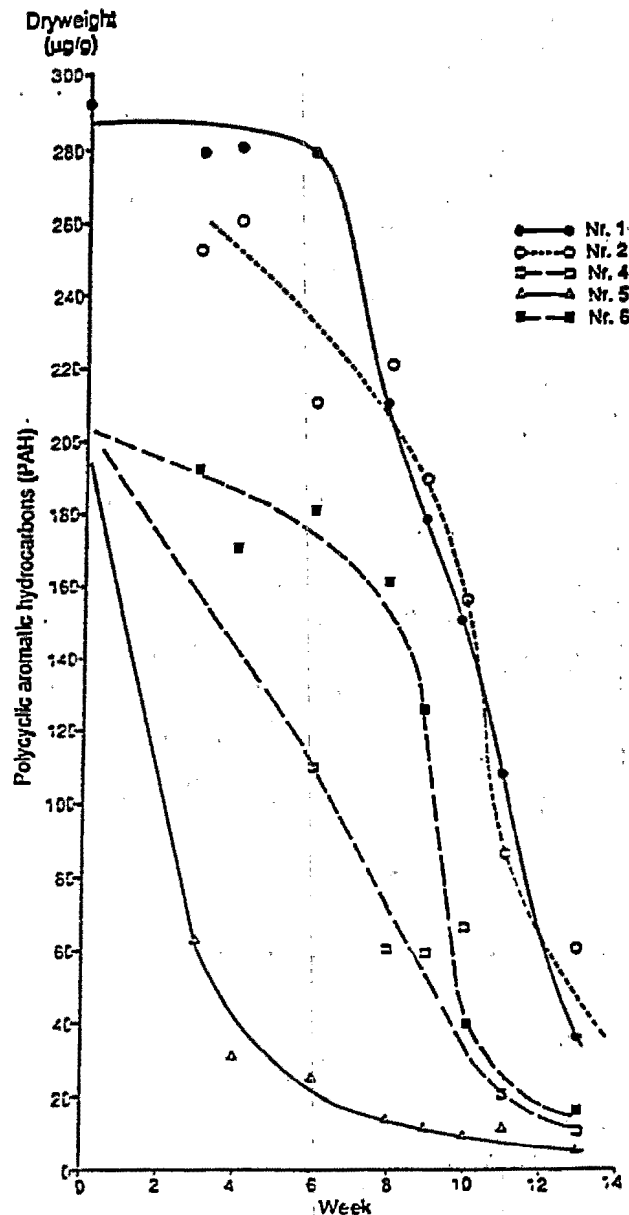


Figure 1. Reduction of Total PAH's.

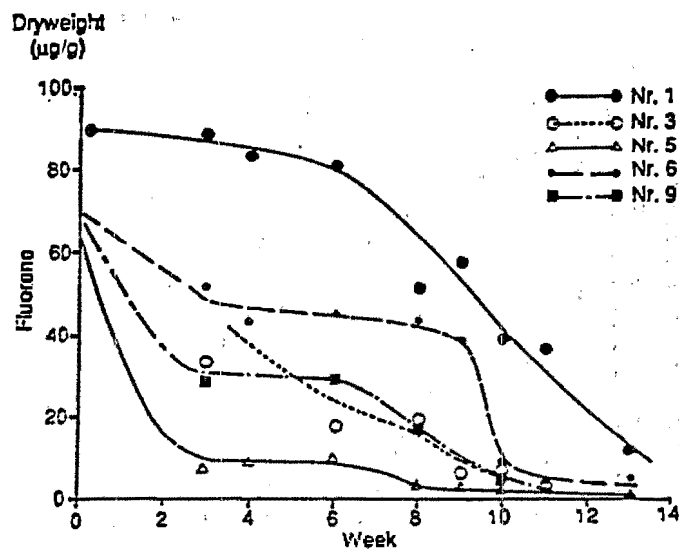
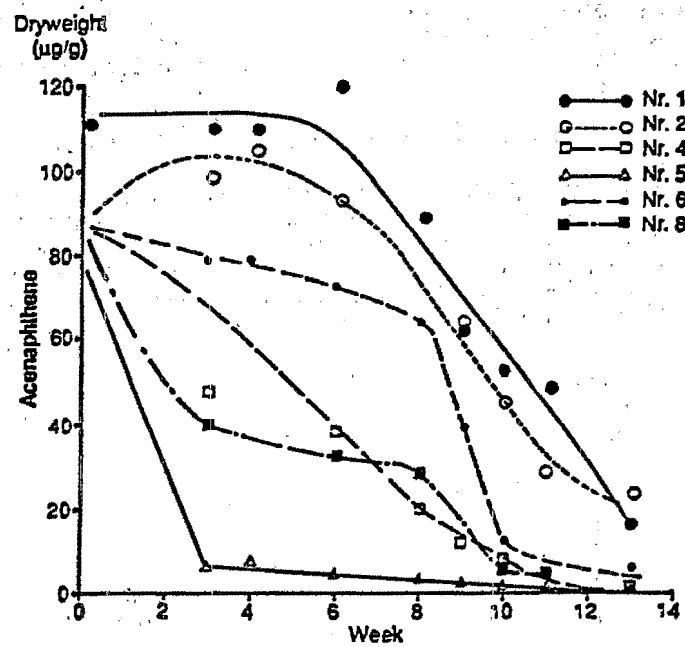


Figure 2. Reduction of fluorene and acenaphthene.

Lastly, the PAH removal results of the water recirculation experiment were unexpectedly low. Therefore, other dispersants were subsequently evaluated in bench scale batch and flow-through column studies. Results showed that another type of dispersant, ECO/+ (R.L. King Assoc. - Dutch Pride Products, 500 Airport Blvd., # 238, Burlingame, CA 94010) greatly enhanced the mobilization and removal of PAH's. In batch mixing studies, low concentrations of ECO/+ at ca. 10°C removed > 62 % of Total PAH's. The product is reported to be biodegradable so that the composting process should not be inhibited.

The results of the PAH reduction aspects of the study are comparable with other published studies (14-16). Where it is possible to directly compare individual compounds, for example with phenanthrene, the half life ($t_{1/2}$) in this study was ca. 14 days under optimal conditions versus 16-200 days under a range of other comparable conditions of temperature (10-20°C) and amendments (added nutrients). The same is true for fluoranthene, with this study reporting $t_{1/2}$ = 48.5 days versus 29 to 440 days. Where total PAH data were available, this study reports $t_{1/2}$ = 22 days under optimal field conditions versus 43 days in a laboratory study (17).

Groundwater Treatment Study

The groundwater treatability pilot study was begun in April 1990 and run over a four month period. The pilot well was placed in the center of the area which had previously been characterized as contaminated with PAH's. The well placement was also chosen to avoid the arsenic-contaminated zone, to avoid complications for the study. However, the arsenic plume had migrated sufficiently such that ca. 200 mg/l As was actually present in the groundwater at the pilot well. The major characteristics of the water are shown in Table 2. The pH was quite high owing to the caustic arsenic tank spill. Also, the chemical oxygen demand (COD) was high initially, 1400 mg/l, and doubled over the period of the study to 2800 mg/l.

Table 2. Composition of the groundwater from the pilot well.

Parameter	Value (range)
pH	9.5 - 10.9
D.O. (mg/l)	1.5 - 2.5
Conductivity (mS/m)	55 - 65
COD (mg/l)	1400 - 2800
Napthalene (mg/l)	0.4 - 1.6
Benzene (µg/l)	60
Σ PAH (mg/l)	1.8 - 2.8
As (mg/l)	200 - 215
Cu (mg/l)	0.005 - 0.05
CN (mg/l)	2.5 - 7.5

After the well was established, it was pumped once a week, producing a 700 l batch for the pilot treatment process. The 700 l volume was, in some cases, pretreated. Thereafter it was pumped into three 200 l tanks for further additions. The 200 l tanks then served as the reservoirs with capacity for 5-7 days operation for the six biofilm reactors. The reactors were placed in different configurations through the study. The three reservoirs and six bioreactors were covered to minimize losses by volatilization. The study was conducted in four phases. Phase 1 included acclimation of the biofilm, and studying the effect of six different loading rates. Phase 2 included two loading rates on four sets of reactors, two of which were in series. The effects of nitrogen and phosphorous additions, and surfactant and solvent addition were also monitored. Phase 3 included chemical pretreatment of the water by lime precipitation and pH adjustment. Phase 4 included chemical pretreatment by precipitation with ferric chloride and lime in series. Also, activated carbon columns were added as a final polishing step. The configuration of the processes is shown in Figure 3.

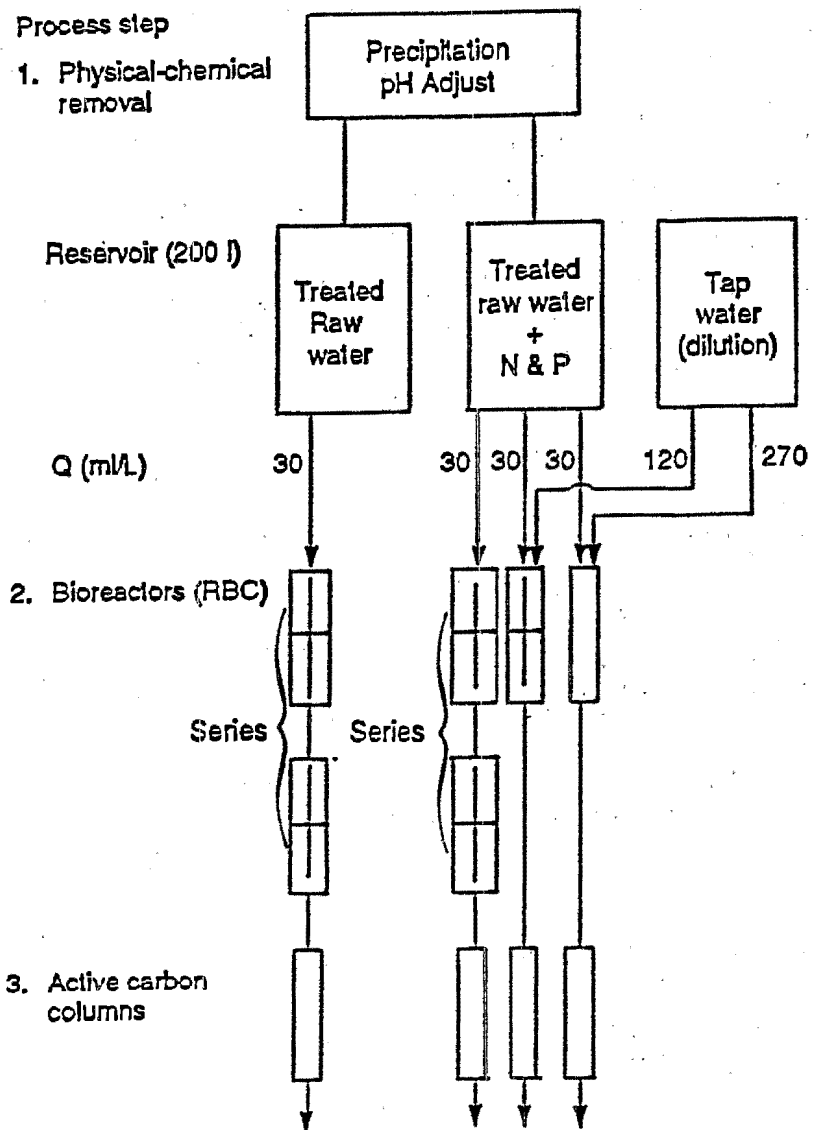


Figure 3. Configuration of the process train in Phases 3 and 4.

Daily measurements were: flow rate in each reactor set; and temperature, pH, and D.O. in each bioreactor. Microscopic examination of special glass slides built into the rotors was done twice weekly. Samples were taken daily from the reservoirs, and before and after each process unit. These were split and analyzed immediately for COD (daily values) and preserved and analyzed weekly for all 26 PAH components (composites). Arsenic, copper, cyanide, and nitrogen and phosphorous were analyzed periodically for control purposes. Toxicity of influent and effluent was measured by Microtox® testing at the completion of the study. The bioreactors were cleaned thoroughly once each week to minimize the contribution of wall growth on degradation/removal rates, a factor of paramount importance for full-scale design.

Groundwater Treatment Study Results

Organics Removal

Removal of COD in the first three phases of the study was negligible. This was due to non-acclimated cultures, range-finding for proper N & P addition, apparent toxicity of influent metals, and unsuccessful early attempts at pH control.

The results for Phase 4 are shown in Figure 4. After about a 10-14 day acclimation period, the removal of COD began to increase dramatically to ca. 95%. To test whether this effect was achieved biologically, the biofilm was scraped from the reactors, causing an immediate decrease in percent removal to the original level. The systems re-equilibrated about two weeks achieving >95% removal. The "20% removal rate" shown for the reservoirs (DT 7 and DT 8) reflects the prior removal of COD in the precipitation pretreatment of the raw groundwater. There was no significant decrease in COD in the reservoirs themselves.

Neither COD nor PAH measurements indicated significant losses due to volatilization. Nonetheless, a separate batch test was run in which 2 l of influent water was violently aerated for 24 hours. COD, naphthalene, and Σ PAH were measured before and after. A maximum of 25% naphthalene was lost, comprising most of the Σ PAH losses as well. Other studies have reported only 0.4 to 7.6% loss of naphthalene in covered RBC's (18), attributing most removal to biodegradation (9). Therefore, in the closed, passively aerated RBC's, volatilization was not considered to be significant.

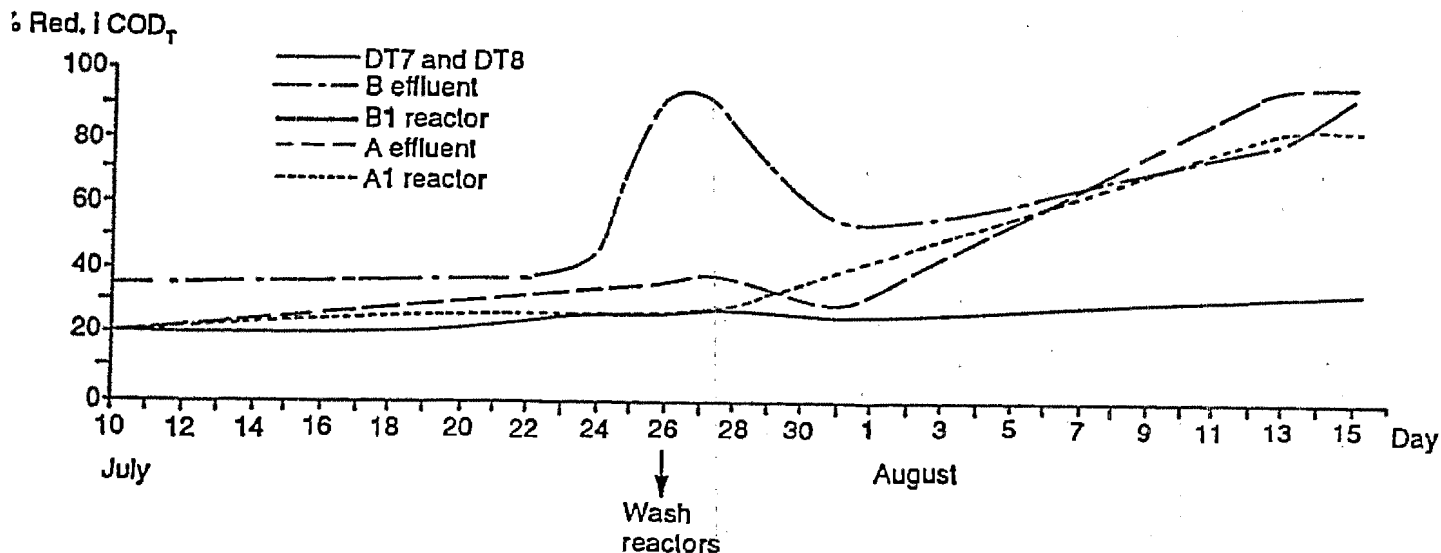


Figure 4. Percent reduction of COD_t during Phase 4.

Arsenic Removal

An immediate increase in arsenic from <5 to >200 mg/l necessitated addition of a process step to remove it. Early jar tests indicated that lime precipitation was not adequate. Subsequent trials with ferric chloride were also unsatisfactory. However, step-wise treatment using lime followed by ferric achieved significant arsenic reductions as well as COD reductions (Table 3). This type of process sequence has also been reported elsewhere (20).

Table 3. Results from jar tests for 2 step lime and ferric precipitation.

	Raw water	1	2	3	4
Ca(OH) ₂ (mg/l)	---	---	---	3.0	3.0
FeCl ₃ (ml)	---	1.5	1.0	1.5	1.5
pH	9.95	4.45	6.3	¹ 4.3 ² 10.1	5.95
COD _{FILTR.} mg/l	2500	1503	1473	¹ 1516 ² 1386	1310
As mg/l	216	183	162	39	134
Cu mg/l	0.007	<0.005	<0.005	<0.005	<0.005
CN mg/l	2.5	6.9	8.0	5.1	7.5

Summary of Results

The results for the groundwater treatment study showed that chemical oxygen demand (COD), Σ PAH, and toxicity were 97, >99, and 93 percent, respectively (Table 4).

Table 4. Groundwater treatment pilot study results.

Sample location	COD _{max}	% Red.	Σ PAH mg/l	% Red.	Toxicity EC ₅₀ (15 min.)	% Red.
	Phase 4	Phase 4				
Raw water	1400	--	2.19	--	30	--
Finished effluent	40	97	0.0042	99.8	427	93

SUMMARY

Both composting and the RBC process performed well in the pilot studies. These biological processes were chosen because of low capital and operating costs, on-site capability (low area requirement), minimal developmental requirements, simplicity for operation at a remote site, and capability for cold-climate, year-round operation. The conclusions for each pilot study follow.

Composting Study

1. Among the amendments evaluated in the study, the addition of bark and nutrients, (primarily nitrogen) and forced aeration, were essential for optimal biological activity.
2. The surfactants chosen for the pilot study did not improve PAH removal. However, subsequent column and batch studies with another commercially available product (ECO/+) were very promising.
3. Cultures adapted to low temperatures showed significant degradation at 4°C, however, better results were obtained at temperatures ranging from 6-16°C, as one would expect.

4. The proposed treatment objective of 20 mg/kg Total PAH was attained within 6-7 weeks, while a more stringent goal of 10 mg/kg was reached within 8-9 weeks.

Groundwater Study

1. A four step process was developed for successful treatment of the water including:
 - * Oxidation for CN destruction and As-pretreatment.
 - * Two stage precipitation with ferric chloride and lime for As removal and some COD reduction.
 - * Addition of N & P and pH adjustment for biotreatment.
 - * Two stage RBC bioreactor for PAH and COD removal. (Activated carbon columns can be added for water not reinjected to the aquifer).
2. Separate studies showed that dispersant addition could mobilize ca. 60 % of PAH's in batch tests. This will be injected into the treated water prior to return to the contaminated aquifer in a pump-and-treat well-point system.

ACKNOWLEDGEMENTS

The pilot study was conducted for the municipality of Mo i Rana with additional support from the Royal Norwegian Council for Scientific and Industrial Research (NTNF) and Norwegian Applied Technology A/S, Stavanger, Norway. Technical support from Dr. Royal Nadeau, U.S. EPA, New Jersey is gratefully acknowledged.

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NATO/CCMS Guest Speaker:

Gjls Breedveld, Norway

In Situ Bioremediation of Oil Pollution in Unsaturated Zone

IN SITU BIOREMEDIATION OF OIL POLLUTION IN THE UNSATURATED ZONE

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ABSTRACT

Leakage of an underground storage tank at the Trandum Army Base caused a 20.000 liter spill of fuel oil. Several options for remediation have been evaluated. In situ bioremediation was chosen as the most cost effective and realistic method and was evaluated in detail. Preliminary laboratory studies showed that a large number of hydrocarbon degrading micro-organisms are present and that good degradation rates can be obtained with the addition of a nitrogen and phosphorus source. Since July 1991 a full scale bioventing installation has been in operation. The preliminary monitoring results give an indication of biological activity.

INTRODUCTION

On October 12, 1990 the loss of 20.000 liter of a light fuel oil from an underground storage tank at Trandum Army Base was discovered. Immediate action was taken by NODCS by removing the tank. The State Pollution Authority ordered immediate measures to prevent spreading of the pollution to the underlying aquifer (October 15.). Consequent clean up of the residual oil in the unsaturated zone should prevent future risks for groundwater pollution.

SITE DESCRIPTION

Trandum Army Base is situated in the Romerike area some 40 km North of Oslo. This area is one of Norway's most important groundwater reservoirs. The unconfined aquifer is composed of glaciofluvial sand and gravel partly underlain by silty glaciomarine deposits. The average thickness of the deposits is 73 m. The unsaturated zone can vary from 1 to 30 m below ground level (Jørgensen and Østmo, 1990). At Trandum near the storage tank (building 111) the groundwater level is at 30 m below g.l. The soil texture can be described as sand and gravel in the uppermost 10 m, silty sand between 10 and 20 m and medium fine sand to silty fine sand between 20 and 30 m (Hauge and Kolstad, 1990).

SITE INVESTIGATION

Immediately after discovery of the leakage interception wells were drilled in the center of the polluted spot and down stream of the groundwater flow direction. Pumping started on October 26. (Storrø, 1991).

Additional borings were carried out to assess the extent of the pollution. A total of 98 samples were analyzed for total hydrocarbon (THC) content by gas chromatography.

Table 1. Vertical distribution of oil in the centre of pollution (Storrø, 1991).

Boring	Depth (m)	THC (g/kg)
PB 2	4	8,5
PB 2	5,5	9,4
PB 2	7,5	10,3
PB 2	9	10,1
3	12	19,4
3	14	18,2
3	16	19,2
3	18	18,5
3	20	13,2
3	24	18,4
3	28	<0,05

An impression of the vertical distribution of the pollution is given in table 1. The data indicate that the main pollution plume has not moved completely vertically, but has partially moved diagonally beneath the building.

Figure 1 gives an impression of the assumed extent of the oil pollution. The boundary indicates approx. 1000 mg/kg THC.

It is believed that the pollution is completely retained in the unsaturated zone at residual concentration levels. The plume has not reached the groundwater level and upto now no oil or aromatic hydrocarbons (BTEX) have been detected in the pumping well (PB 2) in the centre of the pollution (Kolstad et al. 1991b).

REMEDIALTION ALTERNATIVES

Based on the results of the field investigation different options for remediation of the site are evaluated (Hauge and Kolstad, 1990):

- Isolation
- Removal by open excavation of 300.000 m³.
- Removal by excavation inside a sheet pile wall (20.000m³).
- In situ bioremediation.

Isolation was not an actual solution, as the State Pollution Authority ordered complete rehabilitation of the site.

As the cost of in situ bioremediation is excessively lower than excavation and subsequent treatment of the polluted soil, this technique has been evaluated in detail.

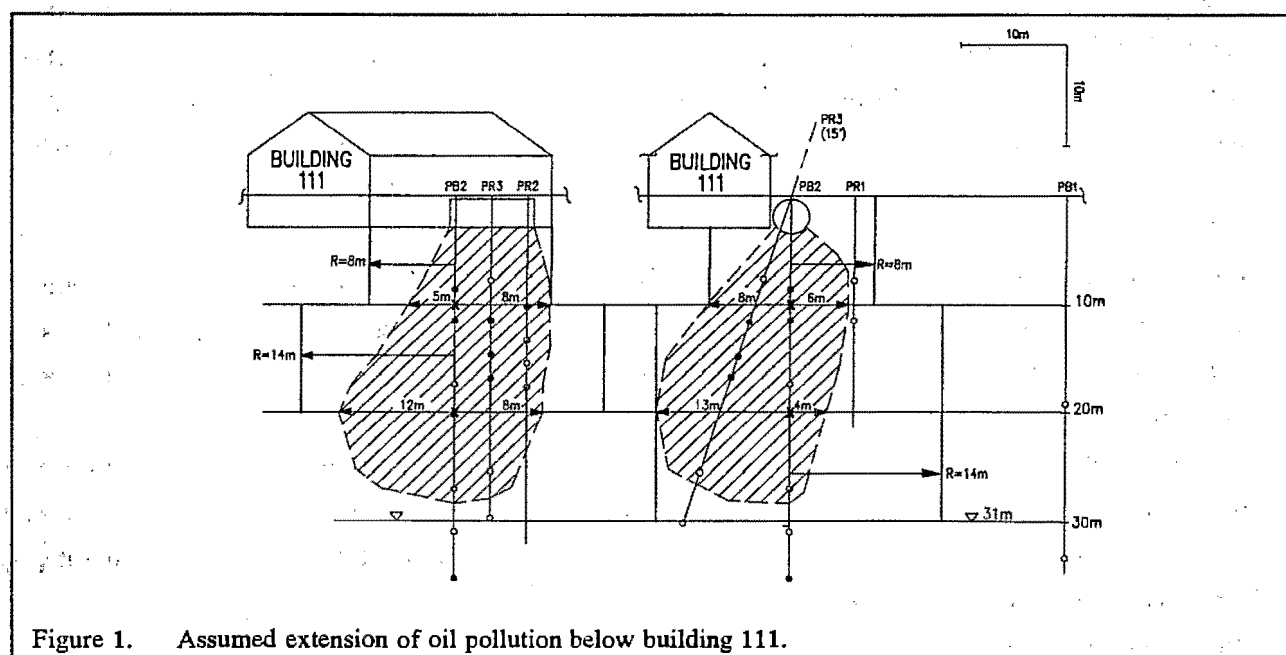


Figure 1. Assumed extension of oil pollution below building 111.

BIOREMEDIATION POTENTIAL

To assess the possibilities for using in situ bioremediation at this site, the following laboratory studies were conducted:

- quantification of the total natural microflora and the number of hydrocarbon degraders.
- degradation rates in microcosms and potential of increasing it by moisture, nutrient and special oil microflora addition.

The natural microflora was determined using plate counts of colony forming units (CFU) on nutrient medium. The number of hydrocarbon degraders was determined using mineral medium and a small "well" of diesel oil as only carbon source (Briseid and Eidså, 1991). Table 2 gives an overview over the vertical variation in the microflora.

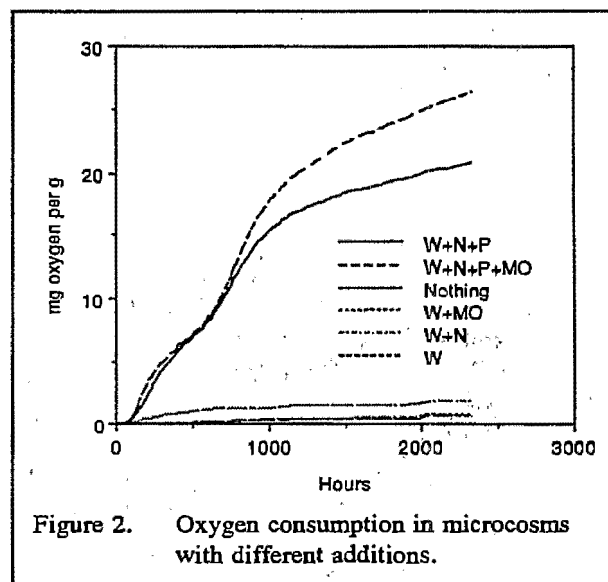
Table 2. Vertical distribution of the microflora in the centre of pollution.

Boring	Depth (m)	Total (CFU)	HC-degr. (CFU)
D1	8	$3 \cdot 10^7$	$1 \cdot 10^7$
D2	12	$2 \cdot 10^7$	$2 \cdot 10^6$
Mix	20-24	$1 \cdot 10^7$	$1 \cdot 10^6$
C1	27	$2 \cdot 10^4$	$5 \cdot 10^3$

A batch of mixed samples (20 to 24 m below g.l.) was used in degradation experiments at 15 °C. The sample can be described as fine sand with some gravel, and contained 29 g THC/kg in the fraction <2mm. The degradation rate was measured in microcosms (10 g.) in a "Sapromat" which measures the oxygen consumption. The effect of the following additions on the degradation rate were tested:

1. nothing, moisture content 5%
2. water, moisture content 15%
3. as 2 + special oil microflora
4. as 2 + nitrogen source (0,4 g/kg)
5. as 4 + phosphorus source (0,1 g/kg)
6. as 5 + special oil microflora

The oxygen consumption was registered over 100 days (figure 2). The results indicate a clear increase in oxygen consumption rates with the addition of a nitrogen and phosphorus source. The addition of a special oil microflora caused only a minor increase in the consumption rate. This effect was clearest visible during the last part of the experiment.



Assuming that the total mineralisation of 1 g of oil consumes about 3,5 g oxygen, a reduction in THC concentration in the nitrogen and phosphorus amended soils with and without oil microflora of 7.6 g/kg (26%) and 5,9 g/kg (20%) respectively should be expected. The data indicate an average degradation rate of 78 mg THC/kg/d and 61 mg THC/kg/d respectively. After 59 days one of every duplo sample was taken out for chemical analyses. The analyses results show the same relative effect of the different additions as the oxygen consumption measurements showed. However the reduction in concentrations is much higher than expected (Table 3). The reduction in the soils where almost no oxygen consumption was registered (1,2,3 and 4) can possibly be caused by evaporation to the gas phase in the microcosm (250 ml).

Table 3. THC concentrations after 59 days incubation in microcosms (W=water, N=nitrogen, P=phosphorus, MO=oil microflora).

Addition	THC (g/kg)	Reduction (%)
1. Nothing	22	24
2. W	21	28
3. W+MO	22	24
4. W+N	21	28
5. W+N+P	13	55
6. W+N+P+MO	11	62

The removal rates in the nitrogen and phosphorus amended soils are much higher: 305 mg THC/kg/d and 270 mg THC/kg/d respectively with and without oil microflora. Relative to the soil without any addition (1) the removal rates in the nitrogen and phosphorus amended soils (5 and 6) increased with 150 and 180 mg/kg/d respectively. This indicates that besides evaporation also not complete mineralisation contributes to the reduction in THC concentrations.

The results show that the natural microflora has a good biodegradation potential if nitrogen and phosphorus are added, besides oxygen.

DESIGN OF THE BIOREMEDIATION SYSTEM

As the pollution is distributed in the unsaturated zone and no groundwater pollution has been registered, bioremediation by "conventional" methods using water recirculation was not acceptable as there would be a large risk for leaching of oil to the groundwater. Therefore a rather new method, bioventing, was chosen (Eijk and Vreeken, 1989; Hincsee and Miller, 1990). This method supplies oxygen to the soil microflora by soilgas ventilation. Because of the large depth of pollution and the registered inhomogenous soil composition a configuration of three soil gas extraction wells at different depth were installed. The pressure gradients in the subsoil are monitored by two sets of piezometers at three depths: 8, 15 and 25 m. To supply water and nutrients a horizontal infiltration gallery around building 111 was installed. Figure 3 gives an overview over the design of the bioventing system (Kolstad et al., 1991a).

OPERATION OF THE INSTALLATION

The bioventing installation was started on 12. July. The extracted gas volume in each well is regulated to a ventilation ratio of one pore volume per day. In this way evaporation of hydrocarbons and water is minimized.

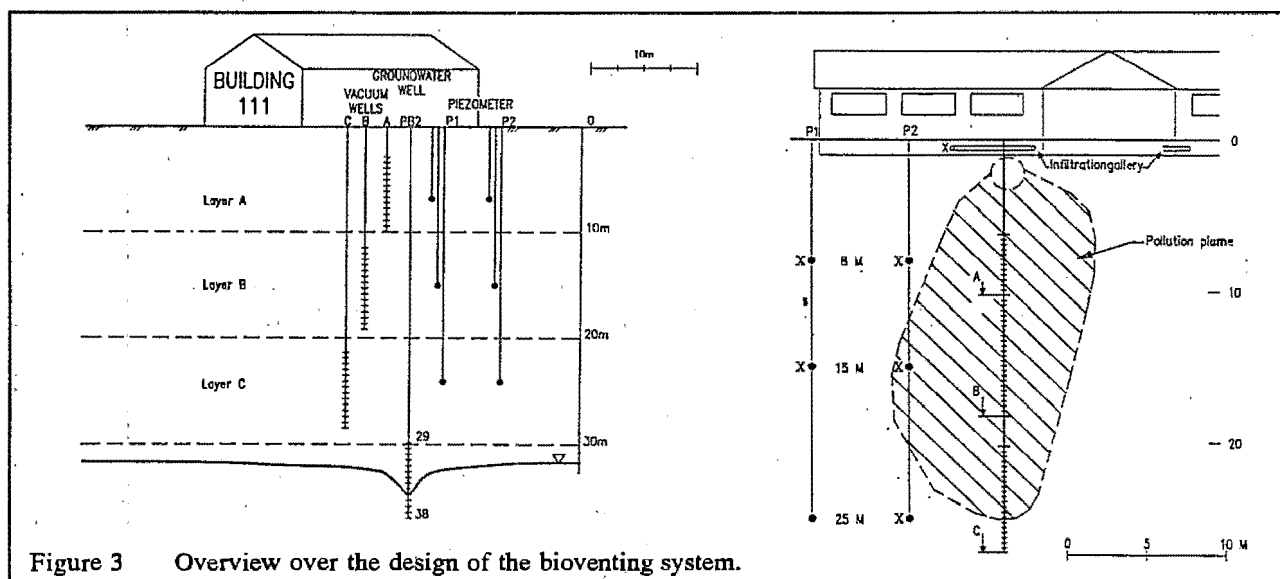


Figure 3 Overview over the design of the bioventing system.

The infiltration gallery is operated at a daily infiltration rate of only 600 liter. This is done to increase the soil moisture content in a controlled way, without increasing the risk for leaching of oil. At this moment no nitrogen or phosphorus source is added. During the first period (July to December) the effect of adding only oxygen and water will be evaluated.

MONITORING OF THE PROCESS

The soil gas extraction system is monitored by daily pressure and temperature readings in the venting wells and piezometers. Relative humidity in the venting wells is also recorded on a daily basis.

The extracted soil gas is monitored weekly for concentrations of oxygen and carbondioxide using a portable instrument. Hydrocarbon vapour in the off-gas is measured using a direct reading photo ionization detector (PID) and by sampling on activated carbon. Water samples are taken from pumping well PB 2 at monthly intervals.

Soil sampling will be carried out after half a year (December 1991), one year (July 1992) and after two years (July 1993).

PRELIMINARY RESULTS

After some initial operation problems in July, the extraction system is working now continuously. Table 4 gives the pressure and flowrate in the three extraction wells.

Table 4. Pressure and flowrates in the three extraction wells.			
Well	Depth (m)	Pressure (Pa)	Flowrate (m ³ /h)
A	6-10	-360	24
B	12-18	-450	75
C	20-27	-650	75

Figure 4 gives an impression of the pressure distribution and flowfield in the subsoil at standard operation conditions. The temperature is stable at 6 til 8°C (8 - 25 m).

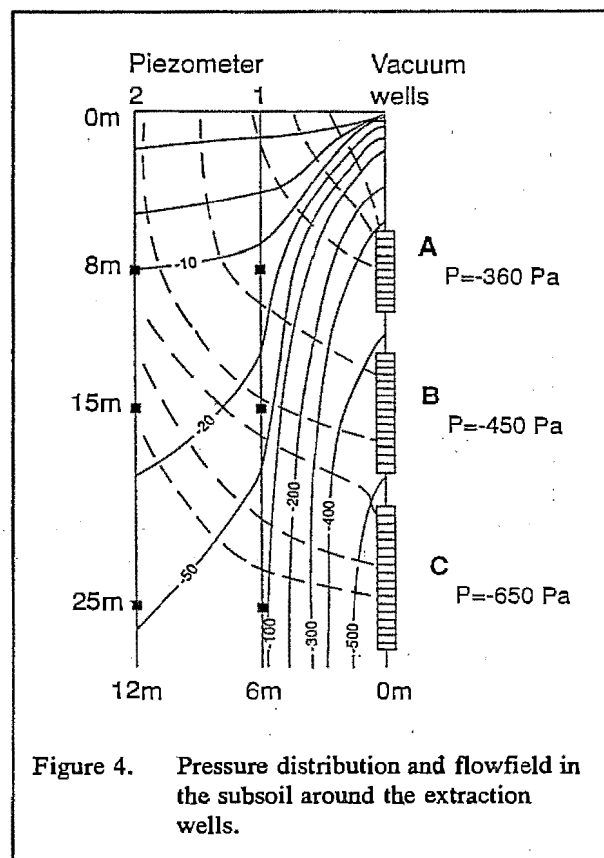


Figure 4. Pressure distribution and flowfield in the subsoil around the extraction wells.

In the off-gas of well A a clear hydrocarbon smell is noticeable. PID readings show a clear decline i hydrocarbon vapour concentrations in well A from initial 540 ppm to 200 ppm (isobutene equivalents) in oktober. Wells B and C show a stable PID reading of ca. 40 ppm.

The first weeks the carbondioxide concentration declined in well A. At this moment a stable concentration between 0,2 and 0,3 vol. % is measured in all three wells (figur 5). The difference i oxygen concentration (air oxygen content - off-gas oxygen content) is fluctuating (figur 6). The cause for this fluctuation is not quite understood, but might be caused by rainwater infiltration.

The results indicate that there is biological activity, how far this activity contributes to hydrocarbon degradation is not yet known.

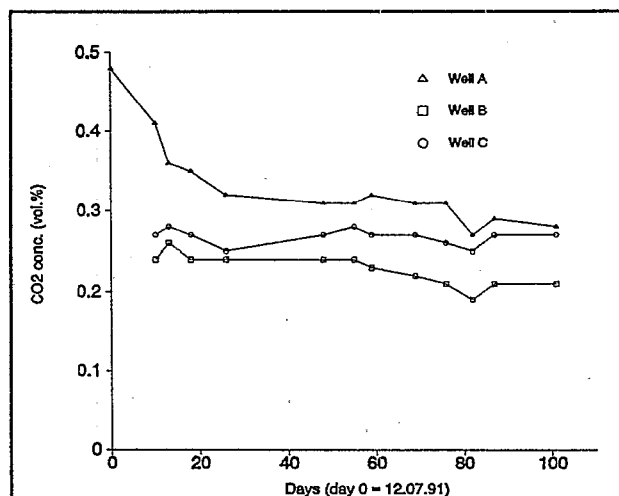


Figure 5. Carbondioxide concentrations in the off-gas of the venting wells (vol %).

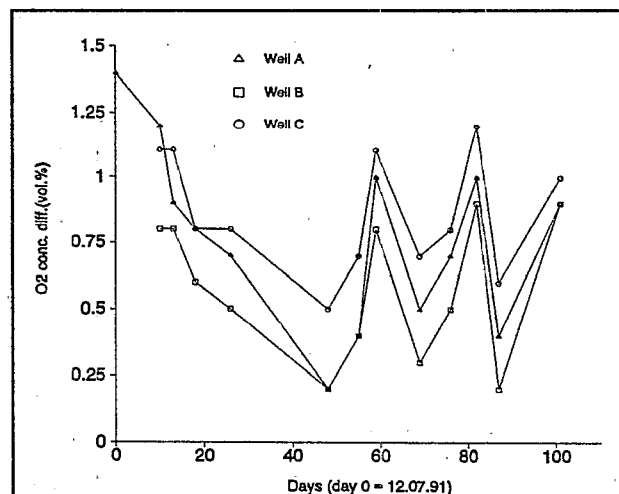


Figure 6. Reduction in the oxygen concentrations in the venting wells (vol %).

If all carbondioxide production should be caused by oil degradation this would mean an average mineralization rate of 6 kg THC per day. A very rough estimate of the oxygen consumption indicates a degradation of ca. 10 kg THC per day.

In December shut down tests will be carried out on the system to assess in detail the biodegradation rates by measuring increase in carbondioxide content and reduction of oxygen levels in the venting wells and the piezometers. Soil sampling will give a first indication if biodegradation is able to reduce the oil content on this site. Based on these results the need for nitrogen and phosphorus addition will be evaluated.

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NATO/CCMS Guest Speaker:

Gunnar Randers, Norway

The History of NATO/CCMS

EXHIBIT 1

Brussels

ACG.SA(69)096
20th March, 1969

His Excellency
Manlio Brosio,
Secretary General,
North Atlantic Treaty Organization.

Dear Secretary General,

I leave for some meetings abroad this morning and would like to write a brief note to you before I leave because there is a matter that will probably be brought to your attention by Mr. Cleveland next Tuesday. It concerns the science activities within the Alliance. Mr. Nixon, in his speech in the Council referred to the national, domestic problems in all countries, like pollution of the air and sea, which will need action in all countries to save our civilisation in the future. He indicated that such problems might be attacked by a common effort of the Atlantic Alliance. I understand that the United States Delegation has had later indications from Washington that this remark was seriously considered by the President, and that it might be appropriate and right to look into the matter here in the Science Division immediately.

I had planned to prepare a brief for you for the Washington meeting, informing you about the fact that we did take the matter up in the Science Committee, and the Oceanographic Sub-Committee after Mr. Nixon's visit, and that we have charged Professor Capart (Belgium) with elaborating a programme of possible action in the pollution problem. We have also decided to have a large scientific meeting on it in 1970, and the Science Committee have considered a public appeal from NATO in order to point out that NATO considers this problem a very serious one.

H.E. Manlio Brosio

20th March, 1969

Ambassador Cleveland has pointed out to me that Mr. Nixon probably wanted to indicate not only the need for technical efforts in the pollution question, but in a long series of problems in modern civilisation, like congestion, noise, youth unrest and so on. This might mean that the President feels that the Alliance could take a leading place in a common attack on many of the urgent problems of our advanced technical society.

I believe the revival of the Science Committee, for example by a system of younger deputies, which I am advocating, and by adopting certain long-range programmes (computers, air-sea interaction, pollution, materials) will make it possible, together with United States support, to make an impact on some of these problems. I shall come back in some more detail in the brief for Washington.

Yours sincerely,

(signed) Gunnar Randers

COUNCIL ON FOREIGN RELATIONS, INC.

58 EAST 68TH STREET, NEW YORK, N.Y. 10021 | TEL. (212) 535-3300 | CABLE: FORAFFAIRS, NEW YORK

April 10, 1972

Dear Ryndy:

With much regret I decided that I could not be with you on the 13th. We have a big affair here I cannot miss.

I did want to report to you an interesting event. On Saturday I was in Cincinnati participating in their World Affairs Institute which brings together 1,000 of the best high school students from an area within 200 miles of the city. The final speaker was Gunnar Randers, who was talking about the work of the Committee on the Challenges of a Modern Society. This was at the end of a strenuous two days and a man speaking from the NATO platform might have had up hill work with these young people.

Randers started by saying that NATO was not a military organization, but a defense organization. Then he went on in a straightforward way to describe the various projects the CCMS is involved with (oil pollution in the seas, safer cars, air pollution in cities, etc.), stressing that the emphasis is on fast action with no new bureaucracy. When he finished, he got a standing ovation from that crowd of young people. NATO will be better and more favorably known in the whole Cincinnati region as a result of that single speech. If more spokesmen for NATO with Randers' charm and message could be sent around to gatherings like this one, the understanding and support for NATO would be much increased.

Sincerely,


David W. MacEachron

Mr. W. Randolph Burgess, Chairman
The Atlantic Council of the United States
1616 H Street, N. W.
Washington, D. C. 20006

cc: Livingston Merchant

CCMS

To Joseph E M LINS, Sec. General NATO 14/7/73
from EUGENE RANKERS Ass. Sec. Chairman CCMS

The CCMS has a much shorter history than the Science Programme and was set up under more doubt and resistance. It was the interest and pressure by the United States that brought the CCMS into being, and it has been the initiative of the USA which has kept this activity alive. Some of the member countries have gradually taken initiatives themselves within the CCMS and others have developed a positive attitude. The programme has created a remarkably good reputation for efficiency among other international organizations.

The CCMS rests upon a few very simple principles:

1. No budget and no secretariat. This is achieved by adopting the pilot country principle.
2. No long-term scientific research.
3. Action by governments within short-time span. These principles (2 and 3) have been difficult to adhere to because action is always difficult to achieve while recommendations for long-term research and study is always tempting. It is interesting that the USA, being the strongest supporter of the CCMS, have sometimes let their pilot projects become long-term studies. For example, it seems difficult to get the Road Safety project to lead to any specific proposals for passive restraints although work has been carried out determinedly for three years in this field. Instead, recommendations for further studies and recommendations for reduction of accidents by a given percentage, as a general principle, may be the result. This tendency may be the most serious problem for the CCMS in the future; to make action recommendations is often connected with political difficulties and general recommendations on long-term development are therefore chosen instead.

4. The fourth principle of the CCMS is emphasis on follow-up. CCMS is supposed not only to make recommendations but to ensure that something happens as a consequence. The way this has been done is to establish a pilot country as responsible for reporting regularly to the CCMS on progress in member countries relating to a recommendation. The follow-up procedure may be decisive in making the NATO environmental programme more substantial than the common or garden variety of international recommendations on environmental undertakings.

NATO/CCMS Guest Speaker:

Robert L. Siegrist, Norway

International Review of Approaches for Establishing Cleanup
Goals for Hazardous Waste Contaminated Land; *and* Sampling Method
Effect on Volatile Organic Compound Measurements in Solvent
Contaminated Soil

THE AGRICULTURAL RESEARCH COUNCIL OF NORWAY
**INSTITUTE OF GEORESOURCES
AND POLLUTION RESEARCH**



**INTERNATIONAL REVIEW OF APPROACHES FOR ESTABLISHING
CLEANUP GOALS FOR HAZARDOUS WASTE CONTAMINATED LAND**

By

Robert L. Siegrist

**INTERNATIONAL REVIEW OF APPROACHES FOR ESTABLISHING
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By

**Robert L. Siegrist, Ph.D., P.E.
Visiting Senior Scientist**

**Institute for Georesources and Pollution Research
PostBox 9, N-1432 Aas-NLH
Norway**

1989

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Inquiries regarding the research may be directed to Dr. Siegrist at GEFO, Postbox 9, 1432 Aas-NLH, Norway, Tel. 47-9-948140 or at 4014 Birch Avenue, Madison, WI, 53711, USA, Tel. 1-608-2387697.

SECTION 1 SUMMARY

Land contaminated by toxic and hazardous substances is a critical environmental problem facing nations throughout the world. Central to resolution of this problem is the development of policies and procedures to enable an assessment of the significance of contamination and the extent of cleanup required at a particular site.

In the study reported herein, an international review was made of the approaches used to assess the significance of contamination and set cleanup goals for hazardous waste contaminated land. The information derived from this study was to assist the Norwegian government in the development and implementation of their programs for assessment and cleanup of contaminated land. Emphasis was placed on the attitudes toward and use of standards-based approaches involving soil and ground water quality criteria. The policies and procedures used in ten nations were reviewed in varying degrees of detail. Ten nations were selected to include those with newly evolving as well as long-established programs for dealing with hazardous waste contaminated land. The following nations were included in this study:

- o United States,
- o Canada,
- o England,
- o The Netherlands,
- o West Germany,
- o France,
- o Denmark,
- o Sweden,
- o Finland, and
- o Norway.

Information was derived from published literature, personal inquiries and site visits.

The results of this study revealed that approaches to establishing cleanup goals for hazardous waste contaminated land vary widely between and within nations. In few cases is there explicit, uniform national guidance. Rather there is enormous variation in the setting of cleanup goals, the process used and results of which are affected by diverse factors such as:

- o Type of contaminated land (e.g. licensed waste disposal site, underground fuel tanks, accidental spill),
- o Type of contamination (e.g. PCBs, Dioxin, petroleum products),
- o Governing laws and regulations (e.g. Federal law, State law),
- o Site ownership (e.g. privately- versus publicly-owned, known versus unknown ownership), and
- o Public attention and perception.

It is not uncommon that cleanup goals in the form of acceptable residual contaminant concentrations are never explicitly established. In these cases an acceptable course of action for remediation is agreed upon, the results of which yield a de facto cleanup goal. Where cleanup goals are explicitly set, various methods have been used, including:

- o Ad hoc site by site negotiation and decision making,
- o Cleanup to background levels,
- o Application of cleanup criteria in the form of predetermined standards, guidelines and criteria (PSGCs),
- o Site-specific mathematical modeling, risk assessments and risk management decisions,
- o A combination of the above.

There has been considerable discussion and debate regarding the most appropriate method(s) for assessing the significance of contamination and establishing cleanup goals for waste contaminated land. The approach which has been most controversial, perhaps, is a "standards-based soil quality" approach involving the use of predetermined standards, guidelines and criteria (PSGCs). An increasing number of jurisdictions have or are in the process of establishing soil and ground water quality criteria for setting cleanup goals, particularly for common, non-catastrophic sites. They range from simple listings of a few common contaminants to comprehensive listings of numerous contaminants. They can address natural soil properties (e.g. organic matter content, grain size) and/or different current and future land uses. In one nation, The Netherlands, criteria have even been developed to characterize "good soil quality".

In few cases are the criteria true "standards". Rather, they are viewed as general guidance subject to site by site review and justification and/or modification. Where they exist, cleanup criteria have often evolved from the adaptation of existing environmental standards and criteria as well as the generation of new criteria based on contaminant transport and fate in the environment and reasonable exposure scenarios for potentially affected populations and ecosystems.

Standards-based approaches involving cleanup criteria are an important component of an overall program for dealing with contaminated land. While there are definite difficulties associated with the development and implementation of soil and ground water quality criteria, there appears to be a clear desire and need for them. They streamline initial assessment and screening of contaminated sites, encourage redevelopment of old industrial sites and facilitate broad-based soil protection programs. However, it is widely recognized that they will not obviate the need for consideration of site specific factors nor quantitative risk assessments and risk management approaches.

It appears that a combined approach to establishing cleanup goals for hazardous waste sites may be most appropriate. Such an approach could include consideration of current and future site use and potentially impacted humans, other biota and environmental resources. A systematic site classification procedure is also needed to preliminarily screen and classify a site according to the potential hazards associated with it. Adoption of a comprehensive listing of soil and ground water quality criteria would facilitate initial assessment of the significance of contamination and preliminary cleanup goals. For sites rated to be of high hazard, a site specific risk assessment would be needed to verify cleanup goals. For low hazard sites, use of soil and ground water quality criteria alone would normally be sufficient. Intermediate sites would require judgement and possibly consideration of cost-benefit factors.

Initial efforts at site remediation (i.e. cleanup) in different nations largely involved either 1) excavation and offsite treatment and/or landfilling, or 2) in place encapsulation and isolation. There is increasing interest in and use of onsite and insitu treatment technologies. Considerable research and development work in progress in several nations. A wide variety of processes are now available for treatment of contaminated land, both offsite, onsite and insitu. Treatment systems involving low temperature thermal evaporation, soil washing, in situ vapor extraction, and solidification/stabilization have growing performance bases. Less established are some onsite/insitu techniques such as bioremediation, in situ steam stripping and in situ vitrification.

It is recommended that the results of this study be considered in light of existing Norwegian regulations and that the issue of establishing cleanup goals for hazardous waste contaminated sites be discussed and resolved. This should be accomplished early in the development of Norway's program for addressing problems with hazardous waste contaminated land. Formulation of a systematic, nationally consistent approach to establishing cleanup goals is an important challenge facing Norway as well as many other nations. The approach which ultimately proves appropriate for Norway will depend on a careful analysis of many factors, including those of a technical, socioeconomic, political and legal nature. A suitable approach may include some form of site, soil and land-use classification combined with soil and ground water quality criteria. This will prove workable for initial site screening as well as setting cleanup goals for common, non-catastrophic sites. For high hazard, catastrophic sites, a site-specific risk assessment and risk management approach will likely be needed.

SECTION 2 INTRODUCTION

2.1 BACKGROUND

Norway has long been regarded as a pristine nation with majestic mountains and enchanting fjords. Unfortunately, during the past few years an increasing number of old waste sites and parcels of contaminated land have been discovered. For example, an old waste site was recently discovered near Oslo during railroad-related construction activities. The site had been used for dumping and burning of flammable liquids in an effort to reduce fires at a municipal landfill. Approximately 10,000 m³ of soil contaminated with solvents ultimately were excavated and properly disposed of.

Since Norway derives most (>80%) of its potable water from surface water, concern over ground water pollution has so far been limited. However, there is growing recognition of potential hazards to public health and the environment via other pathways. While there is little question that contaminated sites exist in Norway, little is known about the nature and extent of the problem. National inventories have recently been initiated including industrial branch surveys and old waste site surveys [1].

Discoveries of abandoned waste sites and contaminated land, often during construction activities, have necessitated prompt action by regulatory authorities. As in the rest of the world, a critical but extremely difficult task has been assessing the significance of contamination at a particular site and determining the extent of cleanup required.

2.2 STUDY OVERVIEW

2.2.1 Study Purpose and Approach

This study was undertaken to gather and review the approaches used in various nations to establish cleanup goals for hazardous waste contaminated land. Of particular interest were the current attitudes toward and use of "predetermined standards, guidelines and criteria" (PSGCs). The information derived from this study was to assist the Norwegian government in the development and implementation of their programs for assessment and cleanup of contaminated land.

Information for this work was gathered by several means. The international literature was surveyed by computerized and manual techniques. Personal inquiries were made to responsible agencies and individuals in ten nations. The nations selected for study included those with a range of characteristics and in which there were newly evolving or long-established programs for dealing with hazardous waste contaminated

land (Table 2.1). The following nations were included in this study:

- o United States,
- o Canada,
- o England,
- o The Netherlands,
- o West Germany,
- o France,
- o Denmark,
- o Sweden,
- o Finland, and
- o Norway.

Personal site visits were made where appropriate and feasible to gather information first-hand.

Table 2.1. General physical characteristics of the nations selected for study [36].

Nation	Population (millions)	Area (10 ⁶ Ha)	Population Density (capita/Ha)	Urban Population (%)
United States	247.5	940	0.26	79
Canada	25.3	998	0.03	76
United Kingdom	56.6	24.4	2.32	92
The Netherlands	14.7	4.1	3.59	88
West Germany	60.2	24.9	2.42	86
France	55.8	57.2	0.98	77
Denmark	5.1	4.3	1.18	84
Sweden	8.4	49.0	0.19	85
Finland	5.0	33.7	0.15	61
Norway	4.2	32.4	0.13	80
Statistic Date	1989	-	-	1980-1986

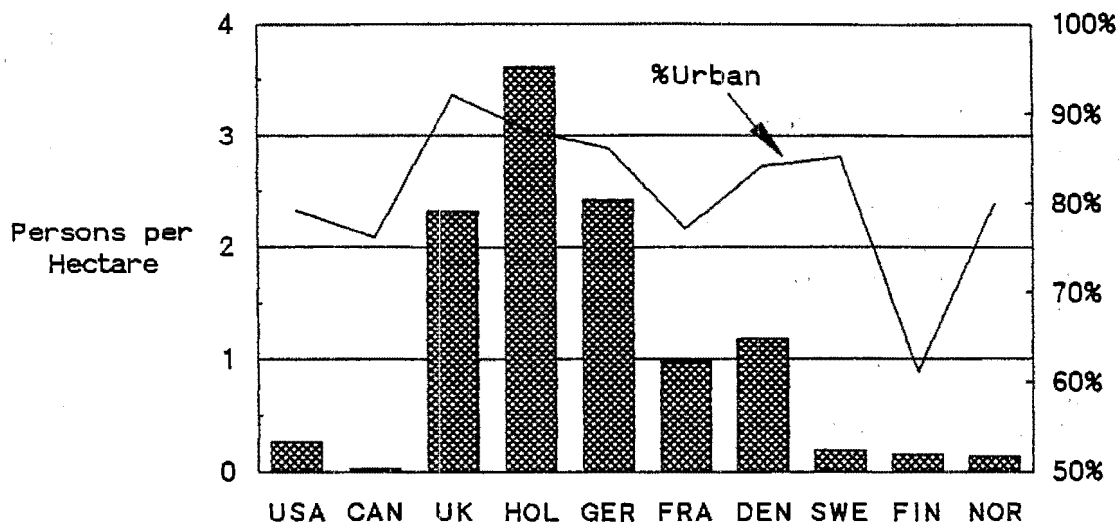


Figure 2.1. Population characteristics of the nations reviewed in this study.

This study was not intended to comprehensively review nor critically evaluate and critique the numerous existing approaches and procedures. Clearly, this would have been an insurmountable task given the resources available for this project. Nor was it intended that this study would necessarily develop a new or modified approach for use under Norwegian conditions. At the onset, it was clear that approaches to assessing contamination and setting cleanup goals include many non-technical issues, including those of a socioeconomic, political and legal nature. Rather, this study was meant to provide a base of information regarding the international state of practice in the area of cleanup goal setting for hazardous waste contaminated land. This information would hopefully facilitate the effective evolution of programs and practices in Norway.

2.2.2 Problems Encountered

At the onset, the subject of this study was recognized as a complex one, intertwined not only with government policies and programs for dealing with contaminated land, but also with those for environmental protection in general. It was accepted that efforts to gather and review all relevant literature and contact all knowledgeable agencies and individuals would be futile. Rather, attempts were made to gather what was perceived to be representative current information. This was made somewhat difficult considering the geographic scope and communication difficulties associated with the foreign nations involved. It was also difficult to describe the

status of approaches to setting cleanup goals due to the diversity of agencies and personnel involved in any one nation, as well as the dynamic nature of this subject both on a local and national level, even in nations with apparently well-established programs (e.g. United States, The Netherlands, West Germany).

SECTION 3

OVERVIEW OF PROGRAMS FOR HAZARDOUS WASTE CONTAMINATED LAND

This section provides an overview of the programs for dealing with hazardous waste contaminated land in the nations selected for study. This information is provided as a framework within which the policies and procedures for assessing the significance of contamination and establishing cleanup goals have evolved.

3.1 WASTE CONTAMINATED LAND CHARACTER

There are many different names used to refer to what might generally be defined as "contaminated land". Few formal definitions of contaminated land exist, however. One which has been put forth is that of the NATO Committee on Challenges to Modern Society (NATO CCMS) [2]:

"Land that contains substances that, when present in sufficient quantity or concentrations are likely to cause harm directly or indirectly to humans, the environment or on occasions to other targets."

This definition suggests that increases in chemical quantity or concentrations in a given parcel of land would not in and of itself necessarily result in the land being considered "contaminated". Thus, to assess whether a given site were contaminated or not requires consideration of site land use as well as the land's relationship to surrounding land uses and the ecosystem.

Contaminated land as defined above could include a wide variety of sites. Typical sites of concern include:

- o Commercial and industrial sites (operating and derelict sites),
- o Solid waste landfills (particularly older ones),
- o Areas where incidental spills have occurred,
- o Leaking underground storage tanks (e.g. chemicals, fuels, wastes), and
- o Land-based waste storage, treatment and disposal sites.

As illustrated by the above examples, the land may or may not have been the intended receiver of the liquid and/or solid wastes. Moreover, the land may have been used for waste containment and long-term storage or alternatively for waste treatment and recycling.

3.2 CONTAMINATED LAND PROGRAM HIGHLIGHTS

3.2.1 Program Development

Programs for dealing with contaminated land have generally evolved in response to the need for public health and environment protection, in some cases driven by the need for industrial site redevelopment for moresensitive uses. The programs can be geared toward site cleanup and risk reduction, land reclamation and reuse, or a combination thereof.

In most cases, one or more notorious incidents has stimulated public attention and inquiry into the problem of hazardous waste contaminated land. This has led to increasing public awareness of the nature and extent of the problem. In response, political action normally has produced governing legislation. Regulations, policies and programs were then formulated.

Early in the evolution of contaminated land programs, inventories are initiated to determine the number, location and potential severity of sites. This is often on a Federal or at least State basis. Following the inventories, Federal and/or State programs for site investigation and cleanup are formalized. Often the results of the inventories are used to evaluate the need and urgency of addressing the problem, including the need for and nature of government financing. In some cases, funding has been provided for research and development efforts.

Some general characteristics of the contaminated land programs in the nations reviewed in this study are summarized in Table 3.1. Some nations embarked on cleanup campaigns almost a decade ago (e.g. USA, The Netherlands) while others have begun in earnest only recently (e.g. Norway, France, Canada). In some nations the programs have been incorporated into broad soil protection programs. The clearest example of this is The Netherlands where a powerful national law was enacted in 1987 (The Soil Protection Act) [3]. West Germany initiated a conceptually similar program in 1985 [4].

The primary driving forces behind the cleanup of hazardous waste contaminated land appear to vary between the nations studied (Table 3.2). Prevention or mitigation of pollution of ground water used for drinking water as well as ensuring safe housing developments on reclaimed industrial sites and waste deposits are often of principal concern.

3.2.2 Nature and Extent of the Problem

The nature and extent of the problem with hazardous waste contaminated land varies widely between nations (Table 3.3). Based on inventories and/or other estimates, the number of known or suspected contaminated sites can be very high. Generally, the number of sites identified initially includes mostly old waste deposits and landfills. Subsequent inventories or site discoveries often include more and more industrial and commercial sites, including leaking underground gasoline tanks. With time, sites continue to be discovered and the number of sites under study continues to grow.

Table 3.1. General characteristics of contaminated land programs.

Nation	General Program Description
<u>United States.</u>	Federal program for cleanup of major uncontrolled hazardous waste sites enacted by "Comprehensive Environmental Response, Compensation and Liability Act (1981), also known as "Superfund", and later amendments (1986). Subsequently State level programs evolved separately, e.g. in New Jersey, California and Wisconsin. Federal and State funding is available for priority abandoned sites.
<u>Canada.</u>	No national program. Special programs initiated recently in a few Provinces, e.g. Quebec (1988) and Alberta (1985). Programs often geared to decommissioning of industrial sites.
<u>England.</u>	Contaminated land reclamation is largely coincident with old waste and industrial site redevelopment. Federal level guidance issued in 1987. Federal funding for reclamation of priority sites from "Derelict Land Grant".
<u>The Netherlands.</u>	Federally initiated program with enactment of "Soil Cleanup (interim) Act" in 1983 and "Soil Protection Act" in 1987. Implementation at Provincial level. Some Federal funding in addition to local funding for priority abandoned sites.
<u>West Germany.</u>	General State level programs initiated in 1970's. Increasing attention at Federal level in late 1970's. Federal guidance and research funding initiated in 1983. Adoption of "Conception for Soil Protection" in 1985 with possible revision and amendment of Federal laws. No dedicated financing programs yet, but discussion of government/industry funding options.
<u>France.</u>	No specific national legislation or directives. National level guidance and cleanup supervision. Limited Federal funding on a case by case basis.
<u>Denmark.</u>	Dedicated legislation in 1983. National inventories completed. Government sponsored research. Government funding of cleanup of abandoned sites.
<u>Sweden.</u>	Specific national legislation enacted in 1988. National level inventory completed (1985). Government sponsored research and limited Federal funding available.
<u>Finland.</u>	No specific national legislation or directives. National level inventories in progress and informal guidance provided. No government funding provisions.
<u>Norway.</u>	No specific national legislation or directives. National level inventories in progress and informal guidance provided. No government funding provisions.

Table 3.2. Apparent principal driving forces motivating site remediation.¹

Nation	Apparent Principal Driving Forces
United States	General public health and environmental risk reduction, often associated with ground water contamination of drinking waters.
Canada	Decommissioning and safe reuse of industrial properties. Sometimes, general public health and environmental risk reduction.
England	Decommissioning and safe reuse of industrial properties. Seldom ground water protection or simple risk reduction.
The Netherlands	Broad-based soil protection including cleanup of contaminated land and prevention of future contamination. Enable safe reuse of industrial sites and general public health and environmental risk reduction.
West Germany	Primarily public health protection from ground water contamination of drinking water. In housing areas, also prevention of direct contact and ingestion.
France	Not clear. Public pressure and political impacts noted.
Denmark	Primarily public health protection from ground water contamination of drinking water. Also safe redevelopment of old industrial sites in urban fringe.
Sweden	Not clear. Mixture of technical, psychological, political considerations. Long-term effects of ground water on surface water recognized.
Finland	In some areas, public health protection from ground water contamination of drinking water. In others, safe redevelopment of old industrial sites.
Norway	In a few areas, public health protection from ground water contamination of drinking water. In others, protection of aquatic resources (e.g. fjords) or safe redevelopment of old industrial sites.

¹The information presented represents current general perceptions on nation-wide driving forces. It is recognized that on a particular incident, the driving forces can be substantially different than those stated.

Table 3.3. National statistics on contaminated site discoveries and remediation.

Site Discoveries	Remediation Experiences	
Nation (ref.) Site Number and Concern	Approx. # of Sites	Example Methods Commonly Used
<u>United States</u> (6,7) 23000 ('87) with 900 ('87) nat. priority (NPL) sites.	130 NPL ?Non-NPL	Excavation/landfill Incineration Insitu treatment
<u>Canada</u> (8) Total unknown.	Few	Excavation/landfill
<u>England</u> (9) 300 estimated.	>500	Isolation/capping Excavation/landfill
<u>The Netherlands</u> (5) 6060 ('86).	380	Excavation/treatment by thermal, washing Excavation/landfill
<u>West Germany</u> (11) 35000 ('85) with 5400 req. immediate action.	?	Encapsulation Excavation/landfill
<u>France</u> (12) 453 ('87) with 82 serious	95	Excavation/landfill Encapsulation Solidification
<u>Denmark</u> (13-14) 1599 ('88). Estimate 9000 potential sites.	30-60	Excavation/landfill Incineration Onsite treatment
<u>Sweden</u> (15) 3800 ('85) old waste sites, 500 est. of concern.	Few	Excavation/landfill Incineration Encapsulation
<u>Finland</u> (16) Total unknown. 1200 landfills with 378 with hazardous wastes, 112 need immediate action.	Few	Excavation/landfill Some incineration Some landfarming
<u>Norway</u> (1) Total unknown.	Few	Excavation/landfill

3.2.3 Remediation Experiences

While the number of sites identified can be large, the number remediated can be very small, typically less than 10% of those discovered (Table 3.3). The number of sites restored to productive use can be even smaller.

Early remediation efforts in most nations typically involved excavation and offsite treatment or landfilling. Some nations have also used in-place containment by capping and other isolation techniques. More recently there has been increased interest in onsite and insitu technologies such as bioremediation, vapor extraction, soil washing, solidification and stabilization. For example, in the Superfund program in the United States, onsite/insitu remediation approaches are now considered desirable. There is considerable research and demonstration work ongoing in the United States, The Netherlands, Denmark and West Germany related to onsite and insitu treatment techniques.

There have also been an increasing number of treatment plants established solely for treatment of contaminated soils. In many cases, these systems were initially mobile units, later established as fixed-based plants. In The Netherlands, for example, there are now numerous thermal, extraction and biological treatment plants with a total annual capacity of nearly 0.5 million m³ [5]. Similar plants have recently been implemented in Denmark and West Germany.

SECTION 4 APPROACHES FOR ESTABLISHING CLEANUP GOALS

4.1 INTRODUCTION

The need to assess the significance of contamination and establish cleanup goals for hazardous waste contaminated land is based largely on public health and environmental protection concepts. In many respects the foundations underlying this need are the same as those behind the existing spectrum of regulations and standards governing contaminants in the environment. These include drinking water standards, ambient air and water quality criteria, air emissions from incinerators, discharges to surface waters from wastewater treatment plants and land spreading of sewage sludges.

Assessing the significance of contamination and establishing cleanup goals for hazardous waste contaminated land is extremely complex due to many factors, but perhaps most importantly:

- o The heterogenous, non-fluid and unpredictable nature of soil,
- o Difficulties in characterizing the occurrence and predicting the transport and fate of hazardous substances in soils,
- o The unknown but typically wide variety of chemicals present in waste contaminated land,
- o The multiple pathways by which contaminants may reach humans and other receptors (Figure 4.1), and
- o Uncertain and highly variable exposure conditions.

4.2 OVERVIEW OF APPROACHES USED

The approaches used to establish cleanup goals within the nations reviewed in this study are discussed below. In Section 5, further discussion is given regarding the use of and perspectives toward soil and ground water quality criteria and cleanup goals. As summarized in Table 4.1 and described below, the approaches used today vary widely both within and between nations. In addition, the approaches in most nations appear to be in a state of evolution, not yet fully developed nor implemented, especially on a nationally consistent basis.

4.2.1 United States

In the United States (USA), there is no explicit, national guidance regarding approaches for establishing cleanup goals for hazardous waste contaminated land. Approaches for establishing cleanup goals vary widely depending on the government agency responsible for regulation and oversight of the remediation (i.e. cleanup) activities. Contaminated sites regulated by different Federal laws and agencies can be handled quite differently (e.g. the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA, 1981; 1986) versus the Resource Conservation and Recovery Act (RCRA, 1976; 1984) as administered by the U.S. Environmental Protection Agency).

In addition those sites regulated by State laws and agencies can be handled differently as well. In most cases, hazardous waste contaminated land has been cleaned up for public health and environmental protection reasons. Only recently has increased attention been given to reclamation and redevelopment considerations during cleanup.

The approaches used by Federal and State government agencies in the USA for setting cleanup goals at hazardous waste sites have been subject to much scrutiny. This is particularly true for the policies and procedures used for national priority sites (i.e. Superfund sites) [e.g. 6,7,17]. The results of a recent review [17] are summarized in Tables 4.2 and 4.3 while highlights of some of the approaches used by various government agencies are given below.

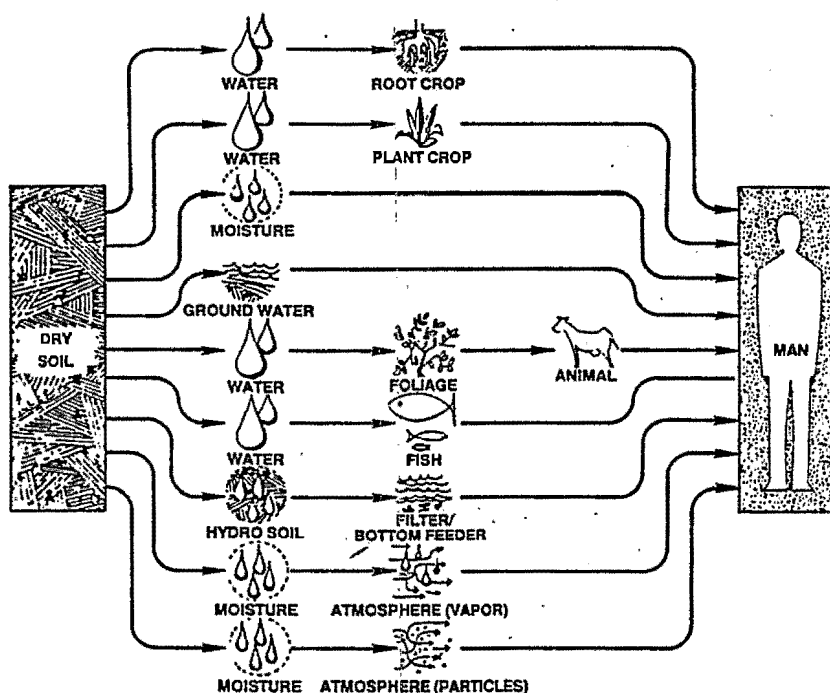


Figure 4.1. Potential transport pathways and exposures associated with hazardous waste contaminated land.

Table 4.1. Approaches used for assessing the significance of contamination and establishing cleanup goals for contaminated land.

Nation	Approaches to Establishing Cleanup Goals
USA	For NPL sites (i.e. Superfund) use applicable, relevant and appropriate Federal and State requirements where available and formalized site-specific risk assessment methodologies. For non-NPL sites, procedures vary widely by State and government jurisdiction and include multiples of generic criteria and background levels as well as site-specific formalized risk assessment methodologies. [6,7,17,18]
Canada	Only Quebec has a formalized approach where a comprehensive list of generic criteria adapted from the "Dutch List" is used for initial guidance and screening with site-specific risk assessments as appropriate. [8,19]
England	No national system. National guidance on "Trigger Concentrations" for some contaminants commonly found on industrial sites often considered for redevelopment (e.g. old gas works). [9,20]
Netherlands	National policy of maintaining soil "multi-functionality". Generic criteria (A-B-C levels) for evaluating significance of pollution enacted in 1983 (often referred to as the "Dutch List"). Reference values for good soil quality (new A-level) enacted in 1987. Contaminated land must be cleaned up to multi-functional quality (A-level) unless it is technically or financially unfeasible or environmentally harmful to do so. [3,5,10,21-23]
W.Germany	No national approach, control by provincial governments (Lander). Use of "Dutch List" with consideration given to local conditions. West German "Guides/Threshold" values for soil contamination now under development based on soil protection policy initiated in 1985. [11,24]
France	No national approach, control by local governments. Use qualitative risk assessments. If pollution by natural substances, must reference background. Development of standards for soil pollution now under consideration. [11,12]
Denmark	No national approach, control by local governments. Use "Dutch List" for general guidance and screening as well as existing Danish standards where available. Final decision on particular site based onsite specific considerations. Formalized risk assessment methods now under development. [13,14]

Table 4.1.cont. Approaches used for assessing the significance of contamination and establishing cleanup goals for contaminated land.

Nation	Approaches to Establishing Cleanup Goals
Sweden	No national approach. Limited experience to date. Use generic criteria (e.g. "Dutch List") if available for initial guidance but site specific decision based on local factors including technical, political, economic and psychological. [15]
Finland	No national approach. Limited experience to date. Use generic criteria (e.g. "Dutch List") for initial guidance. [16,25]
Norway	No national approach. Limited experience to date. Use generic criteria (e.g. "Dutch List") if available for initial guidance. Site specific decision based on intended site use, technical feasibility and cost as well as secondary contamination during cleanup. [1]

Table 4.2. Terminology used by some approaches to establishing cleanup goals for hazardous waste contaminated land in the USA [17].

Description of Term	EPA	California	U.S. Army	Washington State	New Jersey
Acceptable human daily dose of a substance	Acceptable intake for chronic/subchronic exposure (AIC/AIS), mg/kg x day	Maximum exposure level (MEL), mg/day	Acceptable daily dose (\underline{D}_T), mg/kg x day	Not used	Not used
Experimental dose that is considered the threshold of adverse effects	No observed adverse effect level (NOAEL)	No observed adverse effect level (NOAEL)	No-effect level (NEL)	Not used	Not used
Concentration of toxic substance in a medium that does not produce an adverse effect on chronic exposure	Target concentration for chronic exposure	Applied action level (AAL)	Single-pathway preliminary pollutant limit value (SPPPLV) and preliminary pollutant limit value (PPLV)	Not used	Acceptable soil contaminant level (ASCL)
Human dose of a substance expected from contact with contaminant	Subchronic/chronic daily intake (SDI/CDI)	Not used	Not used	Not used	Not used
Average amount of medium consumed daily by an adult	Chronic/subchronic daily intake (CDI/SDI)	Intake factor	Transfer factor	Not used	Intake factor

Table 4.3 Comparison of five approaches to establishing cleanup goals for hazardous waste contaminated land in the USA [17].

Description Of Term	EPA	California	U.S. Army	Washington State	New Jersey
Biologic receptors addressed	Humans	Human biota	Human biota	Humans	Human aquatic life
Media addressed	Air, surface water, soil, ground water, and fish	Air, surface water, soil, and ground water	Air, surface water, soil, ground water, and food chain	Air, surface water, soil, and ground water	Soil, surface water, and ground water
Toxicologic data base	Primary literature	Primary literature	TLV, MCL, FDA standards, ADI, primary literature, and LD ₅₀	Not applicable	WQC, drinking water guidelines, and ADI
Duration of exposure considered	Chronic and subchronic	Chronic	Chronic	Chronic (?)	Chronic
Substances considered	Indicator compounds	All detected	All detected	All detected	Indicator compounds
Routes of absorption addressed	Ingestion and inhalation	Ingestion and inhalation	Ingestion and inhalation	Ingestion and inhalation	Ingestion
Derivation of acceptable daily human dose	From no observed adverse effect level (NOAEL)	From maximum exposure level (MEL) and other standards	From no observed adverse effect level and other standards	Standards	From other standards
Treatment of carcinogenic and noncarcinogenic effects	Separate	Separate	Separate	Not addressed	Separate
Carcinogenic risk goals	10 ⁻⁴ -10 ⁻⁷	10 ⁻⁶	10 ⁻⁵	Not addressed	10 ⁻⁶
Effects from multiple route exposure	Considered additive	Considered additive	Considered cumulative	Not addressed	Not addressed
Interconversion of media-specific or route-specific standards	Not recommended	Yes, with appropriate adjustment	Yes, with appropriate adjustment	Not addressed	Not applicable
No data	Contact EPA	Not addressed	Not addressed	Cleanup to background	Not addressed

U.S. Environmental Protection Agency. Under the Superfund program implemented by the U.S. Environmental Protection Agency (U.S. EPA) as authorized by the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) of 1980 and as amended in 1986, the hazardous waste contaminated sites posing the greatest risks to human health and the environment can be cleaned up. As of 1989, there were approximately 1200 sites on the National Priority List (i.e. Superfund sites). Federal assistance can be received if those responsible for the contamination cannot be identified or are unable to pay for the cleanup.

The U.S. EPA approach for site assessment and cleanup goal setting involves a site-specific risk assessment conducted according to procedures which are comprehensively presented in their Superfund Public Health Evaluation Manual. A synopsis of the approach is presented below.

A variety of terminology is used. Critical toxicity values are a property of chemical dose-response relationships. Acceptable daily intake for subchronic exposures (AIS) is the highest human intake (mg/kg/d) which does not cause adverse effects during short-term exposure. Acceptable intake for chronic exposure (AIC) is the essentially the same as the AIS except that the exposure is long-term. The AIS and AIC values (for non-carcinogens) are derived from no-observed-adverse-effect-levels (NOAELs) and protection of sensitive members of the population considered (e.g. children, elderly). Uncertainty factors are applied to experimentally derived NOAELs. The carcinogenic potency factor is a measure of the carcinogenic potential corresponding to a lifetime cancer risk per unit dose of 1/(mg/kg/d).

The estimated daily intake is the daily dose under the specified exposure route and conditions. The subchronic daily intake (SDI) is the projected human intake averaged over a short time in mg/kg/d. The SDI is the peak short-term concentration (STC) multiplied by the human intake factor times the body weight factor. The chronic daily intake (CDI) is the projected human intake averaged over 70 yr in mg/kg/d. The CDI equals the peak long-term concentration (LTC) multiplied by the human intake factor and the body weight factor.

The estimation of daily intake is made assuming human exposure can occur from different media (air, ground water, surface water, soil and fish) and intakes (ingestion, inhalation, skin absorption). The intake is estimated separately for each indicator compound, route of exposure, duration of exposure and population exposed. Total human intake for each route of exposure is a sum of daily intakes from all media by the same route. Additivity only applies to the same population, same time and same duration (i.e. subchronic vs. chronic).

For carcinogens, CDI values are used to calculate lifetime cancer risk where lifetime risk is equal to the CDI multiplied by the carcinogenic potency factor.

Exposure to multiple chemicals by multiple routes is also considered assuming the principle of additivity. That is, simultaneous exposure to several chemicals that cause the same type of toxicity are additive. For exposure to the same noncarcinogen by multiple routes:

$$\sum_{i=1}^m \frac{SDI(\text{route})_i}{AIS(\text{route})_i} < 1 \quad \text{and} \quad \sum_{i=1}^m \frac{CDI(\text{route})_i}{AIC(\text{route})_i} < 1$$

Similarly, for exposure to the different noncarcinogens by the same route:

$$\sum_{j=1}^n \frac{SDI(\text{substance})_j}{AIS(\text{substance})_j} < 1 \quad \text{and} \quad \sum_{j=1}^n \frac{CDI(\text{substance})_j}{AIC(\text{substance})_j} < 1$$

The overall hazard for multiple routes and multiple chemicals is combined into a hazard index:

$$\sum_{i=1}^m \sum_{j=1}^n \frac{SDI(ij)}{AIS(ij)} < 1 \quad \text{and} \quad \sum_{i=1}^m \sum_{j=1}^n \frac{CDI(ij)}{AIC(i,j)} < 1$$

The assumption of additivity is also applied to carcinogens where,

$$\text{Cancer risk} = \sum_{i=1}^m \sum_{j=1}^n (CDI_{ij} * \text{carcinogenic potency factor } ij)$$

The steps involved in the site assessment and cleanup goal setting according to the above approach include:

- o Selection of indicator compounds for a given site.
- o Estimation of the concentrations of the indicators in media at points of maximum human exposure, both short-term (STC) and long-term (LTC).

- o The STCs and LTCs are first compared with applicable or relevant and appropriate standards (e.g. drinking water standards). If standards are available for all indicators, no further analysis is required.
- o Estimated next are human daily intakes (SDIs and CDIs) for each selected indicator compound, each route of exposure and each exposure duration. Cancer risks are also calculated.
- o The hazard indexes are then computed.

The target levels for cleanup are determined differently for indicator compounds with standards versus those without. If standards exist, that sets the upper limit on target levels. For those without standards, the compounds are divided into two groups, 1) chemicals with noncarcinogenic toxic effects and 2) potential carcinogens. For noncarcinogens, for an individual compound the daily intake must be maintained equal to or less than the acceptable daily intake. In addition, for multiple substances and routes, the overall hazard index must be maintained equal to or less than 1. To maintain the hazard index below 1, the target levels for individual compounds can be apportioned between different media and compounds.

For carcinogens, cleanup is intended to maintain the cancer risk in the range of 10^{-4} to 10^{-7} , with 10^{-6} established as a point of departure. The target concentration is that concentration that will produce a chronic daily intake associated with this range of risks. Again for multiple routes and substances, the target CDI can be apportioned between media and substances in any combination as long as the total cancer risk is within the specified range.

Lack of a consistent method for setting cleanup goals was a primary concern of the U.S. EPA and affected parties and led to explicit language in the Superfund amendments and reauthorization act (SARA) of 1986. SARA establishes cleanup actions and also stipulates the conditions for disposing of wastes off-site [7, 18]. New cleanup standards approaches require that Superfund remedies must be protective of human health and the environment, be cost-effective, and utilize permanent solutions, alternative treatment technologies and resource recovery to the maximum extent practicable. Onsite remedies must meet applicable or relevant and appropriate regulations (ARARs) of other Federal statutes including the Resource Conservation and Recovery Act (RCRA), the Toxics Substances Control Act (TSCA), the Safe Drinking Water Act (SDWA), the Clean Water Act (CWA) and the Clean Air Act (CAA). Where State standards are more stringent than Federal standards, State standards must be met.

The strategies used for establishing cleanup goals by the U.S. EPA under the Superfund program have been the subject of continuing review and critique. In 1985, the U.S. Office of Technology Assessment (USOTA), acting in behalf of the U.S. Congress evaluated past practices associated with setting cleanup goals at Superfund hazardous waste sites [6]. The USOTA identified seven alternative approaches for establishing cleanup goals at Superfund sites:

1. Ad hoc,
2. Site-specific risk assessment,
3. National goals for residual contamination,
4. Clean to background or "pristine" levels,
5. Best available technology or best engineering judgement,
6. Cost-benefit approach, and
7. Site classification.

Based on a review of past and current practices under the Superfund program as well as critical issues relevant to establishment of cleanup goals, the USOTA drew the following important conclusions:

- o It is no longer acceptable to continue cleanups under the current ad hoc approach. Dealing with each site as a unique case is inefficient and there is increasing likelihood that sites with similar problems will not be cleaned to comparable levels of protection.
- o Pursuing cleanup to background or pristine does not make environmental, technical or economic sense.
- o Though seemingly attractive and extensively used, best available technology or engineering judgement approaches do not offer environmental protection comparable to the likely high costs of implementation.
- o Though use of existing standards, risk assessment and cost benefit pose considerable problems, they could be used.
- o The most important conclusion is that a cleanup strategy based on site classification could be the most beneficial approach to be used (Table 4.4). For this strategy to be successful, the decision regarding land use must be made at the local level.
- o There is a need to raise the issue of cleanup goals to the highest levels of policy making with an open debate. The success of the Superfund program and private and State cleanups depends on equitable and technically sound resolution of this issue.
- o What is ultimately important and realistically achievable is consistency in the process of determining cleanup goals, rather than necessarily making all cleanups the same.

Table 4.4 Illustration of a site classification system for selecting cleanup goals as proposed by the U.S. Office of Technology Assessment [6].

Classes of NPL sites (established when site placed on NPL)	Cleanup goals for remedial cleanup set by	Likely course of action	For comparison purposes, EPA classes of groundwater ^a
I. Known or likely exposures to people or sensitive ecological elements requiring restoration of site (for possible rehabilitation or reuse), including cleanup of contaminated groundwater if technically feasible.	Site risk assessment.	1. High-priority initial response to recontrol site using HRS ^b information. 2. Obtain necessary data and perform risk assessment. 3. High-priority full-scale permanent cleanup when technology available to meet cleanup goals.	I. Special groundwaters vulnerable to contamination and: a) irreplaceable source of drinking water to substantial populations, or b) ecologically vital.
II. Known or likely exposures exist, but limited number of people and sensitive environments. Clear alternatives to site cleanup such as relocation and use of alternative water supply; site restoration or reuse not critical.	Cost-benefit analysis.	1. Initial response. 2. After cost-benefit analysis choose risk management option.	II. Current and potential sources of drinking water or have other uses.
III. Site not likely to lead to exposures to people and not situated near sensitive environment. No site restoration or reuse anticipated.	Applicable and relevant environmental standards.	1. Low-priority initial response. 2. Reevaluation every 5 years to assess need for remedial cleanup.	III. Not potential source of drinking water and of limited use.

^aU.S. Environmental Protection Agency, *Ground-Water Protection Strategy*, August 1984

^bAssume an improved Hazard Ranking System.

At a 1987 colloquium sponsored by the Water Science and Technology Board of the U.S. National Research Council, the issue of cleanup goals for Superfund hazardous waste sites was specifically addressed [7]. It was noted that cleanup goals had, in the past, largely been handled on an ad hoc basis with implicit rather than explicit goals set. Legal settlements between government agencies and potentially responsible parties (PRPs) normally resulted in cleanup actions without explicit cleanup goals. These included, 1) cash buyouts where the potentially responsible party (PRP) pays a sum of money in return for release from future liability, 2) agreements to conduct a specific remediation action, and 3) open-ended commitments to do 'whatever is necessary' to protect human health. Few cases explicitly established cleanup goals.

Three major unresolved issues emerged from the colloquium regarding approaches to establishing cleanup goals:

- o The point of compliance must be resolved at which applicable or relevant and appropriate requirements should be applied. Impacted parties generally support compliance at the edge of the waste management unit or site of release. Responsible parties argue for compliance at property boundaries or point of potential impact.
- o An appropriate level of risk and acceptable target levels must be selected. Impacted parties argue for very conservative risk management decisions and there is explicit support for cleanup levels corresponding to a 10^{-6} incremental risk of cancer.
- o The adequacy of the current database for making both risk analyses and risk management decisions is questionable. Exposure assessment using current models of contaminant transport is constrained by a lack of data on contaminant fate. The capability of many remedial technologies to achieve very low levels of residual contamination is not clearly understood. Finally, the toxicological database and methods used to estimate chronic risks at low levels of human exposure are highly uncertain.

State of California. The State of California developed what they refer to as the "California Site Mitigation Decision Tree" (Tables 4.2 and 4.3) [17]. In this approach the maximum exposure level (MEL) is equal to the daily dose (mg/d) with no adverse health effects during chronic exposure. The applied action level (AAL) is the concentration of a substance in a particular media that when exceeded, presents a significant risk of adverse impact to a biological receptor. AALs drive the cleanup process for a site. The cleanup level is the site-specific criterion that remedial action must satisfy to keep biological receptor exposures equal to or less than the AAL. MELs and AALs are substance and species specific.

For threshold substances (i.e. noncarcinogenic), MELs for humans can be derived from several sources. In order of decreasing preference, these include human or animal toxicity data, drinking water standards or guidelines, or occupational exposure limits (e.g. ACGIH TLVs). MELs are derived from human or animal toxicological dose-response relationships as follows:

$$\text{MEL (mg/d)} = \frac{\text{NOAEL (mg/kg.d)} * \text{adult body wt (kg)}}{\text{Uncertainty factor}}$$

The uncertainty factor = 10 for large, controlled epidemiology studies, 10-100 for occupational standards, 100 if NOAELs are derived from chronic animal studies, 1000 if from subacute animal studies, or 100,000 if the NOAELs are from acute animal studies.

MELs are derived from occupational threshold limit values (TLVs) as follows:

$$\text{MEL (mg/d)} = \frac{\text{TLV (mg/m}^3\text{)} * 20 \text{ m}^3/\text{d} * 8 \text{ hr} * 5 \text{ d} * 47 \text{ yr}}{\text{Uncertainty factor} * 24 \text{ hr} * 7 \text{ d} * 72 \text{ yr}}$$

For non-threshold substances (carcinogens) the MEL is the level of exposure at an individual lifetime excess cancer risk equal to 10^{-6} . The International Association of Research on Cancer classification of carcinogens is used. In California, all substances classified as probable or possible human carcinogens are treated as nonthreshold substances.

The AALs are derived as follows:

$$\text{AAL(medium)} = \frac{\text{MEL}}{\text{Average daily intake}} * \text{pharmacokinetic factor}$$

The average daily intake for water is assumed to equal 2 L/d while for air it is 20 m³/d. The pharmacokinetic factor is used to adjust for differences in absorption, distribution and elimination for different exposure routes.

The measured or predicted level (C) of a given toxic substance at a given biologic receptor is compared with those considered safe (i.e. AAL). Similar to the U.S. EPA approach, the assumption of additivity is used to consider multiple substances and exposure routes. The cleanup action chosen must meet the following criteria. For a single compound, in single or multiple media, C must be equal to or less than the AAL. For multiple compounds in multiple media, the following must be satisfied:

$$\sum_{i=1}^n \sum_{j=1}^m \frac{C(ij)}{\text{AAL}(ij)} < 1$$

State of New Jersey. The approach used for establishing cleanup levels for contaminated soils in New Jersey involves setting a range of acceptable soil contaminant levels (ASCLs) for organic compounds while for inorganic compounds, ASCLs are multiples of background levels in soils in New Jersey or elsewhere in the USA [8, 17]. ASCLs are considered as soil concentrations that don't present a significant risk to health under average conditions of chronic exposure to soil or ground water and is protective of aquatic life in impacted surface water.

ASCLs are derived in different ways depending on the medium and receptor in question that is desired to be protected. To protect human health from drinking contaminated ground water,

$$\text{ASCL} = K_d * \text{Standard} * \text{Depth Factor} * \text{Mobility Factor}$$

where, K_d is the soil/water partition coefficient, the Standard is the water quality criteria or drinking water standard, and the Depth and Mobility Factors are soil-related parameters.

To protect human health from ingestion of noncarcinogenic contaminants in soil, the ASCL is derived as follows:

$$\text{ASCL} = \frac{\text{ADI (mg/d)} * 1000 \text{ g/kg} * 10 \text{ kg}}{\text{Daily soil intake by child} * 70 \text{ kg}}$$

For carcinogenic contaminants in soil, the ASCL becomes:

$$\text{ASCL} = \frac{\text{Acceptable cancer risk} * 1000 \text{ g/kg}}{\text{Carcinogenic potency (1/(mg/kg/day))} * \text{Average daily soil intake (g/kg-d)}}$$

where the acceptable cancer risk is defined as 10^{-6} , the carcinogenic potency is the slope of the dose-response curve based on animal bioassays as calculated by the U.S. EPA and the lifetime average daily soil intake is 2.8 mg/kg-d.

Cleanup levels are calculated by a two-step process. In step one, indicator compounds are selected based on a scoring system where the total score is equal to the sum of a relative amount score, toxicity score, volatilization score, leachability score, persistence score, bioaccumulation score and an aquatic toxicity score. In step two, the ASCLs are derived for humans and three pathways (soil, ground water, surface water) and aquatic life, but only two pathways. The ASCL associated with the most sensitive pathway is selected. There is no consideration of multiple chemical multiple route exposures.

Apart from the above approach, cleanup guidelines used in New Jersey have reportedly included those listed in Table 4.5 [8]. Presumably these would have to ultimately be consistent with the results of the site-specific analysis procedure described above.

Table 4.5. Cleanup guidelines used in the State of New Jersey, USA [8].

Substance	Soil	Ground Water
	ppm	ppb
Chromium	100	50
Zinc	350	-
Lead	100	50
Copper	170	-
Arsenic	20	50
Cadmium	3	10
Selenium	20	10
Nickel	100	-
Barium	-	100
Mercury	-	2
Silver	-	50
Total Volatiles	1	-
Volatiles plus Base Neutrals	-	100
Total Hydrocarbons	100	-
Petroleum Hydrocarbons	100	1000

State of Washington. The State of Washington has prepared state guidance on cleanup of waste contaminated sites. In their approach, cleanup goals for each medium are derived by the methods summarized in Table 4.6.

State of Wisconsin. In 1985, the State of Wisconsin adopted a set of standards specific to ground water quality protection [26]. Numerical values for preventive action limits (PALs) and enforcement standards (ESs) were explicitly defined in administrative regulations (Tables 4.7 and 4.8).

Application of the PALs and ESs in Wisconsin is explicitly regulated as illustrated by the following remarks from the administrative regulations:

- o If a preventive action limit (PAL) or an enforcement standard (ES) for a substance is attained or exceeded at a point of standards application, the owner or operator shall notify the appropriate regulatory agency, and the regulatory agency shall require a remedial response.

- o In determining if a preventive action limit or enforcement standard is attained or exceeded or if a change in the concentration of a substance has occurred, the regulatory agency shall utilize the most scientifically valid of the following statistical procedures which provide a 95% level of confidence: Student t-test, temporal or spatial trend analysis, or other scientifically valid test. If a substance is not detected in a sample and the limit of detection is higher than the preventive action limit or enforcement standard, the PAL or ES shall be considered not to have been attained or exceeded.

Table 4.6. Cleanup criteria used in the State of Washington, USA [8,17].

Application	Description
<u>Standard/Background Cleanup Levels</u>	
o General	Existing environmental standards
o Soil	10 times drinking water or water quality standards, or 10 times background water quality levels, or Soil background.
o Ground water/ surface water	Drinking water standard, or Water quality standard or Background.
o Air	U.S. occupational air quality standards, or Ambient air quality standards, or Background.
<u>Soil Protection Cleanup Levels</u>	
o Threat to water	100 times water quality standard, or 100 times background water quality, or 10 times soil background, or Predictive models with site-specific data.
o Threat to air	0.001% of inhalation LC ₅₀ , or Guidelines for respiratory carcinogens.

Table 4.7. Ground water standards in the State of Wisconsin, USA [26].¹

Substance	Preventive Action Limit	Enforcement Standard
	ug/L	ug/L
<u>1. Public Health Ground Water Quality Standards²</u>		
Arsenic	5	50
Barium	200	1000
Cadmium	1	10
Chrome	5	50
Lead	5	50
Mercury	0.2	2
Selenium	1	10
Silver	10	50
Cyanide	92	460
Fluoride	440	2200
Nitrate+Nitrate (as N)	2000	10000
Benzene	0.067	0.67
Toluene	68.6	343
Xylene	124	620
1,4-dichlorobenzene	150	750
Vinyl chloride	0.0015	0.015
1,2-dibromoethane	0.001	0.01
1,2-dichloroethane	0.05	0.5
1,1-dichloroethene	0.024	0.24
Methylene chloride	15	150
Tetrachloroethene	0.1	1
1,1,1-trichloroethane	40	200
1,1,2-trichloroethane	0.06	0.6
Trichloroethene	0.18	1.8
Aldicarb	2	10
Endrin	0.02	0.2
Lindane	0.002	0.02
Methoxychlor	20	100
Simazine	0.43	2.15
Toxaphene	0.00007	0.0007
1,2-dibromo-3-chloropropane (DBCP)	0.005	0.05
Carbofuran	10	50
2,4-dichlorophenoxyacetic acid	20	100
2,4,5-Trichlorophenoxypropionic Acid	2	10
Dinoseb	2.6	13
Bacteria, Total Coliform	Less than 1 per 100 mL for membrane filter or not present in any 10 mL portion by fermentation tube method.	

Table 4.7 cont. Ground water standards in the State of Wisconsin [26].¹

Substance	Preventive Action Limit	Enforcement Standard
	mg/L	mg/L
2. Public Welfare Ground Water Quality Standards³		
Copper	0.5	1
Iron	0.15	0.3
Manganese	0.025	0.05
Zinc	2.5	5
Chloride	125	250
Sulfate	125	250
Total dissolved solids	250	500
Color (in color units)	7.5	15
Odor (in Threshold Odor No.)	1.5	3.0
Foaming agents (methylene blue active sub.)	0.25	0.5

¹Adopted as legal State standards in 1985/1986.

²For all substances that have carcinogenic, mutagenic or terratogenic properties or interactive effects, the preventive action limit is 10% of the enforcement standard. The preventive action limit is 20% of the enforcement standard for all other substances of public health concern.

³For each substance of public welfare concern, the preventive action limit is 50% of the established enforcement standard.

- o Point of standards application: Facilities, practices and activities regulated shall be designed to minimize the level of substances in ground water and to comply with the PALs to the extent technically and economically feasible at the following locations:

- Any point of present ground water use,
 - Any point at or beyond the property boundary,
 - Any point beyond the design management zone (DMZ) established:
- | | |
|----------------------------|-------------------------------------|
| <u>Type of facility</u> | <u>Horizontal distances for DMZ</u> |
| Land disposal systems | 250 feet |
| Wastewater, sludge lagoons | 100 feet |
| Solid waste facilities | 150 to 300 feet |
| Hazardous waste facilities | 0 to 300 feet |
| Spills, discharges | 0 feet |

Table 4.8. Ground water quality indicator parameter standards in the State of Wisconsin, USA [26].¹

Preventive Action Limit Is Greater Of		
Parameter	Minimum Change Rel. to Background	Statistical Change Rel. to Background
Field pH	+/- 1 pH unit	-
Field temperature	+/- 10°F	+/- 3 std. dev.
Specific conductance	+ 200 umhos/cm	+ 3 std. dev.
Alkalinity	+ 100 mg/L	+ 3 std. dev.
Total Hardness	+ 100 mgCaCO ₃ /L	+ 3 std. dev.
Boron	+ 2	+ 3 std. dev.
Calcium	+ 25	+ 3 std. dev.
Magnesium	+ 25	+ 3 std. dev.
Sodium	+ 10	+ 3 std. dev.
Potassium	+ 5	+ 3 std. dev.
Nitrogen - ammonium	+ 2	+ 3 std. dev.
- organic	+ 2	+ 3 std. dev.
- total	+ 5	+ 3 std. dev.
Biochemical Oxygen Demand	+ 25 mg/L	+ 3 std. dev.
Chemical Oxygen Demand	+ 25	+ 3 std. dev.
Total organic carbon	+ 1	+ 3 std. dev.
Total organic halogen	+ 0.25	+ 3 std. dev.

¹Background water quality is established by sampling one or more monitoring points at locations and depths sufficient to yield ground water samples that are representative of background water quality at or near the facility, practice or activity. Background water quality for indicator parameters shall be established by averaging a minimum of 8 sample results from each well.

o Factors to be considered in determining a remedial response:

- Background water quality.
- Reliability of sampling data.
- Public health, welfare and environmental effects.
- Probability that a PAL or ES may be attained or exceeded outside the DMZ.
- Performance of the facility, practice or activity compared to the design.
- Location of the monitoring point.
- Other known or suspected contaminant sources.
- Hydrogeologic conditions.
- Extent of ground water contamination.
- Alternate responses.

o Range of responses for exceedance of a PAL for Indicator parameters and substances of public health or welfare concern:

- No action.
- Sample wells or require sampling of wells.
- Require a change in monitoring, including increased monitoring.
- Require an investigation of the extent of ground water contamination.
- Require a revision of the operational procedures.
- Require a change in the design or construction.
- Require an alternate method of waste treatment or disposal.
- Require prohibition or closure and abandonment.
- Require remedial action to renovate or restore ground water quality.
- Revise rules or criteria on facility design, location or management practices.

o Range of responses for exceedance of a ES for substances of public health or welfare concern:

- Require a revision of the operational procedures.
- Require a change in the design or construction.
- Require an alternate method of waste treatment or disposal.
- Require prohibition or closure and abandonment.
- Require remedial action to renovate or restore ground water quality.
- Revise rules or criteria on facility design, location or management practices.

4.2.2 Canada

In Canada, there is little national guidance for assessing the significance of contamination and setting cleanup goals. Site assessment and cleanup are with few exceptions, handled at the Provincial level [8]. Generally, ad hoc approaches have been used and mainly for decommissioning and redevelopment of old industrial sites. A brief discussion of some approaches used in Canada follows.

Canadian Council of Resource and Environment Ministers. To assist in the assessment of the significance of contamination and setting cleanup goals some criteria (not standards) have been recommended by the Canadian Council of Resource and Environmental Ministers (CCREM) [8,27,28]. These are summarized in Table 4.9.

The criteria proposed by CCREM account for two media (i.e. soil versus ground water) and for two land uses (i.e. residential/farming versus commercial/industrial). Three values, referred to as A-B-C values, are given for each media. The application of these criteria is quite simple. Investigative criteria are values above which detailed investigation is needed while remedial criteria are values above which action is required for protection of humans or other biota. Action could include cleanup, other mitigation, and/or change in land use. For residential or farming land uses, the investigative criteria are equal to the A values and the remedial criteria are equal to the B values. For commercial or industrial land uses, the investigative criteria become the B values and the remedial criteria become the C values.

Province of Alberta. In Alberta, the selection of cleanup levels must be supported or justified by appropriate data [8,29]. To assist with this task, Alberta Environment published guideline levels for acceptable concentrations of some metals in acidic soils. The guidelines were reportedly based on several factors including phytotoxicity and bioaccumulation (Table 4.10).

Province of Ontario. In Ontario, the Ministry of Environment (OME) initially provided guidelines for the decommissioning of major industrial sites in 1984 [8]. Included were basic data and information requirements of OME before a cleanup plan or alteration in site use is permitted. This document included a limited list of criteria for soil (Table 4.11). A revised edition of this document is to include criteria to assist in selecting appropriate cleanup levels.

In determining final cleanup goals, existing OME criteria for air or water can be used as appropriate as well as the soil criteria mentioned above. For other contaminants, criteria must be developed based on the specific contaminants present, physical features of the site and on-site and adjacent land use. A site-specific risk assessment may be needed in some cases. Final cleanup criteria are established in consultation with OME authorities.

Table 4.9. Interim guidelines for contaminated sites recommended by the Canadian Council of Resource and Environment Ministers [27-28].¹

Substance	Land Use	Max. Concentration in the Top 15 cm				
		mg/kg				
Polychlorinated biphenyls	Agricultural soils incl. home gardens	0.5				
	Non-agricultural soils, general public access	5				
	Industrial/commercial, limited public access	50				
Threshold Concentrations						
Component	Soil (mg/kg dry matter)			Ground water (ug/L)		
	A	B	C	A	B	C
<u>Group 1 - Carcinogenic PAHs²</u>						
Benzo(a)anthracene	0.1	1	10	0.01	0.1	1
Benzo(b)anthracene	0.1	1	10	0.01	0.1	1
Benzo(k)fluoranthene	0.1	1	10	0.01	0.1	1
Benzo(a)pyrene	0.1	1	10	0.01	0.1	1
Dibenzo(a,h)anthracene	0.1	1	10	0.01	0.1	1
Indeno(1,2,3-c,d)pyrene	0.1	1	10	0.01	0.1	1
<u>Group 2 - Other PAHs³</u>						
Naphtalene	0.1	5	50	0.2	2	20
Phenanthrene	0.1	5	50	0.2	2	20
Pyrene	0.1	10	100	0.2	2	20
<u>Group 3 - Other organics</u>						
Benzene	Substances of concern, but no guidelines yet.					
Toluene				"		
Xylene				"		
<u>Group 4 - Inorganics</u>						
Iron	Substances of concern, but no guidelines yet.					
Arsenic				"		
Sulfide/sulfate				"		
Iron-cyanide complexes				"		
Free cyanide				"		

¹Application of ABC values: Investigative criteria = values above which detailed investigation is needed. Remedial criteria = values above which action is required for humans or other biota. Action could include cleanup, other mitigation, and/or change in land use. For residential or farming uses, Investigative criteria = A values and Remedial criteria = B values. For commercial or industrial uses, Investigative criteria = B values and Remedial criteria = C values.

²Group 1 substances are designated as carcinogenic by International Agency for Research on Cancer.

³Group 2 substances have not been demonstrated as cancer causing.

Table 4.10. Suggested cleanup guidelines for inorganic contaminants in acidic soils in the Province of Alberta, Canada [8].¹

Element	Acceptable Level for Acidic Soils (pH < 6.5)
	mg/kg
Cadmium	1
Chromium	600
Cobalt (preliminary)	100
Copper	200
Lead	800
Manganese	-2
Nickel	250
Zinc (sheep diet)	100
Zinc (others)	700

¹The values given were developed as guidance for reclamation of industrial sites located on acidic soils. Site specific conditions must be considered and the suggested acceptable levels are only to be used as guidelines towards selecting final cleanup levels.

²No limit recommended for manganese due to high naturally occurring levels.

Province of Quebec. In 1988, Quebec issued a guide to the rehabilitation of contaminated sites [19]. Among other things, this document formalized an "ABC" system of site assessment with a comprehensive list of soil and ground water criteria to assist in determining final cleanup levels (Table 4.12). This approach and the numerical ABC values were derived in large part from that used in The Netherlands. Three concentration values (A, B and C values) are given for both soil and ground water. The A values were equivalent to background levels or analytical detection limits, B values were indicative of moderate contamination and the C values were indicative of severe contamination.

Many of the values from The Netherlands were adopted directly. In some cases, modifications were made as deemed appropriate for Canadian conditions. Specific soil contaminants of concern in Quebec were added. Ground water criteria were revised, with the low values used in The Netherlands, increased due to impracticalities of their use in Quebec. For heavy metals, the B values were set equal to drinking water standards where available and C values were set equal to storm sewer disposal criteria. For certain organic compounds, the ground water criteria were revised in accordance with U.S. Environmental Protection Agency criteria for Estimated Permissible Concentrations in water. It is emphasized that the criteria are at no time to be regarded as standards [19].

Table 4.11. Soil cleanup criteria of the Ontario Ministry of Environment, Canada [8].

Parameter	Criteria for Proposed Development ¹		
	Residential/ Agriculture	Commercial/ Parkland	Industry
	ppm	ppm	ppm
pH	-	6-8	6-8
Conductance (mS/cm)	-	2	2
Sodium Absorption	-	15	15
Arsenic	14	25	50
Cadmium	1-6	4	8
Chromium (6+)	-	10	10
Chromium (Total)	120	1000	1000
Copper	100	300	300
Lead	60	500	1000
Mercury	0.5	1	2
Molybdenum	4	5	40
Nickel	32	200	200
Nitrogen (%)	-	0.6	0.6
Oil and grease (%)	-	1	1
Selenium	1.6	5	-
Silver	-	25	50
Zinc	220	800	800

¹Reference is made to guidelines for Sewage Sludge Utilization on Agricultural lands. Guidelines for Residential/parkland and commercial/industrial are based on phytotoxicity except for cadmium, lead and mercury (human health) and molybdenum and selenium (animal health). For coarse textured (sandy) mineral soils the criteria for metals and metalloids should be reduced by one-half. Criteria for oil and grease is for fresh oil, use 2% for weathered oil.

Application of this ABC system in Quebec is theoretically quite simple. For each of the substances, there are three threshold values which determine three levels of intervention as described below.

- o The A value represents background pollution with respect to contaminants found naturally, such as metals, oils and grease, and the detection limit with regard to man-made organic chemical products. The A-B level is indicative of slight contamination of soil or ground water. At this level of contamination, ground water still satisfies drinking water quality standards and criteria. However, it is worthwhile to investigate possible sources of contamination and, especially in the case of the water table, to ascertain whether new contaminants continue to enter the water. This may lead to intervention focusing on the soil, particularly if the water is used for drinking. Usually, at the A-B level of contamination, decontamination will not be undertaken. Should the land be redeveloped for especially sensitive purposes, e.g. surface soil in a residential or a farming sector, it may prove essential to adopt a number of protection measures, such as the excavation of a superficial layer of soil or the addition of a layer of clean soil.
- o The B value represents a threshold when thorough analyses are necessary. At the B-C level, the soil or ground water are contaminated. Contamination of ground water exceeds drinking water quality standards. Although the soil is contaminated, it will not automatically be decontaminated unless the effect of contaminants on the ground water necessitates such work. However, restrictions on land use may be imposed when this level of contamination is observed in the soil. Restoration work may be necessary before the land is used for farming, residential or recreational purposes. Other uses, e.g. industrial or commercial, may be contemplated without decontamination being carried out. In all cases, the extent of the work to be effected, e.g. the depth to which soil must be excavated and so on, will depend upon the nature of the contaminants, land use and the impact on ground water and the environment in general.
- o The C value is a threshold at which it may be necessary to take prompt remedial action. At and above this value, the soil or ground water are contaminated. Ground water cannot be used for drinking. Concentrations of many contaminants exceed standards governing storm sewer runoff. The water is seriously contaminated; unless it is decontaminated, it will have to be monitored closely. All uses of such land will be restricted. A thorough analysis must be conducted. In all likelihood, restoration will have to be undertaken before rehabilitation occurs.

Table 4.12. Criteria for ascertaining the contamination of soil and ground water in the Province of Quebec, Canada [19].¹

Component	Soil (mg/kg dry matter)			Ground water (ug/L)		
	A	B	C	A	B	C
I - Heavy Metals						
Arsenic	10	30	50	5	50	100
Barium	200	500	2000	50	1000	2000
Cadmium	1.5	5	20	1	5	20
Chrome	75	250	800	15	40	500
Cobalt	15	50	300	10	50	200
Copper	50	100	500	25	50	1000
Lead	50	200	600	10	50	100
Mercury	0.2	2	10	0.1	0.5	1
Molybdenum	2	10	40	8	20	100
Nickel	50	100	500	10	250	1000
Selenium	1	3	10	1	10	50
Tin	5	50	300	10	30	150
Silver	2	20	40	5	50	200
Zinc	100	500	1500	50	5000	10000
II - Mineral Pollutants						
NH ₄ (as N)	-	-	-	200	500	1500
Br (dissolved)	-	-	-	100	500	2000
Br (free)	20	50	300	-2	-2	-2
CN (free)	1	10	100	40	200	400
CN (total)	5	50	500	40	200	400
F (dissolved)	-	-	-	300	1500	4000
F (free)	200	400	2000	-2	-2	-2
PO ₄ (in P)	-	-	-	50	100	700
NO ₃ (in N)	-	-	-	10	10000	-
NO ₂ (in N)	-	-	-	20	1000	-
Sulfide (H ₂ S)	-	-	-	10	50	500
S total	500	1000	2000	-	-	-
III - Monocyclical Aromatic Volatile Compounds (MAVCs)						
Benzene	0.1	0.5	5	0.5	1	5
Ethylbenzene	0.1	5	50	0.5	50	150
Toluene	0.1	3	30	0.5	50	100
Chlorobenzene	0.1	1	10	0.1	2	5
1,2 dichlorobenzene	0.1	1	10	0.1	2	5
1,3 dichlorobenzene	0.1	1	10	0.1	2	5
1,4 dichlorobenzene	0.1	1	10	0.1	2	5
Xylenes	0.1	5	50	0.5	20	60
Styrene	0.1	5	50	0.5	40	120
BTEX ³ (summation)	-	-	-	-	-	-

Table 4.12 cont. Criteria for ascertaining the contamination of soil and ground water in Quebec, Canada [19].¹

Component	Soil (mg/kg dry matter)			Ground water (ug/L)		
	A	B	C	A	B	C
IV - Phenolic Compounds						
Nonchlorinated						
(each) ⁴	0.1	1	10	1	3	20
Chlorophenols						
(each) ⁴	0.1	0.5	5	1	2	5
(summation) ⁵	0.1	1	10	1	4	10
V - Polycyclic Aromatic Hydrocarbons (PAHs)						
Benzo(a)anthracene	0.1	1	10	0.1	0.5	2
1,2 benzanthracene	0.1	1	10	0.1	0.2	1
7,2 dimethyl						
Dibenzo(a,h)anthracene	0.1	1	10	0.1	0.2	1
Chrysene	0.1	1	10	0.1	1	5
3methylcholanthrene	0.1	1	10	0.1	0.2	1
Benzo(b)fluoranthene	0.1	1	10	0.1	0.2	1
Benzo(j)fluoranthene	0.1	1	10	0.1	0.2	1
Benzo(k)fluoranthene	0.1	1	10	0.1	0.2	1
Benzo(g,h,i)perylene	0.1	1	10	0.1	0.2	1
Benzo(c)phenanthrene	0.1	1	10	0.1	0.5	2
Pyrene	0.1	10	100	0.2	7	30
Benzo(a)pyrene	0.1	1	10	0.1	0.2	1
Dibenzo(a,h)pyrene	0.1	1	10	0.1	1	5
Dibenzo(a,i)pyrene	0.1	1	10	0.1	1	5
Dibenzo(a,l)pyrene	0.1	1	10	0.1	1	5
Indeno(1,2,3,c,d)pyrene	0.1	1	10	0.1	1	5
Acenaphtene	0.1	10	100	0.5	20	30
Acenaphtylene	0.1	10	100	0.5	10	20
Anthracene	0.1	10	100	0.2	7	20
Fuoranthene	0.1	10	100	0.1	2	10
Fluorene	0.1	10	100	0.1	2	10
Naphtalene	0.1	5	50	0.2	10	30
Phenanthrene	0.1	5	50	0.1	1	5
PAHs (summation) ⁵	1	20	200	0.2	10	50

Table 4.12 cont. Criteria for ascertaining the contamination of soil and ground water in Quebec, Canada [19].¹

Component	Soil (mg/kg dry matter)			Ground water (ug/L)		
	A	B	C	A	B	C
VI - Chlorinated Hydrocarbons (CHs)						
Aliphatics CH ⁴						
(each)	0.3	5	50	1	10	50
(summation)	0.3	7	70	1	15	70
Chlorobenzene ⁴						
(each)	0.1	2	10	0.3	2	5
(summation)	0.1	4	20	0.3	4	10
Hexachlorobenzene	0.1	2	10	0.1	0.5	2
Polychlorinated biphenyls	0.1	1	10	0.1	0.2	1
Chlorodibenzo-p-dioxines	-	-	-	-	-	-
2,3,7,8 tetrachloro-dibenzo-p-dioxine	-	-	-	-	-	-
Chlorodibenzofuranes	-	-	-	-	-	-
VII - Pesticides						
a) Organochlorinated.						
Aldrine+Dieldrin	-	-	-	0.05	0.7	2
Chlordane (total)	-	-	-	0.05	0.7	2
DDT	-	-	-	0.05	30	60
Endrine	-	-	-	0.05	0.2	0.5
Epoxyde of heprachlor	-	-	-	0.05	3	5
Lindane	-	-	-	0.05	4	10
Methoxychlore	-	-	-	0.05	100	200
b) Carbamates.						
Carbaryl	-	-	-	0.05	70	150
Carbofurane	-	-	-	0.05	70	150
c) Derivatives of chlorophenoxy carboxylic acids.						
2-4-D	-	-	-	0.05	100	200
2,4,5.TP	-	-	-	0.05	10	20
d) Organophosphoric.						
Diazinon	-	-	-	0.05	14	30
Fenitrothion	-	-	-	0.05	7	20
Parathion	-	-	-	0.05	35	70
Parathion-methyl	-	-	-	0.05	7	20
e) Derivatives of pyridylum.						
Diquat	-	-	-	0.05	50	100
Paraquat	-	-	-	0.05	7	20
f) Trichloroacetates.						
Piclorame	-	-	-	0.05	1	2
Pesticides (summation) ⁵	0.1	2	20	0.05	100	200

Table 4.12 cont. Criteria for ascertaining the contamination of soil and ground water in Quebec, Canada [19].¹

Component	Soil (mg/kg dry matter)			Ground water (ug/L)		
	A	B	C	A	B	C
VIII - Indicatory Parameters						
Phenolic compounds by						
colorimetry ⁴	0.1	1	10	1	2	5
Gasoline	100	150	800	1000	1500	3000
Mineral oils/grease	100	1000	5000	100	1000	5000

¹Criterion (A) concerning ground water for elements in Groups I has been evaluated according to the average value of natural concentrations found in Quebec ground water, by compiling findings from more than 25 sampling sites located in 12 Quebec municipalities, with input from the Quebec laboratory and the Direction des eaux souterraines et de consommation. An average of findings for soil analyses drawn from a ministere de l'Energie et des Ressources data bank examined.

N.A. = not applicable. "-" = no criteria available as of 15 Feb. 1988.

²In aqueous environments, so-called "free" forms are dissolved.

³Summative criteria respecting BTEXs (benzene, toluene, xylene) to come.

⁴See the remarks section below.

⁵The sum of content detected for each compound in individual doses.

Table 4.12 Remarks:

(A) **Non-chlorinated phenolic compounds:** The following compounds are considered in this category: 2,4-dimethylphenol, 2,4-dinitrophenol, 2-methyl-4,6-dinitrophenol, 2-nitrophenol, 4-nitrophenol, phenol and cresol(ortho, para, meta).

(B) **Chlorophenols:** The following compounds are considered in this category: ortho-chlorophenol, meta-chlorophenol, para-chlorophenol, 2,6-dichlorophenol, 2,5-dichlorophenol, 2,4-dichlorophenol, 3,5-dichlorophenol, 2,3-dichlorophenol, 3,4-dichlorophenol, 2,4,6-trichlorophenol, 2,3,6-trichlorophenol, 2,4,5-trichlorophenol, 2,3,5-trichlorophenol, 2,3,4-trichlorophenol, 3,4,5-trichlorophenol, 2,3,5,6-tetrachlorophenol, 2,3,4,5-tetrachlorophenol, 2,3,4,6-tetrachlorophenol, and pentachlorophenol.

(C) **Volatile chlorinated aliphatic hydrocarbons:** This category includes the following compounds: Chloroform, Dichloro-1,1-ethane, Dichloro-1,2-ethane, Dichloro-1,1-ethene, Dichloro-1,2-ethene, Dichloromethane, Dichloro-1,2-propane, Dichloro-1,2-propene (cis and trans), Tetrachloro-1,1,2,2-ethane, Tetrachloroethene, Carbon tetrachloride, Trichloro-1,1,1-ethane, Trichloro-1,1,2-ethane, and Trichloroethene.

(D) **Chlorobenzenes:** Trichlorobenzenes (all isomers), Tetrachlorobenzenes (all isomers) and Pentachlorobenzene.

(E) **Polychlorinated biphenyls:** Isomers 1242, 1248, 1254 and 1260.

(F) **Phenolic compounds by colorimetric dose involving 4-aminoantipyrine:** In this instance, phenol itself is considered, along with phenols substituted in ortho and in meta, and even phenols substituted in para by carboxylic, methoxy, and sulphonic acid groups, and by halogens (Cl, F, Br, I). It is acknowledged that the method involving 4-aminoantipyrine does not permit the quantification of phenols substituted in para by alkyl, aryl, nitro, benzoid, nitroso and aldehyde groups.

4.2.3 England

In England, cleanup of contaminated land is driven by reclamation and redevelopment of old industrial sites, often for more sensitive uses. Site contamination has largely been viewed as a "material planning consideration", not as a matter of concern for public health and environmental protection [9, 20]. This has been the subject of much debate and criticism by those who wish to see greater consideration given to these factors.

To assist in site assessment for redevelopment purposes, there is Federal guidance in the form of "Trigger Concentrations" (Table 4.13) [9, 20]. These Trigger Concentrations have been established based in large part on existing criteria and standards. They are available for various land uses and for a variety of contaminants commonly found where industrial sites are being redeveloped for other uses. Application of the trigger concentrations is quite simple. If after a comprehensive site investigation, concentrations of soil contaminants are less than the Trigger Concentrations, it can be assumed that the site is uncontaminated. Development can then proceed as planned. If values are greater than the Trigger Concentrations, some remedial action is required if development is to proceed. Alternatively, a different development plan could be considered. The Trigger Concentrations are not meant to apply to sites already in use and may have to be modified where development has already begun before contamination was discovered.

4.2.4 The Netherlands

Throughout the past five years, considerable effort has been expended on development of environmental "standards" for soil and ground water quality in The Netherlands. As a result, The Netherlands was perhaps the first nation to formally establish a national, comprehensive program for assessing the significance of contamination as well as the extent of cleanup required [3,5,10,21-23]. In 1983 and subsequently in 1987, national laws were promulgated which established the principal of "multi-functionality" for soils in The Netherlands [21]. The principal is as follows, "the multi-functionality of the Dutch soils should be conserved or, when it has been disturbed, be re-established" [21]. Various functions for soil were considered, including agricultural, ecological, carrying, drinking water supply and so forth.

Table 4.13. Tentative "Trigger Concentrations" used in England [20].¹

		Trigger Concentrations	
Compound	Planned Uses	Threshold	Action
<u>Selected Inorganic Contaminants</u>		(mg/kg air-dried soil)	
Arsenic	Domestic gardens, allotments	10	TBD ²
	Parks, playing fields open space	40	TBD
Cadmium	Domestic gardens, allotments	3	TBD
	Parks, playing fields open space	15	TBD
Chromium (VI)	Domestic gardens, allotments	25	TBD
	Parks, playing fields open space		
Chromium (Total)	Domestic gardens, allotments	600	TBD
	Parks, playing fields open space	1000	TBD
Lead	Domestic gardens, allotments	500	TBD
	Parks, playing fields open space	2000	TBD
Mercury	Domestic gardens, allotments	1	TBD
	Parks, playing fields open space	20	TBD
Selenium	Domestic gardens, allotments	3	TBD
	Parks, playing fields open space	6	TBD
Boron (sol.)	Any uses where plants are grown	3	TBD
Copper	Any uses where plants are grown	130	TBD
Nickel	Any uses where plants are grown	70	TBD
Zinc	Any uses where plants are grown	300	TBD
<u>Contaminants Associated with Former Coal Carbonization Sites</u>			
Poly-aromatics	Dom. gardens,allotments,play areas	50	500
	Landscapes, buildings, hardcovers	1000	10000
Phenols	Dom. gardens, allotments	5	200
	Landscapes, buildings, hardcovers	5	1000
Cyanide (free)	Dom. gardens,allotments,landscapes	25	500
	Buildings, hardcovers	100	500
	(complex)	Dom. gardens, allotments	250
Landscapes		250	5000
Buildings, hardcovers		250	None
Thiocyanate	All proposed uses	50	None
Sulphate	Dom. gardens,allotments,landscapes	2000	10000
	Buildings	2000	50000
	Hardcovers	2000	None
Sulphide	All proposed uses	250	1000
Sulphur	All proposed uses	5000	20000
Acidity	Dom. gardens,allotments,landscapes	5	3

¹All proposed values are tentative and/or preliminary requiring regular updating. All values are for concentrations determined on "spot" samples. If all values are below the Threshold Concentrations, site may be regarded as uncontaminated for these contaminants and development may proceed. Above the thresholds, remedial action may be needed. Above the action concentration, remedial action will be required or the form of development changed.

²TBD = to be developed.

As part of the standards development effort and consistent with the principal of multi-functionality, The Netherlands formulated criteria for guiding the assessment and cleanup of waste contaminated land. This list of criteria is often referred to as the "Dutch List". Established in 1983, the "ABC" system included three values for both soil and ground water (Table 4.14). The A-value was a threshold below which soil could be regarded as unpolluted and above which a preliminary investigation of the site would be required. The B-value was a threshold above which further investigation would be required to define the extent of contamination and potential risks. The C-value was a threshold above which there normally would be some removal and/or cleanup, preferably back to the A-value.

The ABC criteria were established within a framework which included three major factors deemed important in assessing the significance of contamination:

1. Nature and concentration of the contaminating substances,
2. Site specific conditions affecting contaminant migration and fate,
3. Use and function of the soil and degree of exposure and risks.

Factors 1 and 2 determine whether contamination poses serious threats while factor 3 suggests urgency. Quantitation of factors 2 and 3 is difficult, so factor 1 is often emphasized in practice. The ABC values were intended only as criteria for the first factor [3].

The A-values for metals were established based on average background levels in unpolluted soils in The Netherlands. For man-made organic compounds, the analytical limits of detection were used.

These ABC criteria were never intended to be standards, but rather trigger values for deciding upon the necessity for carrying out (further) investigations and risk assessments [10]. In practice however, these criteria have been implemented as if they were in fact standards.

One application has been to judging the performance of contaminated soil treatment plants, of which there are a large number and variety in The Netherlands [5]. The estimated annual treatment capacity is on the order of 0.5 million m³. In practice, the ABC criteria are often used by the Provincial governments to set performance requirements. For example, treated soil with values above the C-level are disposed of at a licensed hazardous waste landfill, while those in the B-C level might go to a controlled (lined) landfill, while those in the A-B level might be used as covering on dumps or as construction fill. Where housing developments are involved, the goal for soil quality near the development is often the A level [30].

Table 4.14. Soil and ground water criteria used in The Netherlands for contaminated land ("Dutch List") [31].¹

Component	Soil (mg/kg dry soil)			Ground water (ug/L)		
	A	B	C	A	B	C
1. Metals						
Cr	100	250	800	20	50	200
Co	20	50	300	20	50	200
Ni	50	100	500	20	50	200
Cu	50	100	500	20	50	200
Zn	200	500	3000	50	200	800
As	20	30	50	10	30	100
Mo	10	40	200	5	20	100
Cd	1	5	20	1	2.5	10
Sn	20	50	300	10	30	150
Ba	200	400	2000	50	100	500
Hg	0.5	2	10	0.2	0.5	2
Pb	50	150	600	20	50	200
2. Inorganics						
NH ₄ (as N)	-	-	-	200	1000	3000
F (total)	200	400	2000	300	1200	4000
CN (tot.free)	1	10	100	5	30	100
(tot.comb.)	5	50	500	10	50	200
S (total)	2	20	200	10	100	300
Br (total)	20	50	300	100	500	2000
PO ₄ (as P)	-	-	-	50	200	700
3. Aromatics Compounds						
Benzene	0.01	0.5	5	0.2	1	5
Ethylbenzene	0.05	5	50	0.5	20	60
Toluene	0.05	3	30	0.5	15	50
Xylenes	0.05	5	50	0.5	20	60
Phenols	0.02	1	10	0.5	15	50
Total	0.1	7	70	1	30	100
4. Polycyclic Hydrocarbons						
Naphthalene	0.1	5	50	0.2	7	30
Anthracene	0.1	10	100	0.1	2	10
Fenanthrene	0.1	10	100	0.1	2	10
Flouranthene	0.1	10	100	0.02	1	5
Pyrene	0.1	10	100	0.02	1	5
1,2 benzopyrene	0.05	1	10	0.01	0.2	1
Total	1	20	200	0.2	10	40

Table 4.14.cont. Soil and ground water criteria used in The Netherlands for contaminated land ("Dutch List") [31].¹

Component	Soil (mg/kg dry matter)			Ground water (ug/L)		
	A	B	C	A	B	C
5. Chlorinated Hydrocarbons						
Aliphatics						
(Individual)	0.1	5	50	1	10	50
(Total)	0.1	7	70	1	15	70
Chlorobenzenes						
(Individual)	0.05	1	10	0.02	0.5	2
(Total)	0.05	2	20	0.02	1	5
Chlorophenols						
(Individual)	0.01	0.5	5	0.01	0.3	1.5
(Total)	0.01	1	10	0.01	0.5	2
Chlor. PAHs (Tot.)	0.05	1	10	0.01	0.2	1
PCB's (Tot.)	0.05	1	10	0.01	0.2	1
EOCl (Tot.)	0.1	8	80	1	15	70
6. Pesticides						
Chlorinated organics						
(Individual)	0.1	0.5	5	0.5	0.2	1
(Total)	0.1	1	10	0.1	0.5	2
Pesticides						
(Total)	0.1	2	20	0.1	1	5
7. Other Pollutants						
Tetrahydrofuran	0.1	4	40	0.5	20	60
Pyridine	0.1	2	20	0.5	10	30
Tetrahydrothiophene	0.1	5	50	0.5	20	60
Cyclohexanes	0.1	6	60	0.5	15	50
Styrene	0.1	5	50	0.5	20	60
gasoline	20	100	800	10	40	150
mineral oil	100	1000	5000	20	200	600

¹These values are not "standards" but rather guidelines for use in assessing the significance of contaminated land. A simplified explanation of the ABC levels: A-level implies unpolluted, B-level implies pollution present and further investigation required, C-level implies significant pollution present and cleanup (preferably back to the A-level) required.

A further development of significance in The Netherlands occurred in 1987, when the Federal government enacted a comprehensive Soil Protection Act which reaffirmed the soil multi-functionality concept. It also provided for another list of criteria, "reference values for a good soil quality", as shown in Table 4.15 [21, 22].

During development of the reference values, it was acknowledged that a pure effect oriented approach, where reference values are derived from a complete toxicological analyses of the effects of substances on man, plants, animals and ecosystems, was not feasible. Instead, provisional reference values were derived based on what was considered the best information available. The first stage of the process was to examine soil quality requirements resulting from other areas of policy (e.g. standards for drinking water, surface water and so forth). One important implication of this was that ground water quality should satisfy drinking water standards.

For organic compounds in soils, a linear adsorption model was used which related organic compound sorption to compound octanol/water partitioning and soil organic matter content. For inorganics this approach was deemed inappropriate. Instead, empirical relationships were developed for concentrations of heavy metals in unpolluted Dutch soils as a function of soil clay and organic matter content. The provisional list was discussed and criticized by a committee of experts and a revised list prepared [21,22]. The reference values are to be used to designate areas contaminated by hazardous wastes and to restrict point releases. Although some may try to use them as cleanup goals (but not as legal standards) to be reached by soil remediation techniques, it is unlikely that in practice they will be met [22].

4.2.5 West Germany

In West Germany, the assessment of contamination and determination of cleanup goals lies with the 11 individual States or Lander. There are no uniform procedures or standards [11,17]. The water and waste management authorities in each Lander decide on a case-by-case basis. In many cases, the responsible authorities use the "standards" of The Netherlands. However, there remains considerable variability in the standards or criteria applied from Lander to Lander. The City State of Hamburg is unique in that it has a formalized program for assessment and remediation of contaminated sites.

West Germany has initiated a far-reaching program at the Federal level to provide for the long term safeguarding against the pollution of soils by hazardous substances and against the stress of soils due to usage [4]. Fundamentally it was agreed that natural resources should be protected for their own sake, especially since soil damage is often irreversible. Pollution of soils should be minimized and in the long-term stopped, and contaminated sites such as old industrial sites should be reclaimed.

Table 4.15. Reference values for multi-functional soil and ground water in The Netherlands [31].

Substance	Standard soil (H=10/L=25)	Ground water	
1. Inorganic Compounds			
	mg/kg dry matter		
Cr [50+2L] ¹	100	1	ug/L
Ni [10+L]	35	15	ug/L
Cu [15+0.6(L+H)]	36	15	ug/L
Zn [50+1.5(2L+H)]	140	150	ug/L
Cd [0.4+0.007(L+3H)]	0.8	1.5	ug/L
Hg [0.2+0.0017(2L+H)]	0.3	0.05	ug/L
Pb [50+L+H]	85	15	ug/L
As [15+0.4(L+H)]	29	10	ug/L
F [175+13L]	500	-	
NO ₃ ²	-	5.6	mgN/L
SO ₄ ³	-	150	mg/L
Bromides	-	300	ug/L
Chlorides ³	-	100	mg/L
Fluorides ³	-	0.5	mg/L
Ammonium compounds ^{3,4}	-	2/10	mgN/L
Phosphate ⁴	-	0.4/3.0	mgP/L
(Total phosphate) ²			
<hr/>			
2. Organic Compounds	Reference value at (H=10) dry wt. basis ⁵		
(a) Halogenated hydrocarbons and choline-esterase inhibitors: <1 ug/kg - hexachlorocyclohexane; endrin; tetrachloroethane; tetrachloromethane; trichloroethane; trichloroethene; trichloromethane; PCB IUPAC no. 28, 52. <10 ug/kg - chloropene; tetrachloroethene; hexachloroethane; hexachlorbutadiene; heptachloreposice; dichlorobenzene; trichlorobenzene; tetrachlorobenzene; hexachlorobenzene; monochloronitrobenzene; dichloronitrobenzene; aldrin; dieldrin; chlordane; endosulfan; disulfoton; fenitrothion; parathion (and -methyl); triazophes PCB IUPAC no. 101, 118, 138, 153, 180. <100 ug/kg - DDD; DDE; pentachlorophenol.			
(b) Polycyclic aromatic hydrocarbons: <10 ug/kg - naphthalene; chrysene. <100 ug/kg: fenantiene; anthracene; fluorantene; benzo(a)pyrene. <1 mg/kg - benz(a)anthracene. <10 mg/kg - benzo(k)fluorantene; indeno (1,2,3cd) pyrene; benzo(ghi) perylene			
(c) Mineral oil: <50 mg/kg - total. <1 mg/kg - octane; heptane			

¹H=weight% of organic matter soil, L=weight% of clay fraction in soil.

²Lower values can be required for protection of nutrient poor regions.

³Higer values appear naturally in regions with a strong marine influence.

⁴The lower values apply to ground water in sandy regions; the higher values apply to ground water in regions with clay and peat soils.

⁵Or detection limit if this is higher than the value stated.

The program originated at the Federal level in 1985 as the "Conception for Soil Protection" [4]. In May 1987, the environmental ministers recommended to the Federal government that relevant laws and regulations be amended to incorporate soil protection aspects. Measures to be taken were approved by the Federal cabinet in the end of that year. The concept of "threshold and guide values" has emerged which will include a description of substances endangering soils and delineate threshold and guide values for soil contamination. It is believed that the threshold and guide values for soil contamination can contribute to conserving soils with low contamination levels and trigger remediation before actual public health and environmental damage has occurred.

The components for deriving threshold and guide values for soils are to be compiled from various sources (e.g. limiting values of Ordinance on Sewage Sludge Treatment for land application). There is a study in progress to assess the risks and hazards to soils and the need for reclamation and reuse. This work is currently focused on heavy metals, but later will be expanded. An overview of some preliminary values is shown in Table 4.16.

It is recognized that interpretation of the threshold and guide values can never be based solely on numerical values alone. Apart from the question of whether the values are sufficiently well-founded, their interpretation in a particular case will always necessitate information on soil sampling, analytical methods as well as site usage objectives.

4.2.6 France

In France, there are no particular directives or standards from the Federal Ministry of Environment [12]. As a consequence, setting cleanup goals and site restoration is a local matter. Existing standards and criteria are used as appropriate (e.g. drinking water standards, sludge spreading limits, etc.). Reportedly, risk assessments and decontamination projects are carried out on a pragmatic basis according to site characteristics, environmental vulnerability, pressure of local authorities and in some cases public attention and political impact. The Ministry of Environment is considering the subject of standards for characterizing soil pollution. In cases where contamination is by natural substances, reference will always be made to background conditions [12].

4.2.7 Denmark

Approaches used in Denmark have attempted to recognize a variety of risks associated with contaminated land such as contamination of ground water and drinking water, indoor air pollution and direct contact/ingestion of soil [13,14]. For initial site screening and assessment, reference is often made to the "Dutch List". As appropriate, existing Danish standards are used. For example, drinking water standards have been applied to ground water. Site-specific risk assessments have been performed, particularly where there has been more sensitive uses planned for old industrial sites. While a variety of sites have been assessed and cleaned up, the procedures for setting cleanup goals are as yet not formalized. A systematic risk assessment procedure is being formalized by the Federal government [14].

Table 4.16. Overview of concentrations of some elements in man-affected soils in West Germany [32].

Element	Concentrations in Air-dry Soil (mg/kg)				
	Normal		Contamination	Tolerable	
Arsenic	0.1	-	20	< 8000	20
Boron	5	-	20	< 1000	25
Beryllium	0.1	-	5	< 2300	10
Bromide	1	-	10	< 600	10
Cadmium	0.01	-	1	< 200	3 ¹
Cobalt	1	-	10	< 800	50
Chromium	2	-	50	<20000	100
Copper	1	-	20	<22000	100
Fluoride	50	-	200	< 8000	200
Gallium	0.1	-	10	< 300	10
Mercury	0.01	-	1	< 500	2 ¹
Molybdenum	0.2	-	5	< 200	5
Nickel	2	-	50	<10000	50 ¹
Lead	0.1	-	20	< 4000	100 ¹
Antimony	0.01	-	0.5	< ?	5
Selenium	0.01	-	5	< 1200	10
Tin	1	-	20	< 800	50
Thallium	0.01	-	0.5	< 40	1
Titanium	10	-	5000	<20000	5000
Uranium	0.1	-	1	< 115	5
Vanadium	10	-	100	< 1000	50
Zinc	3	-	50	<20000	300 ¹
Zirconium	1	-	300	< 6000	300

¹Same as values used for cultivated soil treated with sewage sludge as fertilizer (German Sewage Sludge Regulation).

4.2.8 Sweden

In Sweden, the first significant problem with hazardous waste contaminated land occurred in the mid-1970's. However, there are as yet, no formalized approaches for assessing the significance of contamination nor setting cleanup goals [15].

4.2.9 Finland

Approaches to setting cleanup goals in Finland are in development [16,25]. However, as yet there are no formalized methods on a local or national basis. There have been a few sites which have been assessed and where cleanup goals have been explicitly established (e.g. sawmill/wood treatment sites). In these cases, current and future land use conditions and potential exposures have been considered with reference to existing standards and criteria (e.g. "Dutch list"). For a particular site, concentrations of soil contaminants were established which determined the cleanup requirements (e.g. clean, road fill, local landfill, hazardous waste treatment facility).

4.2.10 Norway

In Norway, the problems of hazardous waste contaminated land are just now being addressed. As a result, there are no formalized approaches for setting cleanup goals [1]. Problems of hazardous waste contaminated land have so far been largely caused by old waste deposits encountered during construction activities (e.g. buildings, railways). In most cases, the significance of contamination and need for cleanup was assessed in an ad hoc fashion with some consideration of site use, existing standards such as the "Dutch List" and the perceived available options for remediation. In other cases where the contamination is more complex and has potentially far-reaching public health and environmental impacts (e.g. chemical waste adjacent to or within a fjord or beneath a housing development), investigations have commenced but cleanup goals have yet to be explicitly set.

SECTION 5

SOIL QUALITY CRITERIA AND CLEANUP GOALS

There has been considerable discussion and debate regarding appropriate methods for assessing the significance of contamination and establishing cleanup goals for waste contaminated land. The approach which has been most controversial, perhaps, is a "standards-based" approach involving the use of predetermined standards, guidelines and criteria (PSGCs). In the context of this discussion, the general use of soil and ground water quality criteria and cleanup goals is meant to represent a wide range of predetermined, somewhat generic numerical values, including true legal standards, guidelines and criteria. Moreover, it is important to recognize that "cleanup goals" are but one application of the evolving spectrum of "soil and ground water quality criteria".

5.1 CURRENT ATTITUDES AND USE

In most of the ten nations considered in this review, the desire and need for cleanup criteria specific to contaminated land were evident. Readily available, comprehensive listings were viewed as essential to facilitating initial site review and screening. Many persons cited that there was a demand for unequivocal cleanup criteria, often put forth by owners, developers and future users of contaminated land. Equally evident, however, was a strong appreciation for the difficulties and potential problems related to establishing and implementing cleanup criteria as well as the belief that there must be some site-by-site flexibility for setting final cleanup goals.

The first nation to establish a national, comprehensive set of numeric criteria for contaminated land was The Netherlands. In 1983 a national act was promulgated which put forth the concept of "multi-functionality" for soil and included criteria for assessing the significance of soil and ground water contamination and guiding site assessment and cleanup. In support of a broad soil protection policy, reference values were later enacted for a "good soil quality".

The criteria of the Dutch List were never intended to be legal standards as such, but rather trigger values for deciding upon the necessity for carrying out (further) investigations and risk assessments. In practice however, due to lack of other information, these criteria have been implemented as if they were in fact standards. The "Dutch List" is widely referred to (Table 4.1) and often cited as "standards". In 1988, the province of Quebec, Canada promulgated their own similarly comprehensive list of criteria, based in large part on the Dutch List.

Other national and provincial government agencies have also established cleanup criteria in the form of acceptable limits for soil and ground water contaminants. These have different names including "Trigger Concentrations" (England), "Cleanup Guidelines" (New Jersey, USA), and "Guide/Threshold Values" (West Germany). While far less comprehensive than the Dutch or Quebec lists, they are intended to serve as guidance in site assessment and cleanup. In many cases the criteria are given with

reference to a proposed land use. In most cases, they are not legal standards, but rather guidance criteria intended to be used with due consideration of site specific factors and subject to justification and/or modification.

The use of standards-based approaches appears to be gaining favor in many nations, especially for preliminary assessment of the significance of contamination and the potential extent of cleanup. The Netherlands has used this approach for more than 5 years to remediate several hundred sites. Recently, the Province of Quebec in Canada, issued a similarly comprehensive list of soil and ground water criteria, in large part adapted from the "Dutch List". Establishment of similar criteria lists are also under consideration in other jurisdictions (e.g. Wisconsin, USA; Alberta, Canada; West Germany and France).

Even in those jurisdictions where cleanup criteria have not been formulated specifically for cleanup of contaminated land, reference is commonly made to existing standards, guidelines and criteria (see Table 4.1). Reference to the Dutch List is widespread. There is also direct use or adaptation of existing national or international standards and criteria. Often these were developed under programs and legislation unrelated to contaminated land. Examples of these include:

- o Drinking water standards,
- o Ambient water quality criteria,
- o Storm water runoff criteria,
- o Limits on sewage sludge application to agricultural lands,
- o Occupational air quality standards,
- o Ambient air quality criteria, and
- o Air quality emission limits.

Notably, in several jurisdictions, ground water quality standards (i.e. legal standards) have been established equal to drinking water standards (e.g. Wisconsin, USA; Denmark; The Netherlands). In some cases, use of existing standards, guidelines and criteria has been formally incorporated into a waste site cleanup program (e.g. USA Superfund program).

5.2 CHARACTERISTIC FEATURES

There appear to be several features which are common to the numeric values appearing as cleanup criteria as well as the process by which they have been developed. These are outlined in Table 5.1.

A comparison of acceptable soil quality concentrations and cleanup criteria developed for a common heavy metal contaminant, lead, and a common organic contaminant, PCBs, is presented in Table 5.2. Inspection of the values shown and their structure illustrates some of the general features outlined in Table 5.1. Moreover, the data shown suggest that various judgements (e.g. technical, social, economic) may have played a part in arriving at a given numeric value.

Table 5.1. General features of soil quality criteria and cleanup goals and their development.

General Features	
o	Criteria development has invariably included adaptation of existing applicable or relevant and appropriate standards, guidelines and criteria, often developed under programs unrelated to contaminated land.
	Criteria are often noted to be interim and/or subject to continuing review and refinement. It is commonly emphasized that the criteria are not true legal standards, and are subject to site by site considerations and decision making.
	Information is often available for inorganic contaminants such as heavy metals, with comparatively lesser information for organic contaminants.
	Multiple levels are often put forth to account for different land uses and different investigative and cleanup actions required. These often differ by an order of magnitude from one level to the next.
	Obviously unpolluted soil is often characterized by the following: For inorganic contaminants (e.g. heavy metals), normal soil background levels often serve as the basis. For organic contaminants, particularly synthetic organics, the analytical detection limit is often used as the basis (i.e. the desire is for no detectable levels). Alternatively, equilibrium partitioning concepts have been used to set an acceptable soil contaminant concentration to maintain ground water quality levels at or below drinking water standards.
	Degrees of soil contamination are often characterized as follows: For inorganics, multiples of background are used to characterize moderate and severe contamination. For organics, moderate contamination may be set at a value which does not cause ground water contamination to exceed drinking water standards (based on equilibrium partitioning).
	Where done, land uses are typically classified as to their sensitivity with respect to hazards associated with direct or near-direct contact and/or direct phytotoxicity and bioaccumulation, for example: Most sensitive: agricultural, home gardens and play areas, Less sensitive: parkland or green spaces with open public access, Least sensitive: commercial/industrial with restricted public access

Table 5.2. Comparison of soil quality and cleanup criteria for selected contaminants.¹

Reference	Description	Lead	PCBs
		mg/kg	mg/kg
<u>Canada</u>			
CCREM	Agricultural land uses	-	0.5
	General public access land uses	-	5
	Commercial/Industrial uses	-	50
Alberta	For Acidic Soils (pH<6.5)	800	-
Ontario	Residential/agricultural land uses	60	-
	Commercial/parkland uses	500	-
	Industrial land uses	1000	-
Quebec	A-Level (background, MDL)	50	0.1
	B-Level (investigation)	200	1
	C-Level (cleanup)	600	10
<u>England</u>	Domestic gardens, allotments	500	50/500 ²
	Parks, playing fields, open space	2000	1000/10000 ²
<u>The Netherlands</u>	A-Level (background, MDL)	50	0.05
	B-Level (moderate contamination)	150	1
	C-Level (severe contamination)	600	10
	Good Soil Quality (10%OM, 25%C)	85	<0.010
<u>West Germany</u>	Normal	0.1-20	-
	Tolerable	100	-

¹Refer to appropriate section of the preceding text for complete information regarding the data shown in this table.

²Values shown apply generically to polyaromatic hydrocarbons with the low value indicating the threshold concentration and the high value indicating the action level (see appropriate text section for discussion).

5.3 ADVANTAGES AND DISADVANTAGES

A standards-based approach has been criticized by some as simplistic and unworkable, yet it has been consistently favored by risk managers due to:

- o Once a standard is adopted, application is simple and non-controversial.
- o Standards are easy to justify and defend in court.
- o Provides a means of communication among all participants in the risk management process.
- o Appears to be an objective process grounded in scientific analysis and free of value judgements.
- o Relieves policy makers from cumbersome burden of dealing with uncertainty and from being charged with imposing their own values/beliefs on society.
- o Simplifies problem by automatically determining the goals of risk management activities.
- o Reflects recurrent hope for scientific method for objectively resolving the problem of "How Clean is Clean?" [17].

There appear to be numerous potential advantages and disadvantages of a standards-based approach to establishing cleanup goals (Table 5.3). Approaches employing soil and ground water quality criteria are not claimed to be the best approach for setting cleanup goals, but rather a necessary part of an overall program for dealing with contaminated land. Predetermined criteria facilitate national or regional soil and ground water protection programs and encourage redevelopment efforts for contaminated land. In this context they may be used for both initial screening and contamination assessment as well as for determination of final cleanup goals.

For contaminated sites of national and regional significance (e.g. uncontrolled hazardous waste sites involving large concentrations or amounts of highly toxic materials) such a standards-based approach will probably not be appropriate.

5.3 METHOD DEVELOPMENT

It appears that a standards-based approach represents an important component of an overall program to deal with cleanup of hazardous waste contaminated land and soil and ground water protection in general. The challenge would seem to be one of developing scientifically well-founded (as far as possible, at least) soil quality and cleanup criteria which are consistent with other laws and regulations and supported by the various concerned and affected parties (e.g. scientific and engineering community, regulators and politicians, environmental and citizens groups).

The elements judged by this author to be important to the development and implementation of soil and ground water quality criteria for cleanup goal setting are outlined in Table 5.4. Development of a complete, comprehensive method is ongoing.

Table 5.3. Example advantages and disadvantages to the use of soil and ground water quality criteria for cleanup goals.

Potential Advantages and Disadvantages of Standards-based Approaches

Advantages

- o Speed and ease of implementation.
- o Similar sites would be handled in a similar manner.
- o Useful for initial assessment of significance of contamination.
- o A priori information facilitates planning and action.
- o Encourages developers to undertake decontamination and restoration.
- o Potential consistency with strategies for environmental standards.
- o Reality of contaminated land made easy for layman.
- o Facilitate environmental audits of industrial sites.
- o Facilitates monitoring/permitting of operational industrial sites.
- o Can be used for performance assessments of soil treatment plants.
- o Implies non-negotiability and reduces local political influences.

Disadvantages

- o Some important site-specific considerations cannot be accounted for.
 - o Standards, guidelines and criteria are not formulated for many toxic substances of concern. Existing standards formulated under other programs are not necessarily appropriate for contaminated land.
 - o PSGCs imply a level of understanding, knowledge and confidence which likely does not exist.
 - o Once PSGCs are established, site-specific flexibility may be difficult.
-

Table 5.4. Elements of a standards-based approach for establishing soil and ground water quality criteria and cleanup goals for hazardous waste contaminated land.

Key Elements	
<hr/>	
o	Site classification scheme to screen contaminated sites and rate them according to their apparent hazards (e.g. low hazard, high hazard, catastrophic).
o	Properties and characteristics of chemical occurrence, transport and fate for common contaminated sites.
o	Range of reasonable land-use and exposure scenarios.
o	Generic risk assessment and risk management protocol.
o	Comprehensive, multi-dimensional listings of acceptable soil and ground water quality criteria for range of site characteristics and exposure scenarios.

SECTION 6 OVERVIEW OF CLEANUP TECHNOLOGIES

A separate but very important related issue is the availability, cost and performance of cleanup technologies to achieve the cleanup goals established for contaminated land. In contrast to early cleanup experiences where the preferred approach was simply either 1) excavation and hauling offsite to a licensed landfill or 2) in-place encapsulation and isolation, there is growing interest in and use of onsite and insitu treatment processes.

Comprehensive research and development efforts as well as demonstration projects into the treatment of contaminated soils include the following:

- o Superfund Innovative Technologies Evaluation program (USA),
- o NATO CCMS Demonstration of Remedial Action Technologies for Contaminated Land and Ground water (International),
- o The Spearhead program on Soil Research (The Netherlands),
- o The Soil Treatment Research Project (West Germany), and
- o The Lossepladsprojektet (Denmark).

Results of this work have already provided much information on basic and applied aspects of treatment processes and procedures for hazardous waste contaminated land. The results of continuing work should be even more valuable.

Based on the results of past research and experience, technology screening guides and design manuals have recently been published to assist with the process of identification, evaluation and design of cleanup for hazardous waste contaminated soils [e.g. 11, 32-35]. Summary information from several documents are shown in Tables 6.1 to 6.4. These clearly indicate the wide range of alternative technologies available for treatment of contaminated soil. They also point out the early stage of development and/or demonstration of certain technologies.

While the information base regarding treatment technologies for hazardous waste contaminated land is rapidly expanding, there currently remains much uncertainty above the application and performance of many processes and procedures for the wide variety of waste constituent mixtures and soil environments. This is particularly true for insitu processes. Thus, great care must be exercised in technology screening and evaluation. In many cases, bench and/or pilot scale tests may be necessary and appropriate to confirm the performance capabilities of a given technology prior to its implementation on a full scale.

Table 6.1. Examples of chemical constituents considered within waste groups [after 33].¹

Waste Group	Example Constituents
<u>Organic Contaminants</u>	
Halogenated Volatiles	Chlorobenzene, Chloroform, 1,2-dichloroethane, Methylene chloride, 1,1,1-trichloroethane, Trichloroethene.
Halogenated Semivolatiles	Pentachlorophenol, 1,2-dichlorobenzene, Hexachlorobenzene, 2-chloronaphthalene.
Nonhalogenated Volatiles	Acetone, Benzene, Methanol, Toluene, Methylisobutyl ketone.
Nonhalogenated Semivolatiles	Cresols, Phenol, Anthracene, Benzo(a)pyrene, Dimethyl phthalate, Nitrobenzene.
PCBs	PCBs (Arochlor)-1242.
Pesticides	Aldrin, Chlordane, Dieldrin, Toxaphene.
Organic Cyanides	Organonitriles.
Organic Corrosives	Acetic acid, Formic acid.
<u>Inorganic Contaminants</u>	
Volatile Metals	Arsenic, Lead, Mercury.
Nonvolatile Metals	Cadmium, Copper.
Other Categories	Asbestos.
Radioactives	Radium, Radon.
Inorganic Corrosives	Hydrochloric acid, Sodium hydroxide.
Nonmetallic Toxic Elements	Fluorine.
Inorganic Cyanides	Cyanide, Metallic cyanides.
<u>Reactive Contaminants</u>	
Oxidizers	Chlorates, Chromates.
Reducers	Sulfides, Hydrazine.

¹The compounds listed are merely examples of a wide range of compounds within each group and are for use in application of Table 6.2.

Contaminant		Technology															
		A.1-1	A.2-1	A.3-1	A.5-1	A.6-1	B.1-1	B.2-1	B.3-1	B.4-1	B.5-1	B.6-1	B.7-1	B.8-1	B.10-1	C.1-1	C.2-1
Organic	Table	Fluidized bed incineration	Rotary kiln incineration	Infrared thermal treatment	Pyrolysis-incineration	Vitrification	Chemical extraction	In situ chemical treatment	Soil washing	In situ soil flushing	Glycolate dechlorination	Low temperature thermal stripping	In situ vacuum/steam extraction	Stabilization/solidification	In situ vitrification	Biodegradation	In situ biodegradation
	Halogenated volatiles	●	●	●	●	●	●	○	○	○	○	○	○	○	○	○	○
	Halogenated semivolatiles	●	●	●	●	●	●	○	○	○	○	○	○	○	○	○	○
	Nonhalogenated volatiles	●	●	●	●	●	●	○	○	○	○	○	○	○	○	○	○
	Nonhalogenated semivolatiles	●	●	●	●	●	●	○	○	○	○	○	○	○	○	○	○
	PCBs	●	●	●	●	●	●	○	○	○	○	○	○	○	○	○	○
	Pesticides	●	●	●	●	●	●	○	○	○	○	○	○	○	○	○	○
	Organic cyanides	●	●	●	●	●	●	○	○	○	○	○	○	○	○	○	○
Organic corrosives	●	●	●	●	●	●	○	○	○	○	○	○	○	○	○	○	
Inorganic	Volatiles metals	×	×	×	○	×	○	○	○	○	○	○	○	○	○	×	×
	Nonvolatile metals	○	○	○	○	○	○	○	○	○	○	○	○	○	○	×	×
	Asbestos	○	○	○	○	○	○	○	○	○	○	○	○	○	○	×	×
	Radioactive materials	○	○	○	○	○	○	○	○	○	○	○	○	○	○	×	×
	Inorganic corrosives	○	○	○	○	○	○	○	○	○	○	○	○	○	○	×	×
	Inorganic cyanides	○	○	○	○	○	○	○	○	○	○	○	○	○	○	×	×
Reactive	Oxidizers	●	●	●	●	●	×	○	○	○	○	○	○	○	○	×	×
	Reducers	●	●	●	●	●	×	○	○	○	○	○	○	○	○	×	×

● Demonstrated effectiveness

○ Potential effectiveness

○ No effectiveness

× Potential adverse impacts to process or environment

* Do not use this matrix table alone. Please refer to the cited appendices for guidance.

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Table 6.3. Summary of remedial technologies for treatment of soil contaminated by petroleum products in the USA [34].

Technology	Exposure Pathways ¹	Applicable Petroleum Products ²	Advantages	Limitations	Relative Costs ³
<i>In Situ</i>					
Volatilization	1-7	1, 2, 4	Can remove some compounds resistant to biodegradation.	VOCs only.	Low
Biodegradation	1-7	1, 2, 4	Effective on some non-volatile compounds.	Long-term timeframe.	Moderate
Leaching	1-7	1, 2, 4	Could be applicable to wide variety of compounds.	Not commonly practiced.	Moderate
Vitrification	1-7	1, 2, 3, 4		Developing technology.	High
Passive	1-7	1, 2, 3, 4	Lowest cost and simplest to implement.	Varying degrees of removal.	Low
Isolation/Containment	1-7	1, 2, 3, 4	Physically prevents or impedes migration.	Compounds not destroyed.	Low to moderate

¹Exposure pathways: 1=vapor inhalation; 2=dust inhalation; 3= soil ingestion; 4=skin contact; 5=ground water; 6=surface water; and 7=plant uptake.

²Applicable petroleum products: 1=gasolines; 2=fuel oils (#2, diesel, kerosenes); 3=coal tar residues; and 4=chlorinated solvents.

³Costs are highly dependent on site conditions.

Table 6.3.cont. Summary of remedial technologies for treatment of soil contaminated by petroleum products in the USA [34].

Technology	Exposure Pathways ¹	Applicable Petroleum Products ²	Advantages	Limitations	Relative Costs ³
<i>Non-In Situ</i>					
Land treatment	1-7	1, 2, 3	Uses natural degradation processes.	Some residuals remain.	Moderate
Thermal Treatment	1-6	1, 2, 3, 4	Complete destruction possible.	Usually requires special facilities.	High
Asphalt Incorporation	1-6	1, 2	Use of existing facilities.	Incomplete removal of heavier compounds.	Moderate
Solidification	1-6	1, 2, 3, 4	Immobilizes compounds.	Not commonly practiced for soils.	Moderate
Groundwater Extraction and Treatment	1-6	1, 2, 4	Product recovery, groundwater restoration.		Moderate
Chemical Extraction	1-8	1, 2, 3, 4		Not commonly practiced.	High
Excavation	1-8	1, 2, 3, 4	Removal of soils from site.	Long-term liability.	Moderate

¹ Exposure pathways: 1=vapor inhalation; 2=dust inhalation; 3= soil ingestion; 4=skin contact; 5=ground water; 6=surface water; and 7=plant uptake.

² Applicable petroleum products: 1=gasolines; 2=fuel oils (#2, diesel, kerosenes); 3=coal tar residues; and 4=chlorinated solvents.

³ Costs are highly dependent on site conditions.

Table 6.4. Applicability of techniques for treatment of contaminated soil in Europe [after 11].¹

Treatment Technology	Contaminant Type		
	1	2	3
	Aromatics & Aliphatics		Phenols
	Volatile	Heavy	
Soil Type ²	A, B	A, B	A, B
<u>Applicability of techniques for the treatment of excavated soil</u>			
Extraction	+, + ³	+, +	+, +
Sedimentation/ flotation	--, -	±, ±	-, -
Evaporation	++, ++	++, ++	++, ++
Biological treatment	++, ++	++, ++	++, ++
Stabilization	+, +	++, ++	+, +
<u>Applicability of insitu techniques</u>			
Extraction	±, -	-, -	±, -
Evaporation/ Air stripping	±, -	-, -	-, -
Steam stripping	±, -	±, -	±, -
Biological land farming	+, ±	±, ±	±, ±
Ventilation	+, -	+, -	+, -
Bioextraction	+, -	+, -	+, -
Chemical oxidation/ reduction	±, -	±, -	±, -
Precipitation	-, -	-, -	-, -
Neutrolization/ hydrolysis	-, -	-, -	-, -

¹ For examples of chemical constituents in each waste category, refer to Table 6.1.

² Soil types are cohesionless permeable soil (A) and cohesive soil with a low permeability (B).

³ Explanation of symbols used:

"-" means generally not applicable.

"±" means applicable in principal in some cases.

"+" means applicable in principal.

"++" means in some cases applicability is proven.

"++" means applicability is proven.

Table 6.4.cont. Applicability of techniques for treatment of contaminated soil in Europe [after 11].¹

Treatment Technology	Contaminant Type							
	4		5		6		7	
	Chlorinated Volatile		Hydrocarbons Heavy		Heavy Metals		Cyanide	
Soil Type ²	A,	B	A,	B	A,	B	A,	B
<u>Applicability of techniques for the treatment of excavated soil</u>								
Extraction	+	+	+	+	++	+	++	+
Sedimentation/ flotation	-	-	-	-	++	-	+	+
Evaporation	++	++	+	+	-	-	+	+
Biological treatment	+	+	+	+	-	-	-	-
Stabilization	+	+	+	+	++	++	+	+
<u>Applicability of insitu techniques</u>								
Extraction	+	-	-	-	+	-	+	-
Evaporation/ Air stripping	+	-	-	-	-	-	-	-
Steam stripping	+	-	-	-	-	-	-	-
Biological land farming	-	-	-	-	-	-	+	+
Ventilation	-	-	-	-	-	-	+	-
Bioextraction	-	-	-	-	-	-	+	-
Chemical oxidation/ reduction	-	-	-	-	++	-	+	-
Precipitation	-	-	-	-	++	-	-	-
Neutrolization/ hydrolysis	-	-	-	-	-	-	-	-

¹For examples of chemical constituents in each waste category, refer to Table 6.1.

²Soil types are cohesionless permeable soil (A) and cohesive soil with a low permeability (B).

³Explanation of symbols used:

- "-" means generally not applicable.
- "+" means applicable in principal in some cases.
- "++" means applicable in principal.
- "++" means in some cases applicability is proven.
- "++" means applicability is proven.

SECTION 7 CONCLUSIONS AND RECOMMENDATIONS

7.1 CONCLUSIONS

Based on the information gathered and reviewed during this study, the following conclusions have been drawn:

1. The issue of assessing the significance of contamination and establishing cleanup goals for waste contaminated land is a complex and difficult one. It is the subject of continuing and sometimes heated debate wherever contaminated land problems are addressed.
2. There are very few nations where an explicit, nationally consistent approach to establishing cleanup goals has been promulgated, yet this has been identified by some as essential to successful site remediation. The approach(s) used appear to reflect, in part, the perceived need for cleanup and the general attitude toward environmental protection.
3. Approaches to establishing cleanup goals vary widely within and between nations around the world. Approaches most commonly used include ad hoc site by site negotiation and decision making, reference to background levels, application of predetermined standards and criteria, site specific mathematical modeling and risk assessments, or a combination thereof.
4. The approaches used are subject to continuing re-examination and refinement. Even in nations with apparently long-established programs for dealing with contaminated land, there is much debate regarding the most appropriate approaches for assessing the significance of contamination and establishing cleanup goals.
5. Allowing higher residual concentrations of contaminants (i.e. lower soil and ground water quality) for less sensitive current and future land uses (e.g. industrial site versus housing development) was a consistent component of most approaches.
6. There was an expressed need for site by site flexibility and consideration of local conditions in setting final cleanup levels.
7. Some form of standards-based approach employing soil and ground water quality criteria is viewed as essential for site screening and initial assessment as well as for setting cleanup goals for common, non-catastrophic sites. It is also needed to assess the performance of treatment processes and plants for cleaning contaminated soil. For complex and catastrophic sites, a site-specific risk assessment and risk management approach will likely be necessary.

8. Initial remediation activities largely involved excavation and offsite treatment and/or landfilling. There is increasing interest in and use of onsite and insitu treatment technologies. A wide variety of processes are available for treatment of contaminated soils, both offsite and onsite/insitu. Comprehensive research and development projects are ongoing in several nations to develop new procedures and processes and to develop sound design and performance databases.

7.2 RECOMMENDATIONS

1. It is recommended that the results of this study be considered in light of applicable or appropriate and relevant Norwegian regulations and that the issue of establishing cleanup goals for contaminated land be openly discussed and resolved. This should be accomplished early in the development of Norway's program for addressing problems with hazardous waste contaminated land.
2. The approach which proves most appropriate for Norway will depend on a careful analysis of many factors, of a technical and non-technical nature. It is likely that a combined approach will prove satisfactory. This approach probably will have some type of site classification as a basis. A standards-based approach should prove workable for initial site assessment and establishing cleanup goals for common, non-catastrophic sites. For high hazard and catastrophic sites, a site-specific risk assessment and risk management approach will probably be required.

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SECTION 9
APPENDIX

APPENDIX A
PERSONAL INQUIRIES AND SITE VISITS MADE AS PART OF THIS STUDY

Table A1. Principal inquiries providing information regarding cleanup standards and technologies for hazardous waste contaminated land.

Nation	Agency	Contact
<u>United States</u>		
	o U.S. Environ. Protection Agency, Cincinnati	R. Hill
	o U.S. Environ. Protection Agency, Washington D.C.	Dr. W. Kovalick, Jr.
	o New Jersey Dep. of Environmental Protection	R. Dime
<u>Canada</u>		
	o Environment Canada, Burlington, Ontario	T.W. Foote
	o National Water Research Inst., Burlington, Ontario	Dr. R.E. Jackson
	o Alberta Environ. Res.Ctr., Vegreville, Alberta	D. Conrad
	o Stablex Canada, Inc., Blainville, Quebec	P. Grenier
	o Alberta Special Waste Manage. System, Swan Hills	A. Wakelin
<u>England</u>		
	o Department of the Environment, London	M.J. Beckett
	o Clayton Bostock Hill & Rigby, Birmingham	M.A. Smith
<u>The Netherlands</u>		
	o TNO Div. of Technology for Society, Apeldoorn	M. Hinsenveld
	o TNO Div. of Technology for Society, Delft	Dr. F.B. deWalle
	o Nat. Institute of Public and Env. Prot, Bilthoven	E.R. Soczo
		K. Visscher
		J.J. Vegter
	o Ministry of Housing, Physical Planning and Environment, Leidenscham	
	o Association of Process-Based Soil Treatment Companies (NVPG), Voorburg	F.E. Boeren
		F. Norman
		V. Egmond
<u>Germany</u>		
	o Federal Environmental Agency, Berlin	Dr. V. Franzius
	o Office of Remedial Action, Hamburg	K. Wolf
		Dr. V. Sokollek
<u>France</u>		
	o Hazardous Sites Team, Angers	R. Goubier
<u>Denmark</u>		
	o Agency for Environmental Protection, Copenhagen	L. W. Sorensen
		C. R. Petersen
	o Danish Technical University, Lynby	Dr. T. Christiansen
		Dr. S. Vedby
	o Danish Geotechnical Institute, Lynby	M. Poulsen
	o Geotechnical Soil Cleaning, Kalundborg	S. Hanson

Table A1.cont. Principal inquiries providing information regarding
cleanup standards and technologies for hazardous waste
contaminated land.

Country	Agency	Contact
<u>Sweden</u>		
	o National Environmental Protection Board, Stockholm	M. Appelberg B. Sodermark O. von Hedenstam
	o Swedish Geotechnical Institute, Linkoping	B. Carlson S. Kullberg
<u>Finland</u>		
	o National Board of Waters and Environment, Helsinki	T. Assmuth T. Laikari
<u>Norway</u>		
	o State Pollution Control Authority, Oslo	O. M. Grini J. Johansen M. Helle
	o Oslo Renholdsverks, Oslo	E. Bjerkelund

Table A2. Principal site visits yielding information regarding cleanup standards and technologies for hazardous waste contaminated land.

Nation	Description
<u>The Netherlands</u>	
o	Study visit (11-12 October 1988):
-	TNO Division of Technology for Society, Appeldoorn and Delft.
-	National Institute of Public Health and Environmental Protection, Bilthoven.
-	Assn. of Process-based Soil Treatment Companies, Voorburg.
-	Gouderak waste site cleanup (old shoreline landfill).
-	Ecotechniek soil treatment plant (thermal), Utrecht.
-	HWZ soil treatment plant (extraction), Amsterdam.
<u>West Germany</u>	
o	Study visit (21-22 February 1989):
-	Institute for air, water and soil research, Langen.
-	Office of Remedial Action, Hamburg.
<u>Denmark</u>	
o	Seminar on Remedial Action Technologies in the USA, FRG and Canada, 12 August 1988, Technical University of Denmark, Lynby, Denmark.
o	Study visit (5-6 October 1988):
-	National Agency for Environmental Protection, Waste Sites Office, Copenhagen.
-	Waste contaminated land cleanup (paint factory).
-	Biotechnical Soil Cleaning Ltd.
<u>Sweden</u>	
o	Study visit (28-29 September, 10 November 1988):
-	National Environmental Protection Board, Stockholm.
-	Swedish Geotechnical Institute, Linkoping.
-	SAKAB hazardous waste treatment plant, Kumla.
<u>Finland</u>	
o	Study visit (8-9 Nov. 1988):
-	National Board of Waters and the Environment, Helsinki.
-	Waste sites (paint factory, lead smelter, incinerator).
-	EKOKEM hazardous waste treatment plant, Riihimaki.
<u>Norway</u>	
o	Meetings with the State Pollution Control Authority, Oslo.
o	Visits to various current or potential waste sites in Norway.

**SAMPLING METHOD EFFECTS ON
VOLATILE ORGANIC COMPOUND MEASUREMENTS
IN SOLVENT CONTAMINATED SOIL**

By

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Inquiries regarding the research may be directed to Dr. Siegrist at GEFO, Postbox 9, 1432 Aas-NLH, Norway, Tel. 47-9-948140 or at 4014 Birch Avenue, Madison, WI, 53711, USA, Tel. 1-608-2387697.

SECTION 1 SUMMARY

Soil contamination by volatile organic compounds (VOCs) can lead to time-consuming and costly investigation and cleanup actions. It is therefore essential that decisions regarding the significance of contamination and the need for cleanup be based on accurate measurements of the VOC concentrations present. VOC measurements in soil systems are subject to many sources of error, perhaps the most important of which are the systematic errors or bias associated with sample collection methods. Despite this fact, comparatively little research has been done to elucidate the effects sampling methods can have on the accuracy of VOC measurements in soils. To further the understanding of this subject, research was conducted during early 1989 at the Institute for Georesources and Pollution Research in Aas, Norway.

A laboratory experiment was conducted to investigate the effects of sampling methods on VOC concentrations measured in solvent contaminated soil. Five different methods were used to assess the effects of sample disturbance, container headspace volume, container integrity and infield methanol preservation.

The study soil was a naturally occurring surface soil (top 50 cm) of sand texture (97% sand) obtained from the Mona glaciofluvial deposit near Mysen, Norway. The field moist soil was characterized by a water content of 8.6%, pH of 5.21, total organic carbon (TOC) content of 0.4%, and cation exchange capacity of 4 meq/100g. The study soil was uniformly packed into 15 cm diameter by 15 cm long glass columns. Two columns were prepared, one for control purposes and one for testing the sampling method effects. Spatial uniformity was confirmed by computer-assisted x-ray tomography.

The soil in the test column was uniformly contaminated under conditions simulating a chemical waste discharge. An aqueous solution containing different concentrations of six common VOCs was passed through the column by saturated upflow. The VOCs and the respective feed solution concentrations were methylene chloride (157.5 mg/L), 1,2-dichloroethane (130 mg/L), 1,1,1-trichloroethane (16 mg/L), trichloroethylene (12.8 mg/L), toluene (4.5 mg/L) and chlorobenzene (2.85 mg/L).

Contamination of the soil column occurred in a temperature-controlled room at 10°C. Over a period of ca. 2.5 hr., ca. 15 pore volumes of the solvent solution were passed through the test column at an average flux of 870 cm/d. The control column was treated in a similar fashion but without the target VOCs in the feed solution.

During contamination of the test column, samples of the column feed and outflow solutions were collected. Analyses of each target VOC were made by gas chromatography. The target VOCs were not markedly retarded during saturated flow through the soil column. This observation was consistent with predictions based on empirical relationships for sorption as a function of VOC water solubility and soil organic matter content (retardation factor (RF) = 1.1 to 2.6).

Following contamination, the soil was desaturated by applying a tension to the bottom of the column. Entry air replacing the drainage water had been equilibrated with the feed solution. Following desaturation the test column was allowed to equilibrate at 10°C overnight (ca. 17 hr).

Each soil column was then embedded in a box filled with 10°C soil and moved to an ambient temperature room for sampling (20°C). This was done to simulate field conditions where samples of relatively cool soil are often removed and containerized in a warmer ambient temperature environment.

Replicate soil samples were collected from the test column by five different methods. All samples were stored at 2-4°C immediately following collection and during pre-analytical holding. Each soil sample was analyzed for each of the target VOCs by extraction and gas chromatography. Analyses were also made for soil water content and organic carbon content. Quality control analyses were made of samples of clean soil, soil samples from the control column and of the methanol used for infield preservation.

The results of the soil analyses revealed that sampling method effects can be substantial and significant. Based on a least significant difference analysis, the ranking of VOC concentration by sampling method from the lowest to the highest concentration measured was,

Sampling Method $E < A \leq D < B < C$

where,

Method E= disturbed sample in lab grade plastic bag, low headspace,
Method A= undisturbed sample, Teflon sealed glass jar, high headspace,
Method D= disturbed sample, Teflon sealed glass jar, low headspace,
Method B= undisturbed sample, Teflon sealed glass jar, low headspace,
Method C= undisturbed sample, Teflon sealed glass jar, infield
immersion in methanol.

In general, the sampling methods could be categorized into three groups based on roughly similar measured VOC concentrations:

- 1) Lowest = Method E (non-detectable levels),
- 2) Medium = Methods A, D and B (ca. 11 to 91% of Method C), and
- 3) Highest = Method C.

The differences between VOC concentrations measured by the different sampling methods became smaller with decreasing solubility and volatility of the target compound. For example, the differences between sampling methods for 1,2-dichloroethane were considerably greater than for chlorobenzene.

Assuming the VOC concentrations measured in the samples collected by infield methanol preservation represent the best approximation to the "true" concentration, the reductions in VOC concentrations measured in the other samples may be interpreted as systematic error or bias.

For the soil samples containerized in Teflon sealed glass jars, the lack of infield immersion in methanol contributed the greatest negative bias (up to 81%). High headspace volume and disturbance contributed considerably less bias (up to 17%). The negative bias observed was comparatively less for the VOCs with lower solubilities and volatilities. Collection of disturbed soil samples in plastic bags yielded non-detectable levels of VOCs or essentially 100% negative bias.

Procedures for sampling soils for VOC analyses must account for the special properties and behavior of these compounds. Collection of soil samples with containerization in plastic bags is clearly unacceptable where analyses for VOCs are intended. Containerization in a Teflon sealed glass jar is workable and appropriate, but decisions regarding sample disturbance, headspace volume and infield methanol preservation appear subject to considerations associated with VOC properties and contamination levels.

For analyses of VOCs with relatively low solubilities and vapor pressures (e.g. chlorobenzene), collection of a disturbed sample with containerization in a Teflon sealed glass jar and refrigeration at 4°C would usually provide an accuracy similar to that of more complex methods. For such samples, it is better to collect a disturbed sample and completely fill a sample container rather than collect an undisturbed sample which results in a high headspace volume in the container.

Conversely, for analyses of VOCs with relatively high solubilities and vapor pressures, and particularly where concentrations are anticipated in the range of a cleanup action level (e.g. 1,1,1-trichloroethane at ca. 1 ppm), enhanced accuracy requires the collection of an undisturbed sample with containerization in a Teflon sealed glass jar, infield immersion in methanol and refrigeration at 4°C.

Further research is necessary and appropriate to extend the results of the work reported herein to other VOCs and the diversity of conditions experienced in soil systems and sample collection environments.

SECTION 2 INTRODUCTION

2.1 BACKGROUND

When characterizing waste contaminated land, soil analyses are normally conducted for a wide range of potential contaminants. Due to the widespread use and occurrence of organic solvents, soil samples are often analyzed for volatile organic compounds (VOCs) (e.g. trichloroethylene, toluene). Solvents and related organic compounds are found in products used in households, commercial businesses and industrial facilities. VOCs are routinely present in waste contaminated land (Table 2.1).

Table 2.1. Frequency of occurrence of volatile organic compounds at Superfund hazardous waste sites in the USA [7].¹

Rank ²	Compound	VOC	% of Sites
1	<u>Trichloroethylene</u> ³	*	33
2	Lead		30
3	<u>Toluene</u>	*	28
4	Benzene	*	26
5	PCB's		22
6	Chloroform	*	20
7	Tetrachloroethylene	*	16
8	Phenol		15
9	Arsenic		15
10	Cadmium		15
11	Chromium		15
12	<u>1,1,1-Trichloroethane</u>	*	14
13	Zinc and compounds		14
14	Ethylbenzene	*	13
15	Xylene	*	13
16	<u>Methylene Chloride</u>	*	12
17	<u>Trans-1,2-Dichloroethene</u>	*	11
18	Mercury		10
19	Copper and compounds		9
20	Cyanides (soluble salts)		8
21	Vinyl Chloride	*	8
22	<u>1,2-Dichloroethane</u>	*	8
23	<u>Chorobenzene</u>	*	8
24	<u>1,1-Dichloroethene</u>	*	8
25	Carbon Tetrachloride	*	7

¹ Based on 546 uncontrolled hazardous waste sites.

² Rank of occurrence from highest to lowest.

³ Compounds underlined were selected for inclusion in this experiment.

The transport and fate of VOCs in soil systems involve complex processes in a diverse and dynamic environment. In aqueous solutions, VOCs tend to be mobile in the environment, often only weakly sorbed to soil particles. Under some conditions, VOCs can persist for extended periods. Under other conditions VOCs can degrade, sometimes into harmless breakdown products, but other times into more harmful compounds. VOCs in ground water can pose serious problems as they can be harmful and potentially carcinogenic in drinking waters at very low concentrations (e.g. 5 micrograms per liter (ug/L) or parts per billion (ppb)).

Soil contamination by VOCs can lead to time-consuming and costly investigation and cleanup actions. It is therefore essential that decisions regarding the significance of contamination and the need for cleanup be based on accurate measurements of the VOC concentrations present. Yet accurate and precise measurements of VOC concentrations in soils are difficult to achieve since they are subject to numerous sources of errors, both random and systematic [1].

2.2 SOIL SAMPLING

2.2.1 Soil Sampling Process

There are a number of activities which must take place in order to quantify VOC concentrations in soils (Figure 2.1). Obviously, each of these activities can introduce errors such that the "measured" value deviates, in some cases substantially, from the "true" value. For a given sample location and time, error can arise from sources within both the sample collection and sample analysis processes. While both components are important, the sample collection process is thought to contribute relatively large errors in comparison to the analytical process. This is particularly true of trace level concentrations (i.e. < 1 mg/L). Despite this, efforts to understand the errors associated with sample collection methods and to develop appropriate quality assurance techniques have so far been limited.

Soil sample collection errors can be random or systematic. Random errors can usually be effectively managed through statistical techniques (e.g. increasing number of samples). Systematic error or bias is far more elusive. Positive bias (i.e. measured value $>$ true value) can occur by extraneous sample contamination (e.g. cross-contamination of samples). This bias can normally be managed through quality assurance provisions (e.g. trip and field blanks).

Negative bias in VOC measurements (i.e. measured value $<$ true value) is more difficult to delineate and control. It can be caused by diverse factors including: 1) volatilization losses during soil surface exposure and sample removal from the soil profile, 2) volatilization losses from the sample container during pre-analytical holding, 3) chemical and biochemical transformations during pre-analytical holding and 4) volatilization losses during subsampling for analyses.

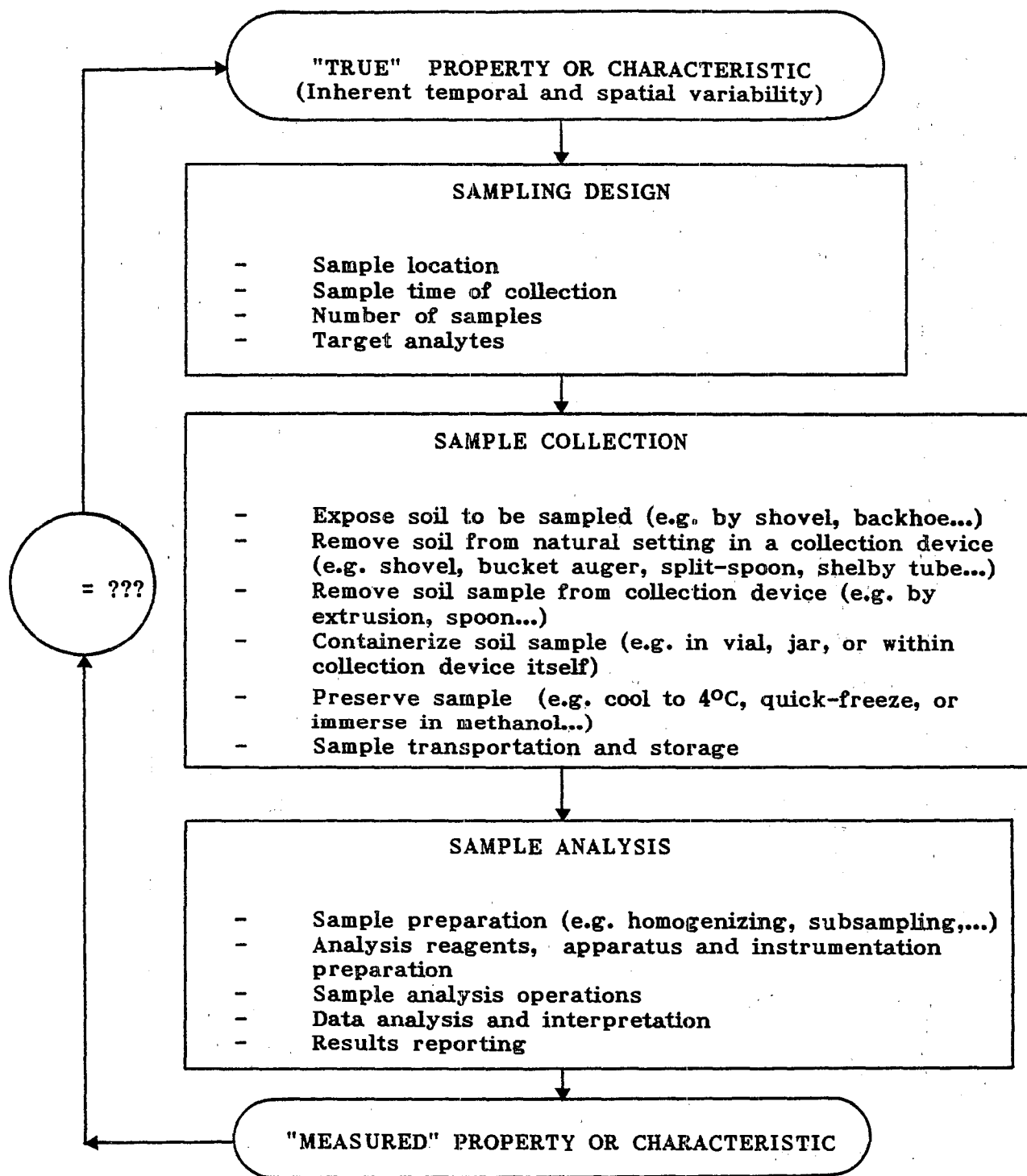


Figure 2.1. Sampling component activities involved in laboratory measurement of soil properties.

In general, negative sampling bias associated with volatilization losses should be inversely related to VOC soil sorption affinity. Sorption affinity in turn is affected by the properties of the organic compound itself (e.g. hydrophobicity) as well as those of the soil system (e.g. water content, organic matter content, mineralogy). For example, lower bias would be anticipated when sampling for VOCs possessing lower solubilities and vapor pressures and in soils possessing higher organic matter contents. Negative sampling bias should also be directly correlated with the presence of conditions in the sampling environment which enhance volatilization (e.g. higher temperature, humidity deficit and air speed). Particularly important would be differentials between conditions in the natural soil versus those imposed by the sampling conditions. Negative sampling bias associated with VOC transformations during pre-analytical holding time should be directly associated with sample preservation conditions.

2.2.2 Current Sampling Practices

There are currently no standardized procedures for sampling soils for VOC analyses. Instead, a wide variety of sample collection methods have been used, in some cases without regard for the serious sampling errors associated with them. Sample collection protocols are often adopted in certain geographic settings or on certain types of projects, largely based on personal preference, regulatory requirements or simply a matter of convenience.

While there are no standardized procedures, guidance information is available in a few published sources (Table 2.2). Recognizing the need, organizations are attempting to formulate standard soil sampling procedures where VOC analyses are involved. For example, the American Society of Testing and Materials (ASTM) is nearing completion of a standard method for sampling soils for VOC measurements [21]. This method (draft form) outlines optional collection procedures, including sample extrusion and infield immersion in methanol.

2.3 STUDY PURPOSE

There is growing concern over the lack of understanding of the effects of sample collection methods on VOC measurements and the absence of standardized sampling procedures. Yet, prior investigations into sample collection effects have been limited and somewhat unsuccessful. For example, in one of the few reported studies the experimental approach used involved sampling soils at uncontrolled hazardous waste sites by different methods, measuring the VOC concentrations in the soils by one or more analytical methods and then comparing the VOC recoveries achieved [19]. Unfortunately, spatial variability was so great that the significance of any differences in the sample collection methods could not be elucidated.

Clearly, further research is necessary and appropriate. The purpose of this study was to provide insight into the field sampling method effects on VOC measurements associated with soil sample disturbance, container headspace volume, container integrity and infield immersion in methanol.

Table 2.2. Examples of documented guidance information for collection and preservation of soil samples for VOC analyses.¹

Test Methods for Evaluating Solid Wastes. U.S. EPA, SW-846, 1986 [23].

- Specific reference to soil sampling for VOCs
- Collect sample (unspecified) and deposit in 4 oz (120 mL) widemouth glass container with Teflon liner
- Minimize sample agitation during collection
- Minimize free air space in container
- Cool sample to 4°C
- Maximum holding time = 14 days
- For high level soils (individual VOCs > 1 mg/kg), extract soil in laboratory with methanol.

Characterization of Hazardous Waste Sites. U.S. EPA, 1984 [8].

- No specific reference to sampling for VOCs
- Two sampling methods given:
 - Soil sampling with a spade and scoop
 - Subsurface soil sampling with auger and thin-wall tube sampler
- Minimize aeration or significant change in moisture content
- Seal sample in glass bottles with Teflon liners, tightly capped and protected from sunlight
- Maintain sample at temperature of sample location or lower
- Refrigerate and analyze as soon as possible

Preparation of Soil Sampling Protocol: Techniques and Strategies. 1983 [14].

- Various sample collection methods noted:
 - For surface soils, scoop or shovel, soil punch, ring sampler
 - For deeper soils, soil probe or augers, power corers or trenching
- For VOCs, use tube sampling (e.g. split spoon, density rings) with Teflon caps, duct tape wrapping, and cool to 4°C

¹ Inclusion or omission of a given method is not meant to be a recommendation, either favorable or adverse, respectively.

SECTION 3
MATERIALS AND METHODS

3.1 EXPERIMENTAL APPROACH

To compare different soil sampling methods, it was necessary to have a volume of soil uniformly contaminated with VOCs under realistic conditions. Uniform contamination was necessary to avoid problems with interpretation when comparing spatially separate samples. It was also desired to know the true level of contamination in order to have an absolute basis for comparison and determination of sampling error or bias. These two objectives were eventually found to be mutually exclusive. Due to anticipated problems with spatial variability under field conditions, it was decided to conduct a laboratory experiment. A soil column would be contaminated by VOCs during saturated upflow of an aqueous solution containing a number of target compounds. By sampling the column by multiple methods, relative comparisons could be made between sampling methods. As an absolute reference, the highest concentration of VOCs determined with acceptable variance could be considered to be the most accurate and assumed to approach the "true" concentration at the time of sampling.

The sampling method effects chosen for evaluation in this experiment are outlined in Table 3.1.

Table 3.1 Sampling method effects evaluated in this experiment.

Sampling Method Effect	Condition
Sample container headspace volume	- 40% of container volume - 80% of container volume
Sample disturbance	- Undisturbed soil core - Spooned aliquots
Sample container integrity	- Teflon sealed glass jar - Polyethylene ziplock bag
Sample preservation	- 4°C refrigeration - Infield immersion in methanol and 4°C refrigeration

The controlled contamination of a natural soil encased in a column was accomplished by saturated flow of an aqueous solution containing six common organic solvents under conditions to simulate a spill of solvent wastewater. Following contamination, desaturation and equilibration, replicate soil samples were collected from the column. Contamination of the column was carried out at 10°C while the sampling of the 10°C column occurred at an ambient air temperature of 20°C. All sampling utensils and containers were also at 20°C. This was done to simulate field conditions where during sampling, cool soil would be removed into a warmer ambient air temperature environment. Soil samples were collected using five methods with elements typical of field procedures (Table 3.1). Experimental analyses included soil physical and chemical properties, computer-assisted x-ray tomography and radioisotope tracer studies, and gas chromatographic analyses of the target VOC concentrations in the column feed solution, outflow and contaminated soil.

3.2 EXPERIMENTAL APPARATUS

3.2.1 Soil Material

The soil used for this study was a naturally occurring surface soil of sand texture. A bulk volume of soil (upper 50 cm) was collected from a sand and gravel pit located in a glaciofluvial deposit near Mysen, Norway. In the laboratory the field moist soil was sieved (4 mm mesh). A composite sample (5-point) was then collected and duplicate subsamples were analyzed for various soil properties by standard methods [2,17]. Water content was determined gravimetrically at 105°C. Particle size analysis was made by sieving and the pipette method. Soil pH was measured electrometrically on a 1:1 soil paste. Total organic carbon was determined by dry combustion. Cation exchange capacity was measured by the ammonium acetate method. The results of these analyses are shown in Table 3.2 and Figure 3.1.

3.2.2 Soil Column Preparation

The field moist soil described above was carefully packed into a specially constructed column with the features depicted in Figure 3.2. The column construction included a 15 cm long glass cylinder with 15 cm outside diameter (o.d.) and 0.5 cm wall thickness. Affixed to the top and bottom ends of the cylinder were aluminum plates. Both plates had a circular groove to facilitate attachment to the glass cylinder. Teflon covered rubber o-rings within the grooves provided a seal between the glass cylinder and the aluminum plates.

Each aluminum plate had a series of circular and radial grooves milled into the interior surface to facilitate distribution and drainage of the contaminant solution (Figure 3.2). Between each of the aluminum plates and the soil within the column was placed a stainless steel screen (0.6 mm mesh) overlain by two layers of glass microfiber filters with pore diameters of 1.6 and 1.0 microns (Whatman GF/A and GF/B, respectively).

Table 3.2. General properties of the soil used in this experiment.

Property	Units	Average Value ¹
Soil texture (USDA)	-	Sand
Grain size analysis:		
2.0 - 0.6 mm	wt.%	50
0.6 - 0.2 mm	wt.%	39
0.2 - 0.06 mm	wt.%	8
0.06 - 0.02 mm	wt.%	2
0.02 - 0.006 mm	wt.%	1
0.006 - 0.002 mm	wt.%	0
< 0.002 mm	wt.%	0
Water content	wt.%	8.6
pH	units	5.21
Total organic carbon	wt.%	0.44
Cation exchange capacity	meq/100g	4.0
Base saturation	%	9.0

¹ Based on duplicate analyses of a 5-pt. composite of field moist soil.

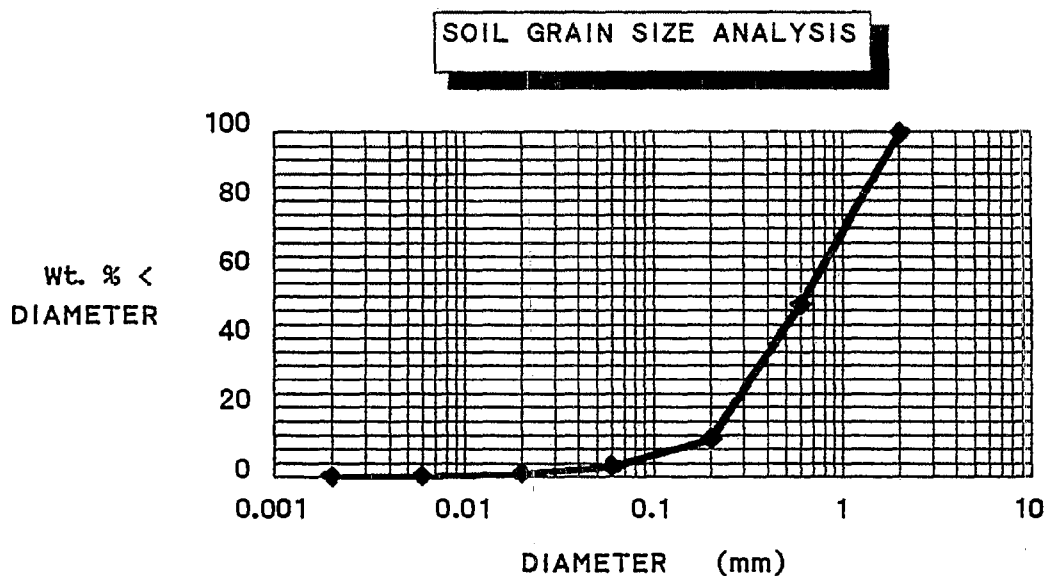
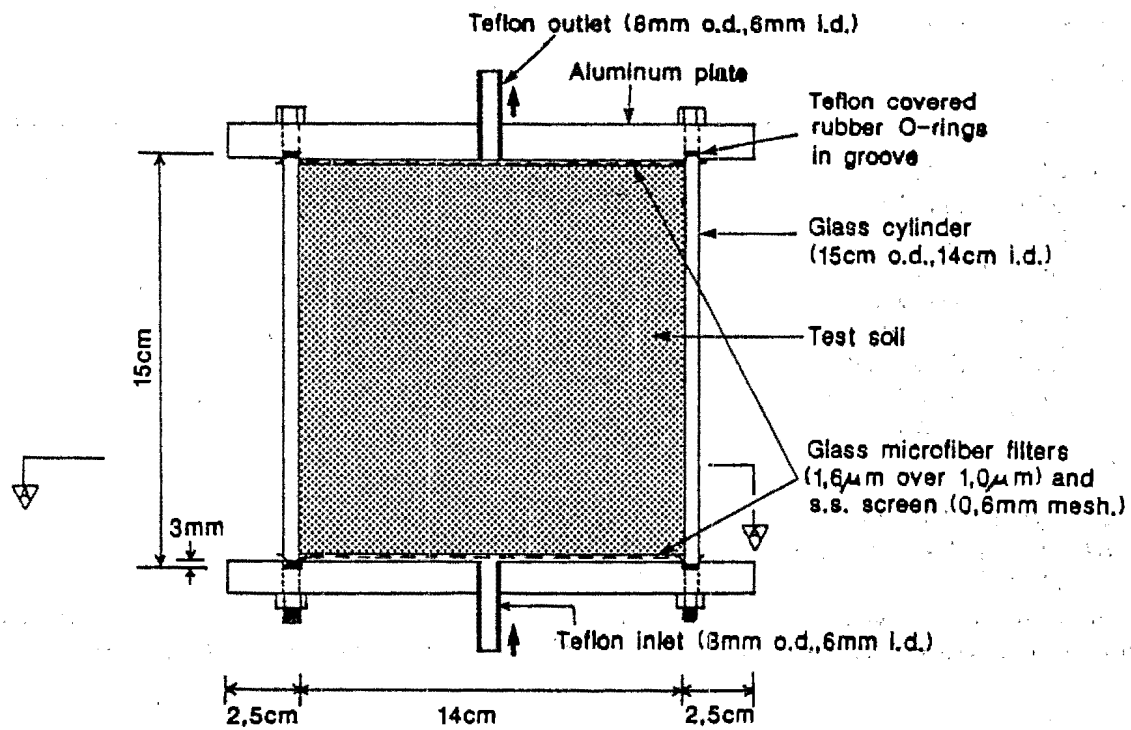


Figure 3.1. Grain size analysis of the soil used in this experiment.

A. PROFILE



B. SECTION A-A

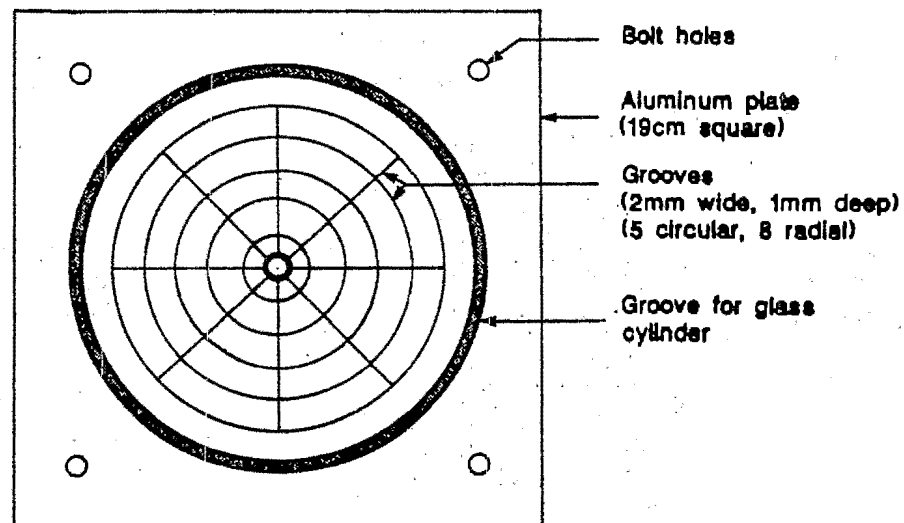


Figure 3.2. Construction details for the soil columns used in this experiment.

The column glass cylinder was first mounted onto the bottom aluminum plate. Then field-moist soil was added to the column in lifts approximately 1.5 cm thick and compacted to uniform density with a heavy tamper (weight=11.3 kg, diameter=14 cm). After placing and compacting each lift, the upper surface of the lift was scarified with a metal knife. After completely filling the column with soil, the upper glass microfiber filters and stainless steel screen were placed and the top aluminum plate was positioned. Then four bolts were used to connect the top and bottom aluminum plates together and seal the glass column between them.

Two columns were packed in this fashion. One was intended for control purposes (control column) while the other was for the experiment proper (test column). During packing, each column was weighed several times to enable determination of soil bulk density (moist). At the time of packing, soil samples were collected and analyzed for water content. These data were combined with the moist bulk density to calculate a dry bulk density. Assuming a particle density of 2.65 g/cm³, the total porosity was calculated. The results of these measurements are summarized in Table 3.3.

Table 3.3. Characteristics of the soil columns prior to contamination.

Characteristic	Units	Control Column	Test Column
Soil dimensions:			
Diameter	cm	14.0	14.0
Surface area	cm ²	153.9	153.9
Length	cm	14.54	14.45
Volume	cm ³	2238	2224
Moist soil weight	g	3667	3641
Moist bulk density	g/cm ³	1.64	1.64
Water content	wt.%	8.6	8.6
Dry soil weight	g	3352	3328
Dry bulk density	g/cm ³	1.50	1.50
Total porosity	%	43.5	43.5
	cm ³	975	968
Water-filled porosity	cm ³	315	313
Air-filled porosity	cm ³	660	655

Following packing, each column was analyzed in an x-ray tomograph to determine spatial uniformity as measured by relative density. X-ray tomography was originally developed for medical purposes but has proven useful in studying the packing arrangement and density within soil columns used for experiments involving water transport and wastewater purification [11]. In this experiment, assessment of spatial uniformity was deemed important since heterogenities, particularly in the horizontal dimension, could confound the interpretation of the sampling method effects which necessarily would be based on samples collected from different horizontal locations.

Scanning of the soil columns was performed with a Siemens Somatom 2 computer-assisted tomograph (Figure 3.3). During the scanning process, an x-ray tube and detector array were rotated continuously around the column, with x-ray scans were made each 0.5 to 1° of rotation. The x-ray absorption profile of each scan was recorded with a scintillation detector array containing multiple NaI detectors (512 over a 42° arc).

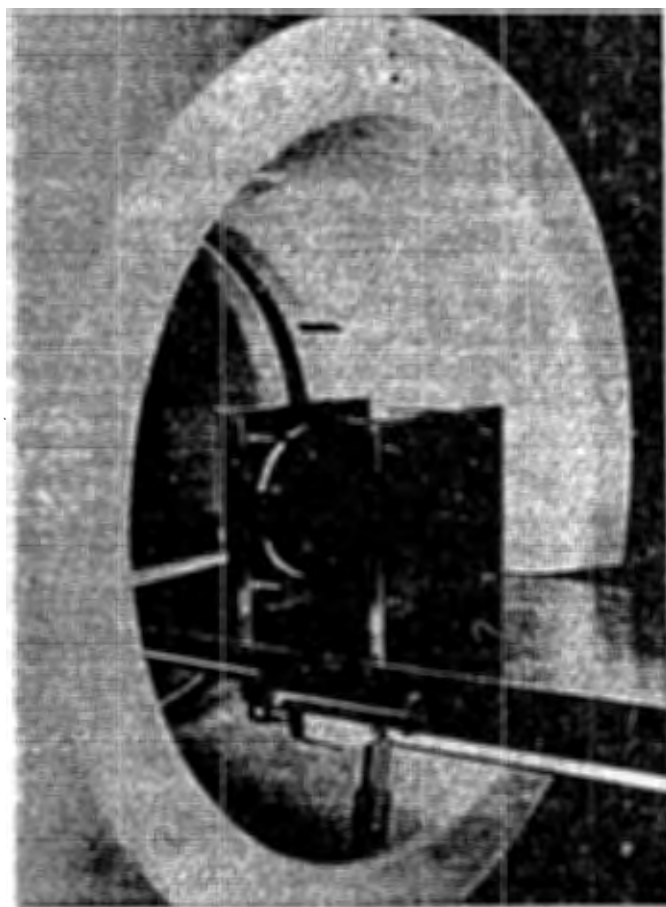


Figure 3.3. Soil column within an x-ray tomograph.

The absorption values, in Hounsfield units or CT values, were mapped into a 256 by 256 array by an image processor. The array was comprised of pixels, the x and y dimensions (i.e. scanning plane) of which were selectable between 0.21 and 2.1 mm and the z dimension (i.e. slice thickness) either 2, 4 or 8 mm. For this experiment, the pixel dimensions (x, y) were 0.7 mm and horizontal sections, 4 mm thick, were analyzed each cm from column top to bottom. The instrument settings were 125 kilovolts for 5 sec. with a dose of 230 milliamps. The x-ray images were recorded on computer tape for later evaluation.

The x-ray image from each column cross-section was visually observed to identify any apparent density anomalies (Figure 3.4). In no case were there any apparent cracks or channels that might have been conduits for preferential flow through the column. Equipped with an image evaluation attachment and measuring program (MSO2), the tomograph was capable of determining density relative to water at each pixel location within an x-ray image (pixel edge length = 0.7 mm).

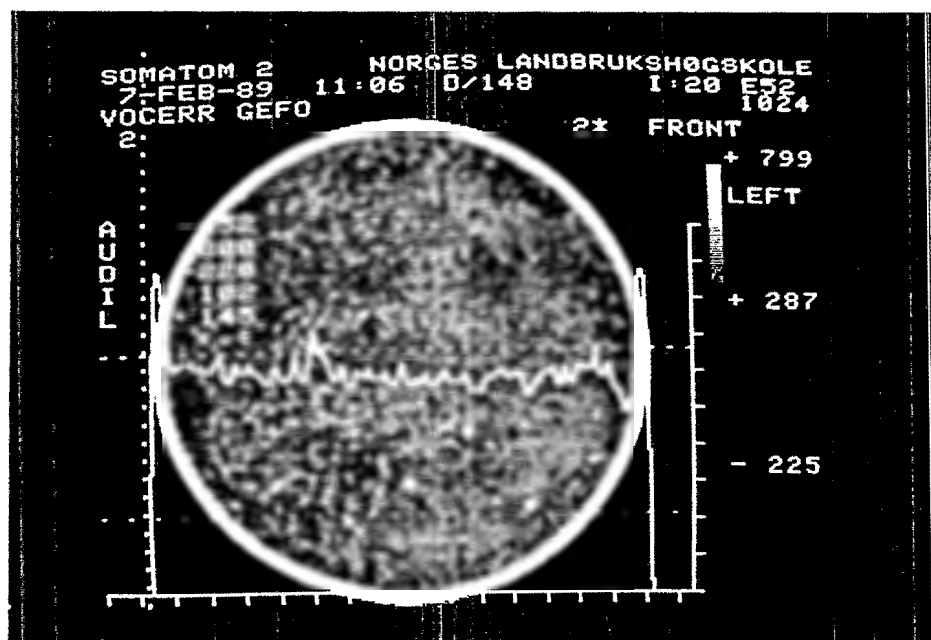


Figure 3.4. Tomography x-ray image of a horizontal section of the test soil column. (Lighter gray shades indicate higher density. White jagged curve displays relative density along diametrical line across center of column section.)

In each horizontal section, quantitative measurements were made of relative density of approximately 28,000 pixels. These pixel locations included both air- and water-filled pores as well as soil particles. The relative standard deviation of these measurements within a given section was consistently in the 10% range, indicating negligible spatial variability in the horizontal dimension. There were some spatial trends in relative density in the vertical dimension (top to bottom) (Figure 3.5). This was probably attributable to the column packing and assembly.

Based on the results of the x-ray analyses (visual and quantitative), it was concluded that the columns were spatially uniform in the horizontal dimension and that the variation in the vertical dimension would not affect the results of this experiment.

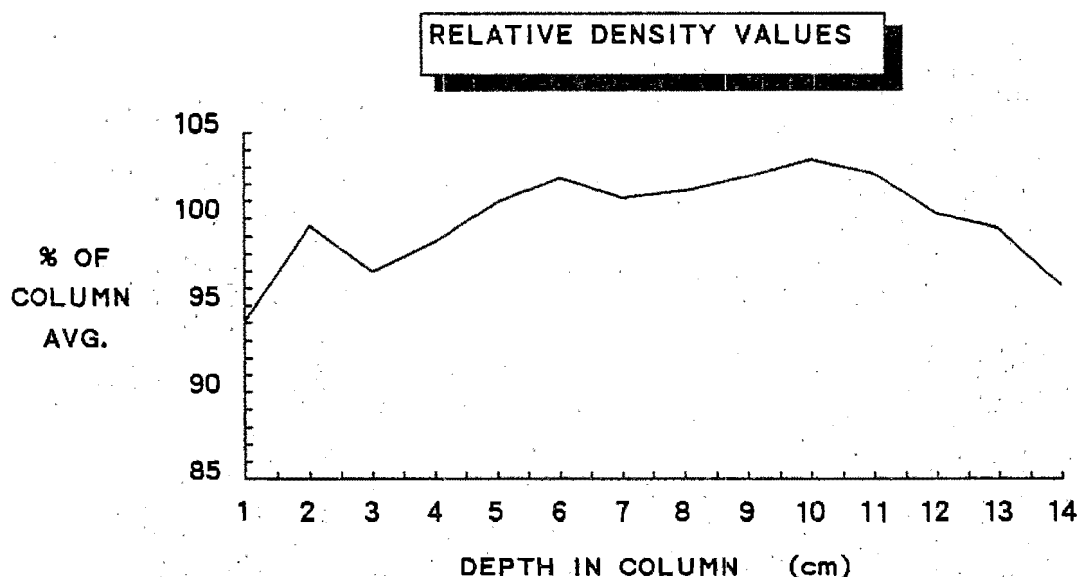


Figure 3.5. Relative soil density variation within 4 mm thick horizontal sections of the test column.
(Section average to column average.)

3.2.3 Soil Column Flow System

Each soil column (Figure 3.2) was setup with the rest of the experimental apparatus in a temperature-controlled laboratory maintained at 10°C (Figures 3.6 and 3.7). The apparatus components contacting the feed solution were fabricated from glass or Teflon. The apparatus included a mariotte-type constant head reservoir (25 L glass) containing the feed solution for the soil column. This reservoir was mixed with a magnetic stirring bar. The replacement gas to the feed reservoir mariotte device was equilibrated with the feed solution as follows. Ambient room air was fed under low pressure by an air pump through activated carbon filters and then through a series of two reservoirs (25 L each) and two gas washing bottles (0.5 L each) (Figure 3.7). This was done so that the air entering the feed reservoir would be in equilibrium with the contaminant solution fed to the column and would not markedly strip VOCs from the feed reservoir during the run. It also provided a source for air entering the soil column during the desaturation period to replace soil pore water removed (discussion later).

Attached to the column inlet was a hanging column for containing feed solution. Following the contamination phase, this hanging column was used to impose a tension on the column to facilitate desaturation of the soil within the column.

The outlet from the column was directed into a 25-L reservoir resting on a scale. This facilitated continuous monitoring of the column outflow and enabled feed and outflow solution sampling at preset outflow volumes.

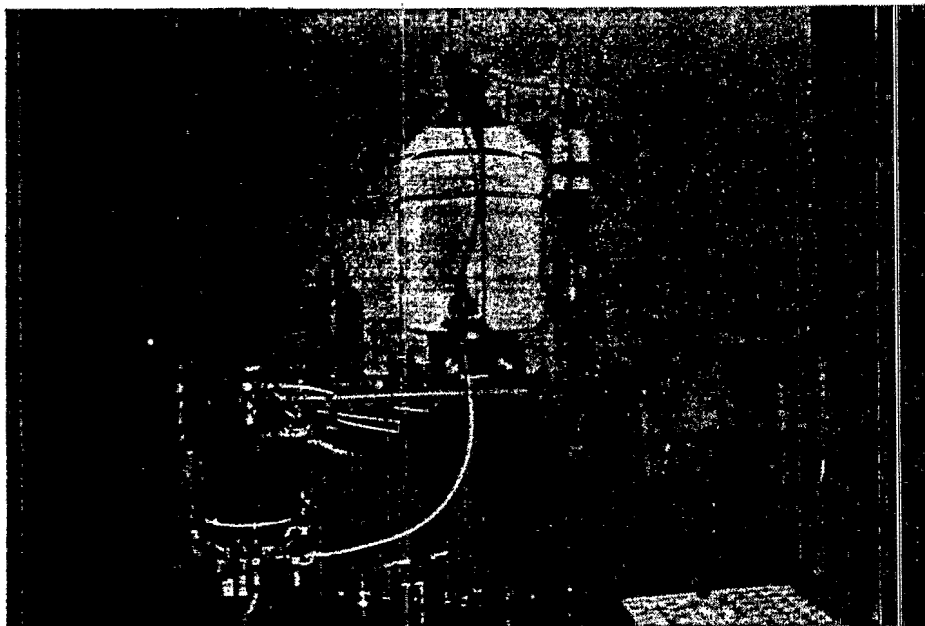


Figure 3.6. Photograph of the experimental apparatus.

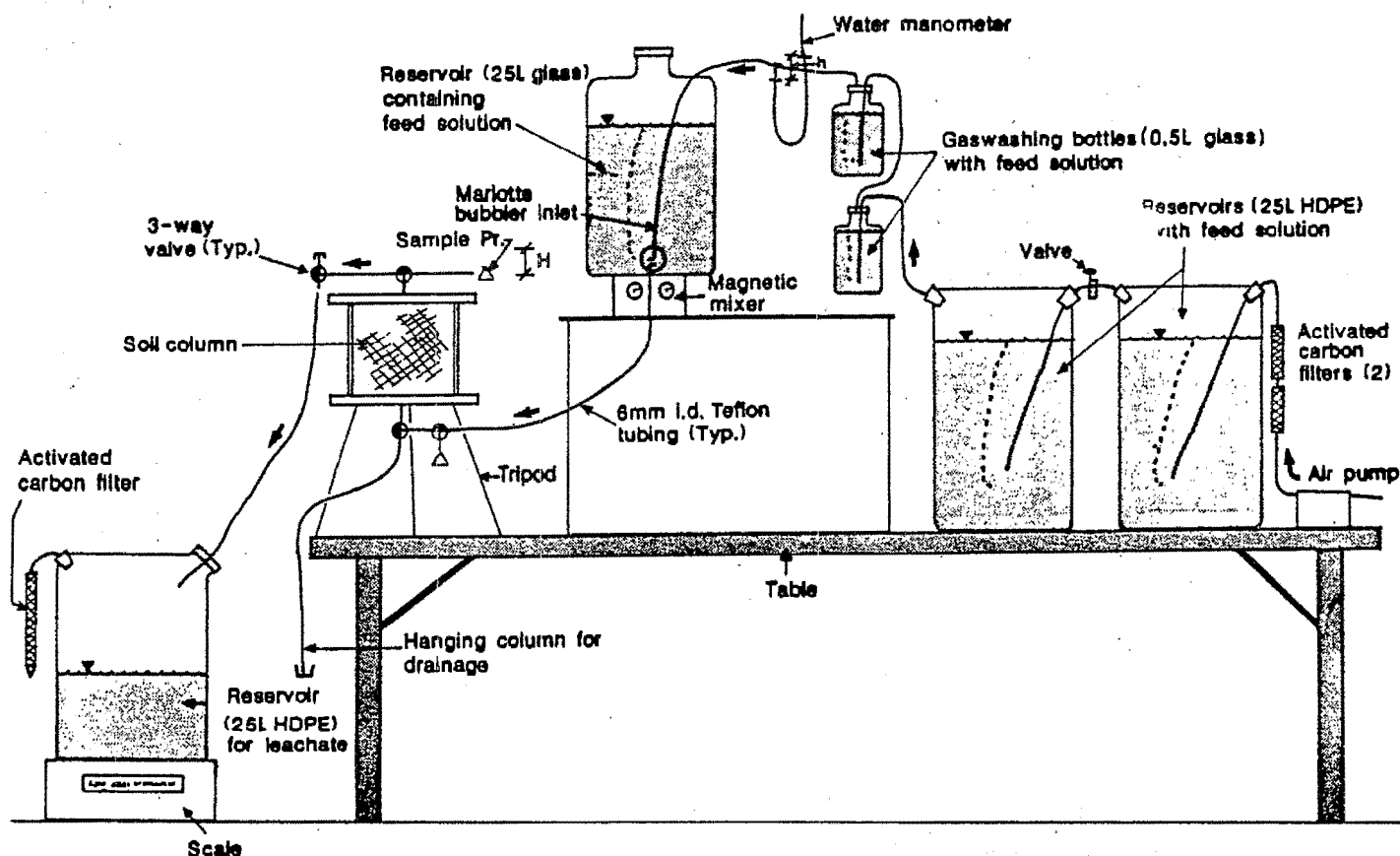


Figure 3.7. Soil column flow system apparatus.

3.3 TARGET CONTAMINANTS AND FEED SOLUTION PREPARATION

Six different VOCs were studied in this experiment: methylene chloride (MC), 1,2-dichloroethane (DCA), 1,1,1-trichloroethane (TCA), trichloroethylene (TCE), toluene (TOL) and chlorobenzene (CB). These were chosen for several reasons including, (1) their widespread usage and common classification as hazardous substances internationally, (2) their prevalence in hazardous waste contaminated land and (3) their range of transport properties and partitioning behavior in soils. Selected properties and characteristics of the target VOCs are presented in Tables 3.4 to 3.6.

Table 3.4. Sources and uses of VOCs selected for inclusion in this study.

Target Compound	Manufacturing Sources and Uses
<u>Methylene Chloride</u>	- Used as paint stripper and solvent degreaser; fumigant; refrigerant; textile and leather coatings; blowing agent in foams. Manufacture of aerosols, photographic film, synthetic fibres (CAS # 74-09-2).
<u>1,2-Dichloroethane</u>	- Component of paints and varnishes; solvent; metal degreaser; chemical manufacturing (CAS # 107-06-2).
<u>1,1,1-Trichloroethane</u>	- Metal degreaser and cleaner; industrial solvent and degreaser; sewer, septic tank and cesspool cleaner (CAS # 71-55-6).
<u>Trichloroethylene</u>	- Dry cleaning operations; metal degreasing and cleaning; refrigerants; fumigant; organic chemical synthesis (CAS # 79-01-6).
<u>Toluene</u>	- Petroleum refining and coal tar distillation (naturally occurring - in coal tar and petroleum). Component of asphalt, naphtha, and gasolines; diluent, thinner and solvent for paints and coatings, gums, resins, and rubbers; adhesive solvent in glues (CAS # 108-88-3).
<u>Chlorobenzene</u>	- Solvent for paints; chemical and solvent manufacturing; degreaser (CAS # 108-90-7).

Table 3.5. Some chemical properties of the target VOCs.

Target Compound	Mol. Wt.	Specific Gravity	Water Solub. (10°C)	Molar Volume	Vapor Pressure (20°C)
	gmol	-	mg/L	L/mol	mm Hg
Methylene Chloride	84.9	1.32	11092	0.064	349
1,2-Dichloroethane	99.0	1.25	10554	0.079	61
1,1,1-Trichloroethane	133.4	1.35	1399	0.099	100
Trichloroethylene	131.5	1.46	1499	0.090	60
Toluene	92.1	0.87	575	0.105	22
Chlorobenzene	112.6	1.11	411	0.101	8.8
Reference	[24]	[24]	[10]	-	[24]

Table 3.6. Transport and fate properties of the target VOCs.

Target Compound	Henry's Constant (10°C)	Octanol/Water Partition Coefficient
	-	mL/g
Methylene Chloride	0.060	17.8
1,2-Dichloroethane	0.050	30.2
1,1,1-Trichloroethane	0.415	147.9
Trichloroethylene	0.232	195.0
Toluene	0.164	489.8
Chlorobenzene	0.105	691.8
Reference	[10]	[22]

The concentrations and quantities of target VOCs to be fed to the test soil column were determined based on several considerations. It was desired to have an easily detectable level of VOCs in the collected soil samples and at a level at which cleanup might be considered (e.g. > 1 to 10 microgram/gram (ug/g) or part per million (ppm)). It was also desired that a sufficient quantity of each VOC be fed to the column so that the sorption capacity of the soil column would be fully exhausted and the VOC concentrations would be uniform throughout the column. Moreover, the volume required to accomplish this had to be workably small (e.g. < 20 L).

To facilitate the determination of the appropriate concentration and quantity of each VOC in the feed solution to the column, consideration was given to how the VOCs would be retained and distributed between the air, water and solid phases within the soil column.

VOCs present in an aqueous matrix flowing through soil tend to distribute between the vapor, liquid and solid phases according to the following relationship [9, 12],

$$C_T = a C_v + \theta C_l + p_b C_s \quad [1]$$

where,

- C_T = VOC concentration per unit volume of soil, ug/mL,
- C_v = soil vapor phase concentration, ug/mL.
- C_l = soil solution concentration, ug/mL,
- C_s = soil sorbed concentration, ug/g,
- p_b = soil dry bulk density, g/mL,
- θ = soil water content, mL/mL, and
- a = soil air content, mL/mL.

Equilibrium sorption of organic compounds from aqueous solutions onto porous sorbents is often described by a Freundlich isotherm:

$$C_s = K C_l^{1/n} \quad [2]$$

where,

- C_s = soil sorbed concentration, ug/g,
- C_l = soil solution phase concentration, ug/mL,
- K = partition coefficient, mL/g, and
- n = empirical constant.

For many situations with dilute aqueous solutions of VOCs, $n=1$ and the isotherm is linear over the concentration range of interest. In these cases, the partition coefficient, K , is often referred to as a distribution coefficient, K_d .

In soil systems, with VOCs dissolved in the water phase, K_d has been shown to be strongly correlated with the fractional soil organic matter content, f_{om} , and the organic matter/water partition coefficient, K_{om} :

$$K_d = f_{om} K_{om} \quad [3]$$

The soil organic matter partition coefficient has been related to the water solubility, S , or the octanol/water partition coefficient, K_{ow} , both of which are interrelated [5,6,9,12,13]:

$$\text{Log } K_{om} = a_1 \text{ Log } (S_w V) + b_1 \quad [4]$$

$$\text{Log } K_{om} = a_2 \text{ Log } K_{ow} + b_2 \quad [5]$$

$$\text{Log } K_{ow} = a_3 \text{ Log } S + b_3 \quad [6]$$

where,

- K_{om} = organic matter/water partition coefficient, mL/g,
- K_{ow} = octanol/water partition coefficient, mL/g, and
- S_w = water solubility, mol/L,
- V = molar volume, L/mol, and
- a, b = empirical constants.

If the soil is unsaturated, VOCs can also partition into the vapor-phase according to Henry's law:

$$C_v = K_h C_l \quad [7]$$

where,

- C_v = soil vapor-phase concentration, ug/mL,
- K_h = Henry's law constant, dimensionless, and
- C_l = soil solution phase concentration, ug/mL.

The retardation factor (RF) is the ratio of the pore water flux to that of the solution VOC flux. A value of 1 indicates that the VOC is not retarded and travels at the same rate as the pore water. The RF for a given VOC can be calculated based on the properties of the VOC and the soil system:

$$RF = 1 + K_d [p_b / \theta] \quad [8]$$

where,

- RF = retardation factor, dimensionless,
- K_d = soil distribution coefficient, mL/g,
- p_b = soil dry bulk density, g/mL, and
- θ = soil water content, mL/mL.

With the preceding in mind, the concentrations of each target compound were chosen inversely proportional to the soil sorption potential (i.e. K_{ow}) and in the range of 1 to 2% of the water solubility. This was done so that the soil associated VOC concentrations would be easily measured and within the same order of magnitude. The VOC concentrations selected for the feed solution were:

Methylene chloride	-	200 mg/L
1,2-dichloroethane	-	125 mg/L
1,1,1-trichloroethane	-	25 mg/L
Trichloroethylene	-	20 mg/L
Toluene	-	7.5 mg/L
Chlorobenzene	-	5.0 mg/L

The volume of feed solution required was estimated by computing the quantity of each VOC sorbed at exhaustion of the column's capacity and the volume of feed solution required to supply this weight of VOCs. The required volume to saturate the column and exhaust the sorption capacity was in every case, equal to less than three pore volume (PV) equivalents. To ensure exhaustion of the sorption capacity of the soil column, approximately 15 pore volumes of the feed solution were passed through the column prior to sampling.

A stock solution of the six target VOCs was prepared in an ethanol matrix at concentrations 1,000 times greater than the chosen feed concentrations. To make the column feed solution, the stock solution was diluted in the column apparatus reservoirs with "reconstituted fresh water" (RFW). This RFW was prepared by adding the following salts to distilled water: 96 mg/L NaHCO_3 , 60 mg/L $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$, 60mg/L MgSO_4 , 4.0 mg/L KCl [20]. The water had a pH of 7.0 and specific conductance (EC) of 290 $\mu\text{S/cm}$.

3.4 SOIL COLUMN CONTAMINATION

The test column was set up as shown previously in Figures 3.6 and 3.7. RFW (10°C) was then added to the feed reservoir and the two gas washing reservoirs. A measured portion of the stock VOC solution (25 mL) was added to the RFW in the feed reservoir and in the two gas washing reservoirs (ca. 23 L RFW in each). Following addition of the VOCs, the three reservoirs were mixed for approximately 1 hr; the feed reservoir by magnetic stirrer and the gas washing reservoirs by gentle air bubbling.

Immediately following addition of the stock solution, several small "globules" (total volume ca. 3 mL) were observed around the perimeter of the bottom of the feed reservoir. It was speculated that these were comprised of undissolved solvent compound(s). Attempts made to disperse and dissolve the globules with a hollow glass tube and gentle air bubbling (pre-equilibrated with the feed solution) proved futile. Since the feed solution was to be monitored, no further attempts were made to disperse or dissolve the globules. As it turned out, the globules did not change in apparent number or size during the course of the experiment.

After the mixing period, approximately 1 L of feed solution was withdrawn from the column inlet sample valve and was used to fill the two, 0.5 L gas washing bottles. Then a measured volume of Tritiated water (5 mL) was added to the feed reservoir as a hydraulic tracer (final feed concentration = ca. 170 Becquerels/mL). Following a few minutes of mixing, flow through the column was initiated.

The feed solution valve was opened and the column feed tubing and hanging column were purged of air. Then flow was directed upwards through the soil column. The hydraulic gradient across the column was approximately 1.5 as measured by a water manometer and elevation data. During initial saturation, the wetting front was observed for uniformity of flow. Column outflow was directed into a container placed on a scale. Periodically during the contamination period, samples of the column feed and outflow solutions were collected via 3-way inlet and outlet valves (Figures 3.6 and 3.7).

Flow through the column was continued until approximately 15 L of solution had passed through the column. This was equivalent to ca. 15 pore volumes (PV) and provided at least five times the weight of each VOC estimated to be required to saturate the column's sorption capacity.

The column feed was then terminated. The sample leg of the outlet sample valve was connected to the inlet gas feed of the 25-L feed reservoir. Then the inlet valve was opened and the column was allowed to drain under a tension of approximately 50 cm until drainage ceased. This occurred over a period of only some minutes. The pore water replacement gas during drainage had been equilibrated with feed solution. The inlet and outlet valves to the column were then shut and it was removed from the apparatus. Following the contamination sequence, the test column was stored at 10°C and allowed to equilibrate overnight (ca. 17 hr.) prior to soil sampling.

The control soil column was treated in a similar fashion, except that the target VOCs and Tritiated water were not added to the RFW feed solution. The control column was run the day preceding the run with the test soil column. The control column was allowed to equilibrate at 10°C for ca. 40 hr prior to sampling.

During the soil column contamination, ambient temperature was monitored periodically by a mercury thermometer immersed in 2 L of water placed adjacent to the soil column apparatus. Relative humidity was measured periodically by digital hygrometer. Immediately prior to soil sampling, each column was weighed to determine column characteristics following contamination.

3.5 SAMPLE COLLECTION, HANDLING AND ANALYSES

3.5.1 Feed and Outflow Solution Samples

During contamination of the test soil column, samples of the feed solution and outflow were collected for analyses of pH, specific conductance (EC), Tritium (^3H) and VOCs (Table 3.7). Immediately prior to sampling, the inlet and outlet sample valves were opened and the first 15 mL of flow were wasted. Then a 15 mL aliquot was collected for Tritium (^3H) analyses. Then, a 70 mL sample was collected for analyses of the six target VOCs. The VOC samples were collected in glass jars with Teflon lined screw caps. Finally, a 50 mL sample was collected for analyses of pH and specific conductance. All liquid samples were stored at 10°C during the collection period after which they were stored at 2 to 4°C pending laboratory analyses.

Table 3.7. Schedule of sampling the test column feed and outflow solutions.

Approximate Outflow in Pore Volumes	Column Feed Solution			Column Outflow Solution		
	^3H	pH,EC	VOCs	^3H	pH,EC	VOCs
First outflow	*			*		
0.5				*		
1	*		*	*		*
1.5				*		
2	*			*		
2.5				*		
3	*	*	*	*	*	*
4	*			*		
5	*			*		
10	*		*	*		*
15 (final)	*	*	*	*	*	*

3.5.2 Column Soil Samples

Soil samples were collected from both the control and the test soil columns as follows. Following the equilibration phase, the intact column was partially embedded (50% of length) in approximately 10 kg of soil, also at 10°C. This was done to provide support to the column during sampling and to maintain the column soil temperature during sampling which was to occur at 20°C. The column was then moved from the laboratory at 10°C to a one at 20°C. This was done to simulate field conditions where during sampling, cool soil would be removed into a warmer ambient air temperature environment.

The column top plate was carefully removed along with the stainless steel screen and glass microfiber filter papers. A paper sampling template was placed on top of the column to maintain the center-point of each sampling location at the same radius within the column. Soil samples were then collected at the locations shown in Figure 3.8 according to the methods outlined in Table 3.8. All sampling tubes were inserted simultaneously and the tops covered with aluminum foil (Figure 3.9). The tubes were then extracted sequentially in a clockwise fashion (sample tube A to E, A' to E') with each soil sample containerized and refrigerated immediately and prior to collecting the next sample (Figure 3.10).

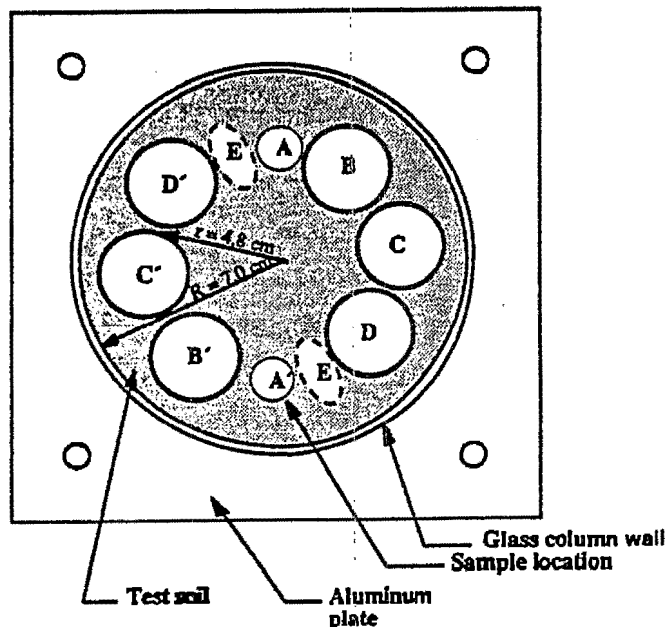


Figure 3.8. Soil sampling plan view of the test soil column.

Table 3.8. Soil sample collection methods evaluated in this study.

Sample Method	Description	(Sample Codes)
A.	<u>Undisturbed sample in empty glass bottle with high headspace (A, A')</u>	
	1.5 cm i.d. by 10 cm long soil sample (ca. 17 mL, 29 g) extracted in a stainless steel tube and carefully extruded into an empty glass bottle (100 mL nominal, 128 mL actual) with Teflon lined screw-top cap. Headspace volume = ca. 85% of container volume.	
B.	<u>Undisturbed sample in empty glass bottle with low headspace (B, B')</u>	
	3.0 cm i.d. by 10 cm long soil sample (ca. 75 mL, 125 g) extracted in a stainless steel tube and carefully extruded into a glass bottle (100 mL nominal, 128 mL actual) with Teflon lined screw-top cap. Headspace volume = ca. 40% container volume.	
C.	<u>Undisturbed sample immersed in methanol in glass bottle (C, C')</u>	
	3.0 cm i.d. by 10 cm long soil sample (ca. 75 mL, 125 g) extracted in a stainless steel tube and carefully extruded into a glass bottle (250 mL nominal, 300 mL actual) with Teflon lined screw-top cap. 100 mL reagent grade methanol immediately added. Headspace volume = ca. 40% container volume.	
D.	<u>Disturbed sample in empty glass bottle with low headspace (D, D')</u>	
	3.0 cm i.d. by 10 cm long soil sample (ca. 75 mL, 125 g) extracted in a stainless steel tube. The contents of the tube were removed in 7 to 10 aliquots with a stainless steel spoon and deposited into an empty glass bottle (100 mL nominal, 128 mL actual) with Teflon lined screw-top cap. Headspace volume = ca. 40% container volume.	
E.	<u>Disturbed sample in empty zip-closure plastic bag (E, E')</u>	
	Soil sample (ca. 40 mL, 70 g) removed from the column directly in 7 to 10 aliquots with a stainless steel spoon and deposited into an empty laboratory grade plastic bag (12 by 18 cm, 0.5 L nominal) with zip-closure. Headspace volume = ca. 40% container volume.	

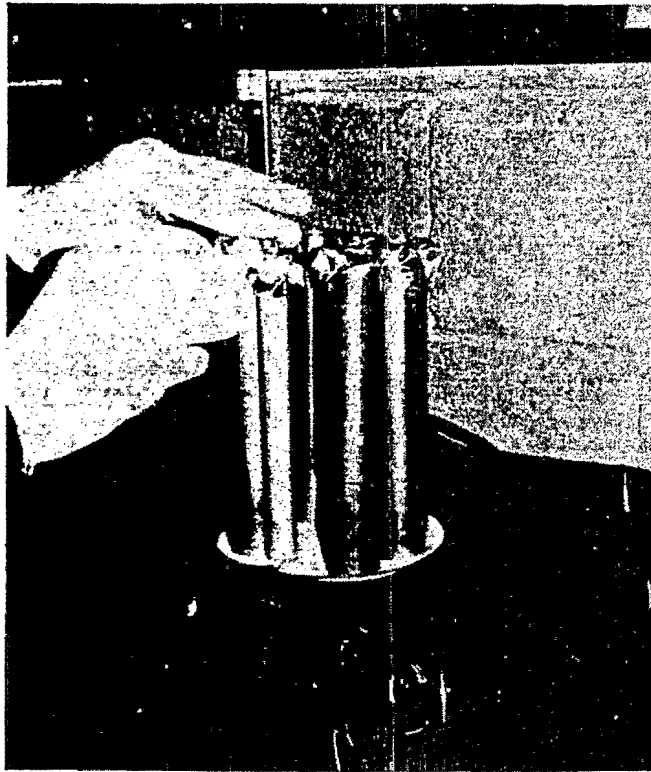


Figure 3.9.
Photograph
illustrating the soil
sampling tube
insertion.

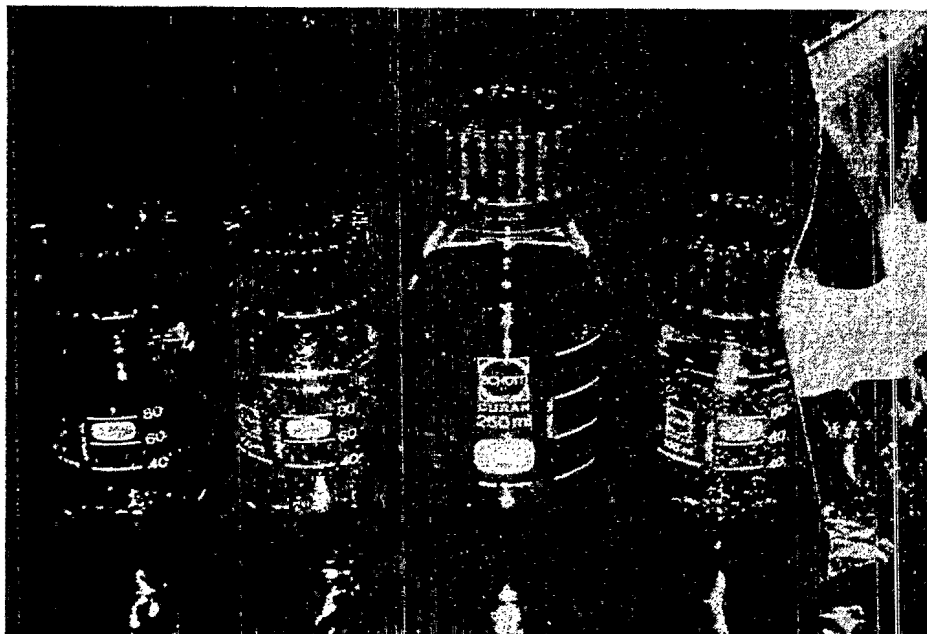


Figure 3.10. Photograph illustrating the five soil samples in their respective containers.

For the control soil column, soil samples for VOC analyses were collected only by methods A, B and C and analyzed as quality control blanks. For the test soil column, soil samples were collected by all five methods (Table 3.8). The first sample from the test column (A) was collected 6.2 min after removal of the column top plate, while the last sample (E') was collected 10.3 min after collection of the first sample. Samples for soil water content and organic carbon content were then collected.

All sampling utensils and bottles were precleaned by detergent wash, distilled water rinses and oven-drying for several hours at 100°C. The stainless steel sampling tubes were precleaned by multiple detergent washes and tapwater soaking/rinsing, wiping with reagent grade acetone, distilled water rinses and 24-hr oven-drying at 100°C. All sampling tubes, utensils and bottles were at 20°C at the time of sampling.

In addition to the samples for VOC analyses, additional samples were collected for analyses of water content and total organic carbon content. Soil samples were collected from each column at 0 to 5 and 5 to 10 cm depth increments at two (test column) or three (control column) horizontally separate locations.

During the sampling, soil temperature and relative humidity were periodically measured. Immediately following collection, all soil samples were stored at 2 to 4°C pending laboratory analyses.

3.5.3 Analytical

Solution Samples. Solution samples were analyzed for pH, specific conductance, Tritium and the six target VOCs. Analyses for pH and specific conductance were made onsite electrometrically (Jenway PW4A pH meter; Digimeter L21 conductivity meter). Tritium analyses were made on a 1 mL subsample by liquid scintillation counting of ^3H . Analyses for each of the target VOCs were made by extraction and gas chromatography as follows. A subsample (4.0 mL) of each solution sample was spiked with 40 ug bromotrichloromethane as an internal standard and then extracted with 4 mL of pentane. The pentane extract was recovered and dried with sodium sulfate prior to gas chromatographic analysis.

Analyses of the four halocarbons were made using a gas chromatograph (GC) (Hewlett Packard Model 5730) equipped with an electron capture detector (Ni^{63}). Analyses of the two aromatics were made on a GC (Hewlett Packard 5890) interfaced with a mass selective detector (5970 series) operated in the single ion monitoring mode. For all GC runs, the injection volume was 2 uL. During analyses, all samples and the resulting sample extracts were kept in an ice-bath to minimize possible evaporation of the target compounds.

Soil Samples. Soil samples were analyzed for soil water content, total organic carbon and the target VOCs. Analyses for soil water content were made gravimetrically after drying for 24 hr. at 105 to 110°C. Analyses for total organic carbon were made by dry combustion. VOC analyses of soil samples A, A', B, B', D, D', E and E' were made as follows.

The refrigerated soil sample was homogenized in the sample container and a weighed amount (10 g) was transferred to a test tube. After adding 40 ug of the internal standard, the soil was extracted with a mixture of 10 mL isopropanol and 4 mL pentane. The solvent mixture was transferred to a small separatory funnel, and the extraction was repeated with 5 mL isopropanol and 4 mL pentane. The extracts were combined and the pentane phase isolated by extraction with deionized water. The pentane extract was washed with 2 mL of water and dried with sodium sulfate prior to gas chromatographic analyses as described above. The water content of each sample was determined on a separate aliquot of soil after drying overnight at 105°C. VOC concentrations were then expressed on a ug per g of dry soil basis.

VOC analyses of samples C and C' (both immersed in methanol) were made differently. The methanol/soil sample was shaken thoroughly. After allowing time for the soil material to settle, an aliquot of the methanol was removed and centrifuged at 3,000 rpm for 5 min. A 4.0 mL sample of the methanol phase was then spiked with 40 ug of the internal standard. 2.0 mL of water and 2.0 mL of pentane were added to the methanol and the mixture was shaken. The pentane phase was removed and the extraction repeated. The two pentane extracts were combined and washed with 2 mL of water and then dried with sodium sulfate prior to GC analyses as above. The VOC results were converted from a ug per mL of methanol basis to ug per g of dry soil basis using the known amount of methanol added to a known amount of moist soil, both of which were measured at the time of sampling, and then converting based on the soil water contents as determined for the specific sample (see above).

Quality Control. All reagents were glass-distilled or GC grade. The sodium sulfate was heated at 550°C overnight. All glassware was precleaned by washing, rinsing with deionized water and drying overnight at 550°C. All reagent solvents were stored at 4°C.

For quality control purposes, the following sampling and analyses were made. All extraction reagents were analyzed for the target VOCs. Analyses of the isopropanol and pentane revealed trace concentrations of 1,1,1-trichloroethane, trichloroethylene and toluene, but no methylene chloride, 1,2-dichloroethane or chlorobenzene. These trace concentrations were near the analytical detection limits and were subtracted from all sample analyses. Soil samples were also collected from the control soil column by methods A, B and C (sample codes C1, C3, C2). Analyses of these samples revealed no detectable concentrations of the target VOCs. Analyses of clean soil (B2) and the methanol used for infield preservation (B1) similarly yielded no detectable target VOCs. Finally, a sample of the clean soil was spiked and recovery analyses were made. The laboratory method detection limits for each VOC and matrix are tabulated in Appendix D.

All samples for VOC analyses were extracted within 14 days of sample collection. Gas chromatographic analyses were completed within 48 hr. of the extractions. During pre-analytical holding, all samples were stored at 2 to 4°C. During all analyses, the samples and extracts were kept in ice baths.

3.6 PAN EVAPORATION TEST

To provide a measure of the evaporative loss potential during soil sample collection, a simple pan evaporation test was conducted in the 20°C room in which the sampling occurred. A plastic media dish, 8.6 cm in diameter and 1.4 cm deep, was placed on an electronic balance and filled with 20 g of solution taken from the feed reservoir. The solution depth was ca. 3 mm. Periodically over a 4.5 hr. period, the loss in weight within the dish was measured gravimetrically. During the measurement period, the room air temperature was 20°C and the relative humidity was ca. 24%.

SECTION 4

RESULTS AND DISCUSSION

4.1 COLUMN CONTAMINATION CHARACTERISTICS

Initial upflow saturation of the soil column occurred over a period of approximately 3 min. The wetting front was observed to be uniform. Immediately following saturation, flow through the test column (upward direction) was continued over a 2.5 hr period. The flux (hydraulic gradient of ca. 1.5) was steady throughout the flow period and averaged 870 cm/d. At a column length of 14.5 cm and a water-filled porosity of $0.435 \text{ cm}^3/\text{cm}^3$, the average hydraulic retention time in the column was very short at ca. 10.4 min. During the contamination period, the temperature and relative humidity were 10°C and ca. 40%, respectively.

The results of the hydraulic tracer study of the test column are graphically depicted in Figure 4.1. The tracer breakthrough pattern indicated that there was some bypassing of and mixing with the ambient soil pore water in the initially unsaturated column. In the initial outflow from the column, the ratio of the Tritium in the outflow solution to that in the feed solution (Co/Ci) was 0.18. Had there been no mixing, but complete short-circuiting, the Co/Ci ratio would have been 1.0. Had there been complete mixing with the pore water, the first outflow from the column would have had a Co/Ci ratio of 0.68. Had there been complete displacement of the pore water, the Co/Ci ratio would have been 0.0. For the test column, by 1.1 pore volume equivalents (PV) of outflow (1.8 PVs of column feed) the Co/Ci ratio approached unity (0.96).

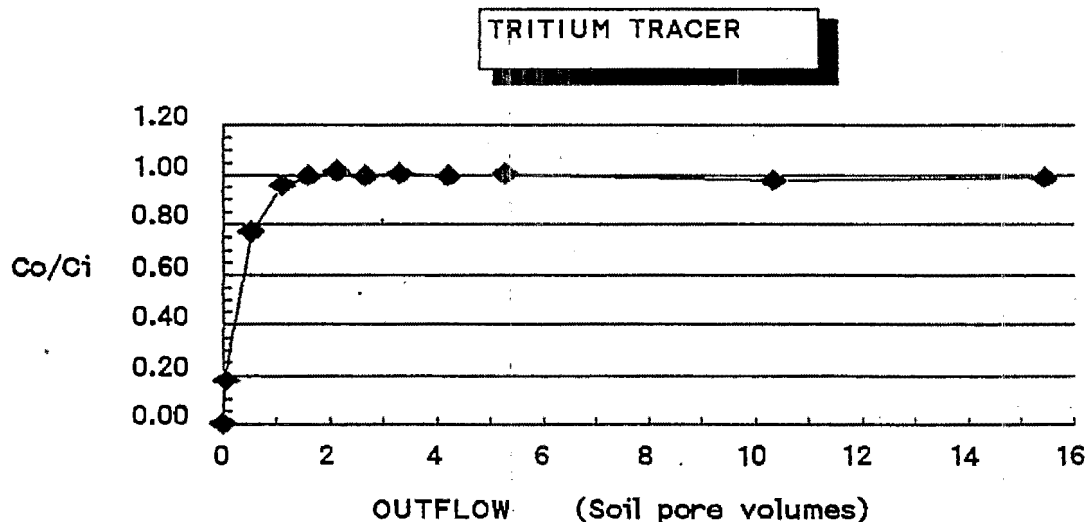


Figure 4.1. Breakthrough curve for the Tritium tracer (^3H) added to the feed solution for the test column.

4.2 FEED AND OUTFLOW SOLUTION CHARACTERISTICS

Results of analyses of pH and specific conductance in the feed and outflow solution are shown Table 4.1. The specific conductance of the RFW was reduced by the addition of the organic solutes. During flow through the soil columns, the pH and specific conductance were reduced somewhat. This was likely due to dilution by the ambient pore water as well as interaction with the acidic soil which had a low pH (5.21) and low base saturation (9%).

A comparison of the concentrations of VOCs in the feed solution to that in the stock solution is shown in Table 4.2. The anticipated ratio (feed solution to stock solution times 1,000) was about 1.1 based on addition of 25 mL of stock solution to approximately 23 L of RFW in the feed reservoir and the two gas washing reservoirs. The fact that the ratios were below 1.1 and there was variability between compounds is suspected to be due to a number of factors including incomplete dissolution of the stock solution added to the RFW and some VOC volatilization during attempts to disperse and dissolve the globules in the feed reservoir.

Analyses of the target VOCs in the feed solution and outflow are graphically depicted in Figure 4.2 and summarized in Table 4.3. For all six VOCs, the concentrations in the feed solution were higher (5 to 17%) in the samples collected at 15.4 PVs of column outflow as compared to 3.3 PVs. The reasons for this are not known but could be due to apparatus conditioning or gradual dissolving of the globules in the feed reservoir.

Table 4.1. Results of analyses of soil column feed solution and outflow samples for pH and specific conductance.

Soil Column Outflow	Sample Point	pH	Specific Conductance
PV		Units	uS/cm
<u>Control Column</u>			
3.3	Feed	7.0	297
	Outflow	6.6	252
15.4 (final)	Feed	6.9	281
	Outflow	6.7	240
<u>Test Column</u>			
3.3	Feed	7.1	126
	Outflow	6.6	108
15.4 (final)	Feed	7.1	129
	Outflow	6.7	116

Table 4.2. Comparison of VOC concentrations in the feed and stock solutions.

Target Compound	Feed Solution ¹	Stock Solution	Ratio ² (x 1,000)
	mg/L	mg/L	-
Methylene Chloride	157.5	200,000	0.79
1,2-Dichloroethane	130	125,000	1.04
1,1,1-Trichloroethane	16	25,000	0.64
Trichloroethylene	12.75	20,000	0.64
Toluene	4.5	7,500	0.60
Chlorobenzene	2.85	5,000	0.57

¹ Feed solution value is average of two measurements (Table 4.3).

² Ratio of feed solution to stock solution multiplied by 1,000.

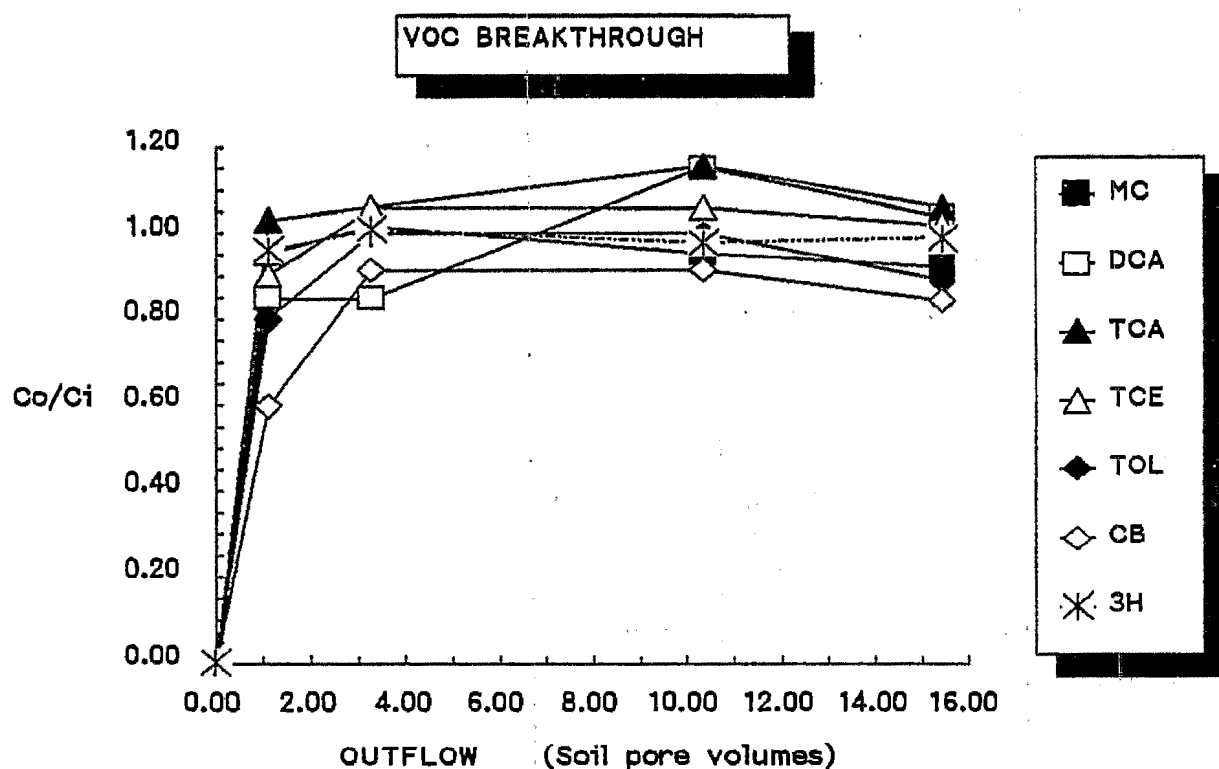


Figure 4.2. Breakthrough curves for the Tritium and the six target VOCs studied.
(See appendix A for the individual VOC curves.)

Table 4.3. Results of VOC analyses of the test soil column feed and outflow solutions.

Target Compound	Outflow Volume	Feed Solution	Outflow Solution	$\frac{Co}{Ci}$ ¹
	PV	mg/L	mg/L	-
Methylene Chloride	1.1	-	150	0.95
	3.3	150	160	1.02
	10.3	-	150	0.95
	15.4	165	145	0.92
	Average =	157.5		
1,2-Dichloroethane	1.1	-	110	0.85
	3.3	120	110	0.85
	10.3	-	150	1.15
	15.4	140	135	1.04
	Average =	130		
1,1,1-Trichloroethane	1.1	-	16.5	1.03
	3.3	15.5	17.0	1.06
	10.3	-	18.5	1.16
	15.4	16.5	17.0	1.06
	Average =	16.0		
Trichloroethylene	1.1	-	11.5	0.90
	3.3	12.0	13.5	1.06
	10.3	-	13.5	1.06
	15.4	13.5	13.0	1.02
	Average =	12.75		
Toluene	1.1	-	3.6	0.80
	3.3	4.4	4.5	1.00
	10.3	-	4.5	1.00
	15.4	4.6	4.0	0.89
	Average =	4.5		
Chlorobenzene	1.1	-	1.7	0.60
	3.3	2.7	2.6	0.91
	10.3	-	2.6	0.91
	15.4	3.0	2.4	0.84
	Average =	2.85		

¹ Co/Ci = outflow solution / average feed solution.

4.3 SOIL COLUMN CHARACTERISTICS FOLLOWING CONTAMINATION

Following contamination, desaturation and equilibration, the characteristics of the soil columns were determined as shown in Table 4.4. The characteristics of the control and test columns were substantially the same.

Compared to the characteristics of the test column prior to contamination (Table 3.3), the water content had increased from 32% to 63% of total porosity, respectively. This increase reflects the altered drainage conditions in the soil in the laboratory column as compared to the soil profile in the field.

Table 4.4. Characteristics of the soil columns after contamination.¹

Characteristic	Units	Control Column	Test Column
Soil dimensions:			
Diameter	cm	14.0	14.0
Surface area	cm ²	153.9	153.9
Length	cm	14.54	14.45
Volume	cm ³	2238	2224
Moist soil weight	g	3950	3936
Moist bulk density	g/cm ³	1.76	1.77
Water content	wt.%	15.1	15.4
Dry soil weight	g	3352	3328
Dry bulk density	g/cm ³	1.5	1.5
Total porosity	%	43.5	43.5
	cm ³	975	968
Water-filled porosity	cm ³	598	608
Air-filled porosity	cm ³	377	360

¹ Refer to Table 3.3 for characteristics of the test column prior to contamination.

The results of analyses of water content and total organic carbon in soil samples collected from the control and the test column are summarized in Table 4.5. These results indicated an increasing water content with depth in the soil column, but similar results at horizontally separate spatial locations. The water content trend with depth is probably due to moisture drainage and redistribution following the contamination period. The water content results for the columns as a whole combined with the results for the top 10 cm within the columns indicate that the soil at the bottom of the columns was likely nearly saturated at the time of sampling.

The total organic carbon content was generally consistent regardless of depth or location. The relative standard deviation for four samples from the test column was only 3.5% (Table 4.5).

Table 4.5. Water content and total organic carbon content in soil samples collected from the soil columns following contamination.

Quadrant	Depth	Water Content	Total Organic Carbon
	cm	% of moist soil	% of dry soil
<u>Control Column</u>			
Northeast	0-5 cm	9.40	0.465
Center	0-5 cm	9.70	0.424
Southwest	0-5 cm	9.50	0.454
Northeast	6-10 cm	12.00	0.433
Center	6-10 cm	12.70	0.420
Southwest	6-10 cm	12.50	0.422
	Average =	10.97	0.436
Complete Column ¹		15.1	
<u>Test Column</u>			
Northeast	0-5 cm	9.20	0.420
Southwest	0-5 cm	9.90	0.415
Northeast	6-10 cm	11.20	0.445
Southwest	6-10 cm	13.40	0.413
	Average =	10.92	0.423
Complete Column		15.4	

¹ Based on gravimetric measurements of the entire column (See Table 4.4).

4.4 VOC DISTRIBUTION

To facilitate analysis and interpretation of the solution VOC retardation and soil sampling method effects data, a VOC distribution analysis was made using the empirical relationships presented earlier. The estimated equilibrium distribution of the six target VOCs under the conditions of this experiment are summarized in Tables 4.6 and 4.7.

As illustrated by these computations, the sorption affinities of all six target VOCs for the sandy soil at 10°C are quite low with K_d values well below 1 and RF values less than 3 (Table 4.6).

Table 4.6. Calculated VOC sorption affinities for the soil used in this experiment.

Target Compound	S_w	V	K_{om}^1	K_d^2	RF^3
	mol/L	L/mol	mL/g	mL/g	-
Methylene Chloride	0.131	0.064	4.96	0.036	1.12
1,2-Dichloroethane	0.107	0.079	4.92	0.036	1.12
1,1,1-Trichloroethane	0.0105	0.099	27.1	0.197	1.68
Trichloroethylene	0.0114	0.090	27.4	0.199	1.68
Toluene	0.0062	0.105	39.6	0.288	1.99
Chlorobenzene	0.0036	0.101	63.6	0.463	2.59

1 $\log K_{om} = -0.813 \log (S_w V) - 0.993$ (after Chiou, 1989)

2 $K_d = 1.72 f_{oc} K_{om}$, with $f_{oc} = 0.00423$ (Table 4.5)

3 $RF = 1 + K_d [p_b / 0]$, with $p_b = 1.5$ and $0 = 0.436$ (Table 4.4)

Table 4.7. Calculated equilibrium distribution of the target VOCs within the test soil column.¹

Target Compound	Phase Conc.			Column Conc.				Soil Conc.
	C _l	C _s	C _v	W _l	W _s	W _v	W _t	C _T
	$\frac{\mu\text{g}}{\text{mL}}$	$\frac{\mu\text{g}}{\text{g}}$	$\frac{\mu\text{g}}{\text{mL}}$	$\frac{\mu\text{g}}{\text{mL}}$	$\frac{\mu\text{g}}{\text{mL}}$	$\frac{\mu\text{g}}{\text{mL}}$	$\frac{\mu\text{g}}{\text{mL}}$	$\frac{\mu\text{g}}{\text{g}}$
Methylene Chloride	145 [1.3] ²	5.2	8.7	26.7 (73) ³	7.8 (21)	2.2 (6)	36.7	24.5
1,2-Dichloroethane	135 [1.3]	4.9	6.8	24.8 (73)	7.4 (22)	1.7 (5)	33.9	22.6
1,1,1-Trichloroethane	17.0 [1.2]	3.3	7.1	3.1 (32)	5.0 (50)	1.8 (18)	9.9	6.6
Trichloroethylene	13.0 [0.9]	2.6	3.0	2.4 (34)	3.9 (55)	0.8 (11)	7.1	4.7
Toluene	4.0 [0.7]	1.1	0.7	0.74 (28)	1.6 (65)	0.2 (7)	2.5	1.7
Chlorobenzene	2.4 [0.6]	1.1	0.3	0.44 (20)	1.6 (76)	0.1 (4)	2.2	1.5

¹ Computations:

C_l = outflow concentration (final), Table 4.3

C_s = K_d C_l

C_v = K_h C_l

W_l = WC C_l

W_s = P_b C_s

W_v = AC C_v

W_t = W_l + W_s + W_v

C_T = W_t / P_b

WC = 10.92% (wt. basis) or 18.4% (vol. basis), Table 4.5

AC = 43.6% - 18.4% or 25.2% (vol. basis), Table 4.5

Soil dry wt. = 3.328 kg, Table 4.4

P_b = 1.5 g/mL

² The number in brackets equals % of water solubility at 10°C.

³ The number in parenthesis equals % of soil associated VOC (wt.%) in that phase.

4.5 SOLUTION VOC RETARDATION

Based on the limited data available (Table 4.3, Figure 4.2, Appendix A), transport of the six VOCs was generally similar to that of the Tritium tracer. Only the aromatics (toluene and chlorobenzene) exhibited any notable retardation during the initial flow period (Figure 4.2). Consistent with the predicted retardation factors (Table 4.6), by three PVs of outflow, the concentration of each VOC in the outflow solution was substantially similar to that in the feed solution. This condition persisted through the balance of the throughput period (Figure 4.2).

It is interesting to note that despite the relatively high flow rate and short retention time within the column (ca. 10.4 min), the sorption observed, albeit minimal, was consistent with that predicted by equilibrium relationships. Some researchers have reported that equilibrium sorption was not likely above a flow rate of 1 m/d [13]. The flow rate in this experiment was substantially higher at 8.7 m/d.

4.6 SOIL SAMPLING METHOD EFFECTS

4.6.1 Sampling Method Comparison

Sampling of the test soil column occurred at a room temperature of 20°C and a relative humidity of ca. 27%. Soil samples were collected by five different methods as outlined earlier in Table 3.8. Following removal of the column top plate, the VOC samples were first collected, containerized and refrigerated. The first soil sample (A) was collected at 6.2 min. of elapsed time following removal of the column top plate, while the last sample (E') was collected at 16.5 min. elapsed time. For each pair of replicates, the second sample was collected ca. 5 min after the first.

The results of VOC analyses of the soil samples collected by the different methods are graphically depicted in Figure 4.3 and summarized in Tables 4.8, 4.9 and Appendix B and C. The variability between replicates was generally quite low (c.v. < 0.15) (Table 4.8). A trend in the replicate data was observed where the VOC concentration in the second replicate collected was typically lower than the first. This was particularly notable for methylene chloride. This suggested that a portion of the soil associated methylene chloride and possibly the other VOCs were lost, presumably by volatilization, even during the short period over which the sampling occurred (i.e. 5 min).

An analysis of variance revealed that sampling method had a significant effect on the determinations of all six VOCs. The effects were highly significant ($p > 99.5\%$) for all VOCs but methylene chloride ($p = 75\%$). The lack of a highly significant effect for methylene chloride may be due in part to replicate variability as discussed above as well as the analytical difficulties often associated with quantification of this compound [18]. As shown in Appendix D, the estimated variance for analyses of methylene chloride in this experiment was ca. $\pm 20\%$ compared to ± 5 to 10% for the other compounds.

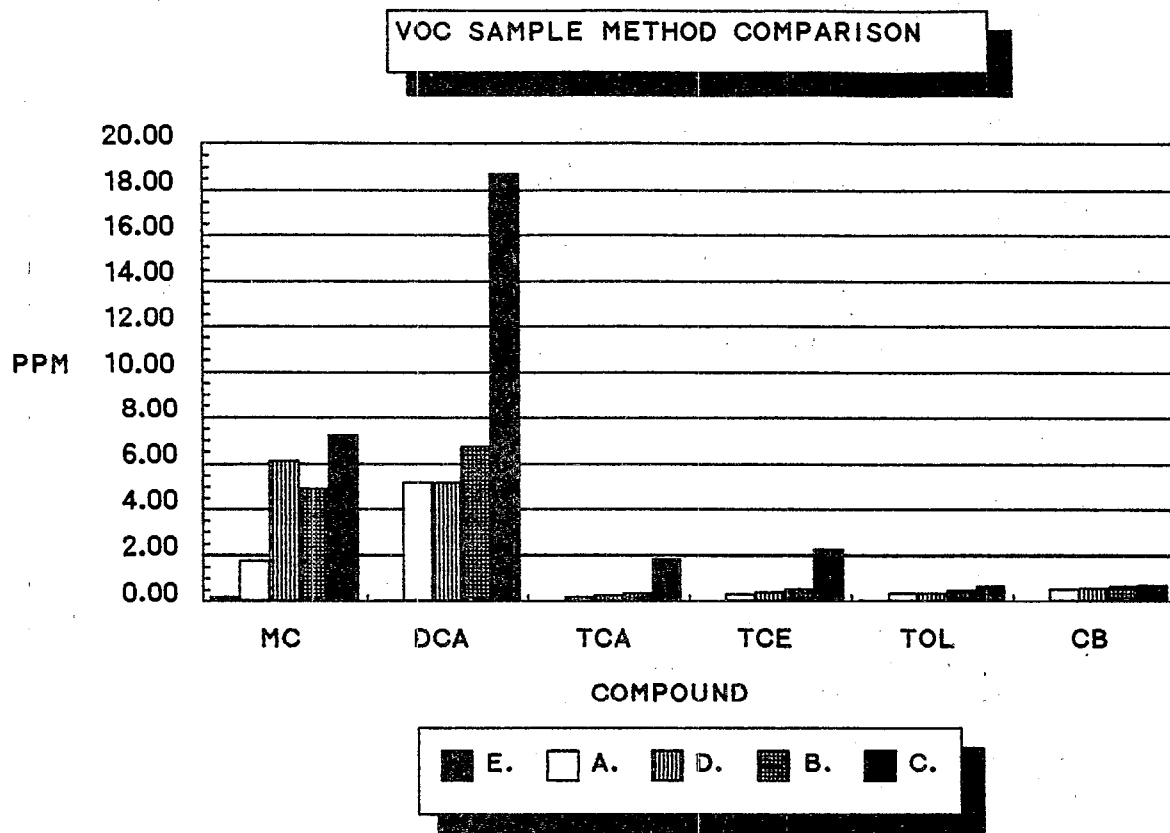


Figure 4.3. Average concentrations of target VOCs in soil samples as a function of sampling method.
 (See Appendix C for individual compound graphs.)

Sample Methods Descriptions:

- E. Disturbed sample in empty zip-closure plastic bag.
- A. Undisturbed sample in empty glass bottle with high headspace.
- D. Disturbed sample in empty glass bottle with low headspace.
- B. Undisturbed sample in empty glass bottle with low headspace.
- C. Undisturbed sample immersed in methanol in glass bottle.

Table 4.8. Concentrations of VOCs in soil samples from the test column.

Target Compound		Sampling Method ¹				
		E.	A.	D.	B.	C.
		ug/g	ug/g	ug/g	ug/g	ug/g
Methylene Chloride	Rep. 1	0.20 ²	1.60	8.00	7.20	10.01
	Rep. 2	0.20 ²	1.90	4.20	2.60	4.39
	Average	0.20	1.75	6.10	4.90	7.20
	Std.dev.	0	0.21	2.69	3.25	3.97
	c.v.	0	0.12	0.44	0.66	0.55
1,2-Dichloroethane	Rep. 1	0.05 ²	5.20	5.70	6.80	19.14
	Rep. 2	0.05 ²	5.10	4.60	6.60	18.30
	Average	0.05	5.15	5.15	6.70	18.72
	Std.dev.	0	0.07	0.78	0.14	0.59
	c.v.	0	0.01	0.15	0.02	0.03
1,1,1-Trichloroethane	Rep. 1	0.01 ²	0.19	0.30	0.35	1.91
	Rep. 2	0.01 ²	0.21	0.25	0.37	1.83
	Average	0.01	0.20	0.275	0.36	1.87
	Std.dev.	0	0.01	0.04	0.01	0.06
	c.v.	0	0.05	0.15	0.03	0.03
Trichloroethylene	Rep. 1	0.01	0.30	0.46	0.53	2.34
	Rep. 2	0.01	0.33	0.38	0.56	2.20
	Average	0.01	0.315	0.42	0.545	2.27
	Std.dev.	0	0.02	0.06	0.02	0.10
	c.v.	0	0.06	0.14	0.04	0.04
Toluene	Rep. 1	0.06	0.35	0.41	0.48	0.72
	Rep. 2	0.05	0.39	0.36	0.49	0.68
	Average	0.055	0.37	0.385	0.485	0.70
	Std.dev.	0.007	0.03	0.04	0.01	0.03
	c.v.	0.13	0.08	0.10	0.02	0.04
Chlorobenzene	Rep. 1	0.005 ²	0.56	0.61	0.68	0.78
	Rep. 2	0.005 ²	0.56	0.54	0.70	0.73
	Average	0.005	0.56	0.575	0.69	0.755
	Std.dev.	0	0	0.05	0.01	0.04
	c.v.	0	0	0.09	0.01	0.05

¹ Refer to Table 3.8 for a complete description of each sample method:

E. Disturbed soil (40 mL) in plastic bag.

A. Undisturbed soil (17 mL) in glass jar (128 mL) with Teflon lined cap.

D. Disturbed soil (75 mL) in glass jar (128 mL) with Teflon lined cap.

B. Undisturbed soil (75 mL) in glass jar (128 mL) with Teflon lined cap.

C. Undisturbed soil (75 mL) immersed in 100 mL methanol in a glass jar (300 mL) with a Teflon lined cap.

² For samples E and E', there were non-detectable levels of methylene chloride, dichloroethane and chlorobenzene. The value shown is equal to 50% of the method detection limit. For trichloroethane, the reported value of < 0.01 is shown. See Appendix D for detection limits.

Table 4.9. Magnitude and significance of differences observed in the sampling method effects.

Target Compound		Sampling Method ¹				
		E.	A.	D.	B.	C.
Methylene Chloride	Ave. ug/g	0.20	1.75	6.10	4.90	7.2
	% of C. ²	2.8	24.3	84.7	68.1	
	LSD (95%) ³	----- 6.66 ug/g -----				
	Ranking ⁴	E = A = D = B; E < C				
1,2-Dichloroethane	Ave. ug/g	0.05	5.15	5.15	6.70	18.72
	% of C.	0.3	27.5	27.5	35.8	
	LSD (95%)	----- 1.14 ug/g -----				
	Ranking	E < A = D < B < C				
1,1,1-Trichloroethane	Ave. ug/g	0.01	0.20	0.28	0.36	1.87
	% of C.	0.5	10.7	15.0	19.3	
	LSD (95%)	----- 0.08 ug/g -----				
	Ranking	E < A < D < B < C				
Trichloroethylene	Ave. ug/g	0.01	0.32	0.42	0.55	2.27
	% of C.	0.4	14.1	18.5	24.2	
	LSD (95%)	----- 0.136 ug/g -----				
	Ranking	E < A = D < B < C				
Toluene	Ave. ug/g	0.06	0.37	0.39	0.49	0.70
	% of C.	7.9	52.9	55.7	70.0	
	LSD (95%)	----- 0.062 ug/g -----				
	Ranking	E < A = D < B < C				
Chlorobenzene	Ave. ug/g	0.005	0.56	0.58	0.69	0.76
	% of C.	0.7	73.7	76.3	90.8	
	LSD (95%)	----- 0.072 ug/g -----				
	Ranking	E < A = D < B < C				

¹ Refer to Table 3.8 for a description of each sample method:

E. Disturbed soil (40 mL) in plastic bag.

A. Undisturbed soil (17 mL) in glass jar (128 mL) with Teflon lined cap.

D. Disturbed soil (75 mL) in glass jar (128 mL) with Teflon lined cap.

B. Undisturbed soil (75 mL) in glass jar (128 mL) with Teflon lined cap.

C. Undisturbed soil (75 mL) immersed in 100 mL methanol in a glass jar (300 mL) with a Teflon lined cap.

² Average VOC concentration measured as a % of Method C.

³ LSD (95%) = Least significant difference at 95% confidence level.

⁴ Ranking indicates lowest to highest VOC measurement based on LSD(95%).

Based on a least significant difference analysis (Table 4.9), the ranking of VOC concentration by sampling method from lowest to highest concentration measured was:

Sampling Method $E < A \leq D < B < C$
where,

Method E= disturbed sample in lab grade plastic bag, low headspace,
Method A= undisturbed sample, Teflon sealed glass jar, high headspace,
Method D= disturbed sample, Teflon sealed glass jar, low headspace,
Method B= undisturbed sample, Teflon sealed glass jar, low headspace,
Method C= undisturbed sample, Teflon sealed glass jar, infield
immersion in methanol.

In general, the sampling methods could be categorized into three groups based on roughly similar measured VOC concentrations:

- 1) Lowest = Method E (non-detectable levels),
- 2) Medium = Methods A, D and B (ca. 11 to 91% of Method C), and
- 3) Highest = Method C

The differences between VOC concentrations measured by the different sampling methods became smaller with decreasing solubility and vapor pressure (i.e. increasing soil sorption affinity) of the target compound (Figure 4.5, Appendix C). For example, differences in concentrations measured for 1,1,1-trichloroethane were greater than those for chlorobenzene (Table 4.9).

4.6.2 Sampling Method Bias

Determination of the absolute sampling method bias (i.e. "true" value - measured value) necessarily requires knowledge of the concentration of soil associated VOCs at the time of sampling. Unfortunately, this could not be determined in this experiment due to method of soil contamination and potential unknown bias due to sample collection and analyses. As an approximation to the "true" concentration of VOCs at the time of sampling, the highest concentration of VOCs determined with acceptable variance between replicates was chosen. In this experiment, the undisturbed soil samples collected with infield immersion in methanol consistently yielded the highest VOC concentrations. Presented in Table 4.10 are the ratios of the highest VOC concentrations measured (Method C with methanol immersion) to the concentrations estimated by the distribution analysis presented earlier (Table 4.7).

The ratios of the highest concentration measured to the estimated soil associated VOCs (including liquid, solid and vapor) were in the range of 0.28 to 0.47, the only exception being 1,2-dichloroethane with 0.83. Ratios for the other sampling methods (A, B, D, E) would obviously have been considerably lower than those for the infield immersion in methanol.

Table 4.10. Comparison of measured VOC concentrations versus estimated concentrations for the conditions of this experiment.

Target Compound	Concentration		Ratio of Measured to Estimated
	Measured ¹	Estimated ²	
	ug/g	ug/g	-
Methylene Chloride	7.2	24.5	0.29
1,2-Dichloroethane	18.72	22.6	0.83
1,1,1-Trichloroethane	1.87	6.6	0.28
Trichloroethylene	2.27	4.7	0.48
Toluene	0.70	1.7	0.41
Chlorobenzene	0.76	1.5	0.47

¹ The highest average concentration measured (i.e. Method C with infield immersion in methanol, Table 4.9).

² The estimated concentration includes all soil associated VOCs (i.e. liquid, solid and vapor) (Table 4.7).

The fact that the highest VOC concentrations measured were consistently less than the concentrations estimated suggests there may have been some undefined negative bias. This may have been due to volatilization losses during soil column exposure and sampling. Alternatively, the estimates of VOC retention may have been too high. Most likely it is a combination of these and perhaps other factors. The fact that the ratios of the measured to estimated concentrations were all <1 and varied inversely with VOC vapor pressure supports the speculation regarding negative bias due to volatilization losses. An assessment of this is given below.

The pan evaporation test revealed an evaporative loss for the feed solution equal to 0.13 mg/min/cm². This loss is presumably due to evaporation of water and the six target VOCs. For methylene chloride, 1,1,1-trichloroethane and trichloroethylene, 50% loss from an aqueous solution at 1 mg/L concentration reportedly occurs over a period of ca. 19 to 24 min at 25°C [24]. At the higher concentrations of this experiment, the evaporation rate would be higher but at the lower temperature, the rate would be somewhat lower. Moreover, the evaporation rate from soil would be further reduced.

For the most volatile VOC in this experiment, methylene chloride, the initial weight in the evaporation pan was 3.1 mg. Assuming 50% volatilization loss from the pan (area = 58.1 cm²) over 20 min, the rate of loss is 0.0013 mg/min/cm². This rate of loss is only about 1% of the total measured rate for the pan. This apparently low percentage may not be unreasonable as the measured rate of loss for the pan was constant over the 4.5 hr

measurement period suggesting a substantial contribution by water evaporation.

At the above rate of loss, the weight of methylene chloride volatilized during sample collection could have been ca. 105 ug (for 3 cm diameter sampling tube and average exposure time of 11.4 min). The highest measured concentration of methylene chloride was 7.2 ug/g dry soil (Table 4.9). In a representative soil sample (ca. 110 g dry soil, Appendix B), the total methylene chloride present would be ca. 792 ug. The estimated volatilization loss of 105 ug is equivalent to a negative bias of about 12%.

This cursory analysis suggests that the highest VOC concentrations measured (i.e. by Method C) likely deviated from the "true" value by appreciable levels due to volatilization losses of VOCs during soil sample collection. This interpretation is supported by the trends in VOC concentrations observed between replicate samples for the more volatile VOCs as described earlier and the differences observed in VOC measurements for disturbed versus undisturbed samples (Table 4.9).

Recognizing that the highest concentrations measured probably deviated from the "true" value by an appreciable but unknown negative bias, it was still possible to compare the relative bias associated with the different sampling method elements using the highest concentration measured as a reference (i.e. Method C). For soil samples containerized in plastic bags, the substantial negative bias (i.e. ca. 100%) clearly demonstrates that collection of a sample in this manner is unacceptable where analyses for VOCs are intended. For soil samples containerized in Teflon sealed glass jars, the relative bias contributions were greatest for lack of infield immersion in methanol, followed by considerably lesser contributions by headspace volume and disturbance (Table 4.11).

Table 4.11. Relative sampling bias associated with selected elements of the soil sampling methods studied.

Target Compound	Relative Bias of Sampling Element from Method C ¹			
	No Methanol	Disturbance	Headspace	Total
	%	%	%	%
Methylene Chloride	-2	-	-	-
1,2-Dichloroethane	-64.2	-8.3	-8.3	-81
1,1,1-Trichloroethane	-80.7	-4.3	-8.6	-94
Trichloroethylene	-75.8	-5.7	-10.1	-92
Toluene	-30.0	-14.3	-17.1	-61
Chlorobenzene	-9.2	-14.5	-17.1	-41

¹ Relative bias computations:

No methanol = [(Method B - Method C)/Method C] * 100%

Disturbance = [(Method D - Method B)/Method C] * 100%

Headspace = [(Method A - Method B)/Method C] * 100%

² Data omitted due to replicate sample variability.

The negative bias contributed by lack of infield immersion in methanol is less for the less volatile compounds (e.g. toluene and chlorobenzene). Thus, infield methanol preservation is most important for highly volatile compounds. The negative bias associated with increased container headspace volume is greater than that of sample disturbance. Therefore it appears better to collect a disturbed sample in a full container than an undisturbed sample in a partially full container.

4.6.3 VOC Bias Mechanisms

There is little question that there are substantial and significant differences in negative bias associated with VOC measurements made with different sampling methods. While the mechanisms responsible for the bias were not elucidated in this experiment, those potentially associated with each of the sampling methods are summarized in Table 4.12.

Appreciable but undefined negative bias was suspected in all of the soil samples collected. As described previously, volatilization was speculated as a plausible mechanism with the VOC loss occurring during soil column exposure and soil sample collection. Of the sampling method effects tested in this experiment, soil sample collection with infield immersion in methanol (Method C), consistently yielded the highest concentrations of VOCs and presumably the lowest negative bias. This is probably due to a combination of factors. The methanol may minimize volatilization losses during pre-analytical holding and laboratory subsampling, inhibit biochemical transformations and enhance extraction of soil associated VOCs.

It was speculated that the substantial negative bias of sampling method E (disturbed sample in a plastic bag) was principally due to vapor leakage through the polyethylene bag during pre-analytical holding with some contribution from a combination of volatilization losses during collection, storage and subsampling in the laboratory. This speculation is supported by data of Slater et al. which indicated substantial leakage of trichloroethylene through multiple polyethylene bags used to encase soil samples contained in Teflon sealed glass vials [19]. The negative bias within sampling methods A, B and D were likely due to a combination of volatilization losses during collection, storage and subsampling in the laboratory. For all methods, transformation losses during pre-analytical holding were probably low based on recent research where good stability was observed for VOCs during holding at 4°C for up to 28 days [15,16].

4.6.4 Implications

The soil sampling results suggest the potential significance sampling method effects can have on the investigation and cleanup of solvent contaminated land. For example, the results for 1,1,1-trichloroethane and trichloroethylene, both very common contaminants, ranged from less than 0.01 ug/g to 2.3 ug/g (ppm). All four sampling methods which did not employ infield methanol immersion yielded concentrations less than 0.55 ug/g. In contrast the sampling method with infield immersion in methanol yielded values of 1.8 ug/g or above. The implications of these results are

far-reaching since 1 ug/g has in many cases been used as the action level for cleanup. Thus, if the sampling had been done without infield methanol immersion, cleanup may not have been initiated. If done with infield methanol immersion, cleanup may have resulted. The cost implications are enormous.

Table 4.12. Potential bias mechanisms associated with the sampling methods tested in this study.

Bias Mechanism ²	Sampling Method ¹				
	E.	A.	D.	B.	C.
<u>Bias Mechanism</u>					
Volatilization during soil exposure	++ ³	++	++	++	++
Volatilization during sample collection	++	+	++	+	+
Volatilization / vapor leakage during storage	++	+	+	+	-
Transformations during storage	+	+	+	+	-
Volatilization / vapor loss during subsampling	+	++	+	+	-
<u>Sampling Method Features</u>					
Disturbance	Yes	No	Yes	No	No
Headspace volume	Low	High	Low	Low	-
Container	Plast.	Glass	Glass	Glass	Glass
Methanol	No	No	No	No	Yes

¹ Sampling method listed from lowest to highest concentration of VOCs measured. Refer to Table 3.8 and text for complete description of sampling methods tested.

² Volatilization losses expected to be greater for more volatile compounds.

³ "-" indicates not likely source of bias,
 "+" indicates possible source of bias, and
 "++" indicates likely source of bias.

An appropriate procedure for sampling soils for VOC analyses must account for the special properties and behavior of these compounds. Collection of soil samples with containerization in plastic bags is clearly unacceptable where analyses for VOCs are intended. Containerization in a Teflon sealed glass jar is workable and appropriate, but decisions regarding sample disturbance, headspace volume and infield methanol preservation appear subject to considerations associated with VOC properties and contamination levels.

For analyses of VOCs with relatively low solubilities and vapor pressures (e.g. chlorobenzene), collection of a disturbed sample with containerization in a Teflon sealed glass jar and refrigeration at 4°C would usually provide an accuracy similar to that of more complex methods. For such samples, it is better to collect a disturbed sample and completely fill a sample container rather than collect an undisturbed sample which results in a high headspace volume in the container.

Conversely, for analyses of VOCs with relatively high solubilities and vapor pressures, and particularly where concentrations are anticipated in the range of a cleanup action level (e.g. 1,1,1-trichloroethane at ca. 1 ppm), enhanced accuracy requires the collection of an undisturbed sample with containerization in a Teflon sealed glass jar, infield immersion in methanol and refrigeration at 4°C. This procedure has been advocated recently and may be incorporated into a forthcoming ASTM standard [4, 21].

SECTION 5 CONCLUSIONS

The purpose of this study was to provide insight into the systematic error or bias associated with field sampling methods when making VOC measurements in solvent contaminated soil. Five different sampling methods were used to assess the effects of sample disturbance, container headspace volume, container integrity and infield methanol preservation.

A naturally occurring sandy soil encased in a soil column was contaminated by saturated flow of a solvent solution. Contamination occurred in a controlled-temperature laboratory at 10°C.

After contamination, desaturation and equilibration, replicate soil samples were collected at an ambient air temperature of 20°C. Experimental analyses included basic soil physical and chemical properties, computer-assisted x-ray tomography and radioisotope tracer studies, and gas chromatographic analyses of the target VOC concentrations in the column feed solution, outflow and contaminated soil.

Based on the results of this research, conclusions regarding sampling method effects and systematic error or bias have been drawn. However, it is important to recognize that there are numerous VOCs commonly encountered in contaminated land (e.g. Table 2.1) with diverse properties and behaviors in soil environments. Moreover, the characteristics of soil systems and the environmental conditions in which they are sampled also vary widely. The research conducted included only six target VOCs, one soil system and one sampling environment. Thus, application of the results of the work reported herein must be made cautiously until further research can be conducted. Recognizing this, the following conclusions are put forth:

1. Soil column preparation and operation resulted in uniform soil conditions, the confirmation of which was facilitated by computer-assisted x-ray tomography (Figures 3.3 to 3.5).
2. Six common VOCs present in an aqueous solution at individual concentrations of 2.85 to 157.5 mg/L, were poorly retarded in the sandy soil under conditions of saturated flow at a flux rate of 870 cm/d (Figure 4.2, Table 4.3, Appendix A). The observed retardation characteristics were generally consistent with predictions made based on VOC water solubility and soil organic matter content (RF = 1.1 to 2.6).
3. Comparison of five different soil sample methods revealed that sampling method effects were substantial and significant (Figure 4.3, Tables 4.8 and 4.9, Appendix C).

4. Based on a least significant difference analysis, the ranking of VOC concentration by sampling method from lowest to highest concentration measured was:

$$\text{Method E} \leq \text{A} < \text{D} < \text{B} < \text{C}$$

where,

Method E = disturbed sample in lab grade plastic bag,
Method A = undisturbed sample, Teflon sealed glass jar, high headspace,
Method D = disturbed sample, Teflon sealed glass jar, low headspace,
Method B = undisturbed sample, Teflon sealed glass jar, low headspace,
Method C = undisturbed sample, Teflon sealed glass jar, infield immersion in methanol.

5. In general, the soil sampling results could be categorized into three groups based on roughly equal measured VOC concentrations:

- 1) Lowest = Method E (non-detectable levels),
- 2) Medium = Methods A, D and B (ca. 11 to 91% of Method C), and
- 3) Highest = Method C.

6. The differences between VOC concentrations measured by the different sampling methods became smaller with decreasing solubility and vapor pressure of the target VOC (Table 4.9, Appendix C).

7. The contributions to negative sampling bias by three key elements of the soil sampling methods tested (i.e. infield methanol preservation, disturbance and headspace volume) were greatest for lack of infield methanol preservation with considerably lesser contributions by headspace volume and disturbance (Table 4.11).

8. Procedures for sampling soils for VOC analyses must account for the special properties and behavior of these compounds. Collection of soil samples with containerization in plastic bags is clearly unacceptable where analyses for VOCs are intended. Containerization in a Teflon sealed glass jar is workable and appropriate, but decisions regarding sample disturbance, headspace volume and infield methanol preservation appear subject to considerations associated with VOC properties and contamination levels.

For analyses of VOCs with relatively low solubilities and vapor pressures (e.g. chlorobenzene), collection of a disturbed sample with containerization in a Teflon sealed glass jar and refrigeration at 4°C would usually provide an accuracy similar to that of more complex methods. For such samples, it is better to collect a disturbed sample and completely fill a sample container rather than collect an undisturbed sample which results in a high headspace volume in the container.

Conversely, for analyses of VOCs with relatively high solubilities and vapor pressures, and particularly where concentrations are anticipated in the range of a cleanup action level (e.g. 1,1,1-trichloroethane at ca. 1 ppm), enhanced accuracy requires the collection of an undisturbed sample with containerization in a Teflon sealed glass jar, infield immersion in methanol and refrigeration at 4°C.

9. Further research is necessary to extend the results of the work described herein to other organic compounds, soil conditions and sampling environments.

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SECTION 7
APPENDIX

APPENDIX A
SOLUTION VOC BREAKTHROUGH CURVES

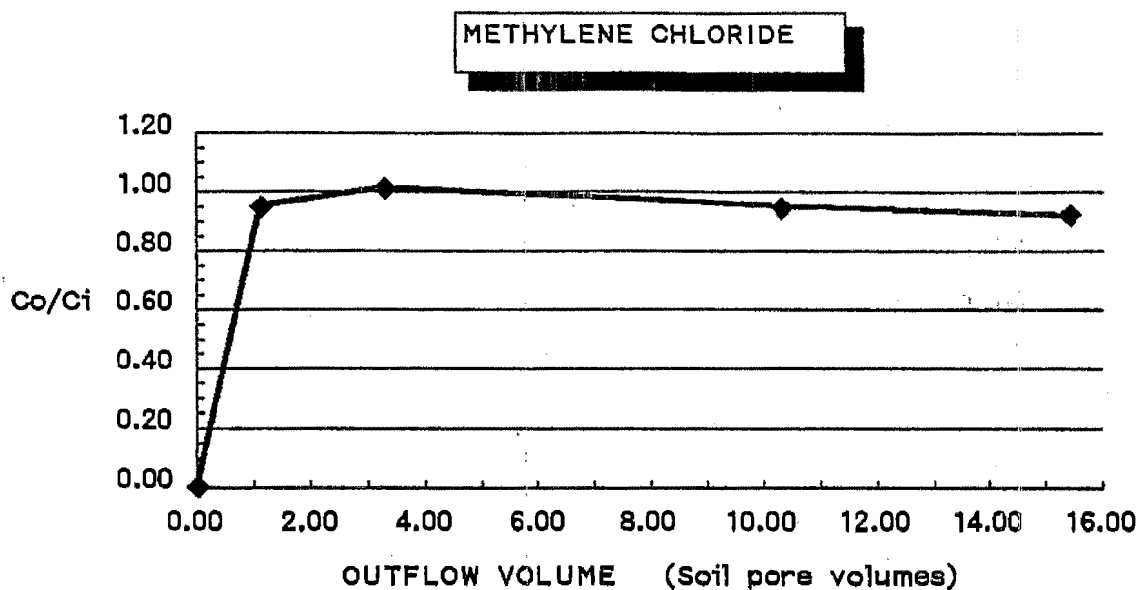


Figure A1. Solution breakthrough curve for methylene chloride.

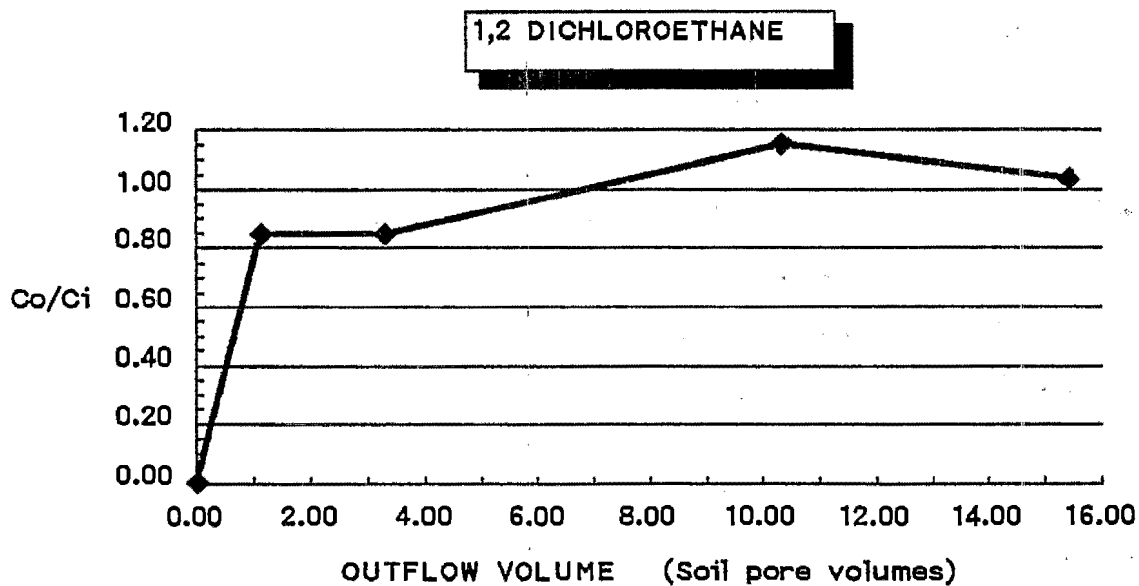


Figure A2. Solution breakthrough curve for 1,2-dichloroethane.

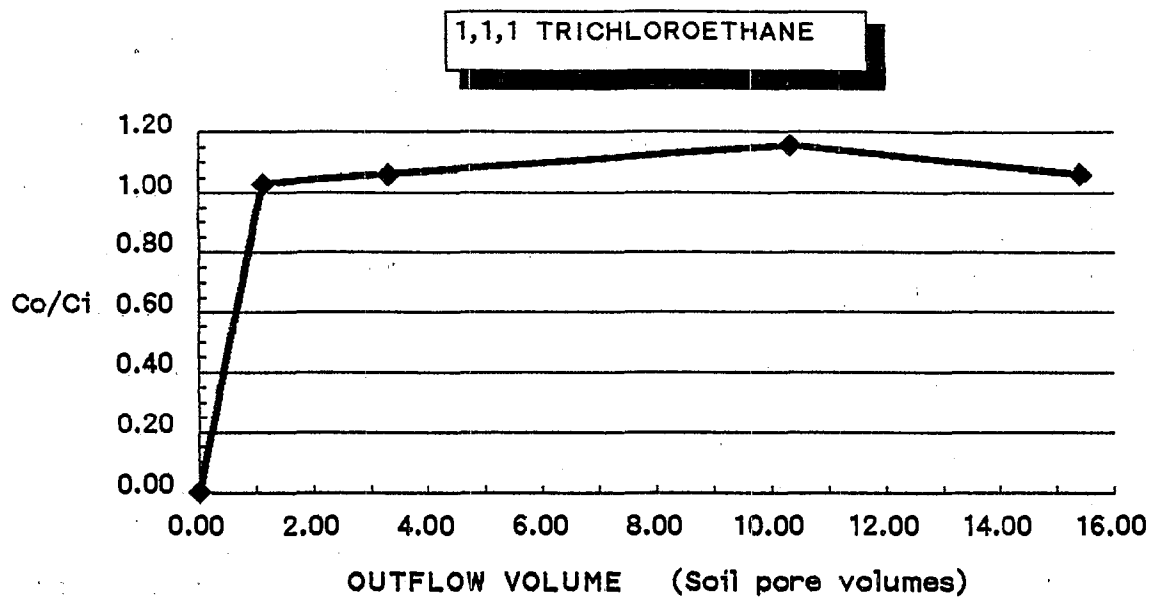


Figure A3. Solution breakthrough curve for 1,1,1-trichloroethane.

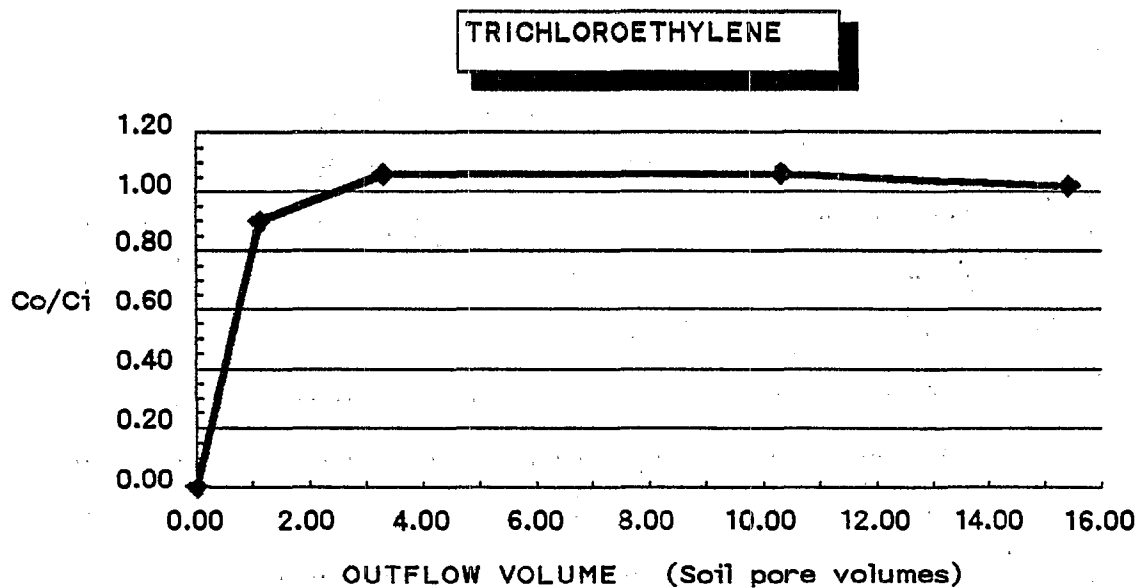


Figure A4. Solution breakthrough curve for trichloroethylene.

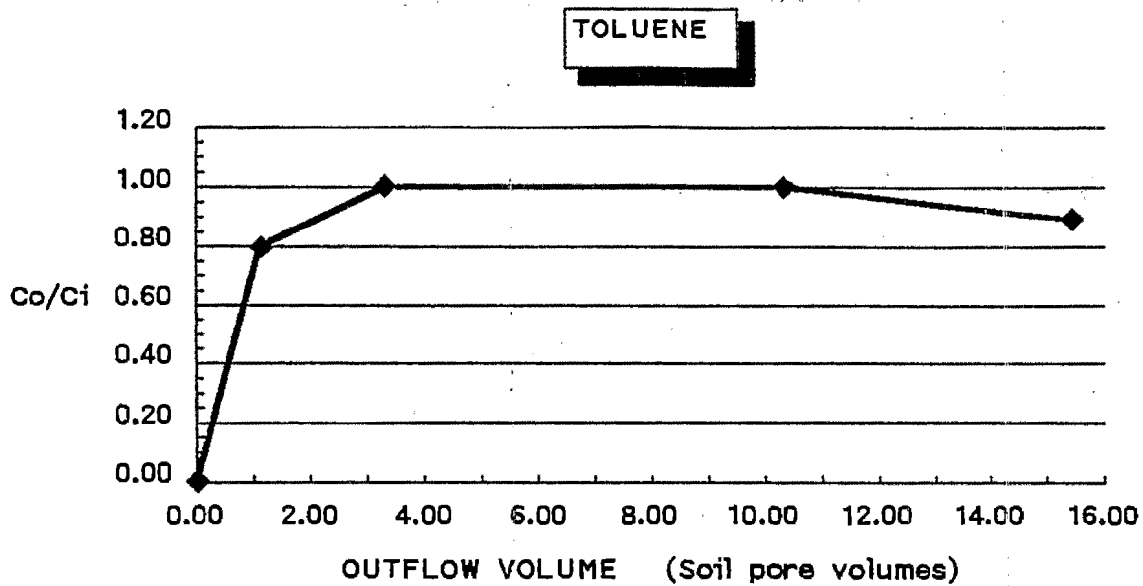


Figure A5. Solution breakthrough curve for toluene.

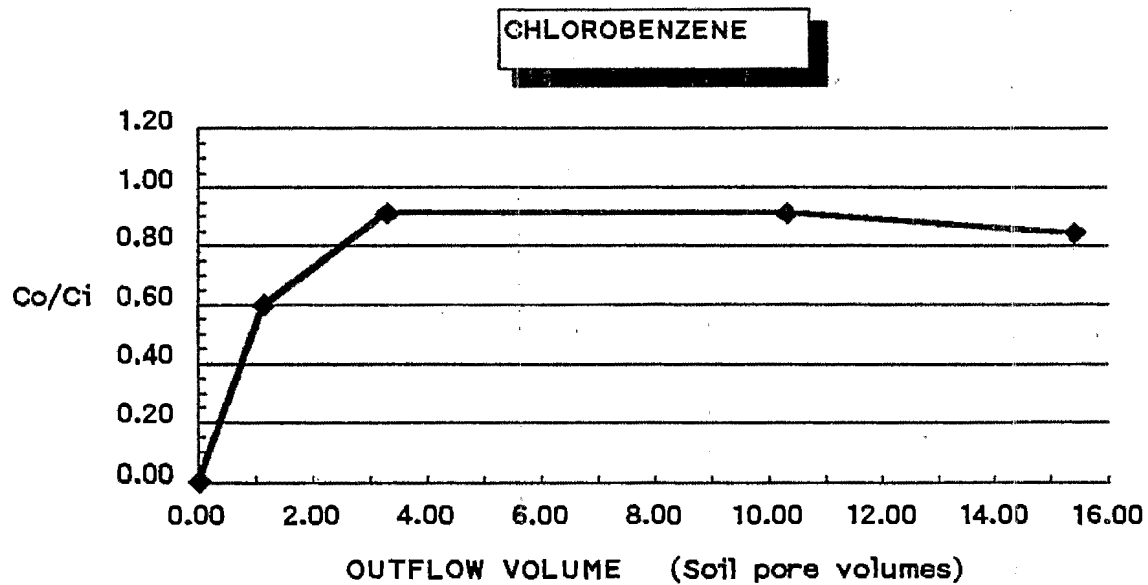


Figure A6. Solution breakthrough curve for chlorobenzene.

APPENDIX B CHARACTERISTICS OF THE VOC SOIL SAMPLES

Table B1. Characteristics of the test column soil samples used for VOC analyses.

Sample	Soil Weights		Soil Volumes ²			
	Wet Soil	Dry Soil ¹	Particle	Water	Air	Total
	g	g	cm ³	cm ³	cm ³	cm ³
A	27.45	24.45	9.2	3.0	4.1	16.3
A'	29.20	26.01	9.8	3.2	4.3	17.3
B	126.16	112.38	42.4	13.8	18.7	74.9
B'	126.24	112.45	42.4	13.8	18.2	75.0
C	128.82	114.75	43.3	14.1	19.1	76.5
C'	122.45	109.08	41.2	13.4	18.2	72.7
D	120.59	107.42	40.5	13.2	17.9	71.6
D'	115.75	103.11	38.9	12.6	17.2	68.7
E	72.56	64.64	24.4	7.9	10.8	43.1
E'	66.37	59.12	22.3	7.3	9.8	39.4

¹ Dry solids content determined gravimetrically on subsamples from samples A,A', B,B', D,D', E and E'.
Average = 89.08%, std.dev.= 0.41%.
Dry soil weight = 0.8908 * wet soil weight.

² Particle volume = dry soil weight / (2.65 g/cm³).
Total soil volume = dry soil weight / 1.50 g/cm³.
Water volume = 0.1092 * wet soil weight.
Air volume = total volume - (particle volume + water volume).

APPENDIX C
SOIL VOC SAMPLING EFFECTS CHARTS

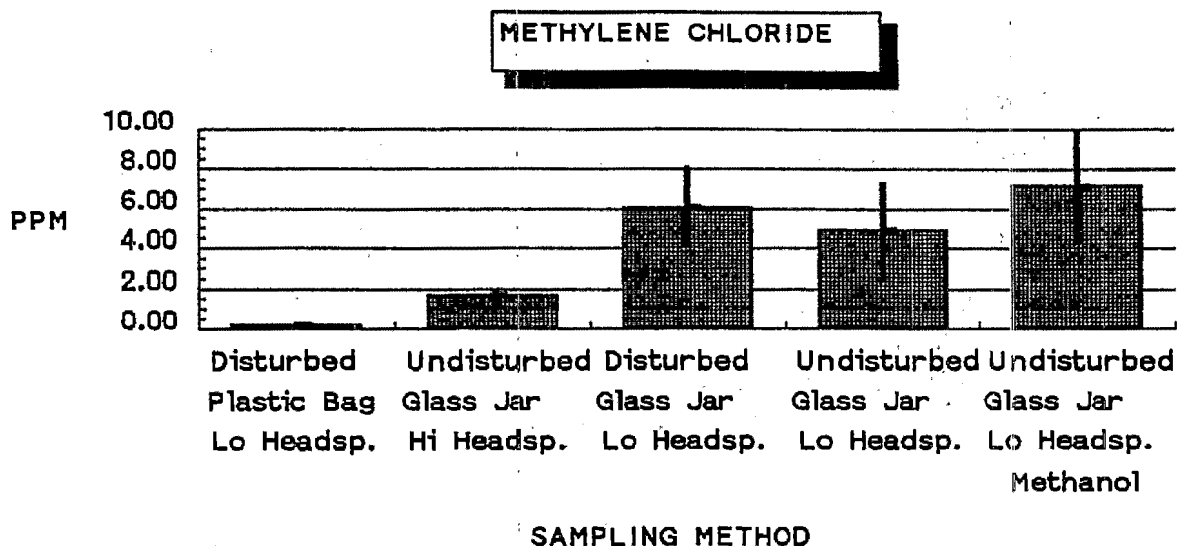


Figure C1. Comparison of sampling method effects for methylene chloride.
(vertical bar indicates standard error of treatment mean)

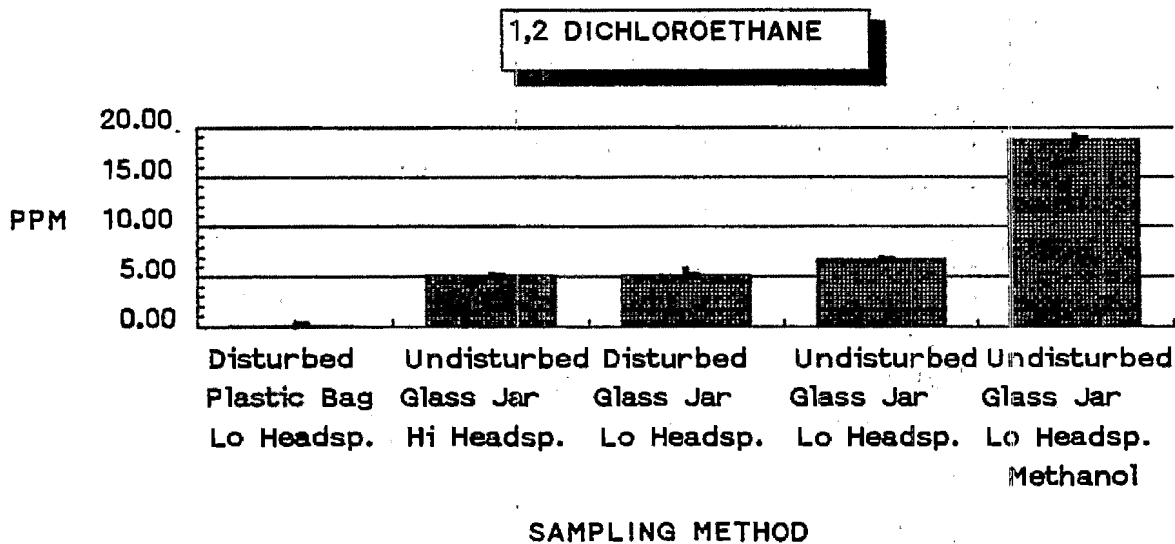


Figure C2. Comparison of sampling method effects for 1,2-dichloroethane.
(vertical bar indicates standard error of treatment mean)

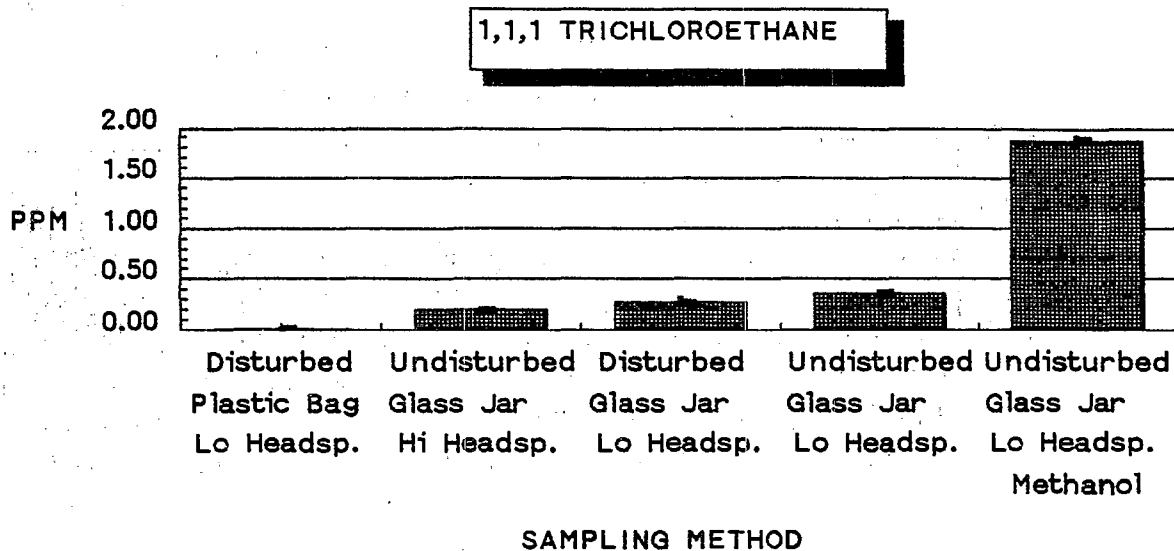


Figure C3. Comparison of sampling method effects for 1,1,1-trichloroethane.
(vertical bar indicates standard error of treatment mean)

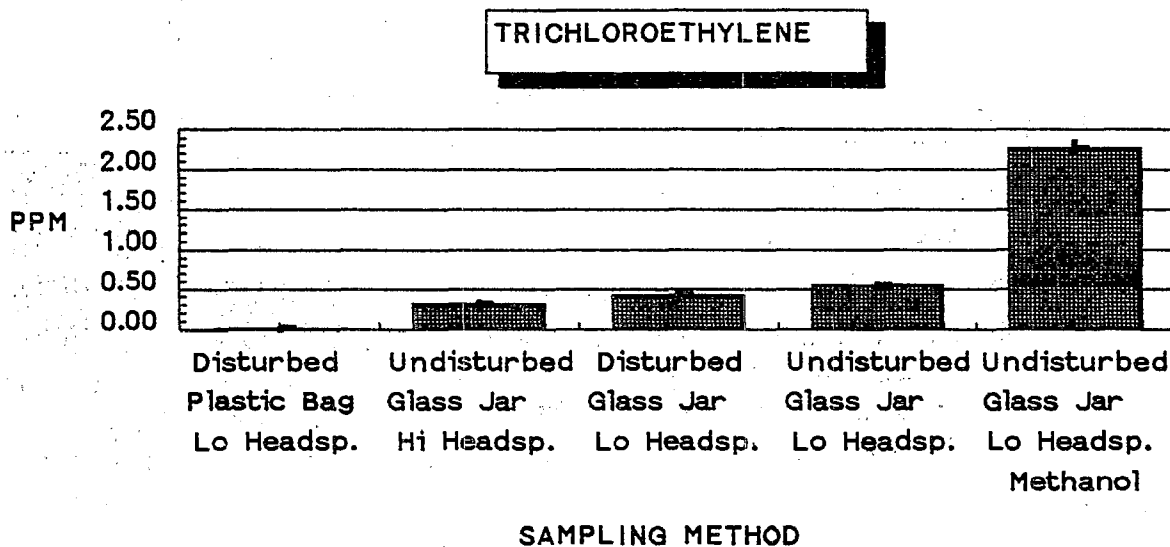


Figure C4. Comparison of sampling method effects for trichloroethylene.
(vertical bar indicates standard error of treatment mean)

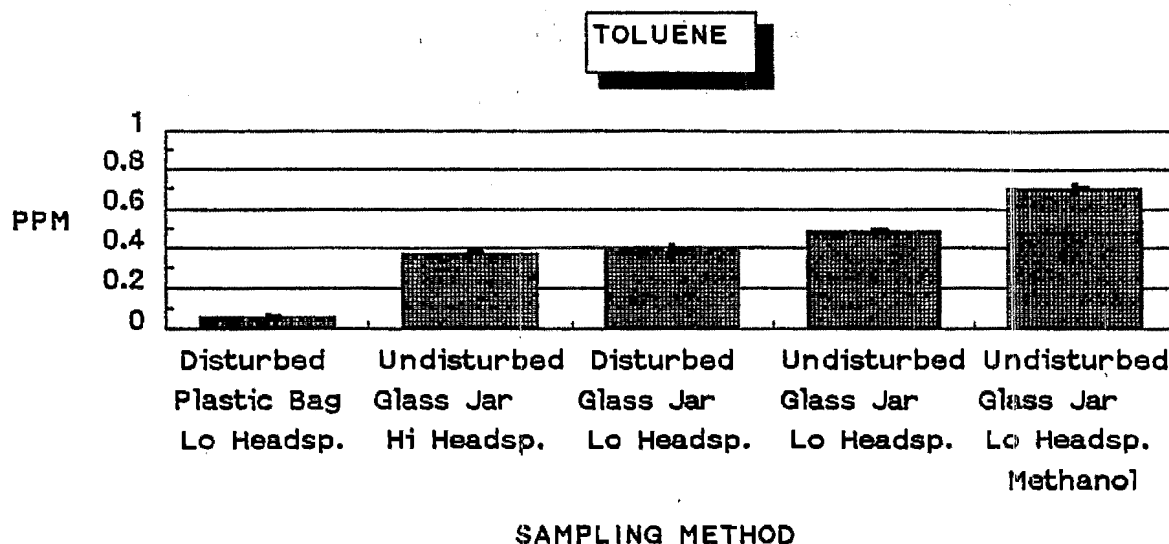


Figure C5. Comparison of sampling method effects for toluene.
(vertical bar indicates standard error of treatment mean)

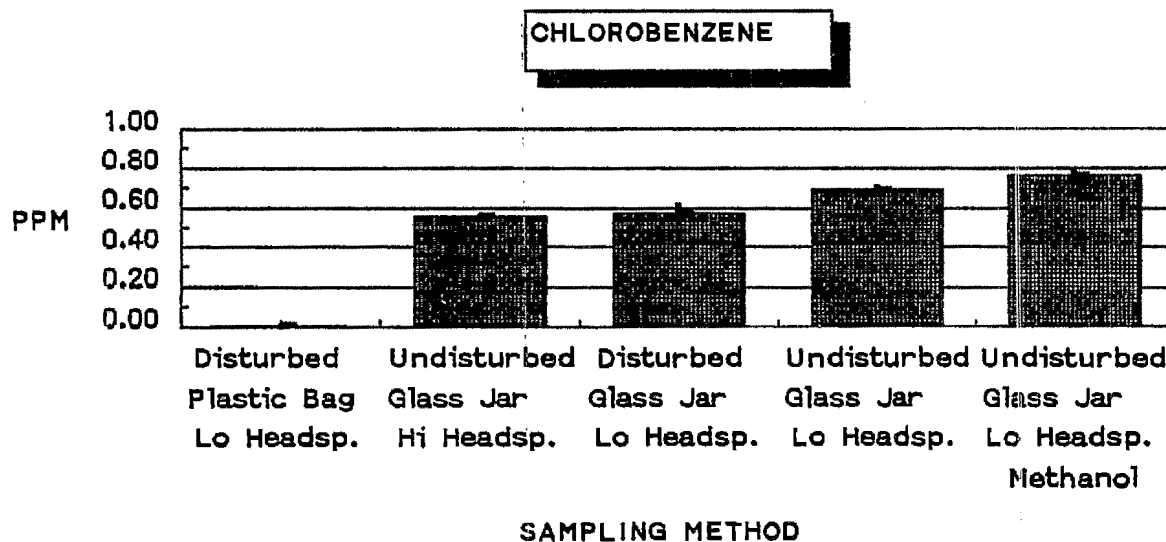


Figure C6. Comparison of sampling method effects for chlorobenzene.
(vertical bar indicates standard error of treatment mean)

APPENDIX D
QUALITY CONTROL SAMPLE ANALYSES

Table D1. VOC analytical method detection limits.

Target Compound	Matrix		
	Water	Methanol	Soil
	ug/mL	ug/mL	ug/g
Methylene Chloride	0.1	0.1	0.4
1,2-Dichloroethane	0.05	0.05	0.1
1,1,1-Trichloroethane	0.005	0.005	0.01
Trichloroethylene	0.002	0.002	0.004
Toluene	0.04	0.04	0.05
Chlorobenzene	0.03	0.03	0.01

Table D2. Characteristics of samples for quality control analyses.

Sample Code	Weight	Description
	g	
B1	73.9	Methanol used for infield preservation.
B2	286.8	Clean soil used in this experiment.
C1	24.8	Soil sample collected from control column by Method A.
C2	99.8	Soil sample collected from control column by Method C (soil immersed in 100 mL methanol).
C3	120.8	Soil sample collected from control column by Method B.

Table D3. Results of VOC spiking and recovery analyses¹.

Target Compound	Spiked Concentration	Recovery Percentage	Estimated Variance
	ug/g dry soil	%	%
Methylene Chloride	20.0	77	+20
1,2-Dichloroethane	12.5	73	+10
1,1,1-Trichloroethane	2.5	100	+5
Trichloroethylene	2.0	112	+10
Toluene	0.75	115	+10
Chlorobenzene	0.5	95	+5

¹ Samples of clean soil (i.e. uncontaminated study soil) were spiked with the concentrations shown and then extracted and analyzed according to the same procedures as for the test soil samples (see text).

NATO/CCMS Guest Speaker:

Guus Annokke, The Netherlands

Biological Treatment of Contaminated Soil and Groundwater

No text available.

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D.B. Janssen, The Netherlands

Degradation of Halogenated Aliphatic Compounds by
Specialized Microbial Cultures and Their Applications
for Waste Treatment

Degradation of halogenated aliphatic compounds by specialized microbial cultures and their application for waste treatment

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Abstract

The biodegradation of halogenated aliphatic compounds by a number of pure bacterial cultures was investigated. It was found that 1-chloro-n-alkanes, several α,ω -dichloroalkanes, chlorinated alcohols and some chlorinated ethers can be used as sole carbon source by various gram-negative or gram-positive organisms. Attempts to isolate bacteria that can grow with compounds such as chloroform, 1,1-dichloroethane, dichloroethylenes, trichloroethylene and 1,1,1-trichloroethane were not successful. Methanotrophic bacteria, however, could convert these compounds by cometabolic oxidation to alcohols or epoxides that may decompose chemically.

Application of microorganisms that use pollutants for growth seems promising in the areas of waste gas treatment and soil cleanup. Thus, addition of dichloromethane-degrading organisms to soil slurries contaminated with this compound resulted in shorter adaptation periods than in non-inoculated soil. Processes that rely on cometabolic conversions are more difficult to realize. Other methods for selective stimulation of the active organisms than the presence of growth substrate need to be employed and an additional energy source will be required.

Introduction

Chlorinated hydrocarbons have found extensive application as degreasing agents, solvents, intermediates in chemical sythesis and agrochemicals (Table 1). Their environmental fate is determined by their resistance to chemical decomposition, the low number of microorganisms that are able to degrade chlorinated organics, and their water solubility and volatility.

Table 1. Production and use of some chlorinated aliphatic hydrocarbons.

compound	production (10 ⁶ tonnes/yr)	use
1,2-dichloroethane	13	vinylchloride, gasoline antiknocking agents, solvent
vinylchloride	12.0	polyvinylchloride
perchloroethylene	1.1	solvent
trichloroethylene	1.0	solvent
carbon tetrachloride	1.0	solvent, CHC
1,1,1-trichloroethane	0.45	solvent
methylene chloride	0.4	solvent
methylchloride	0.35	solvent, blowing agent
2-chlorobutadiene	0.3	polymers
chloroform	0.24	solvent, CHC
1,1-dichloroethylene	0.1	solvents, polymers

During the last several years, we have been studying the biodegradation under aerobic conditions of several important representatives of this class of compounds. Biodegradation rates are often very low, and it has been observed that several chlorinated compounds may persist in polluted aquifers for many years. The cause of these low degradation rates could be unfavourable environmental conditions, physical unavailability of the substrates, or the absence of microorganisms that are able to carry out biotransformation reactions. With halogenated aliphatics, this last factor often is of crucial importance. Even under optimal environmental conditions (neutral pH, 20-30°C, sufficient nutrients available), recalcitrant behaviour is often observed (Table 2). Usually, only specific cultures have the ability to utilize these compounds for growth (Table 3). Therefore, the development of treatment technologies for locally polluted environments and waste streams will require an understanding of the microbial potential and the ecophysiology of the organisms involved. Such information will give insight in the extend of

removal that can be achieved, the conditions that must be optimized and the range of waste streams that can be treated.

Table 2. Bacterial degradation of chlorinated aliphatic hydrocarbons.

	aerobic			anaerobic		
1-chloro-n-alkanes	P	E				
dichloromethane	P	E	C		M	
chloroform			C		M	
carbon tetrachloride	R				M	F
1,2-dichloroethane	P	E	C			F
1,1,1-trichloroethane	R		C			F
vinylchloride	P	E	C	R		
t-1,2-dichloroethene		E	C		M	
trichloroethylene	R	E	C		M	
tetrachloroethylene	R				M	
allylchloride		E				
1,2-dichloropropane	R	E	C			
1,3-dichloropropene	P	E	C			

R, recalcitrant behaviour described

P, pure culture uses compound for growth

E, microbial enzyme capable of degradation known

C, cometabolic conversion by pure culture

M, methanogenic culture

F, fermentative culture

Enrichment cultures

We have used batch and chemostat cultures for the enrichment of microorganisms that can degrade specific pollutants (Table 3). Positive results were obtained with all 1-chloro-n-alkanes tested, with several α,ω -dichloroalkanes, and with a number of chlorohydrins and chlorobenzenes. In all cases, it was possible to isolate a pure culture once an actively growing enrichment was obtained.

Table 3. Pure bacterial cultures that degrade chlorinated compounds.

Strain no.	Identity	Isolated on	Degrades also
<u>chloroaliphatics</u>			
GJ1, GJ3	<i>Pseudomonas</i>	2-chloroethanol	chloroacetic acid
GJ10-12	<i>Xanthobacter</i>	1,2-dichloroethane	toluene, methanol 1-propanol, acetone chloro- and bromoalkanes
GJ20-22	<i>Hyphomicrobium</i>	methylene chloride	formaldehyde
GJ70	<i>Arthrobacter</i>	1,6-dichlorohexane	1-chloroalkanes 1,9-dichlorononane
AD1-3	<i>Pseudomonas</i> <i>Arthrobacter</i>	epichlorohydrin	vic-chlorohydrins
GJ84	<i>Corynebacterium</i>	trans-3-chloroacrylic acid	cis-3-chloroacrylic acid
AD25	<i>Ancylobacter</i>	chloroethylvinylether	2-chloroethanol 1,2-dichloroethane
<u>chloroaromatics</u>			
GJ30	<i>Pseudomonas</i>	chlorobenzene	
GJ31	<i>Pseudomonas</i>	chlorobenzene	toluene, benzene
GJ60	<i>Pseudomonas</i>	1,2-dichlorobenzene	1,2,4-dichlorobenzene 1,4-dichlorobenzene toluene, benzene

All enrichments were negative with chloroform, 1,1-dichloroethane, 1,1,1-trichloroethane, 1,1-dichloroethylene, cis-1,2- and trans-1,2-dichloroethylene, trichloroethylene, perchloroethylene, 1,2-dichloropropane, hexachlorobutadiene and hexachlorobenzene.

It was observed that the outcome of an enrichment experiment was strongly influenced by the nature of the inoculum and the identity of the compounds. All soil and sediment samples used were positive when tested for chloroacetic acid degradation, but only a limited number of inocula gave rise to dichloromethane utilizing enrichments, while 1,2-dichloroethane degradation was even more seldom observed.

The pure cultures that were isolated in general had a broad substrate range. Thus, 1,2-dichloroethane degrading *Xanthobacter* strains (Janssen et

al., 1985) also converted several 1-chloro- and 1-bromo-n-alkanes, and even toluene, acetone, 1-butanol, etc., were used for growth (Table 3). A similar broad substrate range was found for the 1,2-dichlorobenzene degrading organism strain GJ60 (Oldenhuis et al., 1989a). Toluene, benzene, chlorobenzene, 1,4-dichlorobenzene and 1,2,4-trichlorobenzene also stimulated growth of this organism (Table 3).

An important aspect is the stability of the cultures. This was found to be highly variable. Some strains did not show loss of their specific catabolic activity even when they were transferred on selective media for years, while other cultures had to be maintained on the carbon source that was used for enrichment to prevent rapid loss of their activity. This was not related to the compound on which the organism was obtained, since strain GJ31 was a very stable chlorobenzene degrader while GJ30 rapidly lost its activity on nutrient agar.

Repeated attempts to obtain enrichments for a number of compounds were not successful. This included chloroform, 1,1-dichloroethane, the dichlorinated ethylenes, trichloroethylene, and some other compounds. A number of factors could cause that a specific xenobiotic is not used for growth:

- the compound or intermediates are not converted by microbial enzymes;
- degradation does not yield energy or carbon for growth;
- the compound is toxic;
- the compound is converted to toxic metabolites (Fig. 1).

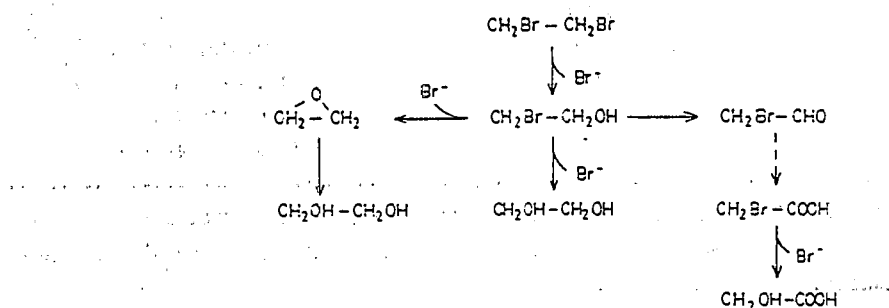


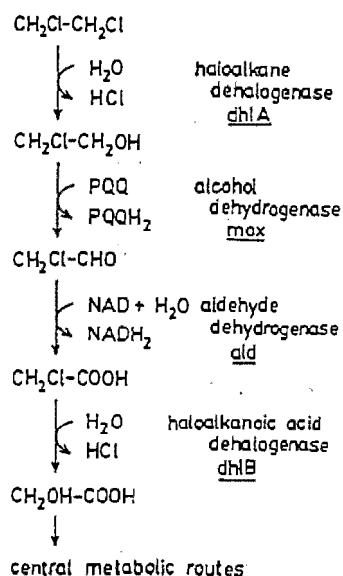
Fig. 1. Possible conversions of 1,2-dibromoethane by different bacterial cultures. Several enzymatic steps enabling dehalogenation and utilization of this compound have been identified. The necessary combination of these activities, yielding a complete catabolic route, however, has not yet been found.

In order to understand the relative importance of these factors, we have decided to study physiological pathways through which halogenated aliphatics can be converted. Special emphasis was given to dehalogenation reactions since this is the step where toxicity is lost. It can also be expected to be a biochemically difficult step, since carbon-halogen bonds are only present in a limited number of natural compounds.

Dehalogenation

Dehalogenation of several chloroalkanes was found to be mediated by low molecular weight hydrolytic dehalogenases. The first enzyme that was found to be able to hydrolyze a chlorinated hydrocarbon not containing other functional groups was identified in a strain of *Xanthobacter* that was isolated on 1,2-dichloroethane (Janssen et al., 1985; Keuning et al., 1985) (Fig. 2). A hydrolytic dehalogenase was also identified in a 1,6-dichlorohexane utilizing organism (Janssen et al., 1988b). A broad range of compounds could be converted by these systems (Table 4).

Fig. 2. Catabolic route for 1,2-dichloroethane by *Xanthobacter autotrophicus*. Two different hydrolytic dehalogenases, produced constitutively, cause dechlorination. The haloalkane dehalogenase has a remarkably broad substrate range. The inducible dehydrogenases are usual enzymes of *Xanthobacter* and play a role in the metabolism of natural alcohols. The final product, glycolic acid, is a normal intermediate in bacterial metabolism.



Recently, the three dimensional structure of the *Xanthobacter* dehalogenase has been resolved (S. Franken, B. Dijkstra et al., in preparation). The structure suggests the involvement of a carboxylate group in the dehalogenation reaction, which would proceed by a nucleophilic displacement mechanism. If this is correct, then it is evident why compounds such as chlorinated ethylenes are not a substrate. The presence of π electrons shields the carbon from nucleophilic groups. Compounds such as chloroform and 1,1,1-trichloroethane probably are not converted because of steric factors.

We have observed a striking degree of correlation between the possibility of hydrolytic dehalogenation and utilization as a growth substrate. One of the compounds for which repeated attempts to isolate a pure culture were not successful is 1,2-dichloropropane. This chemical has entered the environment due to contamination of the nematocide 1,3-dichloropropylene. It also is an industrial waste chemical. The compound is known to persist in the groundwater environment for decades.

Table 4. Substrates of haloalkane dehalogenases.

Compound	GJ10	GJ70	Compound	GJ10	GJ70
methylchloride	28	0	2-bromoethanol	7	55
methylbromide	14	143	3-bromopropanol	-	123
methyliodide	14	75	1-chloro-6-hexanol	4	60
dibromomethane	-	13	1-bromo-6-hexanol	-	68
bromochloromethane	-	5	bis(2-chloroethyl)ether	-	30
ethylchloride	24	0	chloroethylvinylether	-	13
ethylbromide	24	143	1-phenyl-2-bromopropane	-	18
ethyliodide	-	93	1-chloropentane	0	65
1,2-dichloroethane	100	13	1-bromopentane	32	60
1,2-dibromoethane	94	172	2-bromopentane	-	38
1-chloropropane	51	15	1-chlorohexane	3	85
1-bromopropane	29	100	1,6-dichlorohexane	4	67
2-bromopropane	-	97	2-bromooctane	-	-
1,3-dichloropropane	80	102	1,9-dichlorononane	4	26
3-chloropropene	45	139	1,2-dichloropropane	0.6	-
1,3-dichloropropene	-	133	epichlorohydrin	14	-
1,2-dibromopropane	119	148	epibromohydrin	129	-
1-chlorobutane	31	66			
1-bromobutane	27	90			
2-bromobutane	-	60			

Relative activities of purified dehalogenase of *Xanthobacter autotrophicus* GJ10 and *Arthrobacter* GJ70. The purified enzymes have an activity of 6 and 3 U/mg of protein, respectively, with 1,2-dibromoethane.

We propose that this recalcitrance is related to the extremely low activity of hydrolytic dehalogenases towards this compound. The strain GJ10 dehalogenase described in Table 4 has a 160-fold lower activity with 1,2-dichloropropane than with 1,2-dichloroethane. The product of conversion is a mixture of 1-chloro-2-propanol and 2-chloro-1-propanol, which both may serve as carbon source for cultures that have been obtained in our laboratory (Fig. 3). Therefore, the lack of conversion could be related to a single activity being absent.

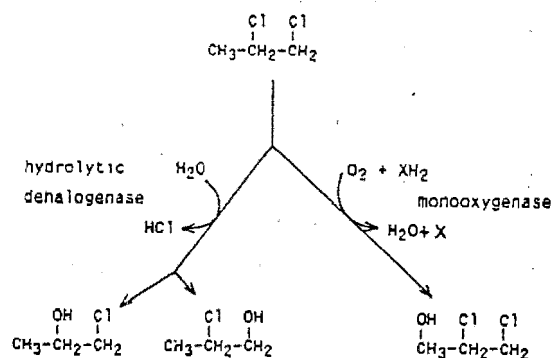
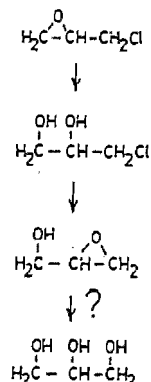


Fig. 3. Conversion of 1,2-dichloropropane by hydrolysis (haloalkane dehalogenase) or by oxidation (methane monooxygenase).

Other mechanisms of dehalogenation have been discovered in dihalomethane degrading organisms and in strains that use haloalcohols for growth. Apparently, there are two possible routes for the direct dehalogenation of haloalcohols: hydrolysis to produce glycols or intramolecular substitution to produce epoxides (Fig 4).

Fig. 4. Catabolism of epichlorohydrin in *Pseudomonas* AD1 involves the activity of an epoxide hydrolase and a dehalogenase that converts vicinal alcohols to epoxides. Both enzymes are inducible (van den Wijngaard et al., 1989).



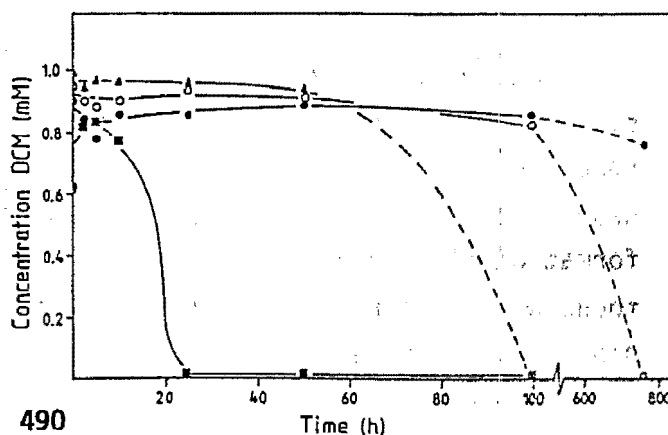
Little is known about the conversion of β -halocarboxylic acids.

Oxidative conversions seem to be rather widespread but their relevance to organisms that use halogenated compounds as a carbon source remains to be demonstrated.

Application of organisms

We have tested whether addition of specific cultures to slurries of contaminated soil can decrease adaption periods or increase degradation rates. It was found that dichloromethane removal occurred faster when dichloromethane degrading organisms (*Hyphomicrobium* GJ21 or *Methylobacterium* DM2) were added to contaminated soil (Fig. 5). Without inoculation, no significant degradation took place within 100 h. Similar results have been obtained with the degradation of chlorinated benzenes and 1,2-dichloroethane. The engineering aspects of bioreactors for the treatment of soil slurries have been investigated by others (Kleijntjes et al., 1987).

Fig. 5. Effect of inoculation on the degradation in soil slurries. Symbols: ●, sterile control; ○, no organisms added; ▲, *Methylobacterium* strain DM2 added (Kohler-Staub and Leisinger, 1985); ■, *Hyphomicrobium* GJ21 added. The concentration of dichloromethane was followed by gas chromatography.



Other areas of application of selected cultures are being developed. This includes immobilization of 1,2-dichloroethane degraders for groundwater treatment in packed bed bioreactors and the use of dichloromethane degrading bacteria for waste gas treatment.

Oxidative cometabolism

Since 1985 (Wilson and Wilson, 1985), the possibility to convert chlorinated ethylenes by cometabolic reactions has received increasing attention (Fogel et al., 1986; Little et al., 1988; Janssen et al., 1988a; Oldenhuis et al., 1989b). Methanotrophs, toluene, propylene and ammonia oxidizers have been tested for their capacity to degrade halogenated aliphatics by cometabolic oxidation. The oxygenases involved have a broad substrate range and convert chlorinated compounds to alcohols, epoxides, etc.

Table 5. Degradation of some halogenated compounds by soluble (sMMO) and particulate (pMMO) methane monooxygenase.

Compound			
	sterile	Conc. sMMO	Left (mM) pMMO
Dichloromethane	0.167	<10 ⁻³	0.024
Chloroform	0.124	<10 ⁻⁶	0.006
Carbon tetrachloride	0.046	0.045	0.040
1,1-Dichloroethane	0.033	<10 ⁻⁴	0.045
1,2-Dichloroethane	0.092	<10 ⁻⁴	<10 ⁻⁴
1,1,1-Trichloroethane	0.065	0.025	0.070
1,1-Dichloroethylene	0.030	0.018	0.032
trans-1,2-Dichloroethylene	0.083	<10 ⁻⁴	<10 ⁻⁴
cis-1,2-Dichloroethylene	0.110	<10 ⁻⁴	0.045
Trichloroethylene	0.050	<10 ⁻⁵	0.050
Tetrachloroethylene	0.069	0.072	0.073
1,2-Dichloropropane	0.129	<10 ⁻⁴	0.083
trans-1,3-Dichloropropylene	0.138	0.019	0.060

Our work has focussed on methanotrophic bacteria that can produce a soluble type methane monooxygenase (Oldenhuis et al., 1989b). The range of compounds that can be converted is impressive (Table 5, 6). In several cases (partial) dehalogenation was demonstrated, sometimes via the formation of chemically unstable intermediates. The rates that we have found were rather attractive: specific degradation activities of up to 150 nmol/min. mg of cells were obtained under appropriate conditions.

Table 6. Degradation of chloroaliphatics by *M. trichosporium* OB3b.

compound	chlorinated product(s) ^a
dichloromethane	chloride
chloroform	chloride
carbon tetrachloride	no conversion
1,1-dichloroethane	chloride
1,2-dichloroethane	chloride
1,1,1-trichloroethane	2,2,2-trichloroethanol
trans-1,2-dichloroethylene	chloride, epoxide
cis-1,2-dichloroethylene	chloride, epoxide
trichloroethylene	chloride, 2,2,2-trichloroethanol
tetrachloroethylene	no conversion
1,2-dichloropropane	1,2-dichloro-3-propanol

^a Incubations were done at 30 °C with resting cells from chemostat cultures grown in medium containing no added copper. Compounds were added at 0.1 mM and formate was used as electron donor.

One of the most important compounds that can be converted by methanotrophs is trichloroethylene. Rapid conversion of TCE was achieved under conditions that stimulate expression of the soluble methane monooxygenase only. The kinetics of TCE degradation by methanotrophs compares favourably to toluene oxidizing organisms that degrade TCE (Oldenhuis et al., 1990). The K_1 values (first order rate constants) are similar but methanotrophs have a higher V_{max} . A problem with both toluene oxidizers and methanotrophs is the toxicity of TCE degradation products. This will require significant amounts of methane to stimulate growth of new active cells if in a treatment system larger amounts of TCE have to be converted.

Application of cometabolism

We have found that addition of methane to soil slurries that were contaminated with chloroform, TCE and perchloroethylene only stimulated chloroform conversion significantly (Fig. 6). In slurries that contained *trans*-1,2,-dichloroethylene, rapid degradation was achieved when either methane or methane plus cells of a *Methylobomonas* culture were added (Fig. 7). By methane addition alone, probably only cells expressing the particulate methane monooxygenase were stimulated. Similar observations have been made in field studies (McCarty et al., 1989). More efficient methods for specific stimulation of methanotrophs expressing soluble methane monooxygenase have to be developed. Copper availability, which regulates the switch from expression of soluble to particulate enzyme will be difficult to manipulate in a natural environment or treatment system receiving complex waste streams.

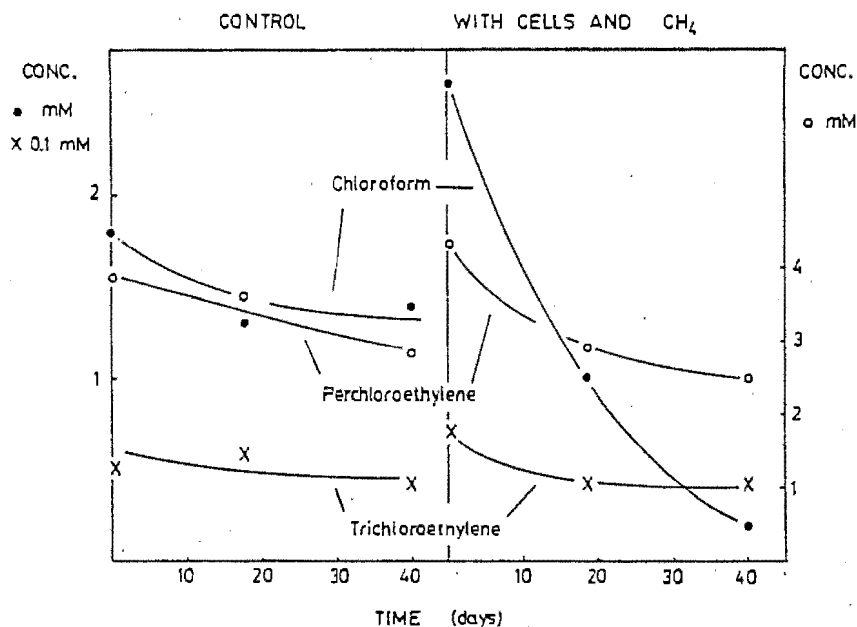


Fig. 6. Degradation of chloroform, trichloroethylene, and perchloroethylene in a soil slurry exposed to methane.

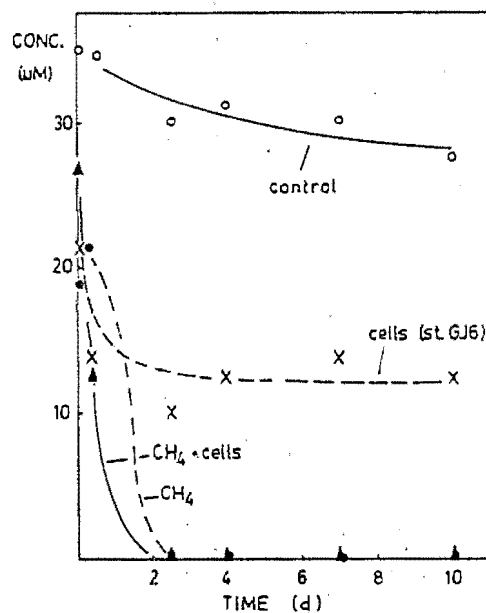


Fig. 7. Degradation of trans-1,2-dichloroethylene in soil slurry.

Treatment systems

Application of selected microbial cultures for cleanup purposes can be attractive in order to reduce adaptation periods. Several areas are promising:

- inoculation of waste gas treatment biofilters and trickling filters;
- startup of fixed beds for groundwater treatment;
- inoculation of bioreactors for soil, sediment and sludge treatment;
- in situ treatment after injection of microorganisms.

Although the number of practical scale experiences with these applications is very limited (Morgan & Watkinson, 1989), several

considerations indicate that inoculations could be very helpful.

Natural polluted ecosystems seem to show variability with respect to presence of microorganisms that can degrade certain pollutants. Thus, subsurface samples often do not show significant degradation of dichloromethane, 1,2-dichloroethane or 1,2-dichlorobenzene unless microorganisms that are capable to use these compounds for growth are added. Cultures that degrade xenobiotics are not always present in a certain polluted environment and this may prevent degradation even after conditions have been optimized.

Experiments with trickling filters for waste gas treatment also show that inoculation may be useful for obtaining rapid establishment of an active microflora (Diks and Ottengraf, 1989).

Cells immobilized on a solid support can be used for groundwater cleanup. Both activated carbon (Stucki, 1990) and diatomeaceous earth (Friday and Portier, 1989) have been used as support material for the *Xanthobacter* strain that degrades 1,2-dichloroethane. These systems are currently scaled up for practical application.

Novel developments will be the application of microorganisms that rely on cometabolic conversion. On a laboratory scale, several interesting reactor setups have been proposed, but the efficiency seems to need further improvement (Strandberg et al., 1989).

Another attractive possibility is the combination of anaerobic and aerobic treatment steps for complete dehalogenation of compounds that are not converted under aerobic conditions. Highly chlorinated compounds are subject to reductive dehalogenation, catalyzed by anaerobic organisms such as clostridia and methanogens (Vogel et al., 1987). The products could be converted further by aerobic treatment.

In all cases, more insight into the ecophysiology of the organisms that carry out the dehalogenation steps will be essential for identifying the basic process conditions that are needed for optimizing the numbers and activity of the xenobiotic degraders. The use of bioreactors that allow fine control of growth conditions will increase the success of these novel treatment technologies.

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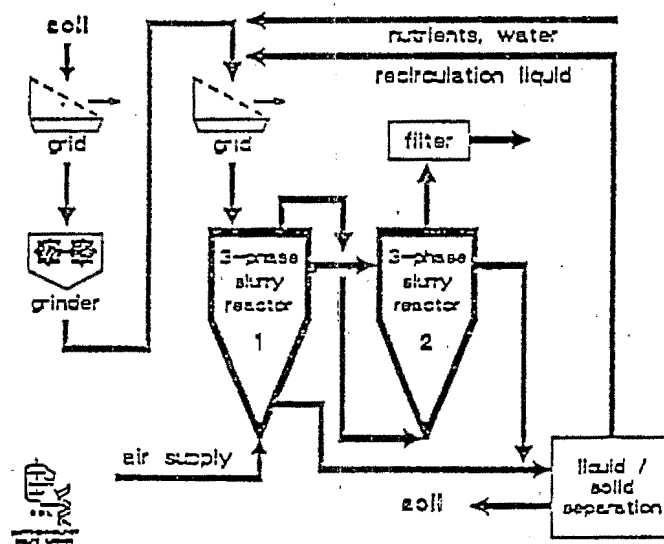
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Microbial Treatment

Technological and kinetical aspects of microbial soil decontamination in slurry reactors on mini plant scale.



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ABSTRACT

Technological and kinetical aspects of microbial soil decontamination in slurry reactors on mini-plant scale

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A new soil slurry bioprocess for the decontamination of polluted soils is developed using an integral research approach. For this reason technological and hydrodynamical research on soil slurries in three phase (S-L-G) suspension reactors is combined with biological degradation experiments in the same type of suspension reactors.

In the kinetical experiments aerobic microbial degradation activity is studied in a slurry mini-plant. The slurry handling in the three stage mini-plant, consisting of two bioreactors in series and a dewatering section, is executed in line with the full scale process design. Also the process conditions are chosen close to the expected full scale conditions. First step in the process is the separation of entering soil into a coarse and fine particle fraction. It is the fluidized coarse fraction which is, after a relatively short residence time, withdrawn from the bottom of the first reactor while the suspended fraction remains in the system. This mode of operation makes the first reactor a bioreactor-separator unit, on which further slurry handling is based.

Preliminary experimental results have shown that separation of polluted soil, in the primal unit, into two different fractions can be achieved in a semi-continuous mode. The average solid hold-up in the first experiment was 15 wt%, in the entering soil diesel present as an oil-like pollutant with an average concentration of 10 g/kg dry matter. In the withdrawn coarse fraction, containing mainly the relatively clean sand particles, a diesel concentration of about 1.5 gr/kg dry matter was detected. The fine soil fraction, containing mainly clay and silt particles which adsorb preferentially the pollutant, is transported from the first into the second bioreactor. It is in the, fines containing, suspension that microbial degradation activity is located. The average residence time for the suspension of fines in the mini-plant is about one week. After remixing the fine and coarse fractions in the third, dewatering, stage an overall diesel conversion of 70 % could be measured.

For the given process conditions, chosen as pH 7, temperature 30 °C, and a nutrient medium of only Fe, Mg, P and N (fertilizer), the microbial system was considered not to be functioning optimally. This conclusion was based on the rather small degradation activity measured in the suspension of fines in the second bioreactor.

A biokinetical model was developed to study the degradation process in more detail. Four flows through the system were to be measured in order to test the model: diesel, oxygen, carbon dioxide and the free proton flow. Preliminary model results predict an overall yield of 0.4 Cmole biomass/Cmole substrate, agreeing with literature values. Also a low rate of nitrification in the system is predicted by the model.

Optimization of the process conditions related to slurry handling and further development of the model is on its way.

Introduction

General aims:

- The development of a continuous slurry bioprocess for soil decontamination.
- The set-up of a kinetical description for aerobic diesel breakdown in the slurry system.

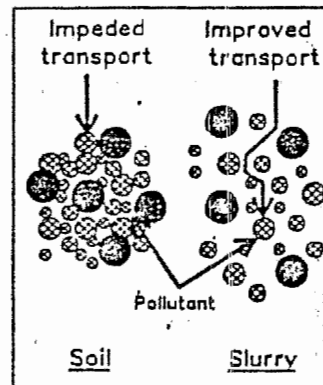
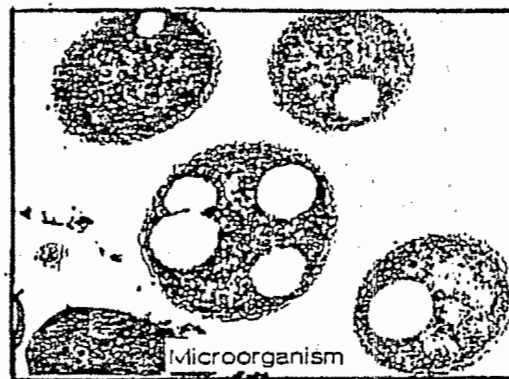
Characteristics of the slurry system.

Soil:

- Particles are agglomerated and packed;
- Pollutants are encapsulated in large soil particles;
- Impeded transport of O_2 , CO_2 and nutrients.

Slurry:

- Particles are freely suspended;
- Improved availability of pollutants due to surface enlargement;
- Increased transport rates.



Set-up of research:

- Construction and development of a continuously operated mini plant;
- Technological description of the three phase slurry (S-L-G);
- Development of a biokinetical model for the aerobic diesel degradation;
- Experimental determination of the diesel breakdown in the mini plant;
- Validation of the model with data from mini plant experiments.

Slurry characteristics in the mini plant

Two important, technological design parameters are investigated:

- the solid hold-up, particle loading of the system;
- the particle size distribution in the slurry.

Classification of soil particles

fine fraction:

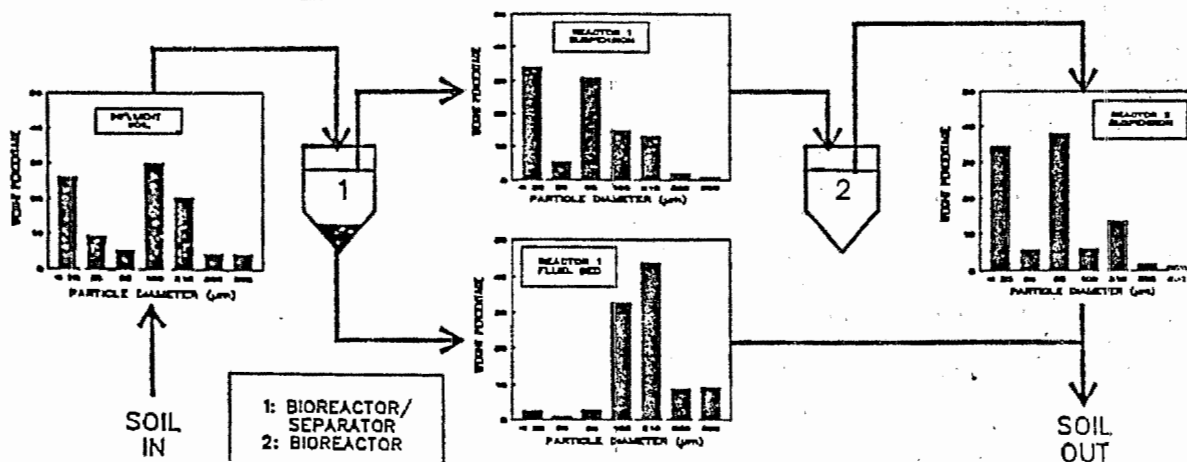
- clay and silt, large specific surface
- $dp=1-50 \mu m$
- high adsorbing power for oil pollutants

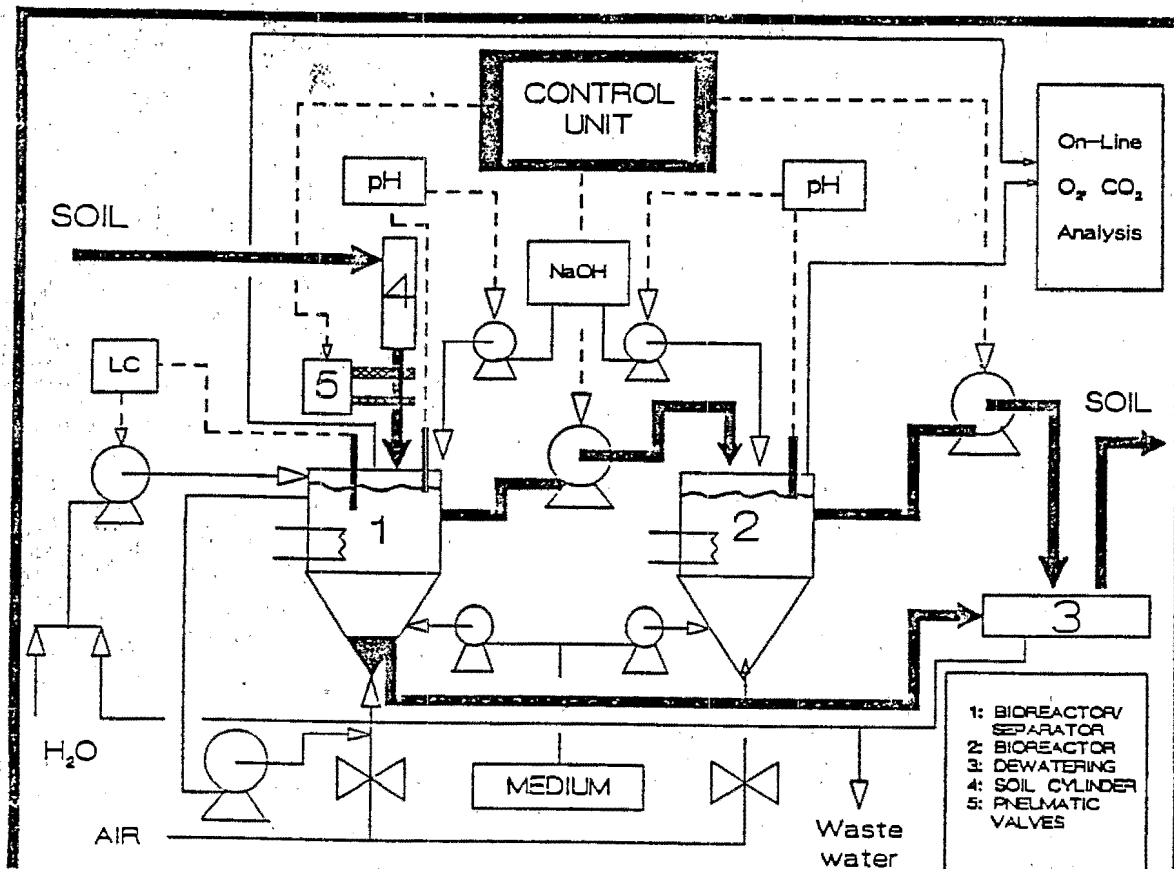
coarse fraction:

- sand, small specific surface
- $dp=100-1000 \mu m$
- low adsorbing power for oil pollutants

As shown in the figure, the influent soil is split into a fine and coarse fraction, which are recombined after the second stage. An average solid hold-up of 15 % (w/v) is reached.

Particle size distribution in mini plant

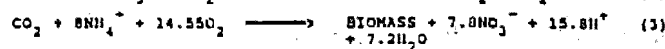
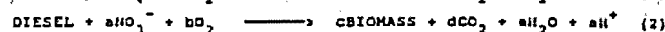




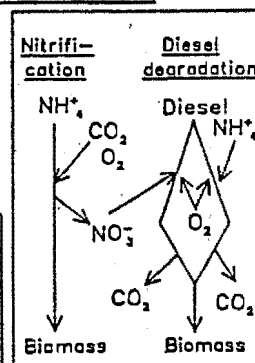
Modelling of continuous, aerobic diesel degradation

- The soil slurry is an ecosystem in which, besides diesel degradation, several other microbiological processes, like nitrification, humification etc. occur.
- Diesel, a mixture containing compounds ranging from alkanes to polyaromatic hydrocarbons, is degraded by a mixed population of microorganisms.
- In the model, only three processes are considered relevant: diesel degradation with ammonium (1) and nitrate (2) as N-source respectively and nitrification (3).

Stoichiometric relations



with DIESEL: $\text{CH}_{1.85}\text{O}_{0.033}\text{N}_{0.0074}$ and BIOMASS: $\text{CH}_{1.8}\text{O}_{0.5}\text{N}_{0.2}$



From these three stoichiometric relations, 7 overall rate equations, for each of the 7 participating compounds, containing 11 variables, can be derived. Thus, 4 variables (conversion rates) have to be determined to solve the system. These rate values are calculated from balance equations in which experimental data are used.

Simplified steady state balance equations

$$r_d = \frac{c_s \cdot \rho_s \cdot (c_{d,s} - c_{d,fb})}{V_s} + \frac{c_{s,fb} \cdot (c_{d,fb} - c_{d,fb})}{V_s} + \frac{c_{s,g} \cdot c_{d,g}}{V_s}$$

$$r_{\text{H}^+} = \frac{v_{\text{NaOH}} \cdot c_{\text{OH}} - v_{\text{med}} \cdot c_{\text{H}^+, \text{med}}}{V_s}$$

$$r_{\text{O}_2} = -\frac{v_g}{V_s} (c_{\text{O}_2, g, \text{in}} - c_{\text{O}_2, g, \text{out}})$$

$$r_{\text{CO}_2} = -\frac{v_g}{V_s} (c_{\text{CO}_2, g, \text{in}} - c_{\text{CO}_2, g, \text{out}})$$

Symbols:

c : concentration
 r : conversion rate
 V : volume
 v : volume fraction of soil
 ρ_s : soil density
 v_{NaOH} : mass flow of NaOH
 v_{med} : volumetric liquid flow
 v_g : volumetric gas flow
 θ : residence time

Indices:

d : diesel
 fb : fluidized bed
 g : gas
 H : protons
 med : medium
 OH : OH-ions
 s : soil suspension

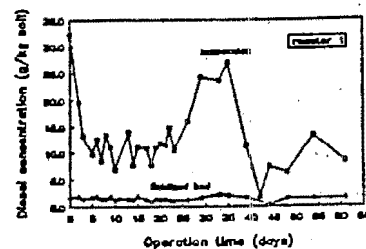
Mini plant performance:

Experimental conditions: - Residence time: 2 x 100 hours
- T=30 C, pH=7.0

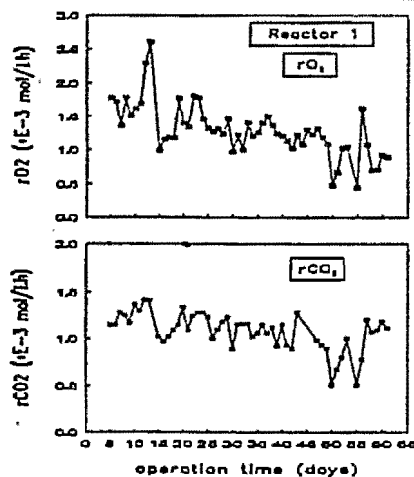
The miniplant was operated for 60 days, giving the following average diesel concentrations:

- influent soil	:	10	g/kg
- reactor 1 - suspension	:	10.5	g/kg
- fluidized bed	:	1.5	g/kg
- reactor 2 - suspension	:	8	g/kg
- effluent soil	:	3	g/kg

- The influent soil can be split into a relatively clean coarse fraction and a more polluted fine fraction (see figure).
- An overall diesel conversion of 70 percent was reached in this system.



Experimental verification of the model:



In reactor 1, the following 4 conversion rates were measured in the "steady state":

- Diesel	:	-1.94	C-mmol/l.h
- Oxygen	:	-1.50	mmol/l.h
- Carbon dioxide	:	1.20	mmol/l.h
- Protons	:	0.25	mmol/l.h

By putting these values in the biokinetical model, other model parameters can be determined. Some preliminary conclusions can be drawn:

- The bruto yield of biomass on diesel is about 0.4, which is in accordance with literature data.
- The nitrification rate is relatively low.

Future research will concentrate on improving the diesel degradation in the second reactor, and making a nitrogen balance over the system for a more profound evaluation of the biokinetical model.

NATO/CCMS Guest Speaker:

Karel Luyben, The Netherlands

Dutch Research on Microbial Soil Decontamination in Bioreactors

Dutch research on microbial soil decontamination in bioreactors

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Micro-organisms are able to convert aerobically a broad range of xenobiotic organic substances into new biomass, carbondioxide and water. This degrading ability can not only be used for water solubilized xenobiotics, but also for substances adsorbed in soil. Major hinderences for in situ biodegradation in soil are firstly the difficulty in contact between organisms and adsorbed pollutant and secondely the poor mass transfer to the bioactive sites.

The use of bioreactors to overcome these hinderences is studied in the Netherlands by means of two research projects on reactor application for microbial soil decontamination. One project is carried out by TNO, the other by TUD. Generally speaking both projects can be characterized by the following research items:

- optimum conditions for biodegradation has to be reached by applying a bioreactor
- the treatment time of the polluted soil in the bioreactor has to be short as possible
- the types of bioreactors that can be used have to be simple and robust
- short term implementation in practice

Due to reasons of confidence neither the TNO nor the TUD project can be treated in detail, nevertheless some features of the projects will be presented:

TNO-project

Preliminary the following overall results are achieved:

- A dry treatment method (10 - 15% humidity of the soil; soil as such) as well as a wet treatment method (soil slurry) have potentials for being applicated in practice.
- The design criteria for the bioreactor types used in the dry and wet method are known.
- Both batch and continuous processes can be applied.
- A variety of soil types (from sand to loam) can be treated.
- Experiments have been carried out on soils polluted with mineral oils and polycyclic aromates (PCA's) with the following results:

treatment method	soil type	contaminant	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	loamy	cutting oil	26,000	9,000	1,200
	sand				
wet	loam	cutting oil	65,000		12,000
wet	loam	PCA's	3,900	1,700	300

TUD project

To overcome the earlier mentioned hinderences for soil decontamination a tapered three phase slurry reactor is under development in which soil particles can be suspended in processwater to create an optimum micro-environment for the biodegradation. Suspension is attained by means of a special designed injection system using compressed air and water. With this newly designed injector it is possible to make optimal use of the natural segregation occurring in a three phase slurry. This segregation results into a bottom fraction containing larger particles and a bulk fraction containing smaller particles.

Degradation kinetics in the slurry are studied measuring the concentrations of substrate, oxygen and carbondioxide as a function of time during batch experiments and during continuous processing. A simple model is developed to describe the kinetics of the system. Both in the model and in experiments attention is paid to mass transfer and suspension characteristics in the three phase slurry.

The suspension behavior of soil particles in the three phase slurries is studied both on laboratory and pilot-plant scale. Understanding the performance of high density suspensions at different scales demands an intens research effort for both technical and theoretical aspects. A combination of insight in the physics of soil suspensions, mass transfer properties and biokinetics should result in optimum operation conditions for this process. This should then lead to a flowsheet including pre- and after-treatment operations in relation to the central slurry reactor. Finally, a study to access the economical feasibility of the process will follow.

NATO/CCMS Guest Speaker:

Yalcin B. Acar, United States

Electrokinetic Soil Processing

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ELECTROKINETIC SOIL PROCESSING (A Review of the State of the Art)

Yalcin B. Acar¹, M.ASCE

ABSTRACT

Electrokinetic soil processing is an emerging technology in waste remediation and treatment. This paper reviews electrokinetic phenomena in soils and provides the fundamentals of contaminant removal by the technique. The results of studies reporting ion/contaminant removal using electro-osmosis are presented. Engineering implications are provided for the further development and implementation of the process in remediation.

INTRODUCTION

Electrokinetic soil processing using low level DC currents (of the order of milliamps per cm² of electrode area) is envisioned to be used for removal/separation of organic and inorganic contaminants and radionuclides, construction of barriers and leak detection systems in clay liners, diversion schemes for waste plumes, and for injection of grouts, microorganisms and nutrients into subsoil strata (Mitchell 1986; Acar and Gale 1986; Renaud and Probstein 1987; Acar, et al. 1989).

Coupling between electrical, chemical and hydraulic gradients is responsible for different types of electrokinetic phenomena in soils (Mitchell, 1976). Electro-osmosis (EO) is one of these phenomena where the pore fluid moves due to application of a constant low DC current (or voltage) by electrodes inserted in a soil mass. In the last five decades since its first application (Casagrande 1947), electro-osmosis has been investigated and used for different applications (Hamed et al. 1991). The potential of the technique in waste remediation resulted in initiation of several recent studies (Putnam 1988; Acar et al. 1989; Khan et al. 1989; Thompson 1989; Mitchell and Yeung 1991). The need to utilize the process in removal/separation of contaminants necessitates a better understanding of the electrochemistry

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associated with electrokinetic phenomena and its relation to the mechanical behavior.

Recent studies provided a better understanding of the electrochemistry and demonstrated that the acid front generated by electrolysis reaction at the anode advances and eventually flushes across the specimen by advection, migration and diffusion (Acar et al. 1989; Shapiro et al. 1989; Acar et al. 1991). Hamed (1990) and Hamed et al. (1991) demonstrated that the movement of this acid front together with migration and advection of the cations and anions under electrical gradients constitute the mechanisms of removing contaminants from soils. The factors influencing the acid/base profile across the porous medium would significantly affect the flow, the flow efficiency, and the extent of ion migration and removal in electrokinetic soil processing.

This paper presents the fundamentals of the process, reviews the results of the on-going studies and provides engineering implications for its implementation.

ELECTROKINETIC PHENOMENA IN SOILS

Coupling between electrical, chemical and hydraulic gradients is responsible for different types of electrokinetic phenomena in soils. These phenomena include electro-osmosis, electrophoresis, streaming potential and sedimentation potential (Mitchell 1976). Electro-osmosis and electrophoresis are the movement of water and particles, respectively, due to application of a low DC current. Streaming potential and sedimentation potential are the generation of a current due to the movement of water under hydraulic potential and movement of particles under gravitational forces, respectively. The effect of coupling becomes more important in fine-grained soils with lower coefficients of permeability.

In electro-osmosis, electrodes can be placed in an open or closed flow arrangement. Open flow arrangement constitutes the case when an electrode is sufficiently permeable to admit ingress and egress of water. In the closed flow arrangement, the electrode is not permeable or porous. Different electrode configurations (open or closed) result in substantial variations in the total matrix potentials across the soil specimen.

The electro-osmotic flow rate, q_e , is defined with an empirical relationship,

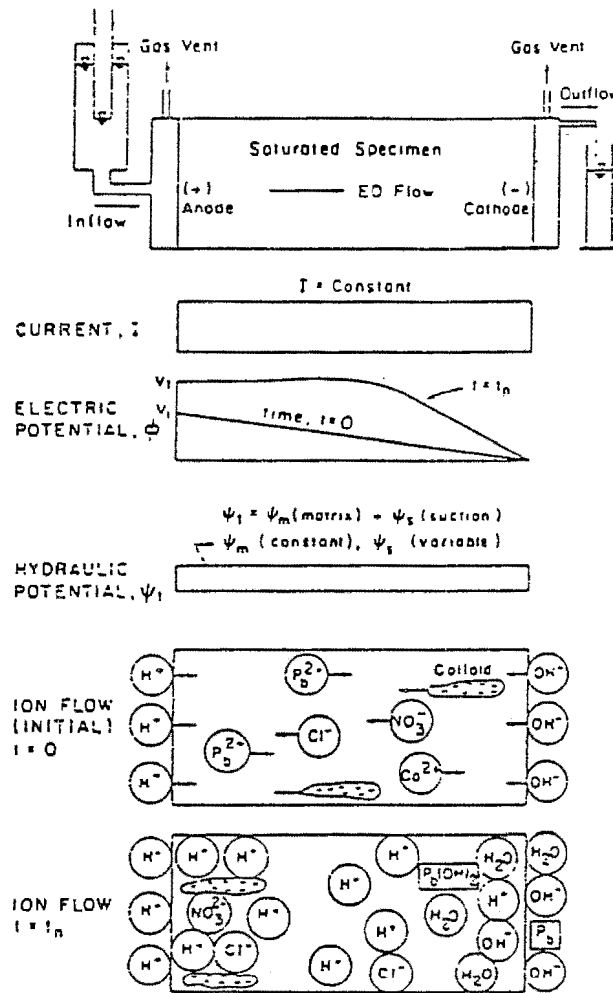
$$q_e = k_e i_e A = k_i I = \frac{k_e}{\sigma} I \quad (1)$$

where k_e = coefficient of electro-osmotic permeability ($\text{cm}^2/\text{sec-V}$), k_i = electro-osmotic water transport efficiency ($\text{cm}^3/\text{amp-sec}$), I = current (amp), σ = conductivity (siemens/cm), i_e = electrical potential gradient (V/cm), A = cross-sectional area (cm^2). Estimates of electro-osmotic flow rates can be made using equation (1). k_e varies within one order of magnitude for all soils; 1×10^{-5} to 10×10^{-5} ($\text{cm/sec})/(\text{V/cm})$, the higher values being at higher water contents.

Figure 1 presents a schematic diagram of one-dimensional laboratory tests in electrokinetic soil processing. The prevailing electrical gradients, and the ion flow are also depicted. A comparison of flows under electrical and hydraulic gradients in clays is also provided. The coefficient of electro-osmotic permeability is independent upon the size and distribution of pores (fabric) in the soil mass. However, hydraulic conductivity is most affected by the fabric. Therefore, hydraulic conductivity decreases by five to six orders of magnitude (10^{-3} cm/sec to 10^{-8} cm/sec) from the fine sands to clays. Figure 3 indicates that under equal gradients, electrical potentials in fine-grained soils may result in orders of magnitude larger flows than hydraulic potentials. Therefore, electro-osmosis induced flow can be considered to be an efficient pumping mechanism in saturated, low permeability, fine-grained soil.

The efficiency and economics of electro-osmotic dewatering is governed by the amount of water transferred per unit charge passed which is quantified by electro-osmotic water transport efficiency, k_i . The parameter k_i may vary over a wide range from 0 to $1.2 \text{ cm}^3/\text{amp-sec}$ depending upon the electrical conductivity of the porous medium. The conductivity changes with water content, cation exchange capacity and free electrolyte content in the soil and also due to the prevailing chemistry during electrokinetic processing. Gray and Mitchell (1967) indicate that electro-osmotic efficiency decreases with a decrease in water content and an increase in activity of the soil. The electro-osmotic dewatering efficiency is independent of variations in electrolyte concentration (sodium ion) for active clays, while an increase in electrolytes tends to decrease the efficiency in inactive clays.

Recent studies by Lockhart (1983) substantiate the conclusions of Gray and Mitchell (1967). k_i increased from 0.32 to $1.20 \text{ cm}^3/\text{amp-s}$ with the decrease of NaCl and HCl concentrations from 10^{-1} M to 10^{-3} M . k_i decreased by an increase in electrical gradients, possibly due to a higher influx of H^+ ions (Hamed, et al., 1991). Lockhart (1983) shows that a higher electro-osmotic efficiency was recorded with H and Cu clays. k_i changed



Electro-Osmotic Flow, Q_e

$$Q_e = k_e \cdot i_e \cdot A$$

k_e = electro-osmotic permeability

i_e = electrical gradient

A = area

Hydraulic Flow, Q_h

$$Q_h = k_h \cdot i_h \cdot A$$

k_h = hydraulic conductivity

i_h = hydraulic gradient

Ratio of Two Flows

$$\frac{Q_e}{Q_h} = \frac{k_e i_e}{k_h i_h}$$

A Comparison of Two Flows in Clays

$$k_e = 1 \times 10^{-5} \text{ (cm}^2\text{/sec)/(v/cm)}$$

$$k_h = 1 \times 10^{-8} \text{ cm}^2\text{/sec}$$

$$i_e = 1 \text{ v/cm (typical for field application)}$$

$$i_h = 1 \text{ (selected for comparison)}$$

$$\frac{Q_e}{Q_h} = 1,000$$

Figure 1. A Schematic Diagram of Electrokinetic Processing, Ion Flow and Comparison of Flow in One-Dimensional Flow Conditions (Hamed et al. 1991).

in the order of $H > Cu > Al > Na > Ca$. Higher voltage gradients were required to initiate flow in Al clays.

POTENTIAL USES OF ELECTROKINETICS IN WASTE MANAGEMENT

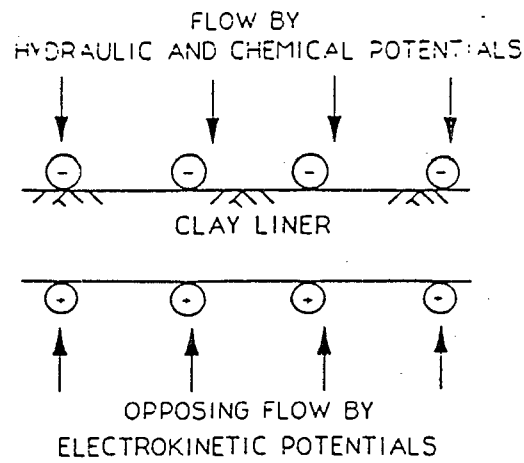
The four electrode configurations described above could potentially be used in the following ways in waste disposal (Acar and Gale 1986; Acar et al. 1989): (1) Dewatering of waste sludge slimes, dredged spoil by first concentrating the solid particles using electrophoresis and subsequent consolidation by electro-osmosis (Mitchell 1986), (2) Electro-osmotic flow barriers (Mitchell and Yeung 1991), (3) Leak detection systems for disposal facilities, (4) Injection of grouts to form barriers, (5) Provide nutrients for biodegrading microcosm, (6) Insitu generation of reactants such as hydrogen peroxide for cleanup and/or electrolysis of contaminants, and (7) Decontamination of soils and groundwater. Figure 4 conceptualizes electrokinetic clay barriers, waste plume diversion schemes, and electro-osmotic injection.

Insitu remediation methods often necessitate the use of hydraulic charge and recharge wells to permeate the decontaminating liquid or stabilization agent through the soil deposit, or to provide nutrients for the biodegrading microcosm. Although such systems may effectively be used in highly permeable soils, they become inefficient and uneconomical in low permeability silts and clayey deposits. Electrokinetic soil processing with open electrode configuration could also be used to achieve an efficient seepage and decontamination method in such soils.

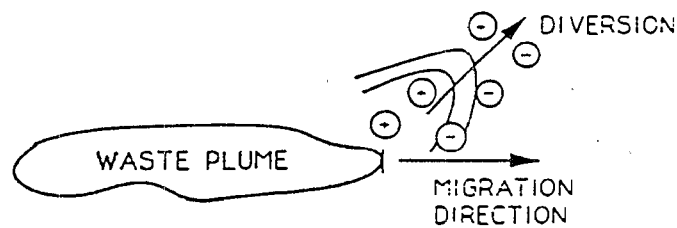
REMOVAL OF CONTAMINANTS BY ELECTROKINETICS

Upon application of low-level DC current (in the order of milliamps per cm^2 of electrode area) to the saturated porous medium, the following processes occur:

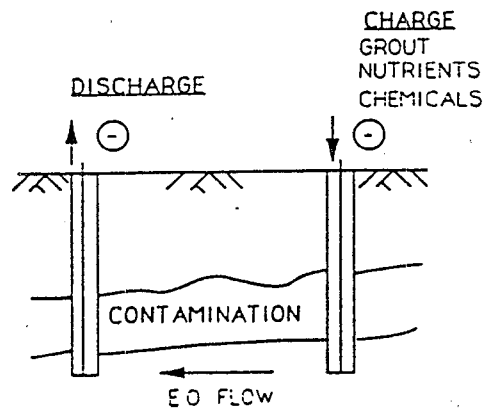
- (1) The water in the immediate vicinity of electrodes is electrolyzed. An acid front is generated at the anode while a base front is created at the cathode. Acar et al. (1989), Shapiro, et al. (1989) and Acar et al. (1990) formalize the development of these fronts. pH at the anode will drop to below 2.0 and will increase at the cathode to above 12.0.
- (2) The acid front will advance across the specimen in time towards the cathode by:
 - (a) advection of the pore fluid due to the prevailing electro-osmotic flow,



(a) Flow Barriers



(b) Plume Diversion Scheme



(c) Electro-osmotic Injection

Figure 2. Schematic View of Different Applications of Electrokinetic Phenomena in Remediation (Acar et al. 1989).

- (b) advection of the pore fluid due to any hydraulic potential differences,
- (c) diffusion due to concentration gradients,
- (d) migration due to the electrical gradients.

Development of these acid and base distributions and movement of ionic species are formalized by Acar, et al. (1991).

- (3) The migration, diffusion and advection will also result in movement of cations and anions to respective electrodes in the porous medium (Hamed et al. 1991; Mitchell and Yeung 1991).
- (4) The acid advancing across the specimen exchanges with adsorbed cations in the diffuse-double layer, resulting in their release into the pore fluid and advance towards the cathode by advection and diffusion (Hamed et al. 1991).
- (5) In case the generation of the acid front is not controlled at the anode, the electrolyte concentration inside the porous medium will gradually rise, resulting in increased conductivity in the vicinity of the anode, decrease in electro-osmotic flow (Hamed et al. 1991), and a corresponding decrease in bulk-flow movement by advection.
- (6) The decreased conductivity at the cathode region (possibly due to anion depletion and/or due to deposition of species as salts) will lead to an increase in voltage and an increase in energy expenditure (Hamed 1990). The chemistry at the anode and the cathode should ideally be controlled to achieve continued advection while providing sufficient H^+ ions for desorption of contaminants and/or solubilization of salts. This control is possible either by decreasing the current to levels where pH is at a desirable level or by frequent flushing at both ends by a fluid of controlled pH and chemistry.

REVIEW OF AVAILABLE DATA

Studies investigating removal of ions from soils by electro-osmosis are rare possibly due to difficulties in understanding the chemistry. Table 1 provides a synthesis and analysis of laboratory studies which reported some form of data related to ion removal from soils. One of the earlier studies is by Puri and Anand (1936) where leaching of Na^+ ions were detected in the effluent in electro-osmotic consolidation. Puri (1949) suggested that in electro-osmosis monovalent ions will move faster than divalent ions due to the former's higher dissociation from the clay surface. It is also noted that

Table 1. Analysis of laboratory data reported for removal of chemicals by electrokinetics

Soil Type/ Chemical	Concentration ($\mu\text{g/g}$)		Current Density and/or Voltage (mA/cm^2) or [V/cm]	Duration (hr)	Charge $\frac{\text{amp-hr}}{\text{m}^3}$	Energy kWh/m^3	Remarks
	Initial	Final					
1 Puri and Anand (1936) High pH Soil - Na^+	N/A	N/A	9.3-14.9 [20.0]	8 (inter- mittent)	N/A	N/A	A Bucher funnel was used in testing. The diameter was 18 in. Cathode is circular brass plate. Anode consists of five cylindrical bars arranged symmetrically along the circumference. Na normality of percolate increased up to 0.6 N. The effluent was 90% NaOH, 10% Na_2CO_3 .
2 Jacobs and Mortland (1959) 5% Bentonite/95% Sand Na-Ca Na-Ca-Mg Na-K Na Ca K	.59/.57 .44/.3/.4 .65/.41 0.78-1.11 0.86-1.0 0.79	0.0/(N/A) 0.0/(N/A) 0.0/(N/A) 0.0 .26-0.30 0.0	0.32-0.64 [N/A]	10-140	2-20	N/A	1-D tests. Cylindrical specimens ($D = 0.75$ in., $L = 1$ in.). Circular platinum electrodes. Rate of removal of monovalent ions were directly related to the amount remaining in the specimens. The rate of removal was in the order of $\text{Na}^+ > \text{K}^+ > \text{Mg}^{2+} > \text{Ca}^{2+}$. Na^+ was removed more efficiently than all other ions. Tests were discontinued when most Na^+ was removed. Concentrations reported are in symmetry units.
3 Krizek, et al. (1976) Slurry/Sediment No. 1 - Na K Ca $\text{NH}_3\text{-N}$ No. 2 - Na K Ca $\text{NH}_3\text{-N}$	320 7 65 138 360 15 340 172	330* 290 640 320 205 160 5800 456	[0.5] [1.0]	150 150	N/A N/A	20 65	Slurries ($w = 100 - 142\%$) from discharge pipes and contaminated bottom sediments are tested. Cylindrical 1-D consolidation tests ($D = 14$ cm, $L = 25$ cm). (*The concentrations are the initial and final effluent values.

Table 1 (continued)

Soil Type/ Chemical	Concentration ($\mu\text{g/g}$)		Current Density and/or Voltage (mA/cm^2) or (V/cm)	Duration (hr)	Charge $\frac{\text{amp}\cdot\text{hr}}{\text{m}^3}$	Energy kWh/m^3	Remarks
	Initial	Final					
4 Hamnet (1980) Silica Sand - NaCl Heavy Clay	3%	N/A	6.25-16.25 [0.6]	12-20	N/A	N/A	A 3-D laboratory model. 35 cm by 8 cm, with 5 cm depth. Carbon rods were used as electrodes. After 12 hours, concentration at anode was a third of the cathode side. The data shows movement of ions to respective electrodes.
5 Runnels and Larson (1986) Silty Sand - Cu(II)	617	290-543	0.01-0.05 [.165]	24-72	N/A	N/A	1-D tests. Cylindrical specimens ($D = 0.75$ in., $L = 6$ in.). Square platinum electrodes (1 in^2). Quartz sand washed with HCl to remove impurities.
6 Renauld and Probststein (1987) Kaolinite - Acetic Acid	0.5-1.3	N/A	1.47 [1.16]	6.7	328	11.5	1-D cylindrical specimens. 30 cm in length, 8 cm in width, and 5 cm in depth. Tests were conducted to assess electro-osmotic water transport efficiency. Efficiency increased with increasing concentration of acetic acid.
7 Thompson (1989) Ottawa Sand SiO_2 flour $\text{Cu}(\text{NO}_3)_2$	0.01 N	N/A	N/A [25]	336	N/A	N/A	A tubular, 3 section test set-up is used. The middle section contained the chemical in solution, the other two sections contained the soil specimen, and contaminant movement into the cathode section was monitored. Transport was a function of pH of the soil.
8 Lageman (1989) Peat Pb Cu Pottery Clay - Cu Fine Clayey Sand - Cd	9000 600 1000 275	2400 200 100 40	N/A N/A N/A N/A	N/A N/A N/A N/A	N/A N/A N/A N/A	101 101 25 198	Details of experiments are not available. From a presentation by Lageman (1990), it is understood that 1-D tests are conducted with rectangular electrodes. The pore fluid at anode/cathode compartment was flushed with a conditioning fluid intermittently in order to control the chemistry at the electrodes and sustain the advection in decontamination.

Table 1 (continued)

Soil Type/ Chemical	Concentration ($\mu\text{g/g}$)		Current Density and/or Voltage (mA/cm^2) or [V/cm]	Duration (hr)	Charge $\frac{\text{amp}\cdot\text{hr}}{\text{m}^3}$	Energy kWh/m^3	Remarks
	Initial	Final					
8 Lageman (1989) (cont.)							
Clay - As	300	30	N/A	N/A	N/A	207	
Fine Clayey Sand							
Cd	319	<1	N/A	N/A	N/A	54	
Cr	221	20					
Ni	227	34					
Pb	638	230					
Hg	334	110					
Cu	570	50					
Zn	937	180					
River Sludge							
Cd	10	5	N/A	N/A	N/A	180	
Cu	143	41					
Pb	172	80					
Ni	56	5					
Zn	901	54					
Cr	72	26					
Hg	0.50	0.20					
As	13	4.4					

Table 1 (continued)

Soil Type/ Chemical	Concentration ($\mu\text{g/g}$)		Current Density and/or Voltage (mA/cm^2) or (V/cm)	Duration (hr)	Charge $\frac{\text{amp}\cdot\text{hr}}{\text{m}^3}$	Energy kWh/m^3	Remarks
	Initial	Final					
9 Shapiro, et al. (1989)							
Phenol	450	<20	N/A	N/A	N/A	N/A	1.8 pore volumes of flow
	45	<10	N/A	N/A	N/A	N/A	1.2 pore volumes of flow
Acetic Acid	0.5 M	<6% of initial	0.035	N/A	N/A	N/A	1.4 pore volumes of flow
	0.1 M	<6% of initial	0.60	N/A	N/A	N/A	1.4 pore volumes of flow
							1-Dimensional tests are conducted. The effect of organic acid concentration on the degree of removal is studied.
10 Banerjee, et al. (1990)							
Silty/Silty Clay - Cr	2460	22	N/A [0.1-1.0]	24-168	N/A	N/A	Eight cylindrical 1-D tests were conducted on specimens brought from the field ($D = 5.1$ cm, $L = 2.5$ cm to 6.7 cm). Electrodes used were Ni-Cu wire mesh. Hydraulic and electrical potentials were applied simultaneously in order to facilitate removal.
	2156	12					
	870	50					
	704	19					
	642	22					
	532	37					
	234	3					
	148	10					
11 Hamed, J., Acar, Y. B., Gale, R. J. (1991)							
Georgia Kaolinite - Pb(II)	118-145	7-40	0.037 [≤ 2.5]	100-1285	362-2345	29-60	1-D tests. Cylindrical specimens ($D = 4$ in., $L = 4$ in. and 8 in.). Circular graphite electrodes. Initial conductivity of speci- mens 75-86 $\mu\text{S/cm}$. Rose up to 1000 $\mu\text{S/cm}$ at the anode, dropped to 22 $\mu\text{S/cm}$ at the cathode after the process. Pb(II) movement and electrochemistry across the specimens are reported.

Table 1 (continued)

Soil Type/ Chemical	Concentration ($\mu\text{g/g}$)		Current Density and/or Voltage (mA/cm^2) or [V/cm]	Duration (hr)	Charge $\frac{\text{amp}\cdot\text{hr}}{\text{m}^3}$	Energy kWh/m^3	Remarks
	Initial	Final					
12 Mitchell and Yeung (1991)	N/A	N/A	N/A	N/A	N/A	N/A	Investigated the feasibility of using electrokinetics to stop migration of contaminants. Electric field slowed down the migration of cations and increased the movement of anions. k_e did not display a marked change by an increase in backpressure, molding water content and dry density.
13 Acar, Y. B., Li, H., Gale, R. J. (1992) Georgia Kaolinite - Phenol	500	25-75	0.037 [≤ 4.0]	100-140	N/A	12-28	Adsorbed phenol was removed by the process. The breakthrough curve did not display retardation.
14 Bruell, C. J., Segal, B. A., Walsh, T. M. (1991) EPK Kaolin		Removal %	N/A [0.4 v/cm]				Cylindrical specimens of 7.6 cm in diameter and 30.5 cm in length were tested. Specimens were loaded with the contaminant. Iron electrodes were used. Writers noted that removal was a function of time of processing. Contaminant removal front in time is presented.
Benzene	1780	15-27		72-120	N/A	N/A	
TCE	1100	15-25		72-120			
Toluene	515	15		45			
m-xylene	146	19		120			
Hexane	10	13		96			
Iso-octane	2.4	7		600			

movement of ions was low at low water contents and significantly increases by an increase in water content.

Jacobs and Mortland (1959) demonstrated that Na^+ , K^+ , Mg^{++} and Ca^{++} ions can be leached out of Wyoming bentonite by electro-osmosis. The amount of the ions removed versus the electro-osmotic flow in bentonite-sand mixtures demonstrates that monovalent ions (K^+ , Na^+) are removed at a faster rate than the divalent ions (Ca^{+2}).

Krizek, et al. (1976) showed that the soluble ions content substantially increased in effluent in electro-osmotic consolidation of polluted dredgings, while they also noted that heavy metals were not found in the effluent during the period they applied the process. Hamed, et al. (1991) show that it is necessary to wait until the acid front flushes across the specimen in order to see any heavy metal ions or depositions on the cathode or the effluent.

Hamnet (1980) studied the reclamation of agricultural soils by removal of unwanted salts by electro-osmosis. Hamnet's tests demonstrated that Na^+ ions move toward the cathode, while Cl^- and SO_3^{-2} ions move toward the anode.

Shmakin (1985) notes that the method has been used in the Soviet Union since the early 1970's as a method for concentrating metals and exploring for minerals in deep soil deposits. Shmakin (1985) mentions its use in prospecting for Cu, Ni, Co, Au. A porous ceramic probe with HNO_3 is placed at the cathode. The migrating ions are extracted with this probe. The quantity of the extracted metal at the cathode and the rate of accumulation is correlated with the composition of the ore and the distance of the sampling locations to the ores.

The potential of the technique in waste remediation resulted in initiation of several recent studies. Runnels and Larson (1986) have investigated the potential use of electromigration to remove contaminants from groundwater. The amount of copper removed increased with processing time (total charge passed). However, the current efficiency decreased as the processing time increased, possibly due to the increase in conductivity as noted by Hamed, et al. (1991).

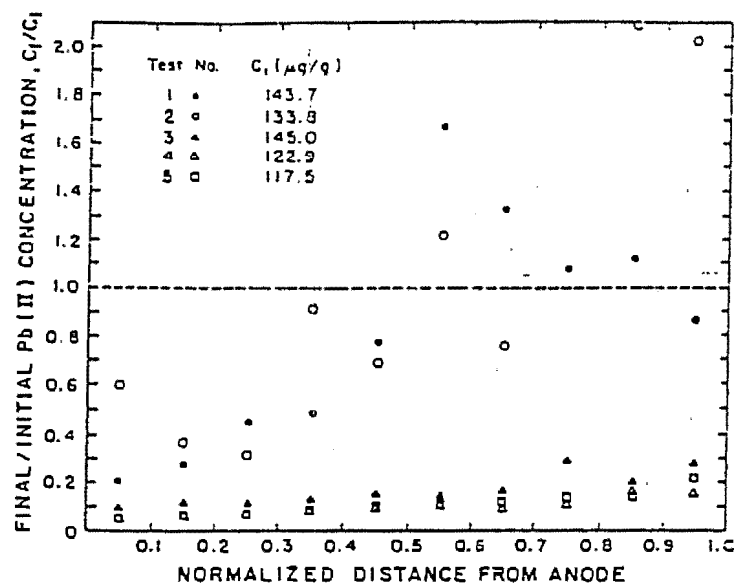
Renauld and Probst (1987) investigated the change in the electro-osmotic water transport efficiency of kaolinite specimens loaded with acetic acid and sodium chloride. This study indicated that the current efficiency increased with higher concentrations of this weak, organic acid. This implies organic acids may increase the efficiency of electrokinetic soil processing.

A better understanding of the chemistry in electrokinetic soil processing is achieved through studies at LSU. Putnam (1988) investigated the development of acid/base distributions in electro-osmosis. Acar et al. (1989), Acar et al. (1990) and Acar, et al. (1991) present the theory for acid/base distributions in electro-osmosis and compare the predictions of this model with the results of the tests conducted by Putnam (1988). A good correlation was noted. This theory and the model provide a preliminary description of the movement of different species in electrokinetics. The significance of the acid base distributions in electrokinetic soil processing is further displayed in studies reported by Shapiro, et al. (1989). These studies demonstrate the movement of the acid front by advection and diffusion and provides the fundamental basis of the chemistry developed during the process.

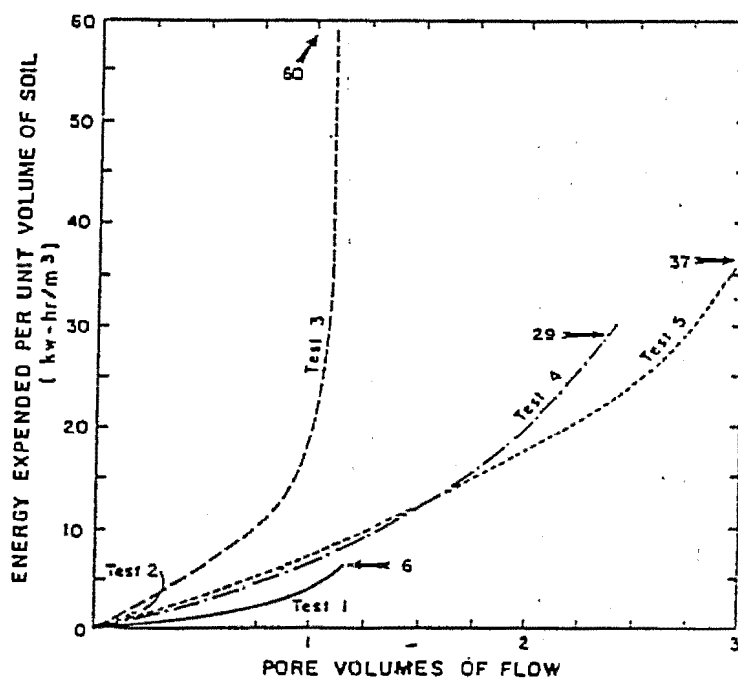
A comprehensive subsequent study on removal of Pb(II) from kaolinite is reported by Hamed, et al. (1991). Kaolinite specimens were loaded with Pb(II) at 118 $\mu\text{g/g}$ to 145 $\mu\text{g/g}$ of dry kaolinite, below the cation exchange capacity of this mineral. As presented in Figure 3, electro-osmosis removed 75 to 95 percent of Pb(II) across the test specimens. The study clearly demonstrated that the removal was due to migration and advection of the acid front generated at the anode by the primary electrolysis reaction. The energy used in the study to decontaminate the specimens was 29 to 60 kWh per cubic meter of soil processed. This study also explains the complicated electrochemistry associated with the process. An interesting finding of this study is electroplating of Pb(II) at the carbon cathode.

Further studies investigating removal of Cd(II) and Cr(III) are also reported by Hamed (1990). Similar results are obtained. Hamed (1990) investigates the effect of increased concentration and current density on the efficiency of the removal process. Higher current densities result in as efficient a removal as in lower current densities while the energy requirement and the cost of processing increases exponentially. The increased energy requirement was found to be due to increased production of H^+ ions and their introduction into the specimen. Other laboratory studies conducted by Lageman (1989) and Banerjee, et al. (1990) further substantiate the applicability of the technique to a wide range of inorganic contaminants and soils.

The applicability of the technique to removing organic contaminants is investigated in studies at LSU. Acar, et al. (1992) report phenol removal from saturated kaolinite using the technique. In this study, kaolinite specimens were loaded by 500 ppm phenol below the phenol adsorption capacity of this mineral. The breakthrough of phenol upon application of the direct current is presented in Figure 4a. The process removed 85 to 95% of the adsorbed phenol. The energy used in removal of phenol was

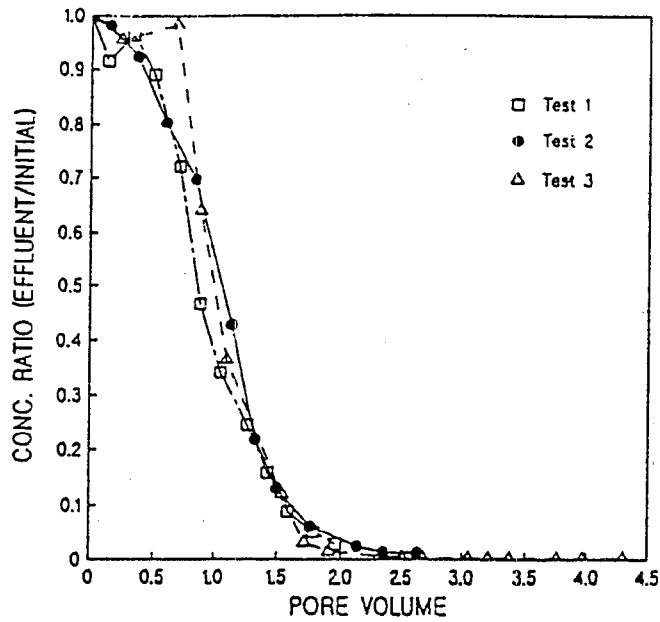


(a) Pb(II) Removal

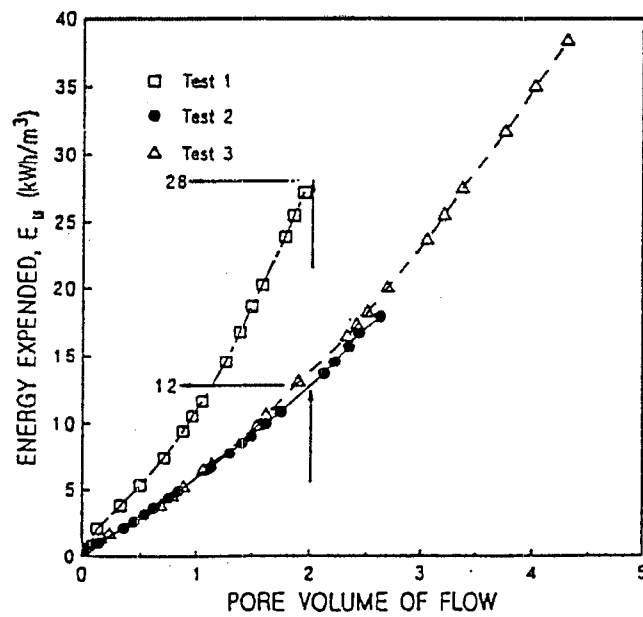


(b) Energy Expenditure

Figure 3. Pb(II) Removal from Kaolinite and Corresponding Energy Expenditure (Hamed et al. 1991).



(a) Breakthrough of Phenol



(b) Energy Expenditure in Phenol Removal

Figure 4. Phenol Removal by Electrokinetic Soil Processing (Acar et al. 1992).

13 kWh to 18 kWh per cubic meter of soil processed (Figure 4b). One very interesting aspect of these tests is the breakthrough achieved in two pore volumes of flow (Figure 4a). Electrokinetic processing did not result in any retardation due to the desorption mechanism. It is hypothesized that this is both due to the movement of the diffuse double layer toward the cathode and advance of the acid front replacing the adsorbed phenol. Bruell, et al. (1991) report removal of the BTEX compounds and trichloroethylene loaded on kaolinite specimens by electro-osmosis. Figure 5 demonstrates that application of DC current resulted in removal of benzene by the electrokinetic processes. These experimental model results display breakthrough curves similar to that encountered in advective-dispersive movement of reactive species (Acar and Haider 1990). However, the process cannot be described only by the analytical model describing transport of contaminants. It involves changing chemistry across the specimen together with coupling of electrical, hydraulic and chemical gradients.

While the above laboratory studies display the feasibility of using electro-osmosis to decontaminate soils, limited field studies are available.

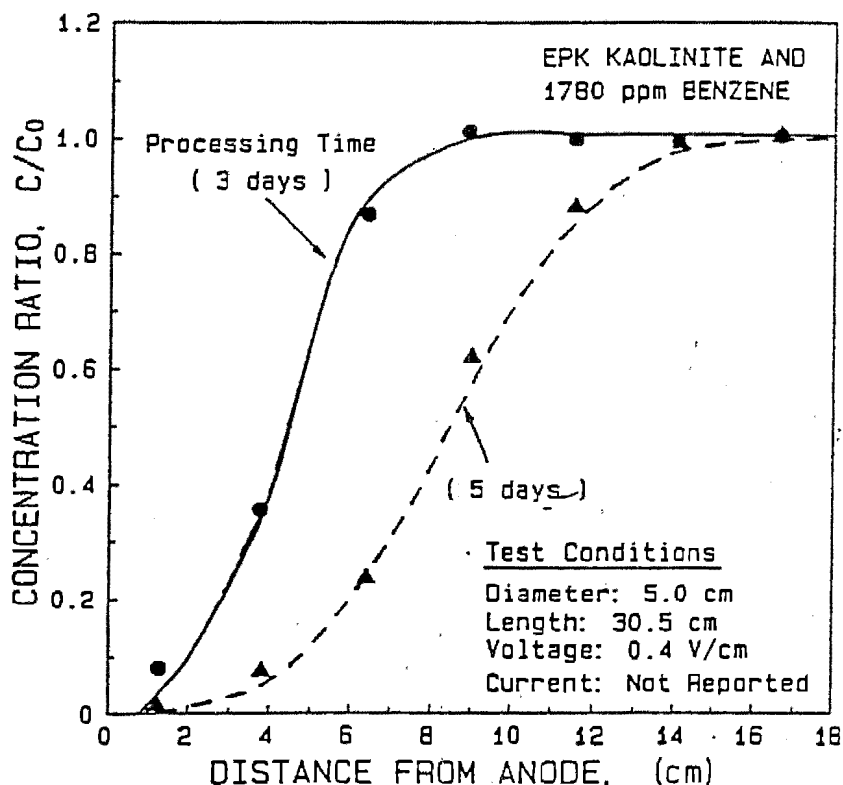


Figure 5. Electrokinetic Removal Rate of Benzene from Kaolinite (redrawn from Bruell, et al. 1991).

Table 2 provides a synthesis of field tests investigating and/or reporting some form of chemical removal from soils. Segall, et al. (1980) present the chemical characteristics of the water accumulated at the electrodes in electro-osmotic dewatering of dredged soil. Their study discovered that:

- (1) There was a significant increase in heavy metals and organic materials in electro-osmosis effluent above that recorded in the original leachate. The concentrations of zinc, lead, mercury and arsenic were especially high,
- (2) Total organic carbon content of the effluent was two orders of magnitude higher than the original leachate. It is postulated that highly alkaline conditions resulted in dissolution and release of the organic material. Pesticides came out at the cathode.

Case and Cutshall (1979) describe a field study for control of radionuclide migration in soil by application of DC current. This study demonstrates that it is possible to migrate radionuclides with the technique. Recent laboratory studies at LSU indicate that uranium at an activity of 1,000 pCi/gm can be removed from kaolinite by the process. Lageman (1989) reports the results of field studies conducted in the Netherlands to decontaminate soils by electrokinetic soil processing. Figure 6 presents a schematic diagram of the reported field process. An electrode fluid conditioning and purification system is noted. The conditioning is for the control of the influent/effluent chemistry, while purification (such as ion exchange resin columns) is for removing any excess ions in the effluent.

A recent study investigating the application of the process to decontaminate a chromium site is also reported by Banerjee, et al. (1990). The results of that study are inconclusive as the investigators monitored only the effluent concentration and removal across the electrodes was not scrutinized. Studies at LSU indicate that unless the processing is continued until the acid front flushes across the electrodes and neutralizes the base generated at the cathode, any conclusion based only on the effluent concentration of an inorganic chemical would not be supported. In earlier stages of the process, the contaminant is removed from the anode section and is often precipitated in the cathode section. Further processing and movement of the acid front to the cathode is one fundamental mechanism by which the contaminants are removed. Furthermore, in evaluation of the feasibility of the technique, the behavior of the contaminant at different pH environments should also be considered. For example, Cr(III) will precipitate below a pH of 3.0. Therefore, the processing parameters (current density and/or influent pH) should be kept at a level which the contaminant would not be allowed to precipitate.

Table 2. Synthesis of field data reported for removal of chemicals by electrokinetics

Soil Type/ Chemical	Concentration ($\mu\text{g/g}$)		Current Density and/or Voltage (mA/cm^2) or (V/cm)	Duration (hr)	Energy kWh/m^3	Remarks
	Initial	Final				
1. Puri and Anand (1936) High pH Soil - NaOH	4.8	2.8	1.35 [2.44]	6	N/A	An area of 4.5 m x 4.5 m was first trenched all around, 1.05 m in depth and 0.30 m in width. Anode and cathode were laid horizontally within this area. Anode was a shot of iron, 0.9 m x 1.8 m laid at top. Cathode was a perforated iron tube, 0.10 cm in diameter and 1.8 m long laid at 0.3 m depth. The concentrations reported are for the exchangeable Na in the top 7.5 cm of the soil.
2. Case and Cutshall (1979) Alluvial deposits - ^{90}Sr	8	50	0.3 [0.05]	5,352	N/A	An area of 11 m by 5 m was investigated. 1.7 m stainless steel rods were driven in an arc-plus-center point array. The arc consisting of 25 anodes and a central cathode. The concentrations reported are for the effluent in a monitoring well.
3. Segall, et al. (1980) Dredged Material Cd, Zn, Pb, As, Fe Na K OH ⁻ HCO ₃ ⁻¹ Organic Nitrogen Ammonia Nitrogen TOC	<1 6150 350 0 0 4 67 3	0.2-20 16300 510 5950 979 15 128 2000	[0.01-1.0]	N/A	N/A	Concentrations noted are for the effluent in electro-osmotic consolidation of dredged material compared to that of water leached specimens. The distance between electrodes is 3-5 m.

Table 2 (continued)

Soil Type/ Chemical	Concentration ($\mu\text{g/g}$)		Current Density and/or Voltage (mA/cm^2) or [V/cm]	Duration (hr)	Energy kWh/m^3	Remarks
	Initial	Final				
4. Lageman (1989)						
Sandy Clay - Zn	70-5120	30-4470	0.8 [0.4-0.2]	1344	287	An area of 15 m by 6 m is studied. Contamination depth: 0.40 m. Temperature rose from 12°C to 40°C. Conductivity increased from 2000 $\mu\text{s/cm}$ to 4000 $\mu\text{s/cm}$. Voltage gradient decreased. 2 cathodes (vertical) at 0.5 m depth. 33 anodes (vertical), 3 rows at 1.0 m depth. Distances: cathode-anode = 1.5 m; anode-anode = 1.5 m.
Heavy Clay - As	90-385	20-240	0.4 [0.4-0.2]	1200	270	An area of 10 m by 10 m was studied within a depth of 2 m. Cathodes (vertical), 2 rows: 1 row at 0.5 m depth; 1 row at 1.5 m depth. 36 anodes (vertical), 3 rows at 2 m depth; 2 rows of 14; 1 row of 8. Distances: cathode-anode = 3 m; anode-anode = 1.5 m. Temperature rose from 7°C to 50°C.
Dredged Sediment						
Pb	340-500	90-300	N/A	430	N/A	An area of 70 m by 3 m was studied to a depth of 0.2 m to 0.5 m. Cathode is laid horizontal, anode (vertical). Cathode-anode 3 m; anode-anode 2 m.
Cu	35-1150	15-580				
5. Banerjee, et al. (1990)						
Silt/Silty Clay - Cr	N/A	N/A	2-4 [0.2-0.24]	<72	Na	Nine field experiments were conducted in an array of electrodes. Combined Hydraulic and electrical potentials were applied. Steel reinforcing bars were used and replaced after each experiment. The results are inconclusive.

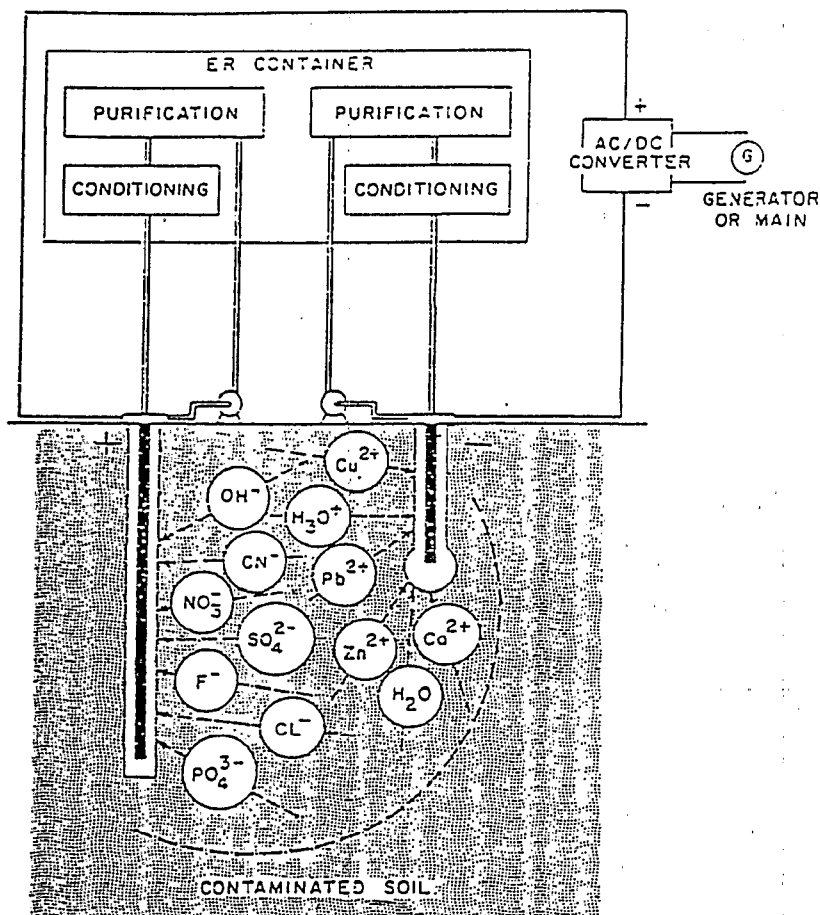


Figure 6. A Schematic Diagram of the Field System Reported by Lageman (1989).

The laboratory studies reported by Hamnet (1980), Runnels and Larson (1986), Lageman (1989), Shapiro, et al. (1989), Acar et al. (1990), Hamed (1990), Hamed et al. (1991), and Acar et al. (1992) together with the pilot-scale field studies of Lageman (1989) display the feasibility of using the process and commercialize in site remediation. Further pilot-scale studies are necessary to improve the technology and establish the necessary field remediation scheme for different site conditions and chemistry.

ENGINEERING IMPLICATIONS

The above review of the present state of knowledge on electrokinetic soil remediation indicates that:

- (1) Type of Soil: The process results in movement of ions in sandy to clayey soils. High water content, low activity soils at low pore fluid electrolyte concentrations will result in higher electro-osmotic efficiencies.
- (2) Type and Concentration of Contaminants: Most available data is on ionic forms of inorganic cations, and some radionuclides (^{90}Sr) and acetic acid. There exists data demonstrating removal at levels of up to 10,000 ppm of Cu(II) and 5,000 ppm of Pb(II) . As concentrations of contaminants (ionic) increase, removal should be mostly by migration as advection (electro-osmotic flow) will substantially decrease. At lower concentrations, both advection and migration will be acting. Recent laboratory studies demonstrate that it is feasible to remove phenol (500 ppm) BTEX compounds (benzene, toluene, ethylene, xylene, and trichloroethylene) from kaolinite by the technique. All current data is on concentration of these organic chemicals below their water solubility limits. There exists the need to investigate the feasibility of the technique at higher concentrations.

Data regarding acid/base distributions indicate that salts (such as PbO) may also dissolve and migrate due to the advancing acid front. However, there is no factual data to validate this hypothesis.

- (3) Mixture of Contaminants: The data indicates that the process also works on a mixture of contaminants (Lageman, 1989). Monovalent ions may be removed at a higher rate than higher valence ions.
- (4) Saturation: Mitchell and Yeung (1991) present data regarding the effect of saturation on k_e . k_e did not change significantly in specimens compacted at different molding moisture contents. This data suggests that the process may be applicable in partially saturated soils.
- (5) Depths: The review of literature indicates that there should not be a depth limitation in the process beyond practical problems that may be encountered.
- (6) Type of Electrodes: Inert electrodes such as graphite, carbon or platinum should be used at anode in order to avoid introducing secondary corrosion products into the soil mass. Open electrodes allow control of influent and effluent chemistry. It should be recognized that some ions will be electroplated on the cathode or they may be precipitated close to the cathode.
- (7) Electrode Configuration: The electrodes can be placed horizontally or vertically. It is noted that the electrical potential gradients

generated due to different electrode arrangements will affect the flow conditions and hence the removal efficiency. The gradients will significantly change by electrode configurations and the depth of individual electrodes relative to the counter electrode.

- (8) Electrode Spacing: Spacing will depend upon the type and level of contamination and the selected current/voltage regime. A substantial decrease in efficiency of the process may result due to increases in temperature when higher voltage gradients are generated.
- (9) Current Level: The current level reported is in the order of milliamps per square cm of electrode area (0.01 to 1.0 mA/cm²). It can be varied to monitor the influent pH level at the anode and to control the rate of decontamination.
- (10) Duration: Process should be continued until the desired removal is achieved. The remediation duration will be site specific. It is necessary to wait until the acid front generated at the anode will advance to the cathode.
- (11) Effluent/Influent Chemistry: It is possible to control the efficiency by controlling the pH and the chemistry of the effluent and the influent. Several alternatives are available: (a) to decrease the current to a level where less H⁺ ions are generated, (b) to flush the anode and/or cathode by a fluid of known chemistry (e.g., introducing acid at the cathode will decrease the voltage gradients substantially), and (c) placement of an acidic ion exchange resin.
- (12) Chemistry Subsequent to the Process: The porous medium will become acidic upon completion of the process. The medium will return to original conditions by diffusion of the acidic pore fluid to the surrounding medium. Cathode effluents may require post-chemical treatments (such as ion exchange resin columns for inorganic contaminants) to achieve concentration of contaminants. Cathodes may necessitate treatment to remove the electroplated contaminants.

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NATO/CCMS Guest Speaker:

Douglas Ammon, United States

United States "Clean Sites"

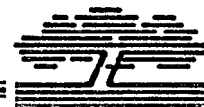
Presentation of
Clean Sites

to the

NATO/CCMS PILOT STUDY

DEMONSTRATION OF REMEDIAL ACTION TECHNOLOGIES

NOVEMBER 1990

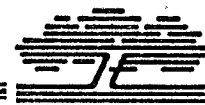


CLEAN SITES

This is Clean Sites

- **A non-profit institution devoted solely to helping speed up the effective cleanup of hazardous waste**
- **A neutral and objective third party**
 - ◆ **Working with involved parties**
 - ◆ **Toward voluntary private settlements and site cleanups**
- **Five functional groups:**

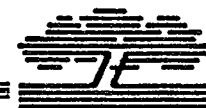
Settlement Services	Public Policy & Education
Technical Affairs	Administration
Project Management	



CLEAN SITES

Clean Sites' Background

- **Creation involved industrial and environmental groups, EPA, and Justice Department**
- **Formal establishment May 31, 1984**
- **General contributions from 140 companies, 8 foundations, 50 individuals**
- **Site-specific cost reimbursement**
- **Staffed by approximately 50 experienced professionals**



Clean Sites' Board of Directors

Mr. Peter A.A. Berle
President
National Audubon Society

Hon. Douglas M. Costle
Dean, Vermont Law School

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Professor Emeritus
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Partner, Resources for
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Founding President, Clean
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Vice President
Bechtel Corporation

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Chairman, World Wildlife Fund
& The Conservation Foundation

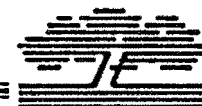
Mr. Hans A. Wolf, Vice Chairman
& Chief Administrative Officer
Syntex Corporation



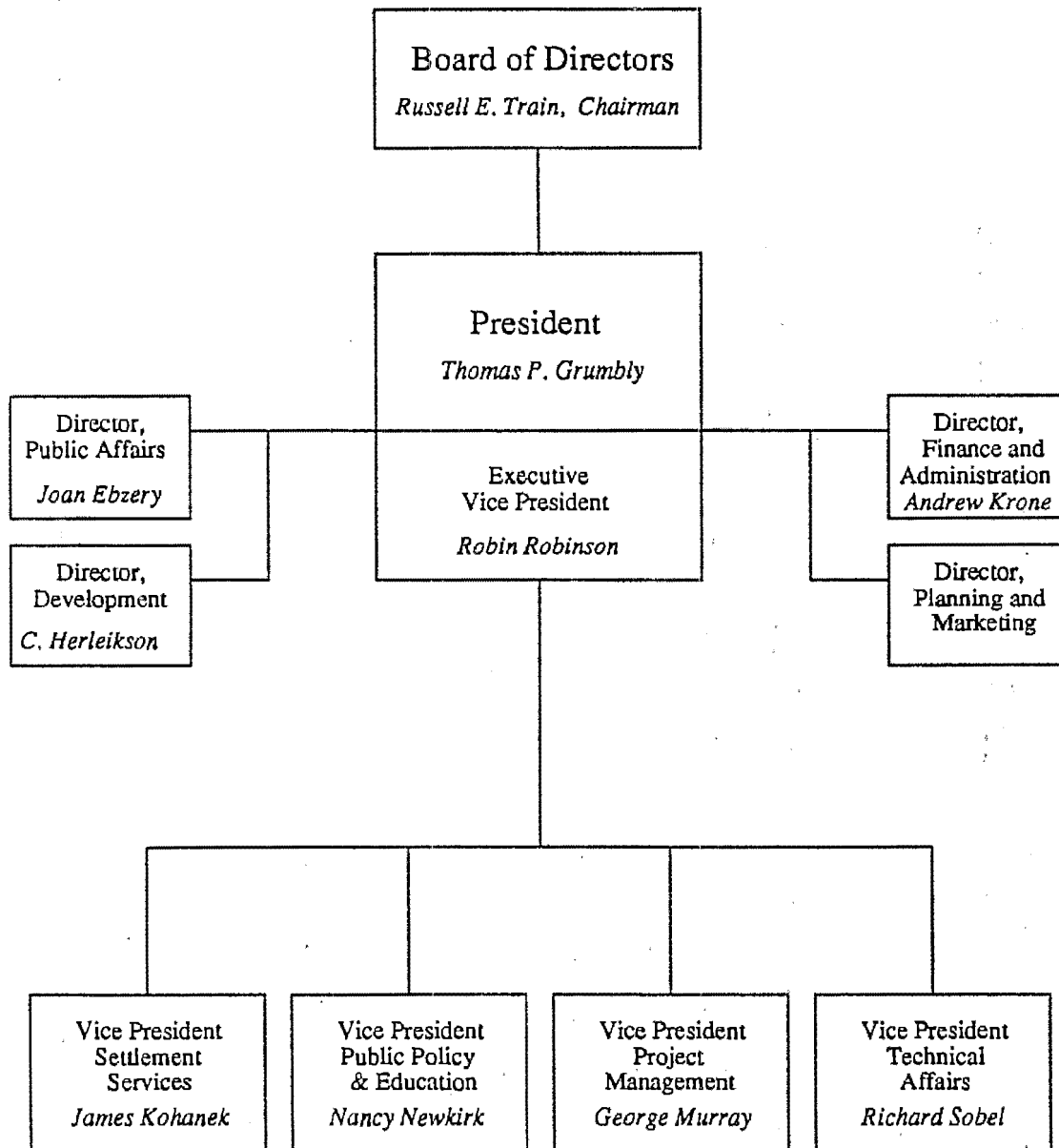
CLEAN SITES

Why Parties Use Clean Sites

- Sole mission is facilitating hazardous waste cleanup
- Highly qualified and experienced staff
- Provides a complete set of services to support cleanup of waste sites
- Assisted at over 60 waste sites
- Prepared more than 25 cost allocations
- Credibility and fairness
- Access, if necessary, to unique Board of Directors and Scientific and Technical Advisory Board
- Sensitive to needs of the parties

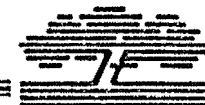


Clean Sites Organizational Structure

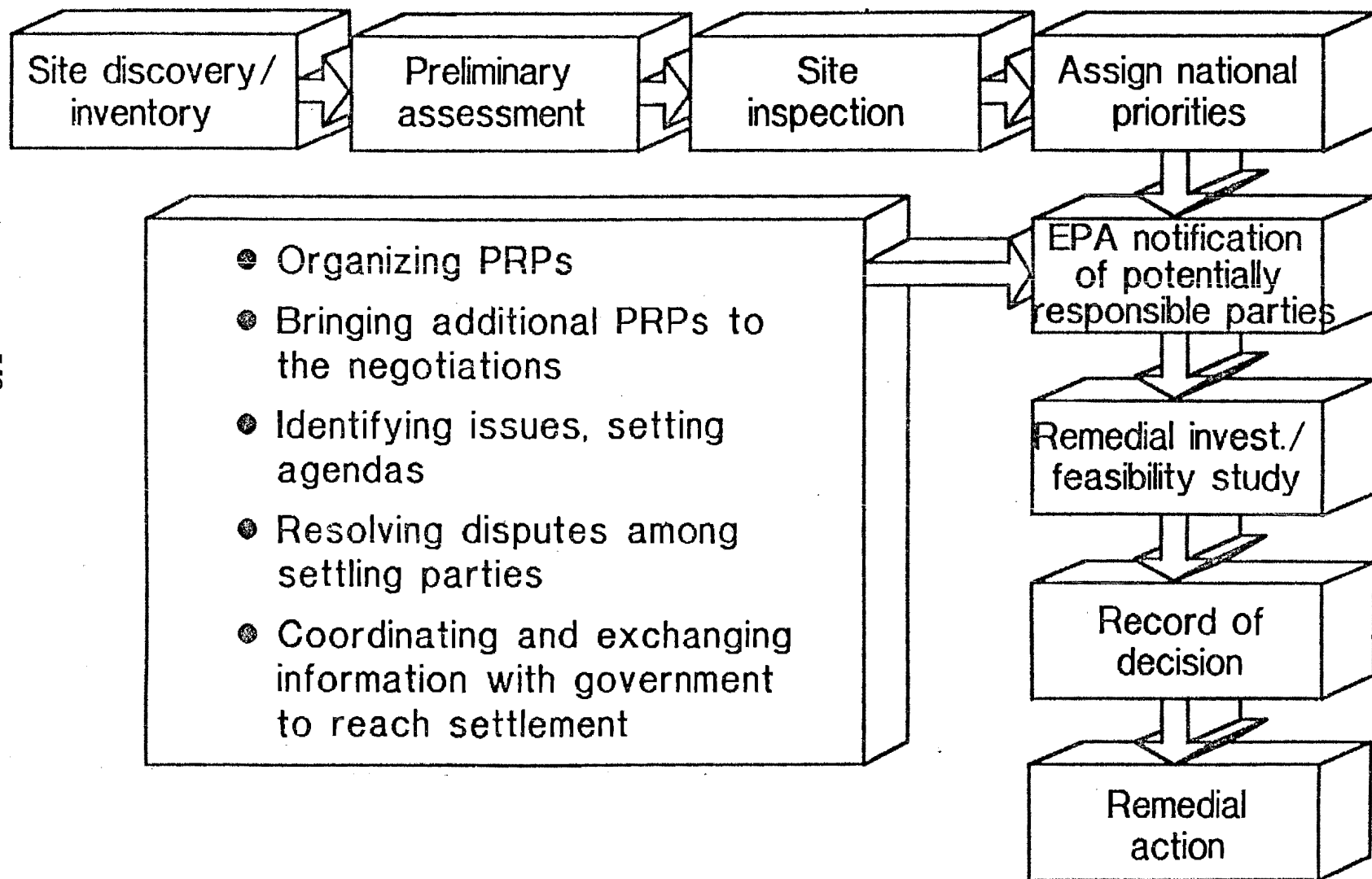


Unique Role of Clean Sites

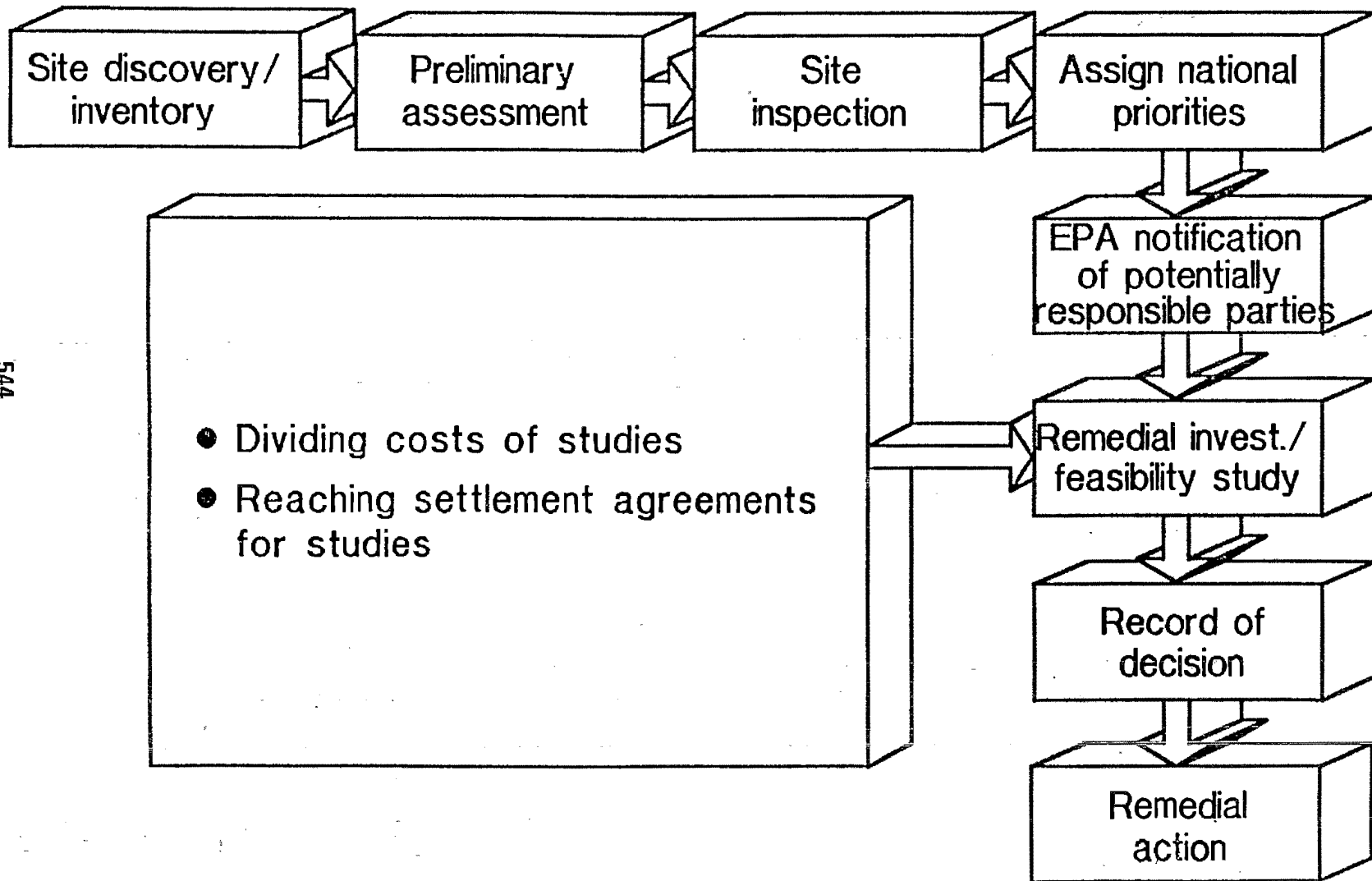
- Settlement Services
 - ✦ Dispute Resolution and Cost Allocation
- Technical Assistance
- Project Management
- Services to Government Agencies
- Funds Management
- Information Services
- Public Policy and Education Activities



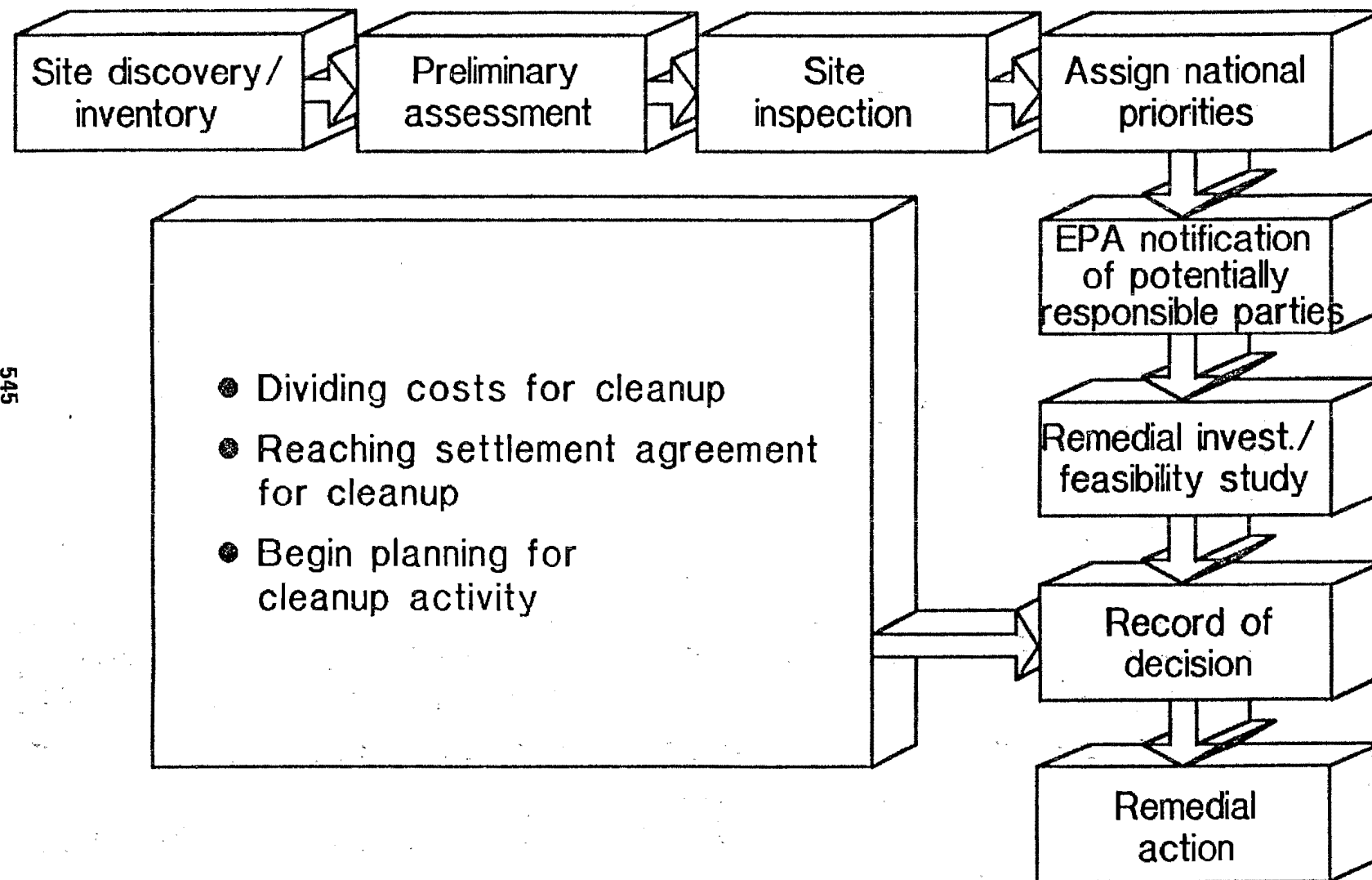
The Role of Clean Sites



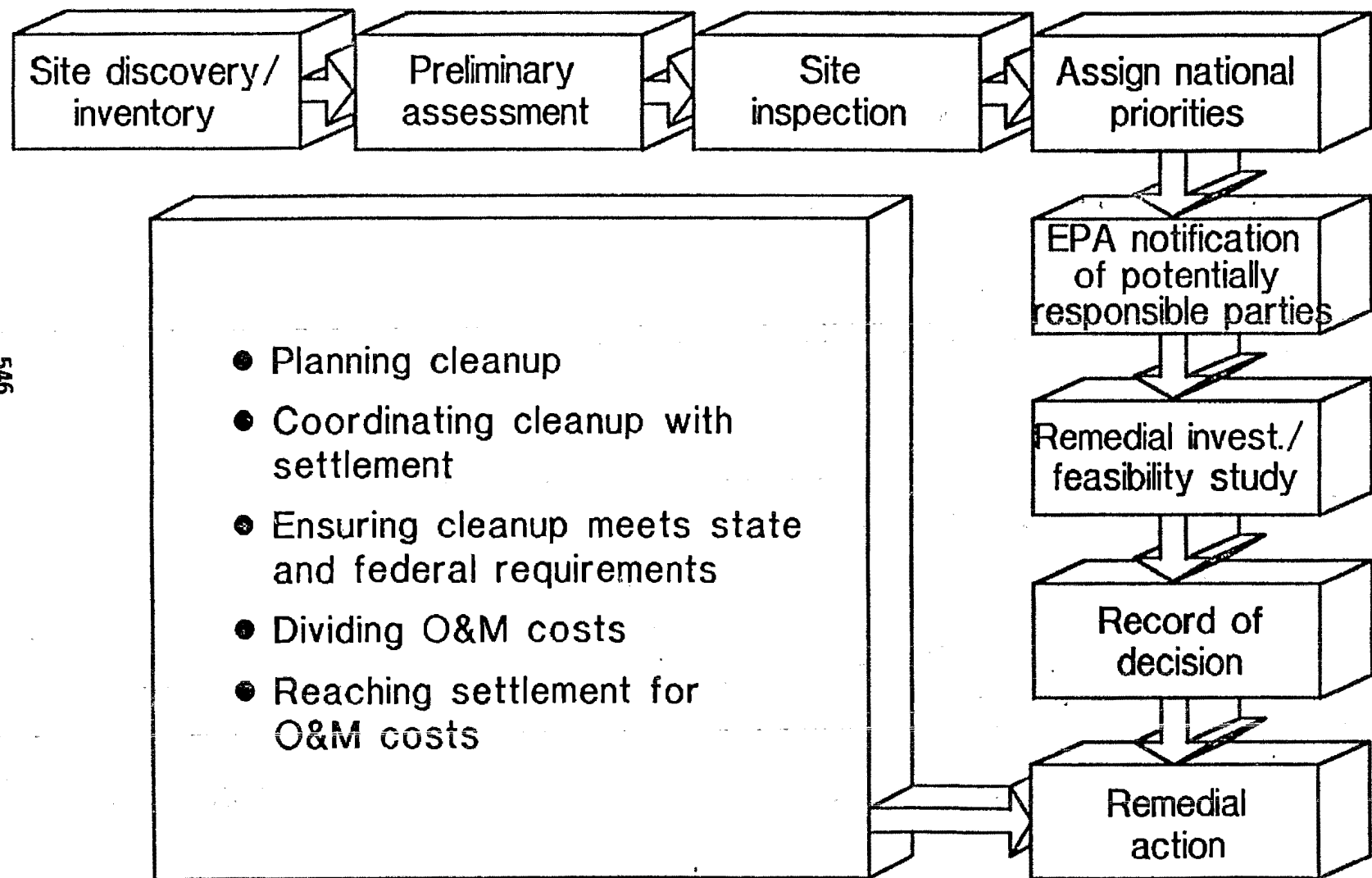
The Role of Clean Sites



The Role of Clean Sites



The Role of Clean Sites



Clean Sites' Activities Do Address Some Major Impediments to Cleanup

Impediment

- Fund is being depleted; transaction costs are inordinately high
- Cleanup is a long and expensive undertaking

Clean Sites' Role

- Encourage private party cleanup and facilitate settlements (dispute resolution)
- Bring more parties into the process (cost allocation/dispute resolution)
- Control costs of cleanup without sacrificing environmental protection (project management)

Clean Sites' Activities Do Address Some Major Impediments to Cleanup

Impediment

- Public has little faith the government is protecting them
- Private party and EPA site studies suffer a "credibility gap"
- Some believe benefits of Superfund are not worth the cost

Clean Sites' Role

- Inform the community about site activities throughout the study and cleanup process (project management)
- Oversight of private party studies to assure they meet EPA requirements and are technically sound (technical assistance)
- Provide information to all parties about ways to speed cleanup without undermining the goals of Superfund (public policy and education)

CLEAN SITES'

PUBLIC INTEREST ACTIVITIES

- Evaluate the current EPA Superfund remedy selection process and make recommendations for change.
- Provide free assistance to citizens to help them obtain Superfund Technical Assistance Grants from EPA.
- Conduct educational seminars entitled Successfully Resolving Multi-Party Hazardous Waste Disputes, providing scholarships to government officials to facilitate their attendance.
- Analyze the impact of hazardous waste disposal on the rural poor for the Ford Foundation.
- Authored a paper entitled "Making Superfund Work", an analysis of and recommendations for the Superfund program, which was presented to the Bush transition team.



CLEAN SITES

CLEAN SITES' **PUBLIC INTEREST ACTIVITIES**

continued

- **Conduct the Community Industry Forum - a series of facilitated dialogue sessions between citizens and PRPs involved at Superfund sites.**
- **Facilitate policy dialogues between EPA and other interest groups involved in the superfund process.**
- **Perform initial mediation and facilitation services at selected Superfund sites free of charge to help organize PRP groups and to facilitate settlement.**

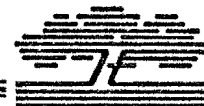


CLEAN SITES

Public Policy and Education Activities

(continued)

- Provide policy, legal and technical support to help state agencies develop their own Superfund programs.
- Develop (in conjunction with the Environmental Law Institute) a State Superfund Information Network to facilitate sharing of information between states.
- Facilitate policy dialogues between EPA and other interest groups involved in the Superfund process.
- Perform initial mediation and facilitation services at selected Superfund sites free of charge to help organize PRP groups and to facilitate settlement.



CLEAN SITES

CLEAN SITES' ASSISTANCE TO STATE SUPERFUND PROGRAMS

Provide policy, technical, legal support to State hazardous waste cleanup programs. Clean Sites helps states develop:

- **Regulations**
- **Site cleanup related procedures**
- **Settlement, enforcement and administrative policies**
- **Program management tools**
- **Training courses**



CLEAN SITES

Technical Affairs

- **Technical staff manages and reviews site cleanup studies, advises responsible parties and their contractors**
- **Goal is to ensure quality and content in studies as needed by EPA to select appropriate remedy**
- **Assist parties to resolve technical disputes**
- **Technical Advisory Board, whose members have international stature in their speciality areas, supports in-house staff**
- **Conducting an independent analysis of the Superfund remedy selection process under EPA grant**



CLEAN SITES

Scientific & Technical Advisory Board

Gilbert S. Omenn, (Chairman)

Dean, School of Public Health and
Community Medicine,
University of Washington

John Doull

Professor of Pharmacology and
Toxicology University of Kansas
Medical Center

Gary F. Bennett,

Professor of Biochemical Engineering
Department of Chemical Engineering
The University of Toledo

Serge Gratch

Professor of Mechanical Engineering
GMI Engineering and Management
Institute

Kenneth E. Biglane

Independent Environmental Consultant
Formerly, Director of Hazardous Response
Support at U.S. EPA

Perry McCarty

Professor and Past Chairman
Department of Civil Engineering
Stanford University

David W. Miller

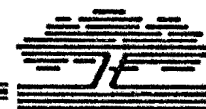
President and Chief Operating Officer
Geraghty and Miller, Inc.



CLEAN SITES

Technical Services

- **Oversight of Remedial Investigations and Feasibility Studies**
- **Manage Remedial Designs**
- **Technical Advice Involving Allocations Issues**
- **Peer Review to Ensure Accuracy and Objectivity**
- **Technical Assistance to all Clean Sites personnel**

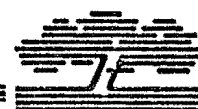


CLEAN SITES

Technical Services

continued

- **Technical and Data Mediation**
- **Ensure Consistency with NCP for RI/FS**
- **Site Assessment for Real Estate Transfers**
- **Preparation of Guidance Documents**



Project Management

- Assist responsible parties in carrying out the many tasks required for cleanups
- Adhere strictly to regulations; work effectively with EPA and State agencies
- Assign an on-site project team (for large jobs) and/or headquarters staff to monitor, control, and report
- Provide contracting, scheduling, cost estimating and control services
- Community relations activities are an integral part of project management



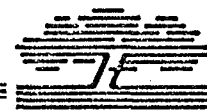
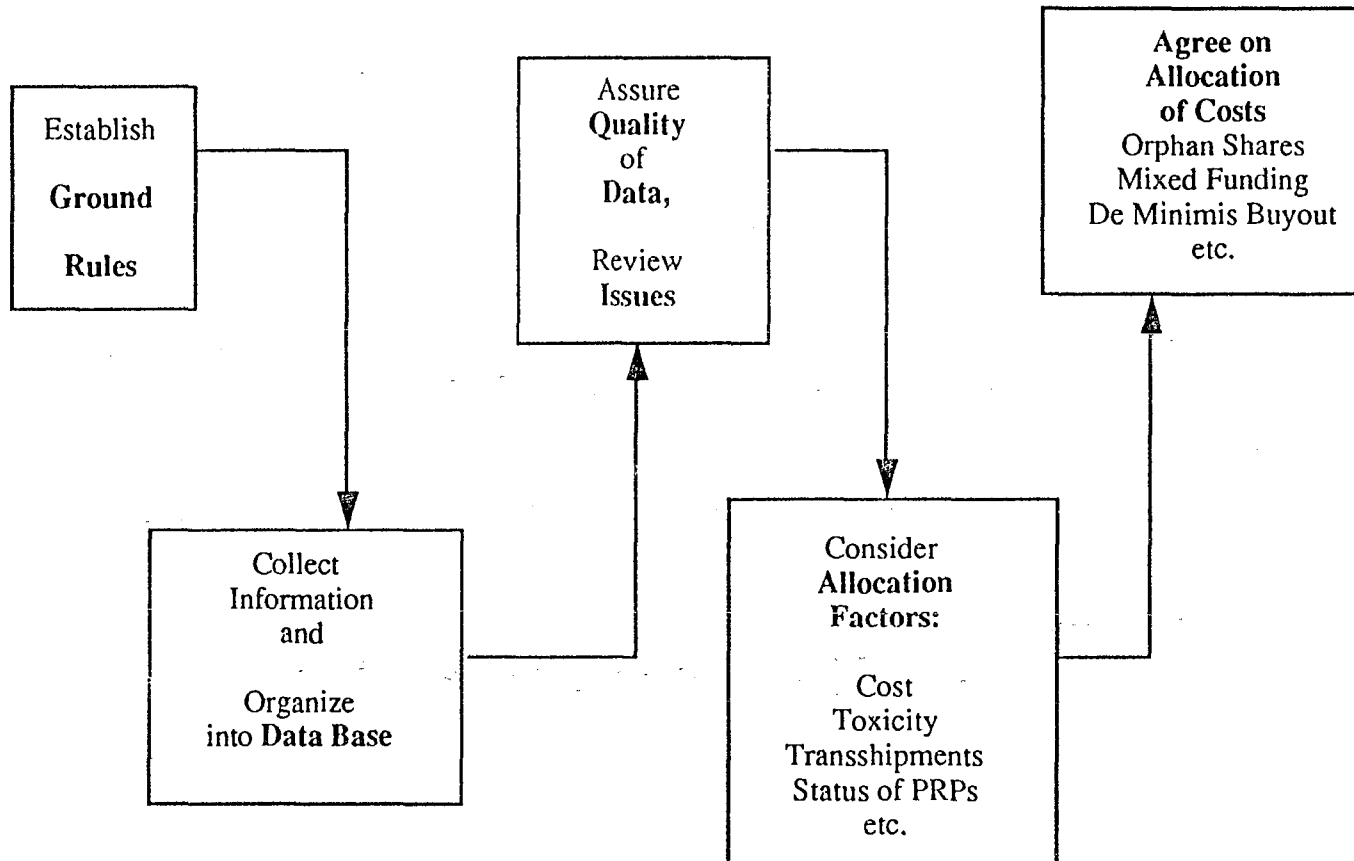
CLEAN SITES

Fund Management

- **Manages and disburses funds for PRP Groups and Steering Committees**
- **Over \$20 million under management at eight sites**
- **Integrated with Project Management and Site Committee activities**



COST ALLOCATION PROCESS



Technical Dispute Resolution

- **Neville Chemical Co., CA**
(Technical Mediation)
- **Magnolia Street, CA**
**(Independent experts to allocate
responsibility for contamination plume)**
- **NPL Site, TX**
**(Blue Ribbon Panel to review
RI/FS, EA)**



CLEAN SITES

SETTLEMENT SERVICES

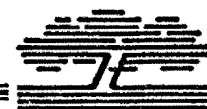
- **Organizing and Increasing Participation of Parties**
- **Facilitate Communication Among All Involved Parties**
- **Identification, Assessment and Prioritization of Issues**
- **Mediating and Resolving Disputes Among Participants**
- **Coordinating and Exchanging Information with the Government**
- **Allocation of Costs Among Parties**
- **Administrative Support**



CLEAN SITES

Settlement Services

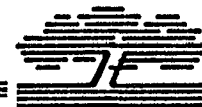
- **Assists in the organization of PRPs**
- **Encourages the involvement of new PRPs in the Allocation process**
- **Assists parties in defining issues and designing the process**
- **Develops and evaluates innovative approaches**
- **Collects and analyzes data**
- **Provides computerized data base management services**
- **Provides dispute resolution services, if desired**



CLEAN SITES

Settlement Services Experience

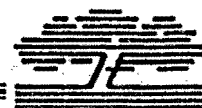
- **Helped bring about final settlement agreements**
 - ◆ **For twenty sites**
 - ◆ **For removals, remedial actions, or cleanup studies**
 - ◆ **Cleanup activities value of \$193 million**
- **Helped divide cleanup costs among responsible parties**
 - ◆ **For twenty-five sites**
 - ◆ **Collection and analysis, verification and array of data in computerized data base form**
 - ◆ **Highly qualified professional staff**



CLEAN SITES

Allocation Experience

- **Successfully developed allocations with large number of PRPs (over 800) and diverse interests**
 - ◆ **large and small companies**
 - ◆ **municipalities, federal agencies**
 - ◆ **transporters, owner/operators**



CLEAN SITES

Allocation Experience

continued

- Instrumental in assisting development of mixed funding and de minimis buyouts as part of allocation
- Developed information to list names of additional PRPs
- Developed allocations using
 - ◆ non-volumetric measures such as toxicity, mobility, processing considerations, cost of remedial activity
 - ◆ volumetric measures
 - ◆ other considerations such as transshipment, recycling, BTU values, past ownership of facility



CLEAN SITES

NATO/CCMS Guest Speaker:

Roy C. Herndon, United States

Environmental Contamination in Eastern and Central Europe

Presentation to the NATO/CCMS Conference

NATO Committee on the Challenges of a Modern Society

*Pilot Study on the Demonstration of Remedial Action Technologies
for Contaminated Land and Groundwater*

**"Overview of Environmental Contamination
in Eastern and Central Europe: A Focus on Hungary"**

Presented by:

Dr. Roy C. Herndon, Co-Director

Joint Center for Hungarian-American Environmental Research
Florida State University

and

Dr. Peter I. Richter, Co-Director

Joint Center for Hungarian-American Environmental Research
Technical University of Budapest

Prepared in Cooperation with *Dr. Donald Alexander*
U.S. Department of Energy

Washington, D.C.
November 19, 1991

I. INTRODUCTION AND BACKGROUND MATERIAL

This presentation was prepared for the NATO/CCMS Conference which was held on November 18-22, 1991 in Washington, D.C. This NATO Committee on the Challenges of a Modern Society focuses on the demonstration of remedial action technologies for contaminated land and groundwater, a challenging issue for both NATO and non-NATO countries alike. This presentation addresses environmental contamination in central and eastern Europe (with a focus on Hungary) and serves to illustrate the extent and nature of current environmental problems in this region of the world. The presentation is given by Dr. Roy C. Herndon of the Florida State University (FSU) and Dr. Peter I. Richter of the Technical University of Budapest (TUB), and consists of four parts:

- ◆ Introduction and Background Material;
- ◆ Overview of Environmental Contamination in the Region: A Focus on Hungary;
- ◆ Sources of Environmental Contamination in the Region: A Focus on Hungary; and
- ◆ Priorities for Addressing Near-term Environmental Problems in the Region.

Drs. Herndon and Richter have worked jointly on environmental research for over 10 years and co-direct the joint Center for Hungarian-American Environmental Research which is administered at FSU and which involves participation by the faculties of both FSU and the TUB. This joint environmental center conducts research on common environmental problems (e.g., the

restoration/remediation of contaminated land and groundwater), facilitates the transfer of environmental technologies through joint environmental research and training, and facilitates the exchange of research faculty and graduate students (including postdoctoral students) from academic institutions in Hungary with universities in the U.S.

One of the current activities of this joint center is the 1992 International Symposium on Environmental Contamination in Central and Eastern Europe (*Budapest '92*) which will be held in Budapest, Hungary on October 12-16, 1992. Approximately 500-600 participants are expected to attend the symposium. This symposium will include presentations by academic and agency researchers as well as demonstrations and exhibitions by providers of environmental goods and services. A major emphasis of the symposium will be on evaluating technology transfer and exchange opportunities related to environmental technologies. The response to the first symposium announcement, which was distributed more than one year before the date of the symposium, has been very strong. To-date, over 500 responses to the first announcement have been received from all over the world and include academic researchers, agency researchers, and private companies and individuals who have indicated a desire to participate at the symposium. The second announcement for the symposium will be distributed within the next few months.

This joint center is designed to work cooperatively with a variety of organizations which are involved with environmental problems in the region, including the Regional Environmental Center

for Central and Eastern Europe (REC). The REC was established to accomplish a variety of regional environmental objectives, including:

- ◆ collecting and disseminating environmental data and information;
- ◆ facilitating institutional development, in the context of environmental decision-making within the region;
- ◆ serving as an environmental clearinghouse for the region; and
- ◆ providing education and training on environmental issues.

II. OVERVIEW OF ENVIRONMENTAL CONTAMINATION IN THE REGION: A FOCUS ON HUNGARY

Over the last 40-50 years, extensive environmental contamination has occurred throughout central and eastern Europe. In the absence of effective controls for the management of air emissions, hazardous and industrial waste, sewage and wastewater there are significant environmental problems that have occurred throughout the region. As a result, there are extensive acute and chronic health problems in the region that can be attributed to environmental contamination.

These adverse health and environmental problems are associated with contaminants originating from a variety of sources, including emissions from automobiles and smokestacks, and the mismanagement of hazardous wastes. Many urban and industrialized areas in the region have problems ranging from serious smog-related incidents to relatively high rates of lung cancer.

as a result of exposures to airborne contaminants. Power plant emissions have also adversely affected significant areas of forestland throughout the region. There are little data available that can be used to effectively characterize the extent and nature of these problems or to identify and prioritize the major sites of contamination. However, there is little doubt that these problems are extensive and will require a great deal of regional as well as international cooperation in order to effectively manage these problems within the nearterm and longterm.

Surface waters have become contaminated with a variety of substances, including heavy metals. Much of the surface water in the region is unsuitable for drinking and, in many instances, is also unsuitable for agricultural uses. Groundwater in many areas of the region has also become contaminated to the point where it is not safe to consume.

In urban and heavily-industrialized areas, soils are significantly burdened with a variety of contaminants as a result of the longterm dumping of hazardous wastes. In many cases, farmlands and associated surface waters have become contaminated with a variety of industrial wastes.

One-third of Poland's 38 million people live in "ecological hazard areas" according to the Polish Academy of Sciences. In Poland, more than 600,000 acres of woodland have been damaged by acid rain. Also in Poland, approximately 80 percent of surface waters are considered undrinkable, and approximately 33 percent are not fit for industrial uses. In Crackow, Poland, approximately 60

percent of the food grown is considered unfit for human consumption because of high levels of heavy metals in the soil.

Half of Czechoslovakia's drinking water fails to meet the country's own health standards. In Teplica, Czechoslovakia, air pollution from coal mines and power plants keeps school children inside their homes for one month during the winter and forces parents to send the children to schools in cleaner towns for up to six months each year. In Czechoslovakia, approximately 1,000,000 acres of woodland have been damaged by acid rain believed to be attributed to power plant emissions.

The City of Dorog is considered to have some of the more extensive environmental problems in Hungary. It has been characterized as a city so contaminated that the Peace Corps determined that the environmental problems are so serious there that it was judged to be too risky to place a Peace Corps volunteer in the city. One in ten Hungarians lack access to safe drinking water and are reported to die as a result of pollution-related diseases.

Bronchitis and eczema reportedly affect half of the children in eastern Germany's industrialized areas. Industrial waste has contaminated nearly 70 percent of Bulgaria's farmland and approximately 65 percent of its river water. Romania's largest city, Bucharest, has no sewage treatment plants and elsewhere in Romania most of the country's sewage treatment plants do not work properly. In Copsa Mica, Romania most structures within a 15-mile radius are blackened by soot from factories.

III. SOURCES OF ENVIRONMENTAL CONTAMINATION IN THE REGION: A FOCUS ON HUNGARY

Automobile emissions generated by two-cycle engines which burn diesel and petrol produce significant amounts of carbon monoxide, nitrogen oxide (diesel), hydrocarbons, and lead. Air pollution problems from automobile emissions are, in some areas, significant even in the countryside. For example, it is estimated that Hungary's motor vehicle fleet produces the following annual pollution loads into the atmosphere: one million tons of carbon monoxide; 130,000 tons of hydrocarbons; 120,000 nitrogen oxides; 36,000 tons of particulates; and over 500 tons of lead and lead compounds. Measurements at congested road intersections in Budapest also demonstrated that concentrations of carbon monoxide, lead and formaldehyde often exceed permissible levels.

Industrial sources generated by chemical plants, paper mills, mining, metallurgical plants, oil refineries, foundries and other industrial operations introduce large quantities of airborne and waterborne contaminants into the environments of countries in central and eastern Europe. In Hungary, the raw material, extractive industries are the most environmentally harmful. For example, the mining of coal, uranium ore and bauxite have adversely affected groundwater quality and have severely ruined extensive areas of Hungary's landscape. Both metallurgical operations and power plants generate relatively large quantities of air pollutants, particularly sulfur dioxide and solid particulates. These activities also generate relatively large quantities of contaminated wastewater which typically is discharged untreated. The chemical industry in the

region produces a variety of hazardous pollutants (e.g., gases, alkali wastes, pigments, solvents, toxic sludges and solutions).

Agricultural sources of contamination generate waste streams that consist of fertilizers, pesticides (including phosphates and nitrates), and farm animal wastes which can cause longterm contamination of the groundwater and promote the growth of algae in rivers and lakes. With the growth of mechanized agricultural production has also come a prodigious increase in the use of fertilizers. In particular, the use of nitrogen-based fertilizers has contributed to nutrient leaching in certain areas of the region as well as a rise in the nitrate levels in groundwater, endangering drinking water supplies. Herbicides, fungicides and insecticides are applied in some areas of the region in doses that are believed to pose unacceptable environmental risks. These substances can pollute the ecosphere and endanger the equilibrium of ecosystems by adversely affecting the foodchain.

Solid and hazardous waste-related sources of contamination are believed to have severely damaged groundwater, surface water and soils throughout the region. Despite the adoption of hazardous waste regulatory programs in some central and eastern European countries in the early 1980's, little has been done to protect human health and the environment from exposure to hazardous waste. It is reported that heavy metal-laced industrial wastes have tainted much of central and eastern Europe's waters and foodchain. For example, in the area of Poland's Upper Silesia, soil concentrations of lead, cadmium, and other heavy metals have been found to exceed acceptable limits. In a recent study, 35 percent of the children in

this area of Poland showed evidence of lead poisoning. In addition to the discharge of untreated hazardous and industrial wastes into surface waters, holding ponds, and other typically unlined and unmonitored impoundments, few precautions or proper management practices are utilized throughout the region.

As an additional source of pollution within the region, transboundary sources have adversely affected air, water, and land. Shared water and air resources in the region are typically not managed effectively so as to prevent the movement of pollution generated in one country to another country. For water resources, the areas of greatest concern are the Black and Baltic Seas and the Odra, Vistula, Elbe and Danube Rivers. For air resources, the area of greatest concern is "the sulfur triangle" - which is an area associated with the intersections of eastern Germany, Poland and Czechoslovakia. This area has experienced substantial declines in forest stands with resulting severe adverse consequences for the landscape and the water balance within the region. One additional type of transboundary pollution involves the transportation and ultimate mismanagement of hazardous wastes between countries in the region as well as from sources outside of the region.

IV. PRIORITIES FOR ADDRESSING NEAR-TERM ENVIRONMENTAL PROBLEMS IN THE REGION

Given the extent, nature and complexity of the environmental contamination problems in central and eastern Europe, it is important to identify priorities for addressing the many and varied

aspects of these problems. This is particularly important in the context of the prevailing regional economic conditions. The following priorities for addressing near-term environmental problems of the region have been suggested:

- ◆ Economic Reform - economic reform is considered to be a prerequisite for the implementation of successful environmental protection programs in the region. Key elements of economic reform include privatization and the development of property rights, restructuring and modernization of industry, elimination of state subsidies to industry, and the use of market-determined prices for energy and natural resources.
- ◆ Environmental Regulation and Enforcement - an important component of implementing effective environmental management systems in the region should include the adoption of appropriate environmental legislation that is consistent with the environmental standards and regulations of the European Community and other western countries, and that is implemented in conjunction with properly-funded and effective enforcement programs.
- ◆ Environmental Education and Public Awareness - environmental education and public awareness activities should be conducted at all levels of education and professional training. It was also suggested that, using mass media and other appropriate mechanisms, public awareness of environmental problems and proper management practices should be heightened.
- ◆ Scientific/Technological Development and Exchanges - research as well as technology transfer and exchange activities should be prioritized and focused in the near-term on solving practical environmental contamination problems. These practical solutions should result in incremental improvements in environmental conditions and/or management in the region that are consistent with the available resources and economic constraints of the individual countries.

- ◆ Regional and International Cooperation - regional and international cooperation for addressing the near-term environmental problems facing the region will be necessary for establishing effective institutional management systems for controlling air, water and soil contamination and for remediating existing environmental sites in the region. Organizations such as the Regional Environmental Center for Central and Eastern Europe (Budapest), the Commission on European Communities, the European Bank for Reconstruction and Development, the European Environmental Agency, the World Bank, the World Health Organization and other international organizations can play an important role in facilitating regional and international cooperation among the countries in the region.

In addition to regional and international cooperation, it will also be important to identify appropriate technologies that can be used for addressing specific near-term environmental problems in the region. These technologies relate to both the preventative (control technology) aspects as well as remedial aspects of these problems. Appropriate categories of technologies include:

- ◆ reclamation technologies for land and water;
- ◆ pollution control technologies for air and water; and
- ◆ solid and hazardous waste treatment and disposal technologies.

NATO/CCMS Guest Speaker:

Gregory Ondich, United States

The Use of Innovative Treatment Technologies in Remediating Waste

THE USE OF INNOVATIVE TREATMENT TECHNOLOGIES
IN REMEDIATING HAZARDOUS WASTES

by

Gregory G. Ondich
Acting Director
Waste Minimization, Destruction and Disposal Research Division
U. S. Environmental Protection Agency
Cincinnati, Ohio

for presentation at
The Second International NATO/CCMS Meeting on the Demonstration
of Remedial Action Technologies for Contaminated Land and Ground Water
The Netherlands
November 7-11, 1988

U. S. Hazardous Waste Programs

Eight years ago the U. S. Congress enacted the Comprehensive Environmental Response, Compensation and Liability Act of 1980, frequently referred to as "Superfund" or "CERCLA." This law was created in response to the discovery of numerous uncontrolled and abandoned dumpsites throughout the United States and the lack of funding and authority under existing national laws to clean up such sites. CERCLA provided the U.S. federal government for the first time with resources (\$1.5 billion over five years) and authority to respond to uncontrolled releases of hazardous wastes or materials from any facility. In addition to funding, CERCLA established a method for imposing liability on parties responsible for these dumpsites.

In addition to CERCLA, the Resource Conservation and Recovery Act (RCRA) and its 1984 amendments are intended to prevent the creation of problem sites through stringent controls on ongoing waste management, to reduce the land disposal of hazardous wastes and to encourage the use of waste minimization practices. Together the Superfund and RCRA legislation form the core for the U.S. programs to address hazardous waste problems, both past, present and future. Each of these legislative

mandates creates opportunities for the use of innovative treatment technologies in remediating hazardous wastes. The United States (U.S.) nearly decade-long experience with the cleanup and management of hazardous wastes has shown that simple containment of wastes in the land - with clay caps and subsurface walls - fails to protect human health and the environment from the dangers associated with hazardous waste.¹

RCRA Best Demonstrated Available Technology (BDAT)

Despite this early recognition of the significant role of land disposal at problem hazardous waste sites, Superfund cleanups throughout the early years of the program continued to be based on re-land disposing of wastes dug up at these sites. In the 1984 reauthorization of RCRA, the U.S. Congress mandated restrictions which prohibit the continued land disposal of untreated hazardous wastes beyond specified dates. The statute requires EPA to set "levels or methods of treatment which substantially reduce the likelihood of migration of hazardous constituents from the waste so that short-term and long-term threats to human health and the environment are minimized."²

The restrictions established by the 1984 RCRA Amendments are significant and carry strict timetable dates. These so-called land ban restrictions set up a 5-year program to establish treatment standards that wastes must meet before being land disposed. A timetable for each group is given below.

Land Ban Restrictions Timetable	
Dioxins and Solvents	November 8, 1986
California List (Metals and Cyanides, Corrosives, Halogenated Organics)	July 8, 1987
First-Third of Remaining Hazardous Wastes	August 8, 1988
Second-Third of Remaining Hazardous Wastes	June 8, 1989
All Hazardous Wastes	May 8, 1990

The RCRA legislation requires mandatory notification of waste generation and the manifesting of waste shipments. These requirements and the permits required for storage, treatment, and disposal facilities have created cradle-to-grave control of these wastes. This waste management approach has created an opportunity for the development of adequate and cost effective treatment methods. For many of the wastes generated, a process to adequately treat them cost-effectively or that has sufficient capacity to handle the waste volume is absent. This technology vacuum provides a great incentive and opportunity to develop and market new technologies.

As a result of the 1984 RCRA Amendments, EPA will establish a performance level of treatment based on the best demonstrated available technology (BDAT) identified for hazardous constituents. These treatment levels will be monitored by measuring the concentration level of the hazardous constituents in the waste or treatment residual or an extract of the residual. Ultimately, the RCRA BDAT requirements will promote the use of innovative technologies by those waste generators who are looking for more cost effective methods of treatment than existing technologies.

In addition to authorizing very stringent treatment and disposal regulations, the 1984 RCRA Amendments also stated that the U.S. top waste management priority was a redirection towards "waste minimization" as a preferential strategy for encouraging improvement in environmental quality. The legislation states:

"The Congress hereby declares it to be the national policy of the United States that, wherever feasible, the generation of hazardous waste is to be reduced or eliminated as expeditiously as possible. Waste that is nevertheless generated should be treated, stored, or disposed of so as to minimize the present and future threat to human health and the environment".²

This waste minimization requirement will foster the development of innovative technologies that are not convenient "end-of-the-pipe" treatment approaches.

Looking beyond "end-of-the-pipe" treatment also has many benefits in solving pollution transformation problems. Some treatment technologies, while solving one waste management problem, may create others. Air pollution control devices or wastewater treatment plants can prevent wastes from going into the air and water, but the toxic ash and sludges removed from these systems constitute enormous hazardous solid waste problems requiring attention. Solid wastes deposited in landfills or deep wells can become water pollution problems; evaporation from ponds and lagoons can turn solid or liquid wastes into air pollution problems. Likewise, some waste management facilities, such as landfills to bury wastes or incinerators to destroy them, are facing growing local public opposition to siting proposals.³

Defining Waste Minimization

Waste minimization means the reduction, to the extent feasible, of any solid or hazardous waste that is generated or subsequently treated, stored or disposed of. Reducing the generation of hazardous wastes can be achieved in many ways. Process chemistry can be changed. Potential waste streams can be recycled within a manufacturing process or back into the process. Process technology and/or equipment can be modified to produce products more efficiently, resulting in less waste. Plant operations, i.e., "house-keeping" methods can be changed or controlled to produce fewer and smaller waste streams of less waste in general. Changes in raw materials (feedstocks) can lead to fewer waste streams or less-hazardous waste streams, and changes in the end products from manufacturing operations can, in some instances, be made so as to affect the types and quantities of wastes emitted. The early

introduction of these and other waste reduction techniques into broad commercial practice is one of the objectives of the EPA Waste Minimization Research Program.⁴

In order to carry out the intention of the RCRA Amendments to reduce the generation of hazardous waste in the U.S., the EPA has developed a multi-faceted non-regulatory hazardous waste minimization program. This program includes innovative technology evaluations, plant and/or process assessments, technology transfer activities and extensive communications with industry, states, universities and the general public.

There is encouraging news regarding the study of waste minimization practices in the U.S. chemical industry. After three years of intensive research into the hazardous waste minimization practices of 29 U.S. organic chemical plants, INFORM, a non-profit U.S. research organization, found reports of 44 innovative waste reduction practices. These practices involved a variety of process, product, equipment and operational changes that substantially reduced or eliminated individual chemicals in waste streams at the plants. To the extent that INFORM was able to document the actual impact of the practices, it was found they prevented the generation of at least seven million pounds of hazardous chemical wastes and saved companies nearly \$1 million annually in reduced raw material and waste disposal costs. These 44 practices taken together suggest the range of possibilities that exist for the more than 1,000 U.S. organic chemical plants to reduce wastes at the sources.³

Land Ban Restrictions

In May, 1988, EPA proposed rules for the "first-third" of listed RCRA wastes that will be affected by the RCRA Amendments land disposal restric-

tions. Land disposal restrictions on "second-third" and "final-third" wastes will be phased in over the next two years.

As stated earlier the 1984 RCRA amendments require EPA to restrict land disposal of all hazardous wastes by 1990. Source reduction and waste recovery (recycling), respectively, are the preferred EPA waste management practices with treatment and land disposal following in this hierarchy. One example of this preference for waste reduction and recovery is the EPA requirement for metals recovery of electric-arc-furnace dust from emission-control devices at steel mills.⁵

The EPA requirement in the May, 1988 proposal was for waste generators to treat first-third wastes prior to land disposal to reduce volume, hazardous constituency and mobility. EPA's proposed treatment standards recommend that generators use the best demonstrated available technology (BDAT) to treat wastes. The standards also require generators to achieve specific toxicity concentrations, which vary by waste. Incineration and stabilization were two commonly recommended BDATs in the proposed rule on first-third wastes.

These proposed EPA rules do not preclude use of other waste-treatment technologies. However if those processes cannot produce the same toxicity reductions achieved by BDAT, the wastes cannot be land disposed.⁶

Superfund Innovative Technology Evaluation (SITE) Program

The growing concern about on-going Superfund cleanups that favored containment caused significant debate when the Superfund program was scheduled for Congressional reauthorization in 1985. Reliable data on the performance and cost of new and innovative treatment technologies were not yet available for hazardous wastes and/or substances. Thus,

passed, one important provision was for EPA to establish an "Alternate and Innovative Research and Demonstration Program."

In response to SARA, EPA has established the SITE program to:

- ° accelerate the development, demonstration, and use of new or innovative treatment technologies and
- ° demonstrate and evaluate new, innovative measurement and monitoring technologies.⁷

In Superfund's nearly eight year history, it has been evident that a premium must be placed on the use of permanent treatment technologies in conducting response actions. Continued use of inherently temporary and potentially unreliable methods such as land disposal or containment can be expensive and inefficient over the long run because of the recurring need to monitor and correct disposal/containment facilities. While some alternative treatment methods are coming into use, overall the development of new treatment technologies has proceeded very slowly.

Just as in the RCRA BDAT program when the terms "demonstrated" and "available" needed to be defined, so too in the SITE program "alternative" and "innovative" needed definition. To be considered a "demonstrated" treatment technology for purposes of the RCRA regulations, a full-scale facility must be known to be in operation for the waste or similar wastes. Likewise, an "available" treatment technology must meet several criteria:

1. "It does not present a greater total risk than land disposal;
2. A proprietary or patented process can be purchased from the proprietor; and
3. the process must be able to substantially reduce the toxicity or migration of hazardous constituents."⁸

SARA defines "alternative technologies" as "those methods, which permanently alter the composition of hazardous waste through chemical, biological, or physical means so as to significantly reduce the toxicity, mobility, or volume (or any combination thereof) of the hazardous waste or contaminated materials being treated."⁹ Under the SITE Program, alternative technologies are categorized by their development status as follows:

- ° Available Alternative Technology. Technologies, such as incineration, that are fully proven and in routine commercial or private use.
- ° Innovative Alternative Technology. Any fully-developed technology for which cost or performance information is incomplete, thus hindering routine use at hazardous waste sites. An innovative alternative technology requires full-scale field testing before it is considered proven and available for routine use.
- ° Emerging Alternative Technology. An emerging technology is one in an earlier stage of development; the research has not yet successfully passed laboratory- or pilot-scale testing.⁷

The SITE Program assists technology developers in the development and evaluation of new and innovative treatment technologies. This enhances the commercial availability and use of these technologies at Superfund sites as alternatives to land-based containment systems presently in use.

SITE Program

There are four principal components of the EPA SITE Program:

- ° field-scale demonstration evaluations
- ° emerging technology development
- ° EPA developed technologies
- ° technology transfer clearinghouse.

Each of these components is designed to enhance the use of alternative and innovative treatment technologies in remediating hazardous substance sites.

Field Scale Demonstration Evaluations

One of the largest components of the SITE Program is the evaluation of full-scale demonstrations. This is one of the most important aspects of the program because these successfully demonstrated technologies should then be available for remedial selection in Superfund cleanups. The purpose of the demonstration and evaluation of selected technologies is to develop performance, cost-effectiveness, and reliability data on the applicability of these technologies to specific waste characteristics. Two EPA reports will be produced on each demonstration scale evaluation - a performance data report and an application analysis report. These reports will identify the limitations of the technology, the wastes and media to which they can be applied, the operating procedures, and the approximate capital and operating costs. Normally, the demonstrations are carried out at full-scale or in some cases, at a scale that allows valid comparison and direct scale-up to commercial size units. The duration of the demonstration varies depending on the type of technology -- from three to four days for a thermal process to several months for a biological or vacuum extraction process.

The costs for the demonstration evaluations are shared between the EPA and the developer. The EPA pays for evaluating the technology -- sampling and analysis, data quality assurance and quality control, and report preparation. The technology developer is expected to pay the costs to transport their equipment to the site, operate the equipment on-site during the demonstration, and remove the equipment from the site. Normally, there will be no exchange of funds between the EPA and the developer for the demonstration evaluation. In a few instances where the technology is unique, unusually promising, and high in financial risk,

the EPA will consider bearing a greater portion of the total project cost if the developer is unable to obtain financing elsewhere.

Since 1986 EPA has issued three requests for proposal under the demonstration program -- more than 100 developers have responded. Solicitations are issued annually each January. To date, nearly 30 technologies have been accepted into the program. These technologies include:

- ° solidification/stabilization -- eight
- ° thermal -- eight
- ° biological -- five
- ° physical -- five
- ° chemical -- three

See Table 1 for a list of these technologies. As of September 1988, seven demonstrations/evaluations of these technologies have been completed or are underway. Details on these demonstrations are summarized in Table 2. Preliminary results of these demonstrations/evaluations are summarized in Table 3. And in Table 4, a list is provided on the use and/or further demonstration of some of these SITE technologies.

Emerging Technology Development

Less than a year ago, the Emerging Technologies Program was started. This Program will foster the further development of technologies or approaches that are not yet ready for demonstration. The goal is to ensure that a steady stream of more cost-effective technologies will be ready to be demonstrated, thereby increasing the number of viable alternatives available for use in Superfund cleanups.

The Emerging Technologies Program will deal with innovative technologies for recycling, separation, detoxification, destruction, and solidification/stabilization of hazardous constituents and material handling technologies. Candidate technologies must show promise at the bench/laboratory scale. This program will enable technology developers to advance from the bench/laboratory to pilot scale through cooperative funding with EPA. The Emerging Technology Program was started in the fall 1987. Of the 84 proposals that were submitted seven were selected for funding. The second solicitation was made in July 1988. The seven technologies selected from the first solicitation are summarized in Table 5. These projects should begin within the next two months.

EPA Developed Technologies

Over the past few years, EPA's Office of Research and Development has been developing alternative technologies for the destruction and cleanup of hazardous waste. Several of these technologies are approaching the field evaluation and demonstration stage. After the technologies are satisfactorily demonstrated on Superfund wastes, it is expected that the technologies will be commercialized and marketed by private industry. The Technology Transfer Act of 1986 simplifies the U.S. government-industry partnership necessary to bring these technologies to commercialization. It is expected that the marketing risk in commercializing these technologies will be reduced and development accelerated by conducting field evaluations under the SITE Program. Some of the technologies in the program are listed in Table 6.

Technology Transfer Clearinghouse

EPA will document the SITE demonstration results in reports to be made available to Federal, State and private cleanup managers and other interested parties. Recognizing that access to this, and other, treatment information

is essential to the acceptance and use of alternative technologies, the SITE program has developed an information clearinghouse to collect, synthesize and disseminate technology performance data.

The clearinghouse has three components:

- ° A national telephone referral service will provide callers with up-to-date information on SITE projects, demonstration schedules and the availability of the results, and will also refer callers to other sources of information.
- ° An electronic bulletin board, part of a planned computerized data base network, provides summary information on the SITE projects, demonstration schedules and results. Currently, this bulletin board is available only to Federal and State hazardous waste clean-up personnel.
- ° A collection of reports, journals and other documents is housed in the EPA Library's Hazardous Waste Collection. This collection is available at EPA's ten regional and five laboratory libraries. The bibliographic data base is accessible using a personal computer. SITE documents will be added as they become available.¹

We are in the second phase of the clearinghouse implementation where we plan to include pertinent data generated by other EPA programs -- such as the RCRA BDAT data and other treatability data bases on the electronic bulletin board. As the amount of data base information expands, short two/three-page abstracts of the data will be available on the bulletin board and a centralized computer network for to those requesting technology-specific information. This will provide a proactive consulting system with real-time information retrieval capability that will enable us to access many more data sources including our own laboratory experts and their state-of-the-art knowledge.

CONCLUSION

Given the impetus placed on the development of "best demonstrated" and "innovative/alternative" treatment technologies by the RCRA Amendments and the SARA legislation, the future use for these technologies in hazardous wastes is promising. However, the need to disseminate field performance data on these technologies remains great. Given the number of demonstration evaluations underway and the means to disseminate data from these evaluations via the SITE Clearinghouse, it is expected that the use and familiarity of these technologies will grow rapidly.

TABLE 1

SITE DEMONSTRATION PROGRAM PARTICIPANTS

<u>DEVELOPER</u>	<u>DESCRIPTION</u>
<u>Solidification/Stabilization</u>	
Geosafe Corporation, Richland, WA	<u>In Situ</u> Vittrification
Chemfix Technologies, Inc. Metairie, LA	Soluble silicate reagents
HAZCON, Inc., Katy, TX	Portland cement, fly ash, kiln dust and proprietary chemicals
International Waste Technologies, Wichita, KS	<u>In Situ</u> inorganic polymers and pro- prietary chemicals
Separation and Recovery Systems, Irvine, CA	Lime-Based reagents
Silicate Technology Corporation Scottsdale, AZ	Silicate reagents
Soliditech, Inc., Houston, TX	Pozzolanic reagents and proprietary chemicals
Waste Chem Corporation Paramus, NJ	Asphalt binders
<u>Thermal Treatment</u>	
American Combustion, Inc. Norcross, GA	Pyretron Oxygen Burner
Haztech/EPA. Region IV Atlanta, GA	Shirco Electric Infrared
Shirco Infrared Systems, Inc. Dallas, TX	Electric Infrared Thermal
Ogden Environmental Services, San Diego, CA	Circulating Fluidized Bed Combuster
Retech, Inc., Ukiah, CA	Plasma Heat
Toxic Treatments, Inc., San Mateo, CA	<u>In Situ</u> Steam/Air Stripping
Westinghouse Electric Corp., Madison, PA	Pyroplasma System

TABLE 1
SITE DEMONSTRATION PROGRAM PARTICIPANTS (Continued)
Thermal Treatment (Continued)

<u>DEVELOPER</u>	<u>DESCRIPTION</u>
Roy F. Weston, Inc. West Chester, PA	Low temperature reactor
Chemical Waste Management Oak Brook, IL	Low temperature thermal dryer
<u>Biological Treatment</u>	
Air Products and Chemicals, Inc. Allentown, PA	Fixed film, fluidized bed
Biotrol, Inc. Chaska, MN	Fixed film plug flow reactor
DETOX Industries, Inc. Sugarland, TX	Batch reactor
MoTec, Inc. Mt. Juliet, TN	Liquid/Solid Contact Digestion
Zimpro Environmental Control Systems, Rothschild, WI	Batch reactor, powdered activated carbon and wet air oxidation
Detox, Inc. Newport Beach, CA	Fixed film reactor
<u>Physical</u>	
Biotrol, Inc. Chaska, MN	Soil Washing
CBI Freeze Technologies, Inc. Plainfield, IL	Volume Reduction by Freezing
E. I. Dupont de Nemours, Inc. Newark, DE	Microfiltration
Sanitech, Inc. Twinsburg, OH	Ion Exchange
Terra Vac, Inc. Dorado, PR	<u>In Situ</u> Vacuum Extraction
<u>Chemical Treatment</u>	
CF Systems Corporation, Cambridge, MA	Solvent Extraction
Resources Conservation Company, Bellevue, WA	Solvent Extraction
Ultrox International, Santa Ana, CA	Ultraviolet Radiation and Ozone

TABLE 2

COMPLETED SITE DEMONSTRATION EVALUATIONS

<u>Technology</u>	<u>Site</u>	<u>Date</u>
1. the Haztech/Shirco electric infrared system (100 ton per day)	Peak Oil Superfund Site Brandon, FL	Jul 31- Aug 5, 1987
2. the Shirco electric infrared system (1 ton per day)	Rose Township Superfund Site Rose, MI	Nov 2-13, 1987
3. the HAZCON solidification/stabilization process	Douglasville Superfund Site Reading, PA	Oct 12-16, 1987
4. the American Combustion System oxygen enhanced burner	EPA Combustion Research Fac. Jefferson, AR	Dec 16, 1987 - Jan 29, 1988
5. the Terra Vac vacuum extraction process	Groveland Wells Superfund Site Groveland, MA	Feb 11 - Apr 8, 1988
6. the International Waste Technology in-situ solidification/stabilization process	General Electric Site Hialeah, FL	Apr 11-16, 1988
7. The C.F. Systems chemical solvent extraction process	New Bedford Harbor Superfund Site, New Bedford, MA	Sep 6-26, 1988

TABLE 3

SITE DEMONSTRATION EVALUATIONS PRELIMINARY RESULTS

Haztech/Shirco

- processed 360 tons of waste oil sludge with PCBs and lead
- DE varied between 83 - 99 % based on PCBs in ash
- HCL and SO2 emissions low
- EP Toxicity tests indicate lead in ash is leachable
- PM emissions exceeded regulatory limit for two of four days

Shirco/Rose

- processed 2 tons of waste soils with dioxins/forans, PCBs and lead
- DRE for PCBs greater than 99.99%, DE varied between 99.64 - 99.98%
- PM and HCL emissions low
- no conclusive evidence of lead fixation in ash

American Combustion Demonstration

- processed mixed waste--Stringfellow Acid Pits and Decanter Tank Tar Sludge (K087)
- DRE greater than 99.999%
- low PM emissions
- feed rate was doubled to 210 lb/hr

HAZCON

- volume of solidified soil doubled
- Chloran improved Unconfined Compressive Strength (UCS) and impermeability
- inverse relationship between UCS and organic content
- permeability of solidified soils were low
- EP Toxicity and TCLP tests indicate metals were stabilized, volatiles and semivolatiles were not

Terra Vac

- continuous trouble free operation of system confirmed
- 1,000 lbs TCE recovered in 56 days
- highest recovery rate 100 lbs TCE per day
- extraction maintained at different soil depths

International Waste Technology

- Geo-Con deep soil mixing equipment used for in-situ injection
- PCB contaminated soils treated to 16 ft depth
- two separate sectors about 200 sq ft each were treated

C.F. Systems

- 300 and 5000ppm PCB-contaminated waste sediments treated
- 20 drums of harbor sediment processed
- Propane was the liquefied extraction solvent

TABLE 4

USE OF INNOVATIVE TECHNOLOGIES

<u>Name</u>	<u>Location</u>	<u>Waste Type</u>	<u>Volume Treated</u>
airco	Florida Steel Corp Indiantown, FL	PCB Contaminated Soil	16,000 cu. yds.
	LaSalle Electric Corp LaSalle, IL	PCB Contaminated Soil	35,000 cu. yds.*
	U. S. Army Ammunition Depot, Twin Cities, MN	PCB Contaminated Soil	12,000 cu. yds.*
	Geisur RCRA Site Geisur, LA	PCB Contaminated Soil	40,000 cu. yds.*
ZCON	Mid South Wood Products Mena, AR	Creosote Contaminated Soil	* *
	Sand Springs Petrochemical Complex, Tulsa County, OK	Abandoned Solvent & Waste Oil Recycling Site	* *
	Basin F, Rocky Mountain Arsenal, Denver, CO	Metals-bearing evaporation ponds and sludge	* *
rra Vac	Tyson's Dump Superfund Site, Reading, PA	PCE, TCE and TCP Contaminated Soil	20-100 lbs/day for 30 days
	Upjohn Facility Superfund Site, Barceloneta, PR	Carbon Tetrachloride	250 lbs/day for 30 days
	Verona Well Field Superfund Site, Verona, MI	PCE, TCE & MEK	2000 lbs/day; ongoing cleanup
	Florida Environmental Agency, Belleview, FL	Gasoline	2000 lbs/day for four months

Estimation of the total site cleanup

Demonstration for potential cleanup

TABLE 5

SITE EMERGING TECHNOLOGIES

<u>Developer</u>	<u>Description</u>
Atomic Energy of Canada, Ltd., Ontario, Canada	Toxic Metals Removal
Battelle Memorial Institute, Columbus, OH	Electro-acoustic Soil Decontamination
Bio-Recovery Systems, Inc. Las Cruces, NM	Sorption of Heavy Metals by Alga SORB
Colorado School of Mines, Golden, CO	Wetlands Treatment to Remove Heavy Metals
Energy & Environmental Engineering, Inc., Somerville, MA	Laser Stimulated Photochemical Oxidation
Envirite Field Services, Inc. Atlanta, GA	Solvent Soil Washing
Western Research Institute, Laramie, WY	<u>In Situ Oil Recovery and Biodegradation</u>

TABLE 6

EPA DEVELOPED TECHNOLOGIES

<u>Technology</u>	<u>Remarks</u>
Mobile Soils Washer	This System has been designed for extraction of a broad range of hazardous materials from spill-contaminated soils using water as the extraction solvent. The prototype has been developed utilizing conventional equipment for screening, size reduction, washing, and dewatering of the soils. The washing fluid-water may contain additives, such as acids, alkalies, detergents, and selected organic solvents--to enhance soil decontamination. The nominal processing rate is 4-yd ³ of contaminated soil per hour when the soil particles are primarily less than 2 mm in size, and up to 18-yd ³ per hour for soil of larger average particle size.
KPEG Treatment System	Potassium polyethylene glycolate reagents are effective dehalogenators of aromatic and aliphatic organic materials, including PCB's and other toxic halides. The KPEG reagent reacts with the chlorine atoms in the aryl ring of halogenated aromatic contaminants to produce innocuous ether and potassium chloride salt. In some KPEG reagent formulations, dimethylsulfoxide is added as a co-solvent to enhance reaction rate kinetics. KPEG reagents are stable in air, tolerate moisture, are easily stored, and can be safely transported to problem sites unlike conventional anaerobic dehalogenating reagents. A large portable KPEG reactor (400 gallons) has been demonstrated on PCB-contaminated soils and a smaller pilot unit on oily pesticide wastes and liquid woodpreserving wastes.
Mobile Incineration System	The mobile incinerator consists of specialized equipment mounted on four trailers. In the rotary kiln on the first trailer, organic wastes are fully vaporized and completely or partially oxidized at approximately 1800°F. Incombustible ash is discharged directly from the kiln. The gas from the first trailer passes through a secondary combustion chamber (SCC) on the second trailer at a temperature of 2200°F where the thermal decomposition (oxidation) of the contaminants is completed. The flue gas exits from the SCC and is then cooled by water sprays from 2200°F to approximately 190°F. Excess water is collected in a sump. The gases then pass into the air pollution control equipment on the third trailer. Here, any submicron-sized particulates are removed from the gas stream as it passes through a high-efficiency air filter, and byproduct acid gases generated by the destruction process are neutralized in an alkaline scrubber. Gases are drawn through the the system by an induced draft fan, which maintains an overall vacuum to ensure that no toxic gases escape from the system.

TABLE 6

EPA DEVELOPED TECHNOLOGIES

<u>Technology</u>	<u>Remarks</u>
	The cleaned gases are discharged from the system through a 40-foot high stack. The incinerator can process 9,000 pounds of contaminated soil, or 75 gallons of liquid per hour. Hazardous substances that could be incinerated include compounds containing chlorine and phosphorous, e.g., PCB's, kepone, dioxins, and organophosphate pesticides, which may be in pure form, in sludges, or in soils.
Mobile Carbon Regeneration System	This System was designed for field use in reactivating spent granular activated carbon used in spill or waste site cleanup operations. When contaminated granular activated carbon (GAC) is heated in the kiln, organic substances are desorbed and volatilized. All vapors and gases from the kiln flow through a duct into the secondary combustion chamber where an excess oxygen level is maintained. Temperature and residence time are controlled to assure desorption/detoxification of hazardous organic substances, including chlorinated hydrocarbons. Off-gases are water-quenched and scrubbed with an alkaline solution before being vented to the atmosphere. Stack gases and used process water are monitored.

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NATO/CCMS Guest Speaker:

Ronald Probstein, United States

Electroosmotic Purging for *In Situ* Remediation

ELECTROOSMOTIC PURGING FOR IN SITU REMEDICATION

by

**Ronald F. Probst
M.I.T.**

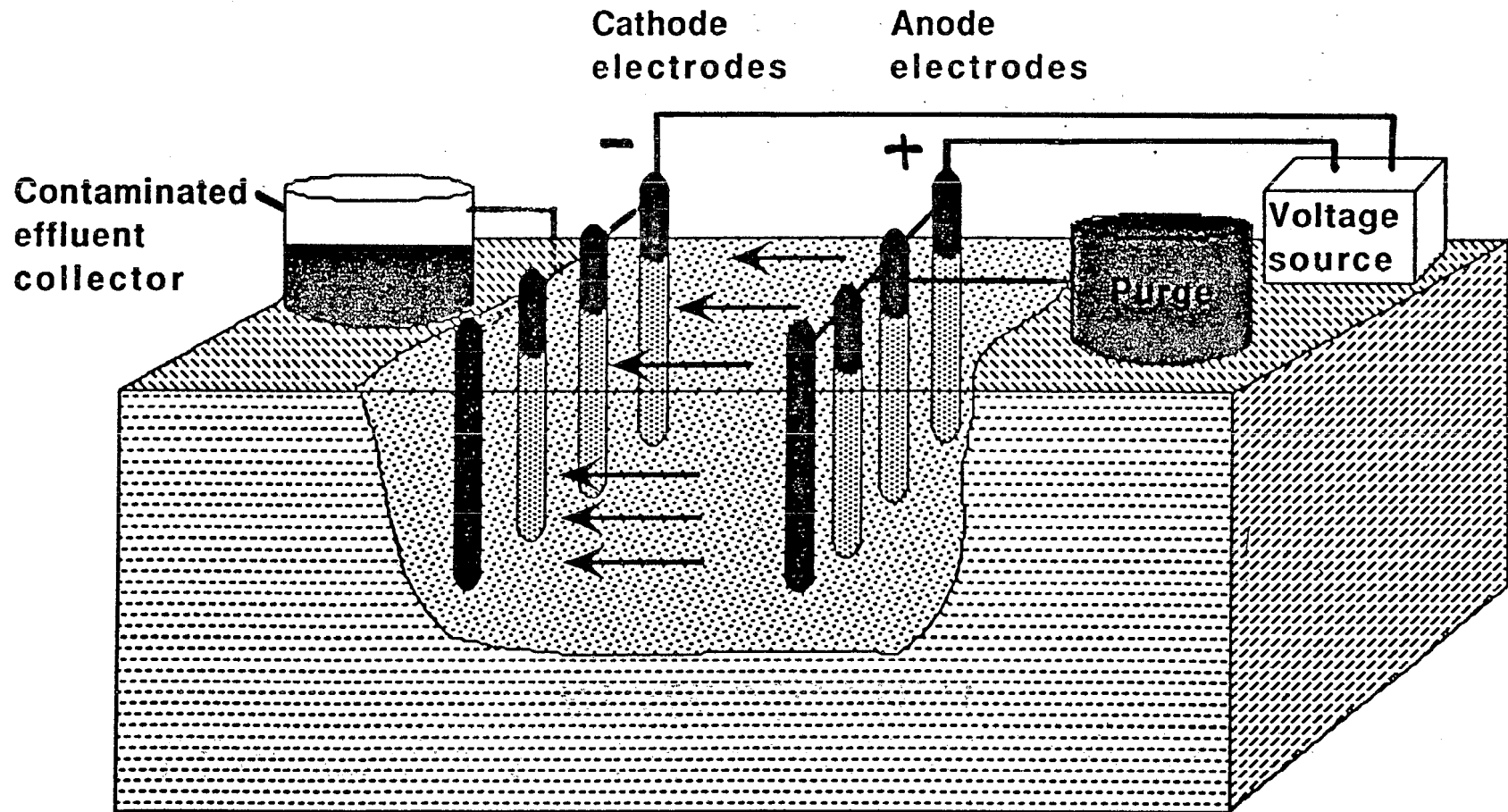
**NATO/CCMS Pilot Study on Demonstration of Remedial Action Technologies
for Contaminated Land and Groundwater**

Washington, DC

November 18-22, 1991

ELECTROOSMOTIC DECONTAMINATION

OF A HAZARDOUS WASTE SITE



COMPARISON OF ELECTROOSMOSIS AND PRESENT TECHNOLOGIES

PRESENT TECHNOLOGIES

**Excavation/washing
Excavation/incineration**

- costly
- exposes workers to health risks
- can lead to air pollution

Vitrification

- very expensive
- increases waste volume

Pumping/draining

- cannot control flow direction (channeling)
- impossible in low permeability soils
- soil rupture possible

ELECTROOSMOSIS

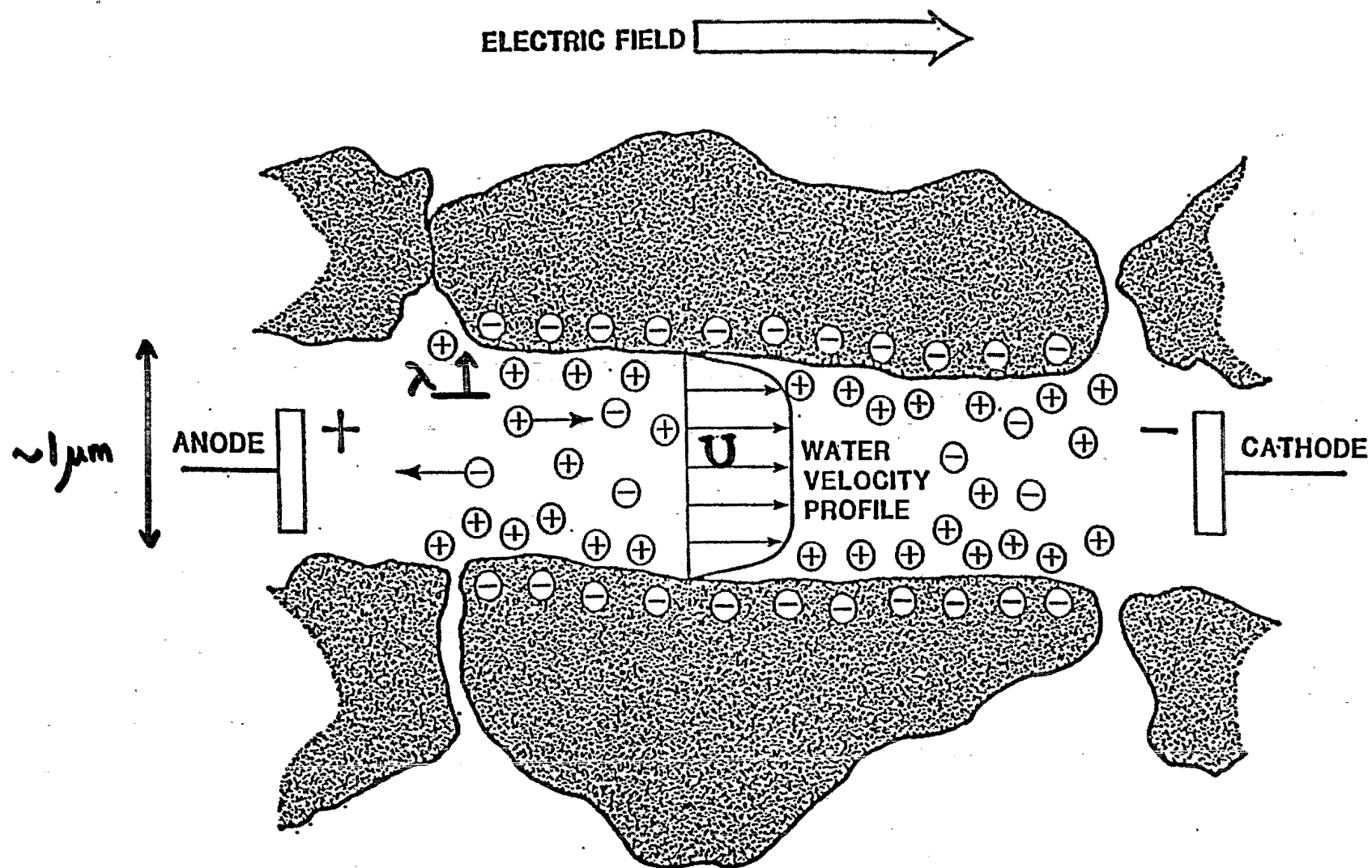
- in situ
- high degree of control of flow direction
- high degree of contaminant removal
- low energy costs (\approx \$0.01/gallon or \$2.5/ton)

PARAMETER RANGES

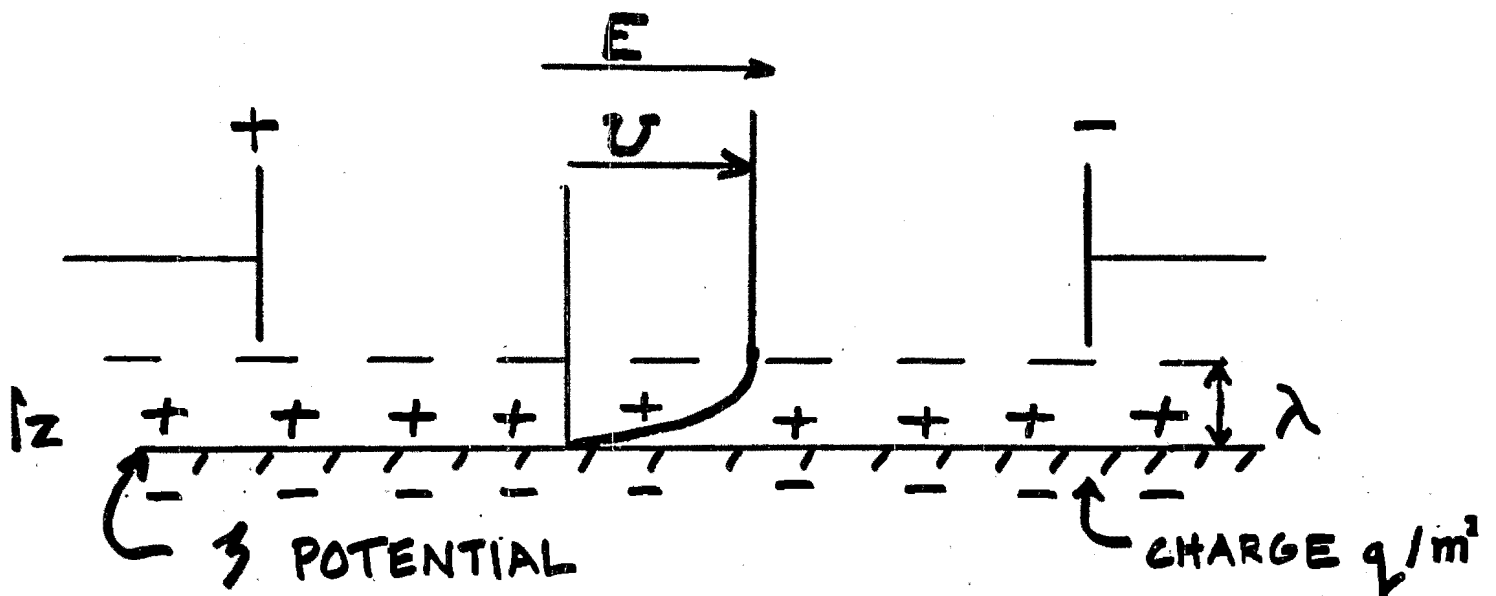
Applied voltage	$\Delta\phi$	50 - 500 V
Voltage gradient	$\Delta\phi/\Delta x$	20 - 500 V/m
Electrode spacing	Δx	1 - 5 m
Electrode depths	z	5 - 15 m
Current density	i	0.5 - 5 A/m ²
Hydraulic permeability	k_h	$< 10^{-12}$ m ²
Flow rate/unit area	q_e	10^{-7} - 10^{-6} m/s

ELECTROOSMOTIC PRINCIPLE

809



ELECTROOSMOTIC VELOCITY



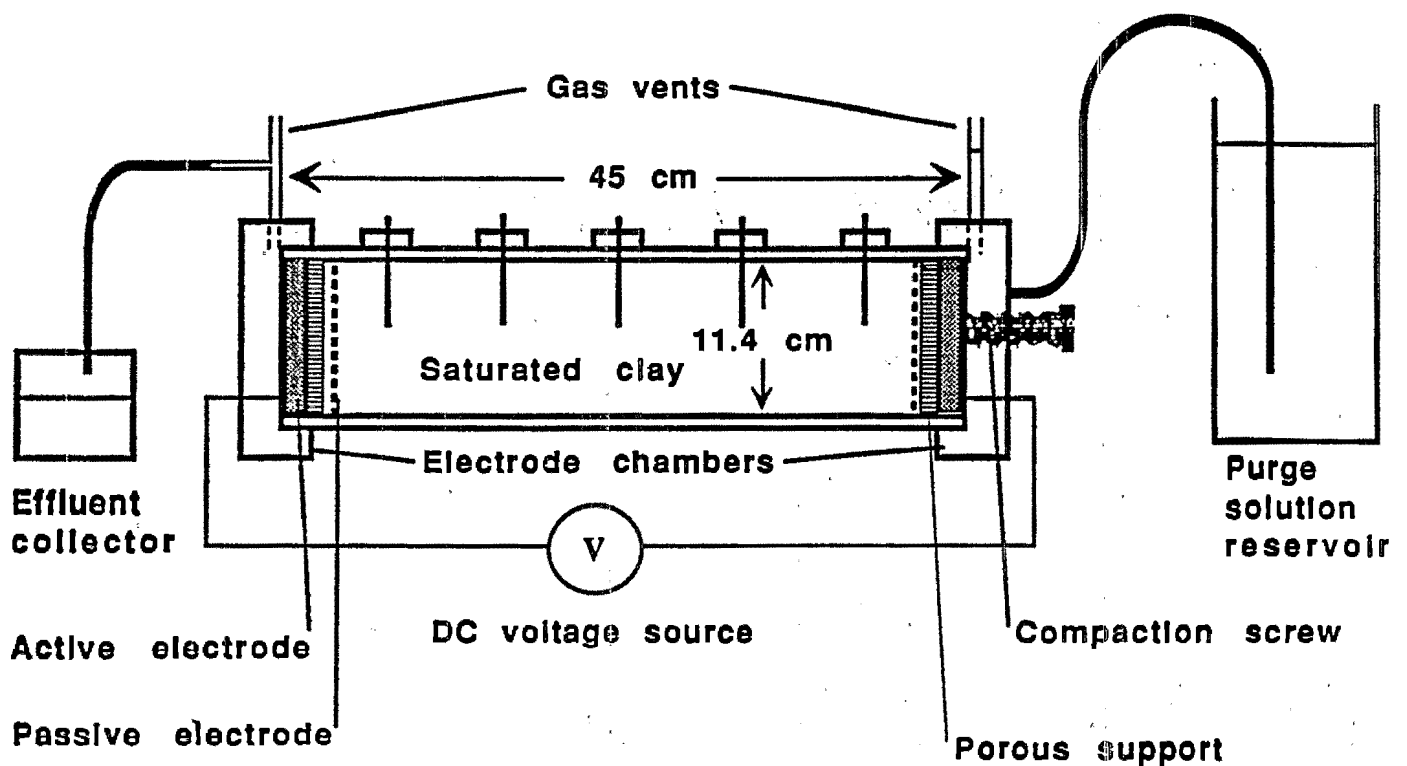
VISCOUS FORCE = ELECTRICAL FORCE

$$\mu U / \lambda = q E$$

$$q = \epsilon \left. \frac{\partial \phi}{\partial z} \right|_{z=0} = \epsilon \zeta / \lambda$$

$$U = \frac{\epsilon \zeta}{\mu} E$$

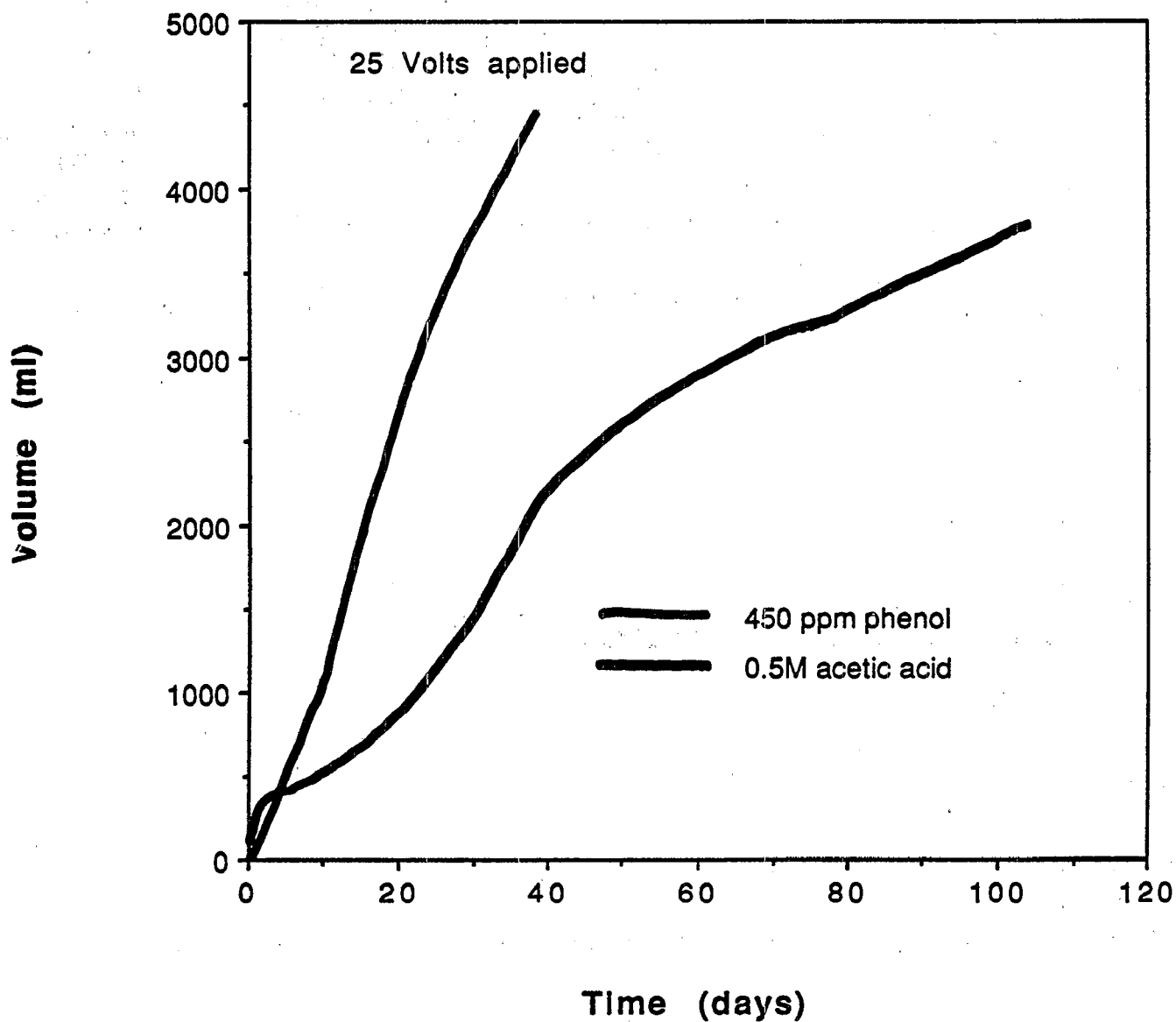
ELECTROOSMOSIS APPARATUS



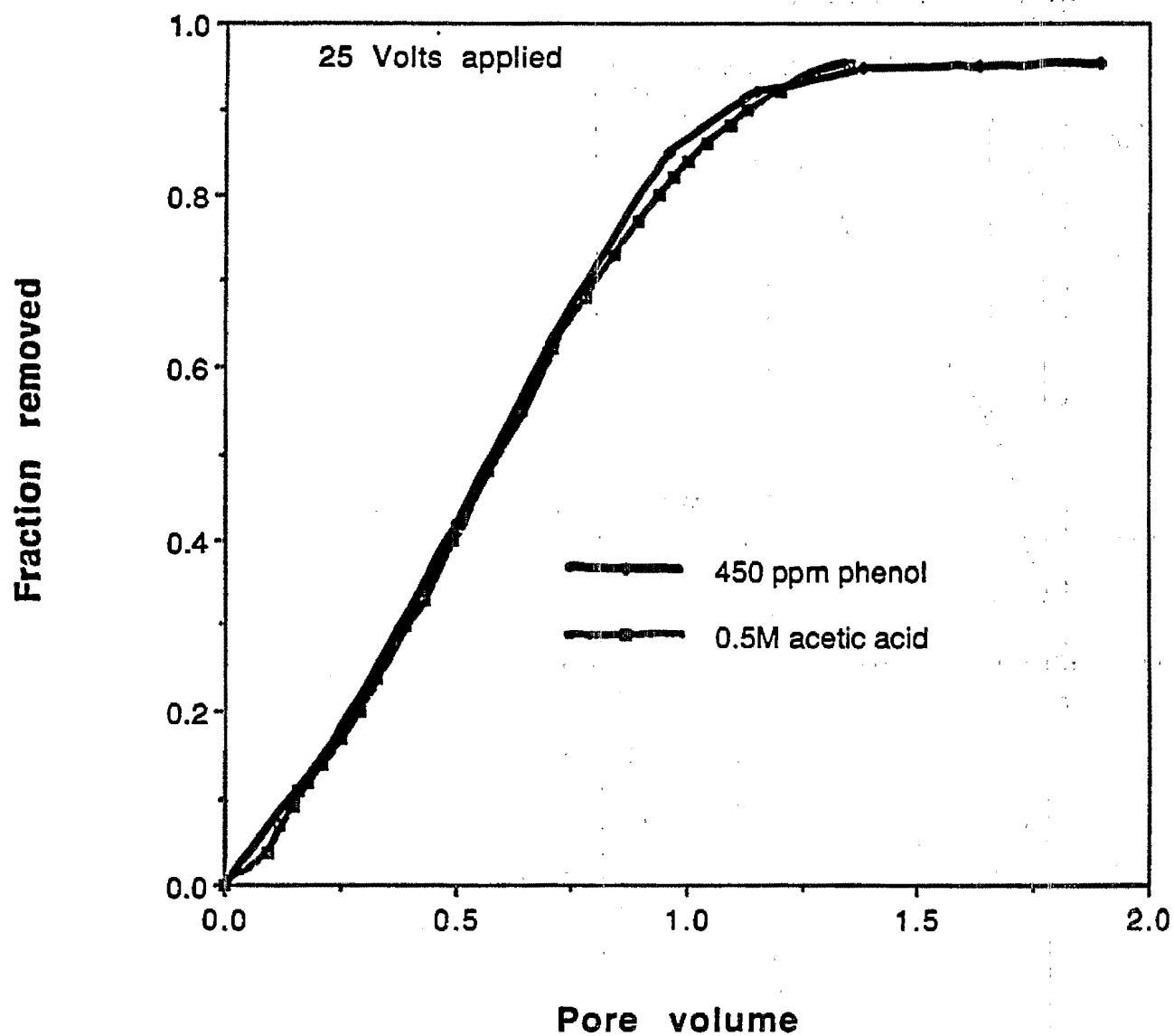
ELECTROOSMOSIS MEASUREMENTS

- Voltage distribution
- Current
- Electroosmotic velocity
- Chemical composition and pH of effluent
- Fraction of chemical removed vs pore volumes removed
- Distribution of chemicals remaining in the sample

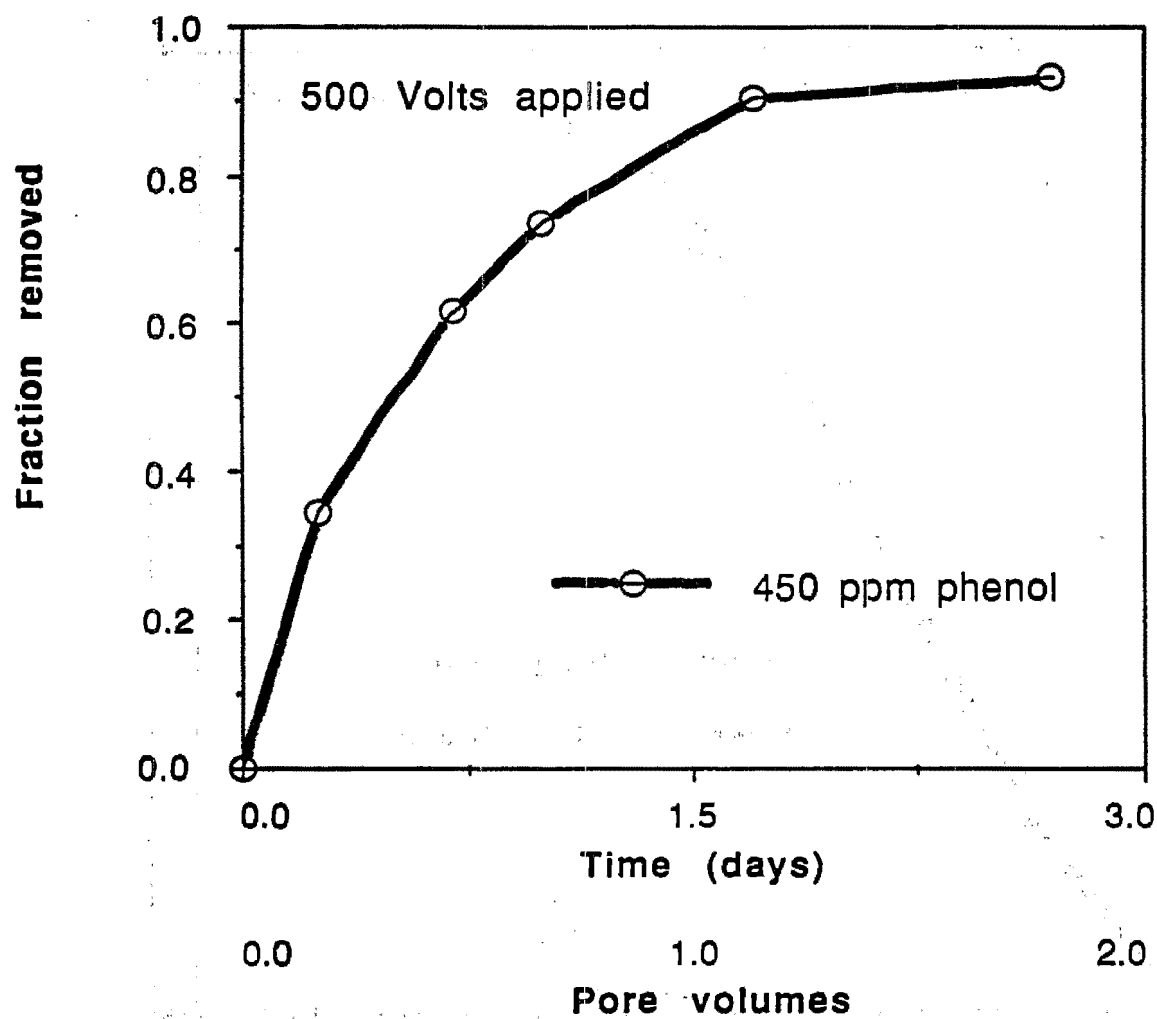
VOLUME OF EFFLUENT VS TIME



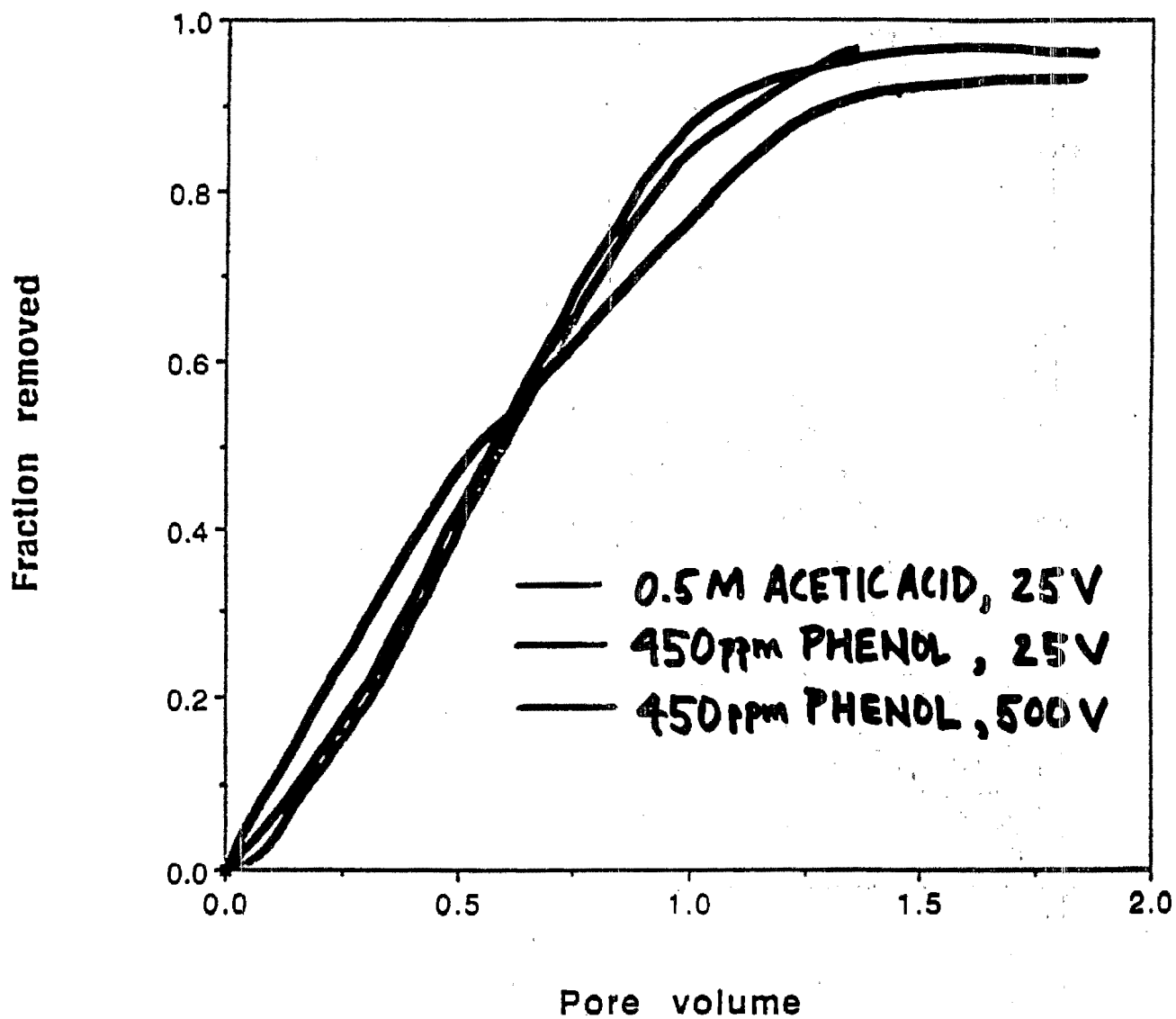
FRACTION REMOVED VS PORE VOLUMES REMOVED



FRACTION REMOVED VS TIME

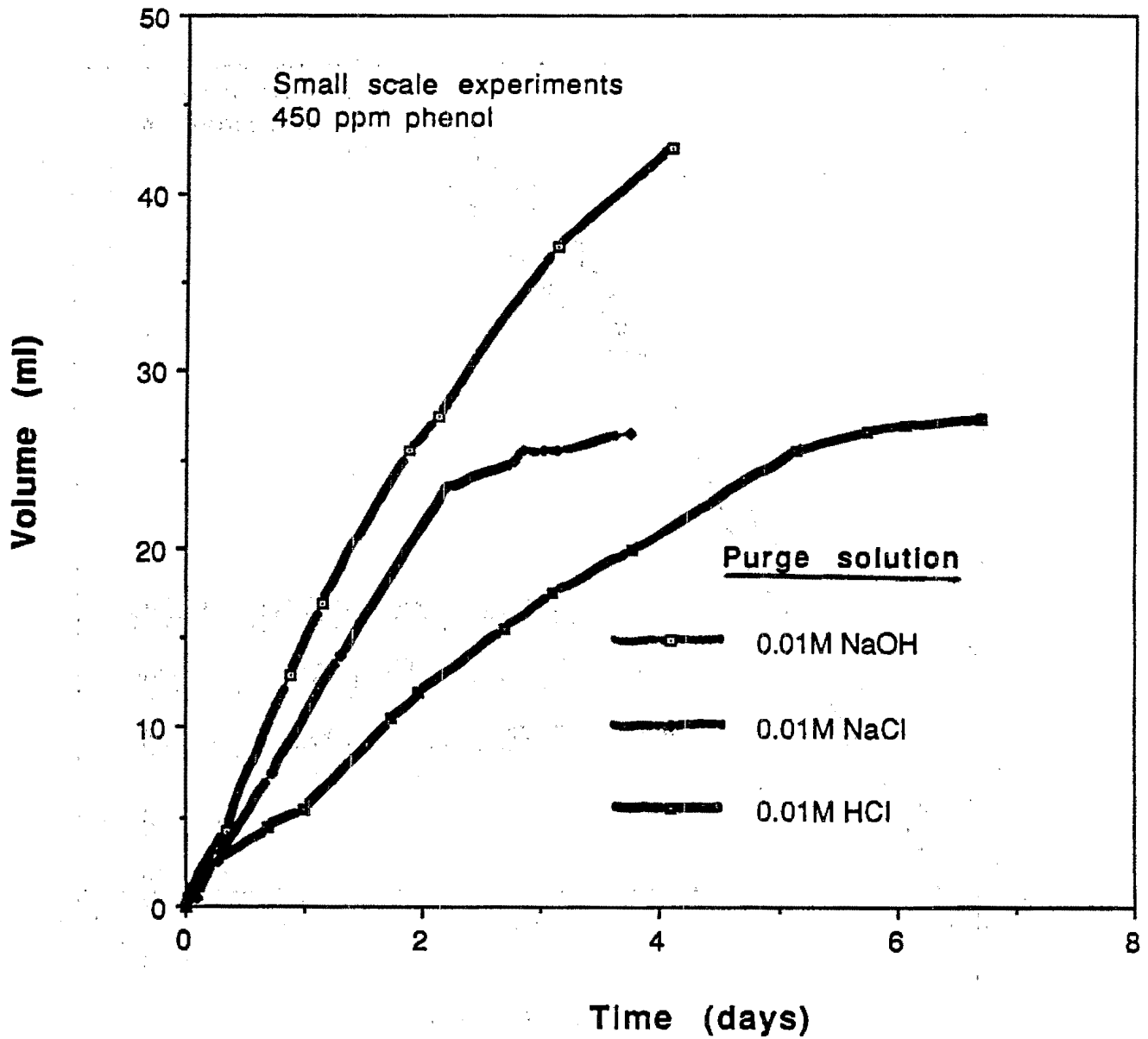


FRACTION REMOVED VS
PORE VOLUMES REMOVED



VOLUME OF EFFLUENT VS TIME

Effect of purge solution pH



MODEL

Electroosmotic transport of chemical species in porous media involves:

- Convection of pore liquid, "electroosmosis"

$$\overline{u_{EO}} = - \frac{\epsilon}{\mu} \langle \zeta \bar{E} \rangle$$

- Migration of ions in electric field, "electromigration"

$$\overline{u_{ei}} = v_i z_i F \bar{E} = \frac{D_i}{RT} z_i F \bar{E}$$

- Diffusion

$$\overline{u_D} = - \frac{D_i}{c_i} \nabla c_i$$

- Chemical reactions

CHEMICAL REACTIONS

- BULK: EQUILIBRIUM CHEMISTRY

e. g. a) weak acid



$$\frac{[\text{H}^+][\text{A}^-]}{[\text{HA}]} = K_a$$

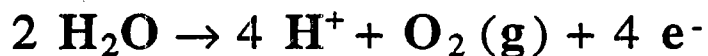
b) adsorption isotherm

$$[\text{HA}]_{\text{ads}} = K_{\text{ads}} [\text{HA}]_{\text{bulk}}$$

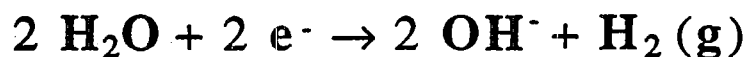
- ENDS: EQUILIBRIUM ELECTRODE REACTIONS

e. g. electrolysis of water

anode:



cathode:



CONVECTIVE-DIFFUSION EQUATION

For i^{th} species

$$\frac{\partial c_i}{\partial t} + \frac{\partial}{\partial z} (c_i (u_{EO} + u_{ei})) = \frac{D_i}{\tau^2} \frac{\partial^2 c_i}{\partial z^2} + R_i$$

Electroosmotic velocity

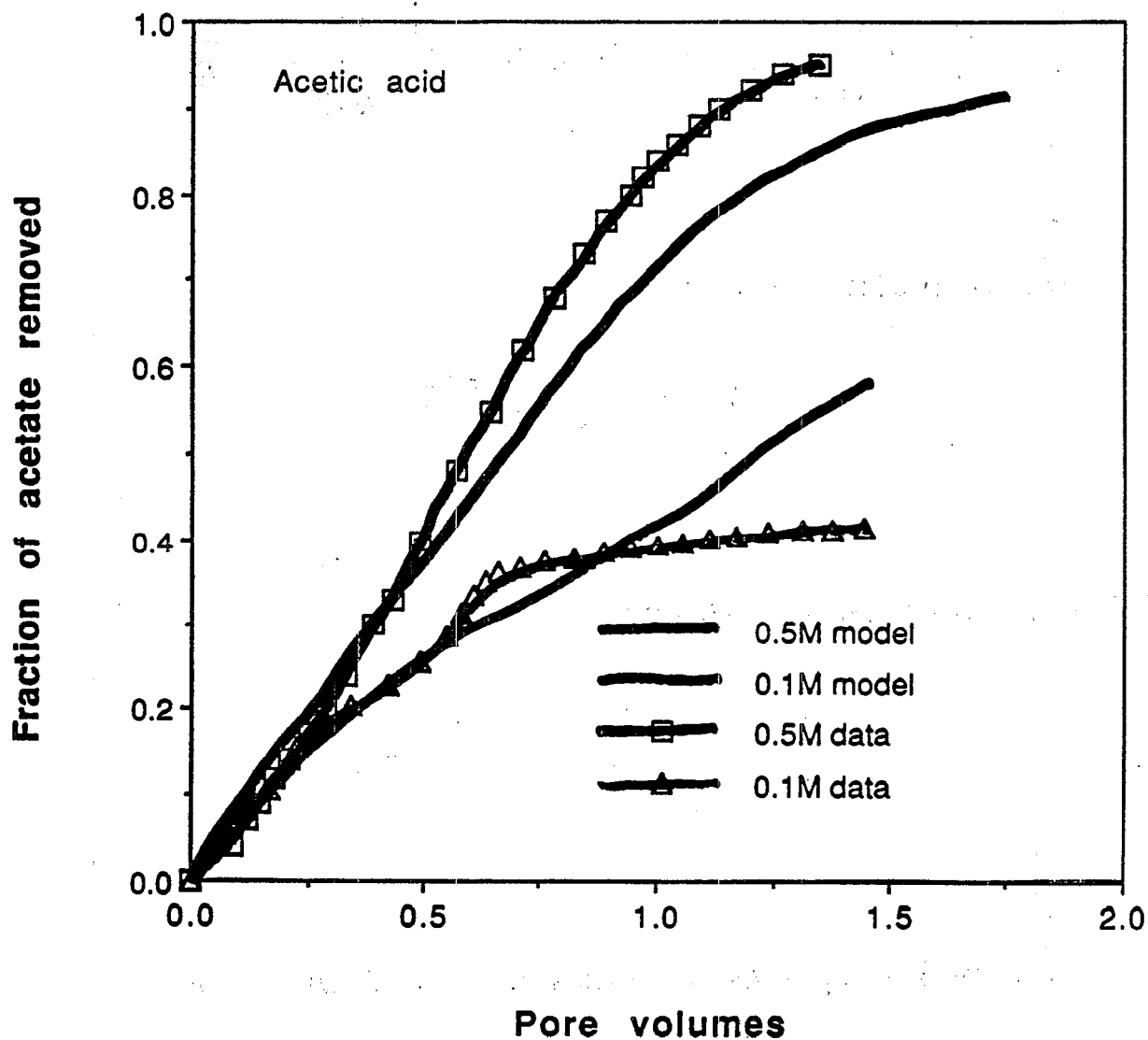
$$u_{EO} = - \frac{1}{\tau^2} \frac{\epsilon}{\mu} (\zeta E)$$

Electromigration velocity

$$u_{ei} = - \frac{1}{\tau^2} v_i z_i F \frac{\partial \phi}{\partial z}$$

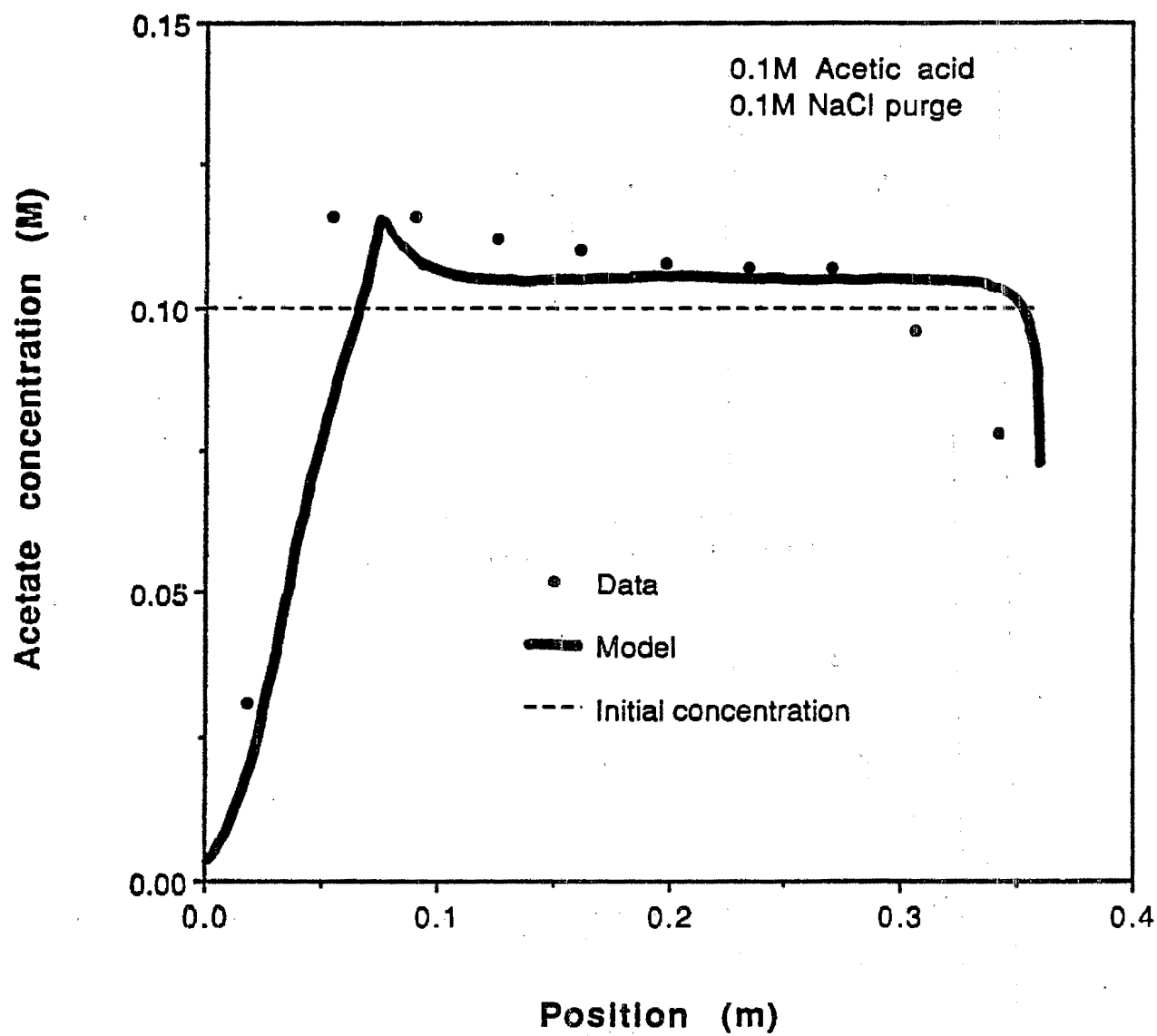
R_i = molar species production rate / unit volume

FRACTION REMOVED VS PORE VOLUMES REMOVED



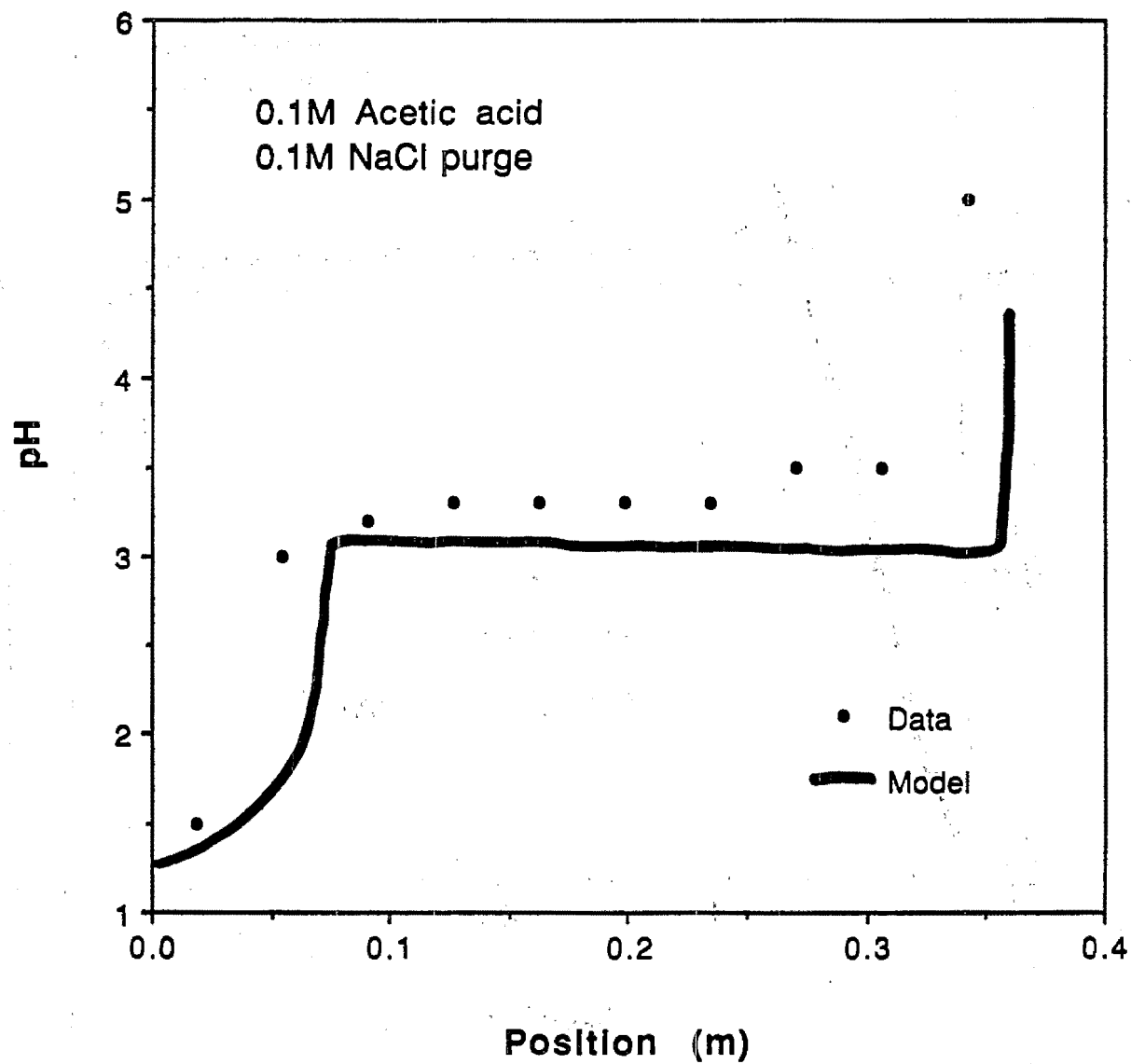
CONCENTRATION PROFILE

Comparision of experlment and model

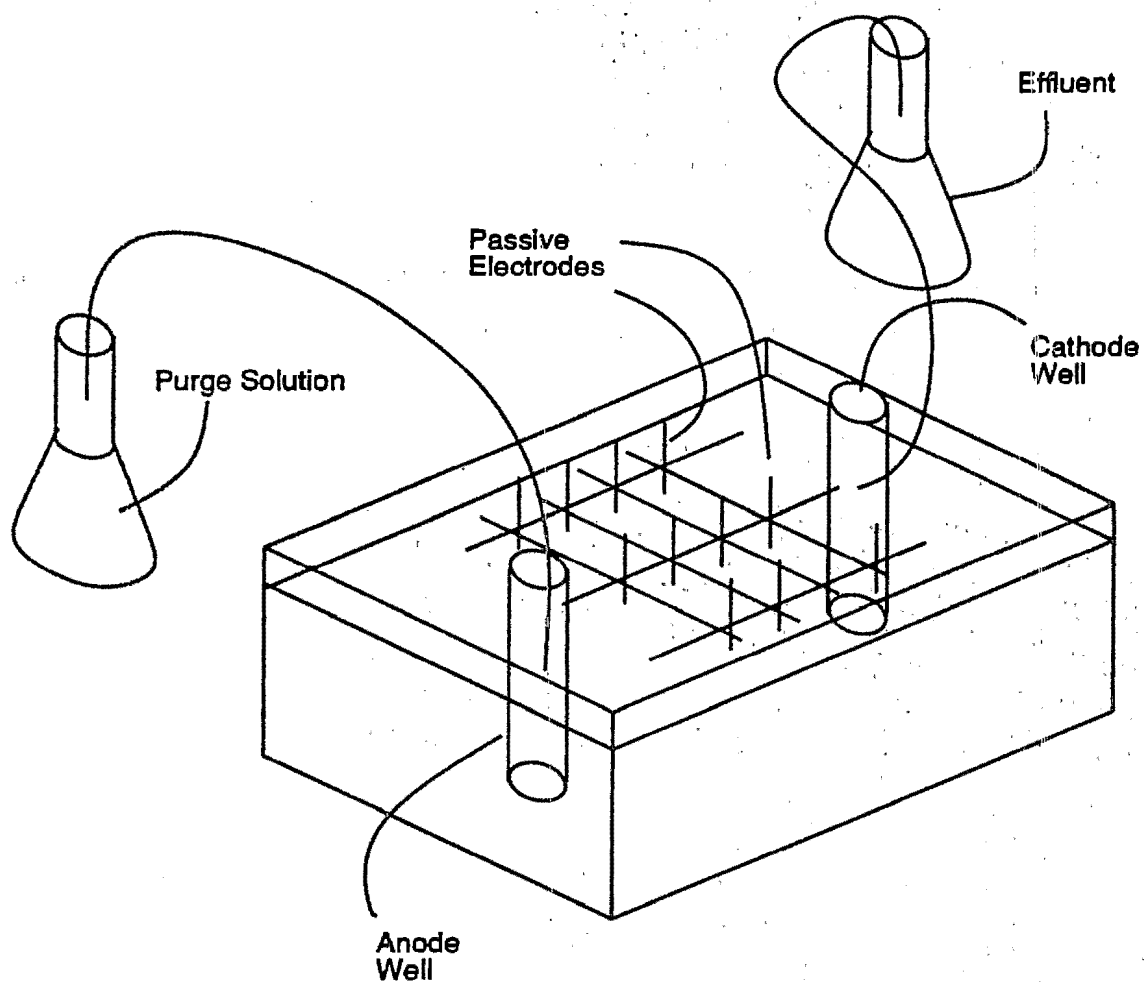


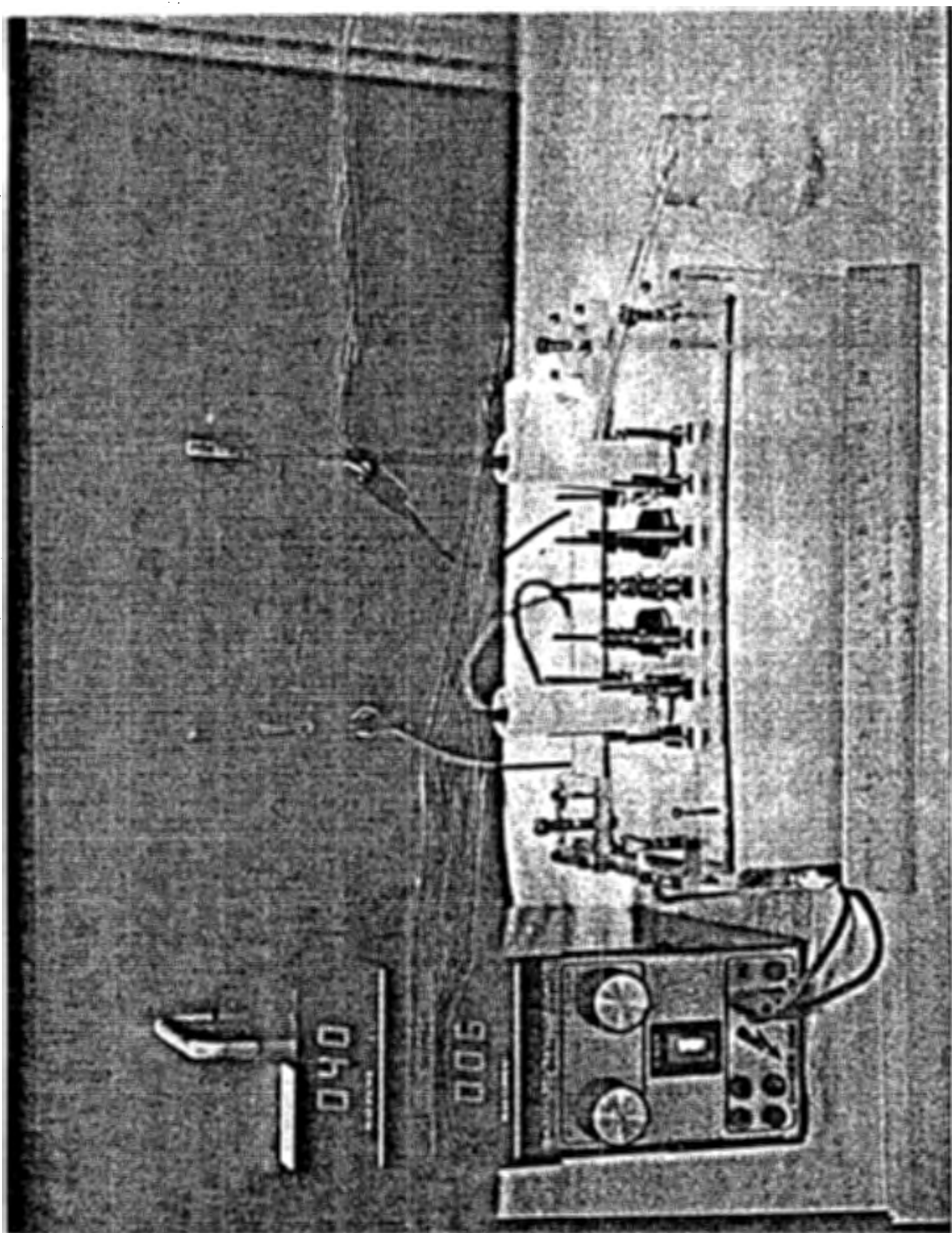
pH PROFILE

Comparison of experiment and model



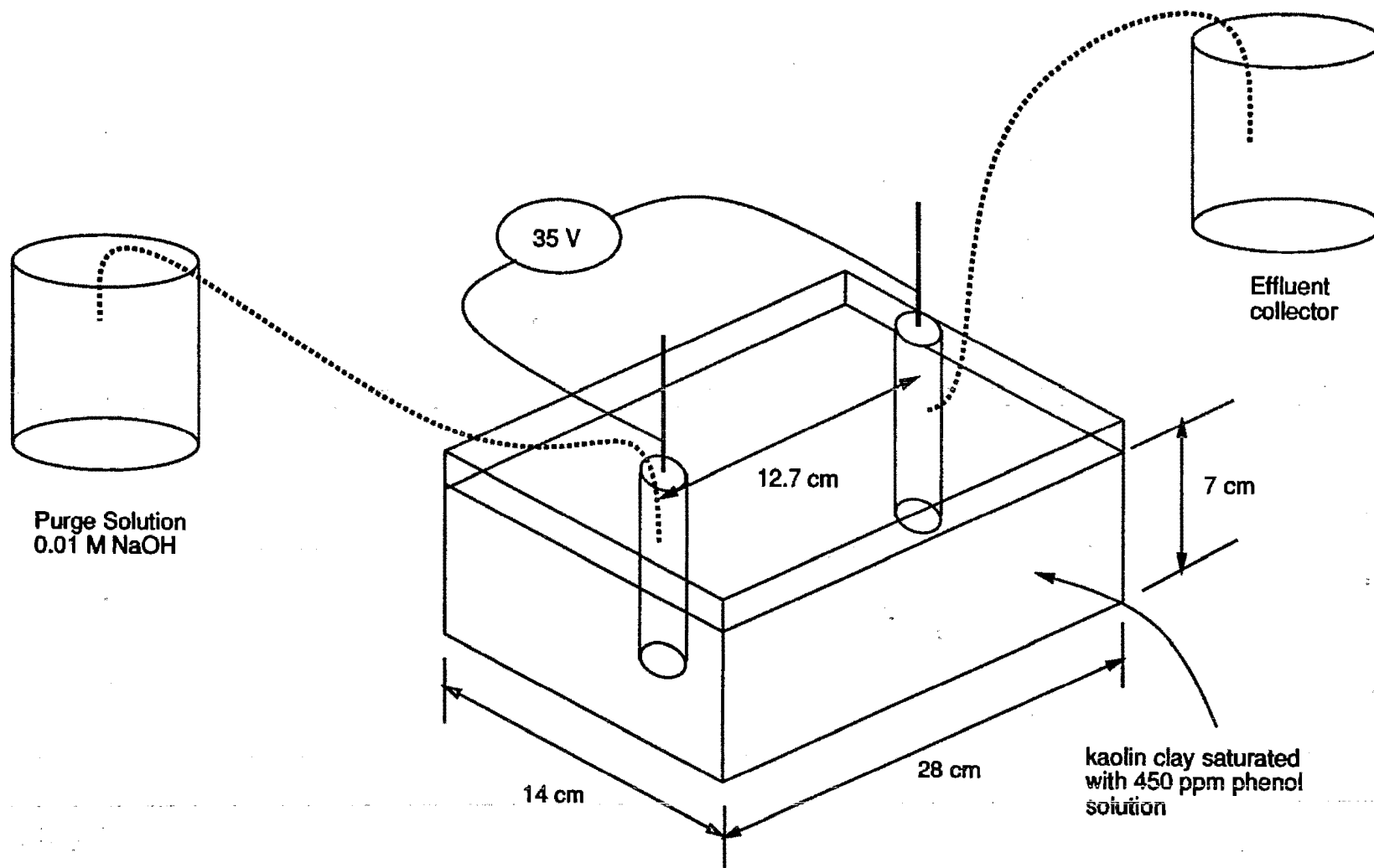
SKETCH OF 3-DIMENSIONAL TEST CELL



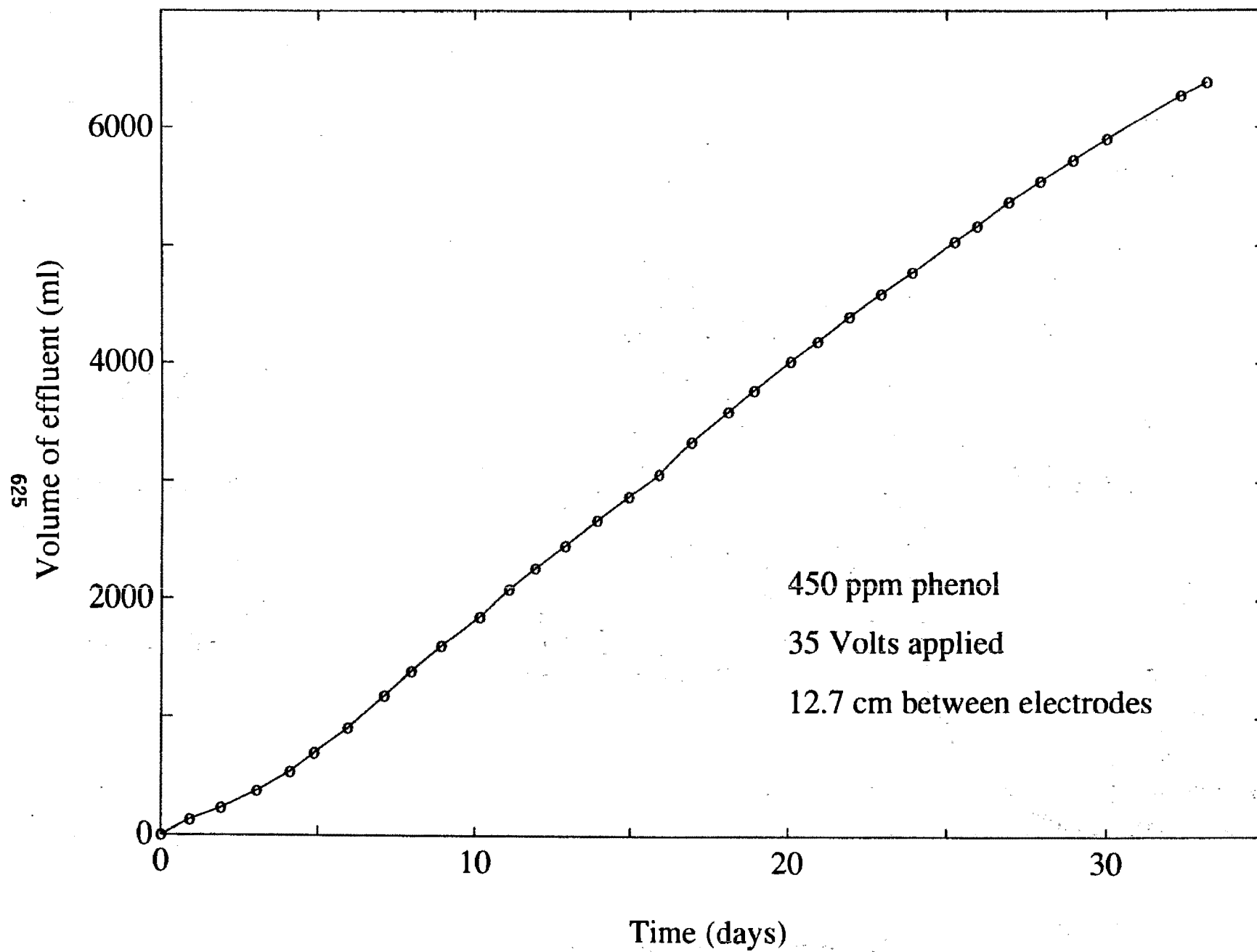


2D PHENOL EXPERIMENT SETUP

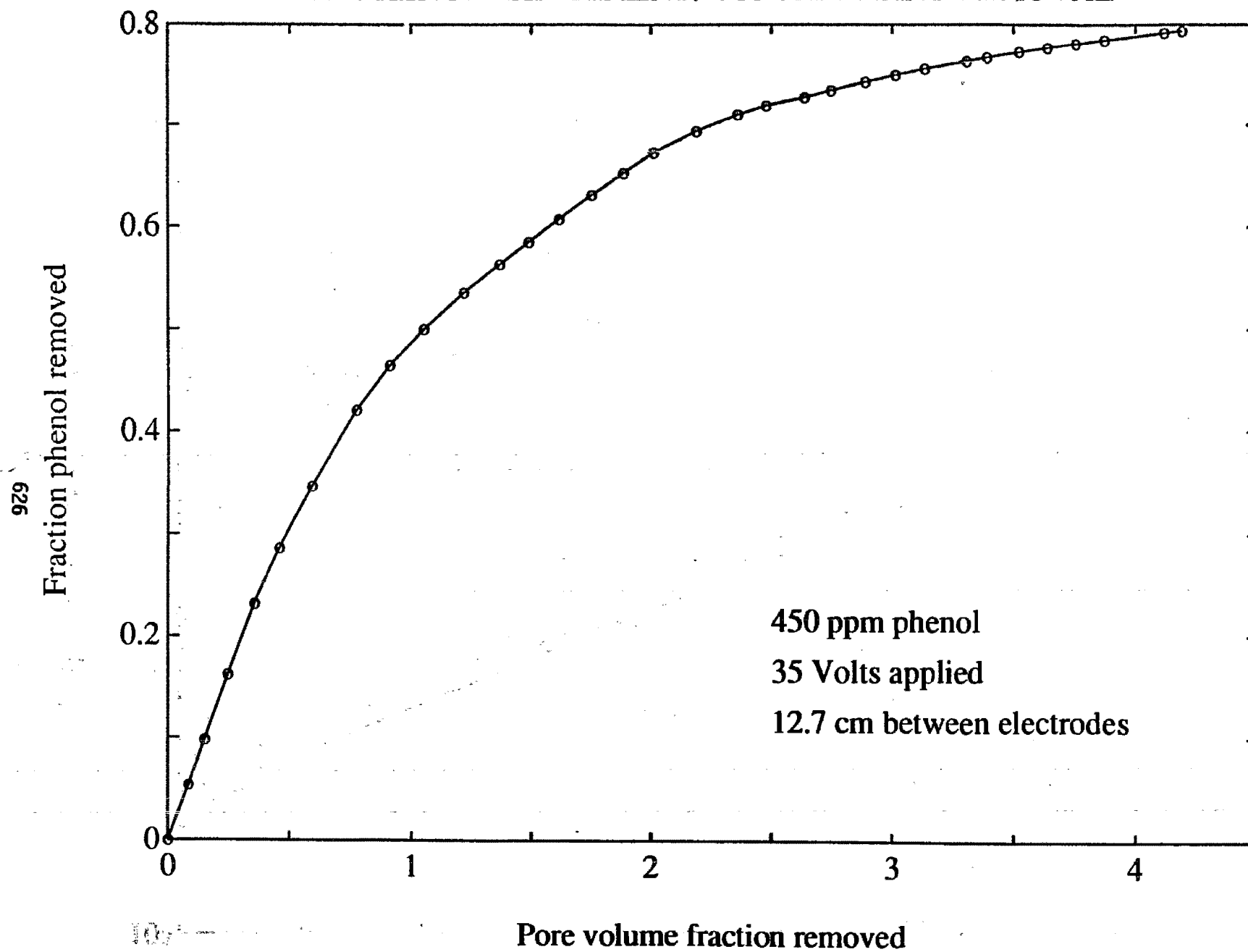
624



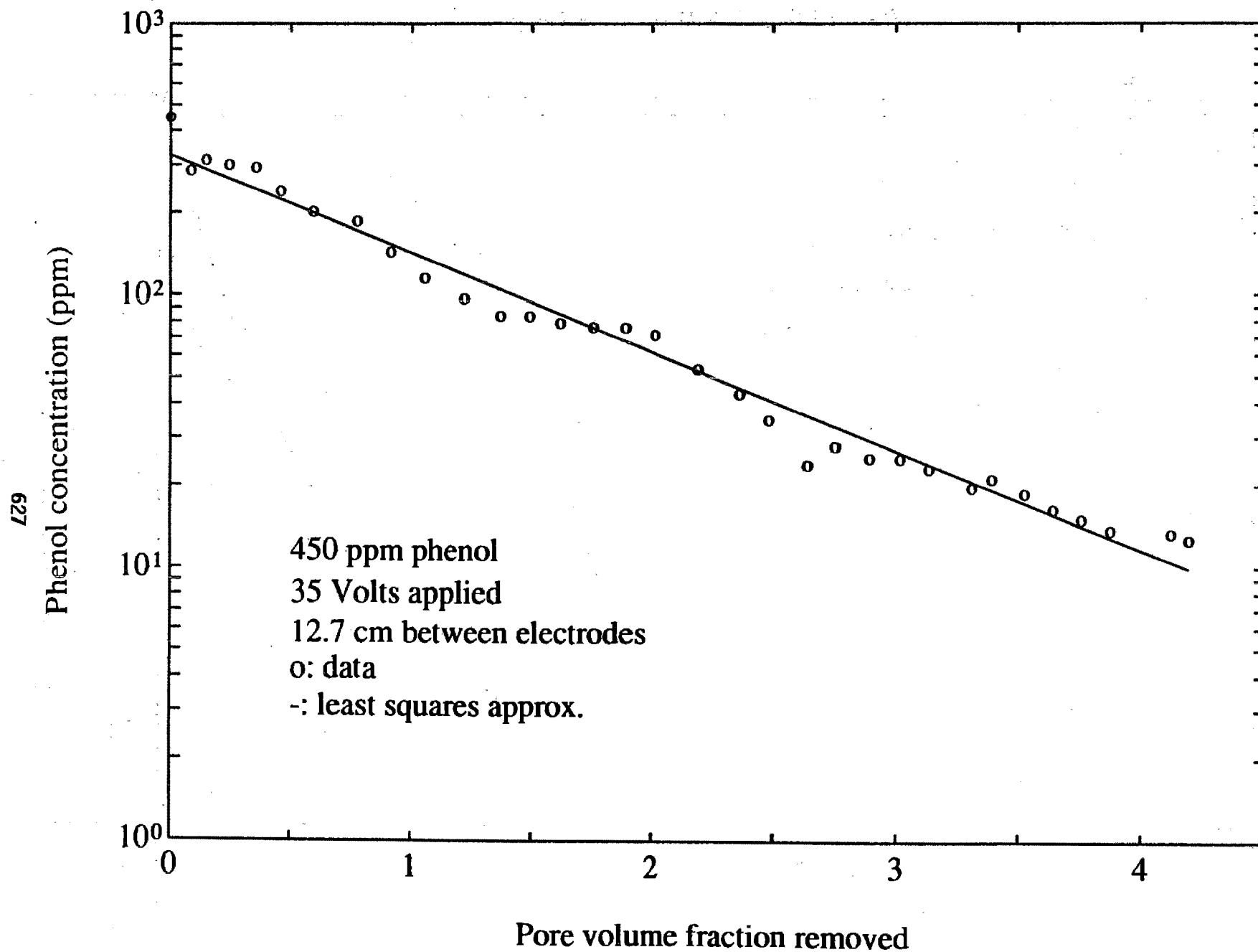
2D PHENOL EXPERIMENT. VOLUME OF EFFLUENT VS TIME



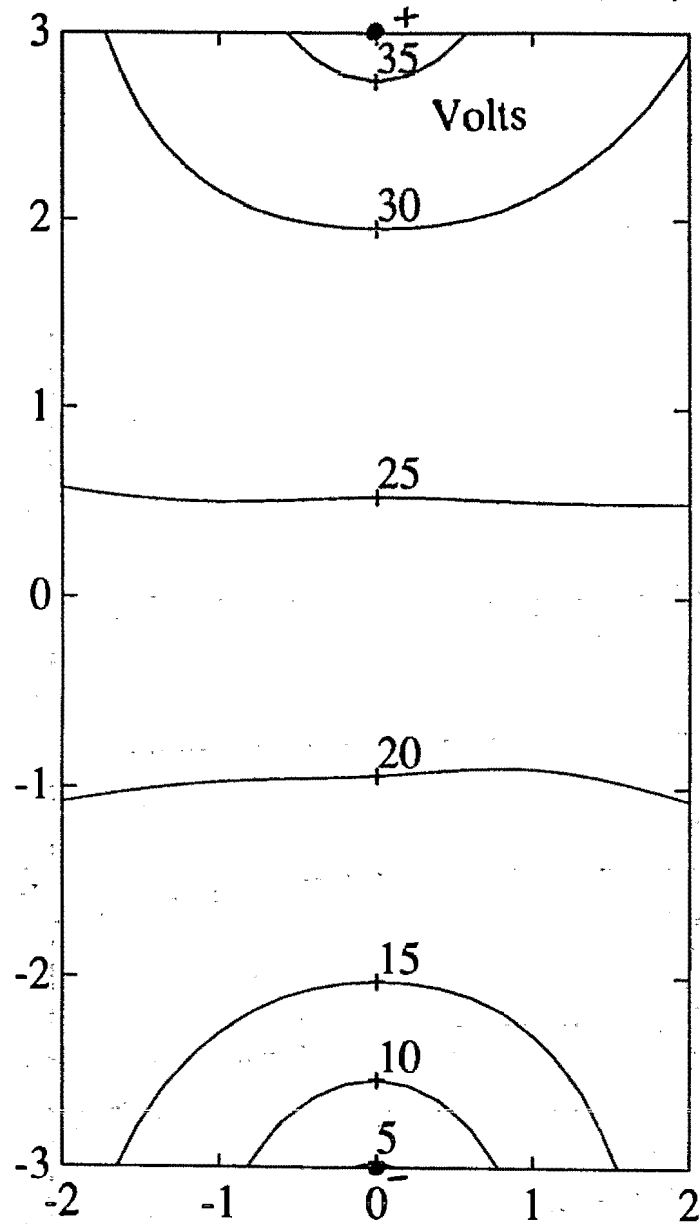
2D PHENOL EXPERIMENT. CONTAMINANT REMOVAL



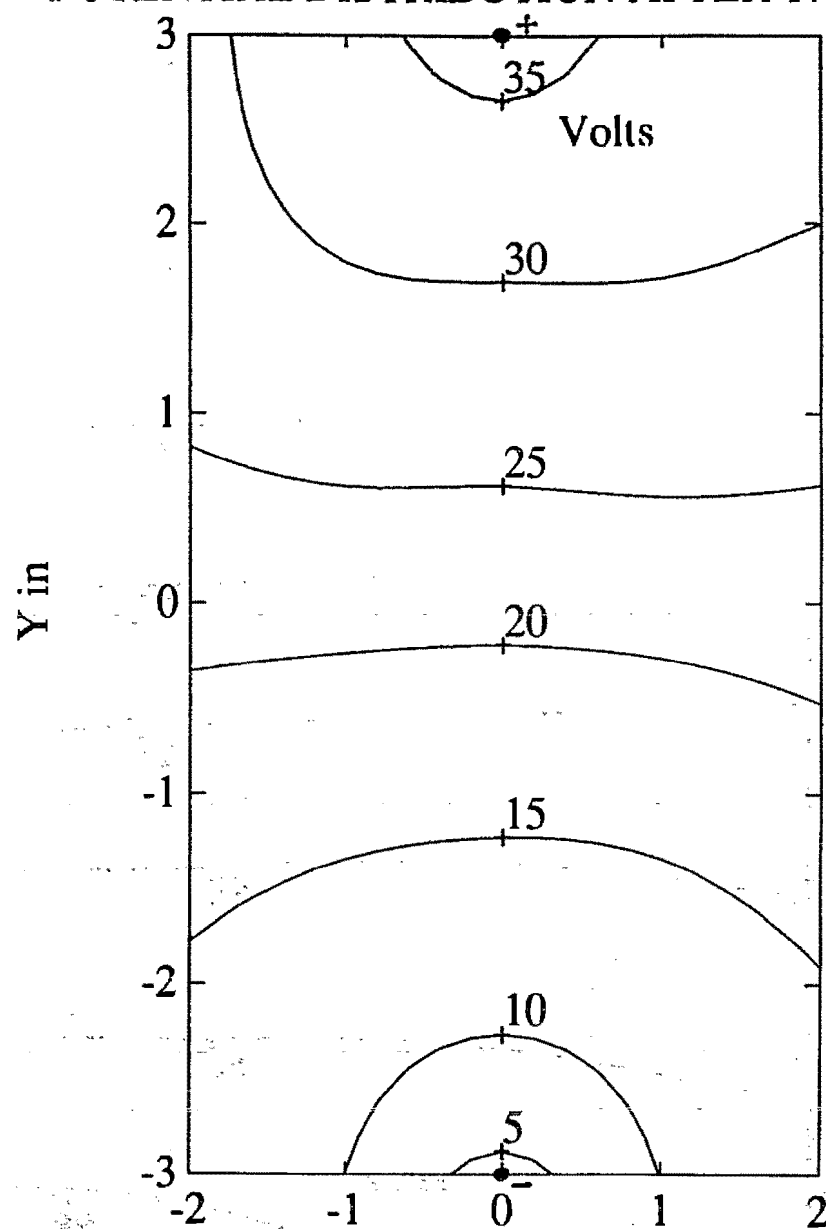
2D PHENOL EXPERIMENT. CONTAMINANT CONCENTRATION IN EFFLUENT



POTENTIAL DISTRIBUTION AT $t=0$

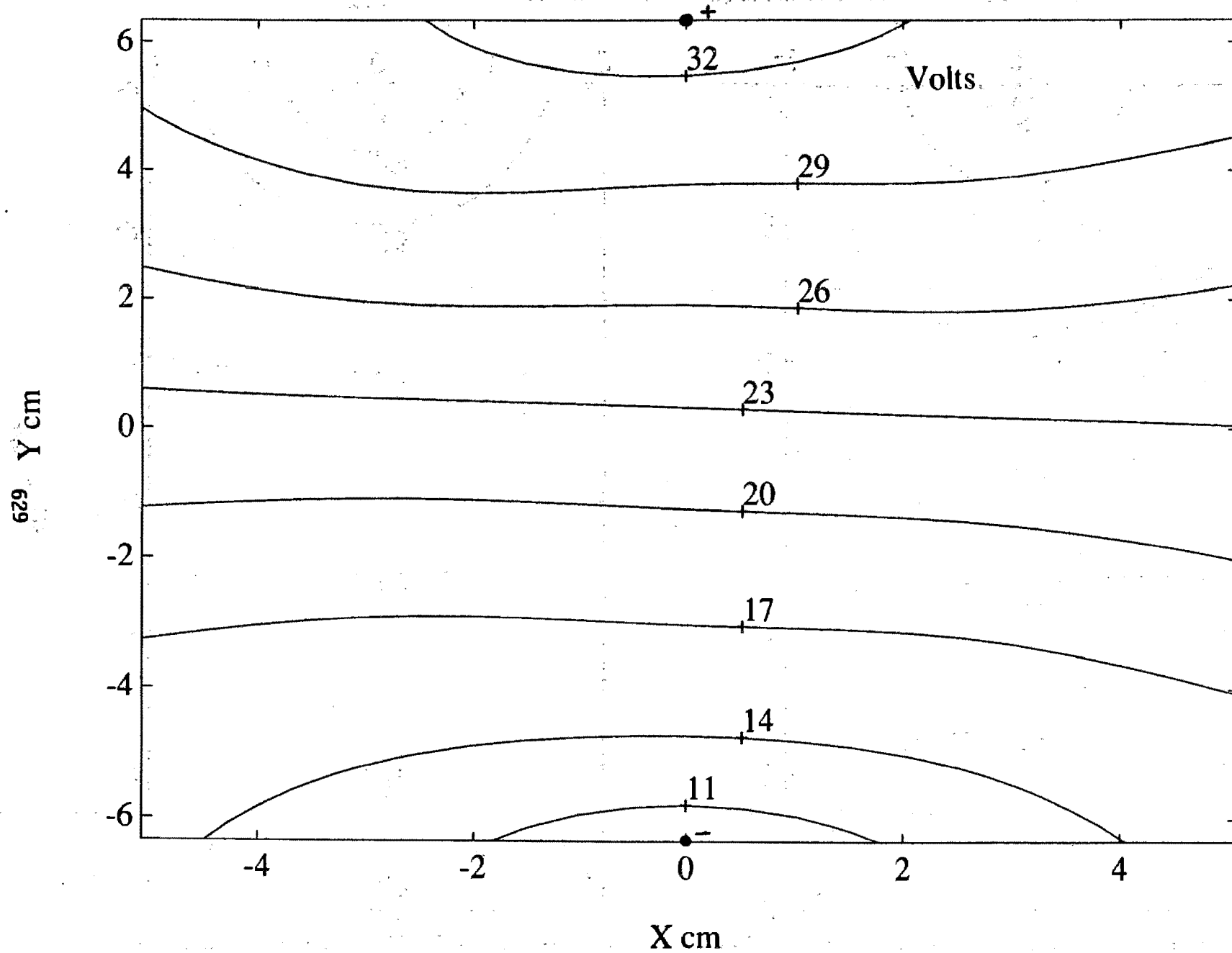


POTENTIAL DISTRIBUTION AFTER 17 DAYS



2D PHENOL EXPERIMENT

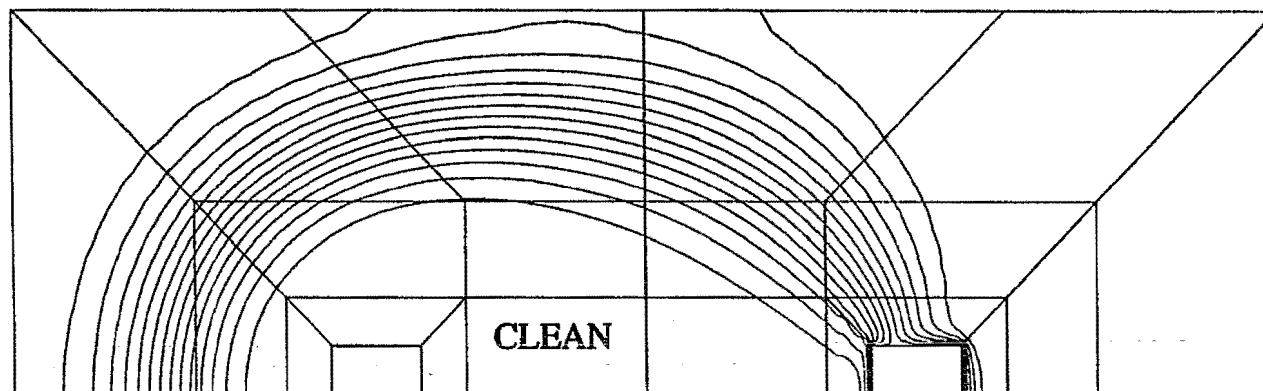
2D PHENOL EXPT. POTENTIAL DISTRIBUTION AFTER 27 DAYS



MODEL

CONTAMINANT CONCENTRATION DISTRIBUTION

AFTER 4 DAYS



Anode

Flow direction →

Cathode

450 ppm phenol

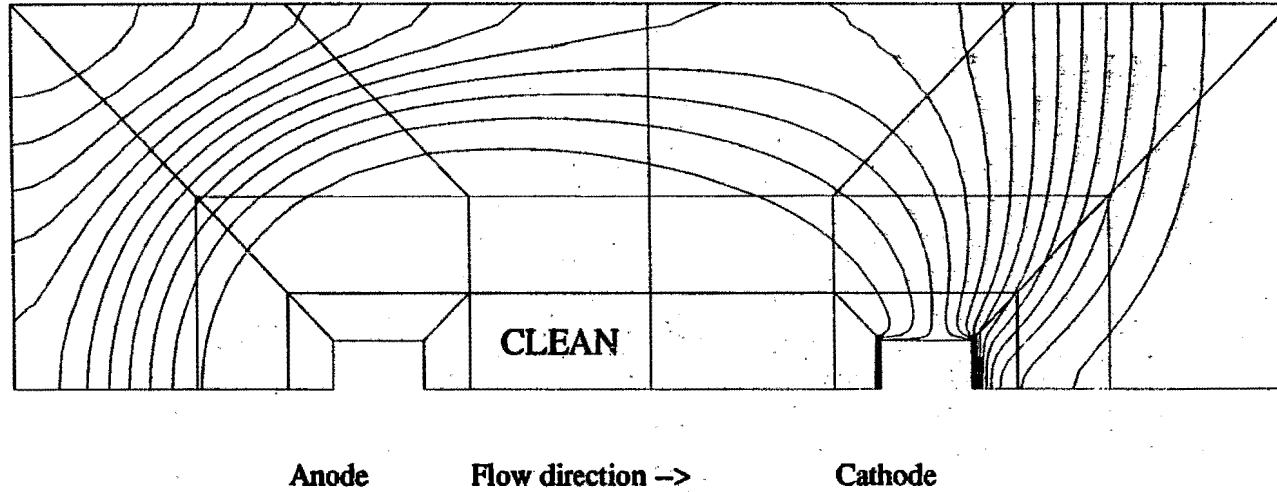
35 Volts applied

12.7 cm between electrodes

MODEL

CONTAMINANT CONCENTRATION DISTRIBUTION

AFTER 13 DAYS



450 ppm phenol

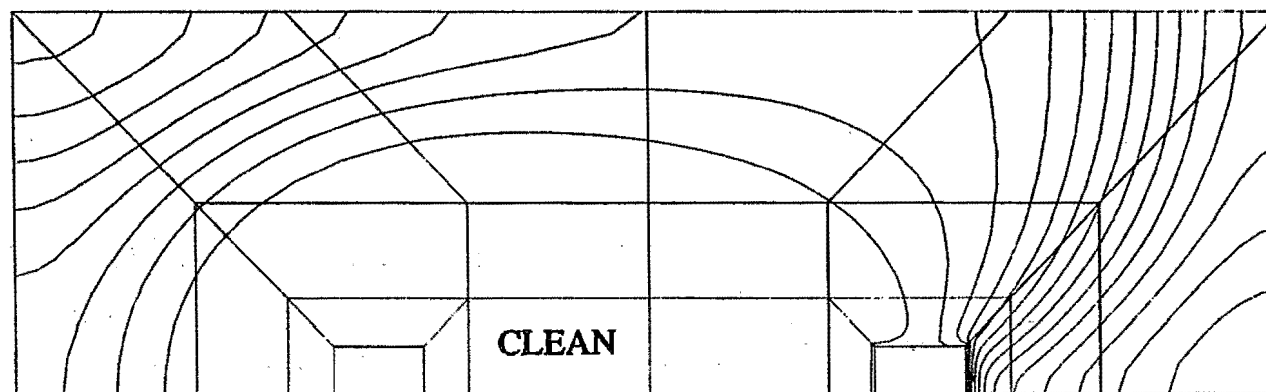
35 Volts applied

12.7 cm between electrodes

MODEL

CONTAMINANT CONCENTRATION DISTRIBUTION

AFTER 27 DAYS



Anode

Flow direction -->

Cathode

450 ppm phenol

35 Volts applied

12.7 cm between electrodes

CONCLUSIONS

- By tailor-making purge solutions for site-specific conditions, electroosmotic purging has potential to remove a large variety of pollutants including radioactive materials
- Electroosmosis offers advantages of control of flow direction and uniform flow through heterogeneous soils
- Lab experiments on electroosmotic purging show a high degree of removal (~95%) at low energy costs (< \$0.01/gallon or \$2.50/ton)
- Additional laboratory studies are still required with different chemical species, soils, saturation geometries, electric fields, and 3-D geometries to build up generic database for optimal field operation

NATO/CCMS Guest Speaker:

Hans-Joachim Stietzel, European Economic Community

Soil Protection Against Point-Source Contamination
in the European Community

NATO/CCMS PILOT STUDY OF REMEDIAL ACTION TECHNOLOGIES FOR
CONTAMINATED LAND AND GROUNDWATER
BILTHOVEN, THE NETHERLANDS, NOVEMBER 7-11 1988

Soil protection against point-source contamination in the
European Community

Dr. Hans Joachim Stietzel
Mr. Eusebio Murillo Matilla

Soil protection against point-source contamination in the European Community

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V References

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I. Definitions and types of soil contamination and deterioration

1. Definitions

There exists no generally accepted definition for contaminated land in the European Community. Some Member States have defined it in the following way:

Denmark: Land which presents a threat to groundwater sources or to the health of local residents (Danish National Agency on Environmental Protection, 1985)

Germany: Land that presents a potential direct or indirect adverse impact upon the health and welfare of humans and economically important natural resources, such as livestock, crops and groundwater sources. (BMFT, 1981)

UK: Land, which because of its former use, now contains substances that present hazards likely to affect its proposed form of redevelopment, and which requires an assessment to determine whether the proposed development should proceed or whether some form of remedial action is required. (DOE, 1983)

Netherlands: Land, where substances are present in soil in concentrations higher than those in which they would normally expect to occur and where they pose a serious threat to public health and the environment. (Ministry of Housing, Physical Planning and Environment, 1983)

Generally speaking two types of soil pollution can be distinguished:

2. Diffuse contamination: pollution of a large area caused by an exogenous source

- atmospheric pollution ("acid rain"): emissions of sulphur dioxide, nitrogen oxides, etc. by industry, domestic fuels, traffic, etc.
- agricultural practice: prolonged and excessive use of fertilizers, pesticides, herbicides, sewage sludge

3. Point source contamination: geographically restricted local pollution by accidental/incidental/ deliberate anthropogenic activities

industry:

- transport of chemicals/materials
- storage of raw materials
- production processes
- storage of products (leakage, spillage)

- disused production plants and former industrial sites

waste disposal:

- municipal landfills
- hazardous waste landfills
- co-disposal landfills
- abandoned waste disposal sites

II Relevance of Council Directives, Action Programmes and Parliament Resolutions for soil protection against point source contamination.

Soil protection against point source contamination has not received major attention and has not been a priority issue of the EC environmental policy until very recently. Whilst the effects of agricultural practice, the spreading of sewage sludge and the excessive use of fertilizers and pesticides, has been investigated by the agricultural research of the Commission (DG VI) or by other research programmes (Cost 68, 681; DG XII), the study of point source contamination is still in an early stage.

Soil protection should be considered as a multimedia approach, since the soil is part of various ecosystems and tackling the problems of soil pollution should not lead to problems in other compartments of the environment (water, air). Taking account of the fact that the soil is linked with the atmosphere, hydrosphere, biosphere and lithosphere, there are a number of EC directives which have relevance to soil protection but the only one which has a special relevance to soil and which sets up some limit values for pollutants is the directive on sewage sludge in agriculture (86/278/EEC).

To a certain extent, the following articles of directives can be applied for the benefit of soil protection.

1. Council Directives/18/

1.1 Council Directive of 15.07.1975 on waste (75/442/EEC)

Article 4

Member States shall take the necessary measures to ensure that waste is disposed of without endangering human health and without harming the environment, and in particular:

- without risk to water, air, soil and plants and animals,
- without causing a nuisance through noise or odours,
- without adversely affecting the countryside or places of special interest.

1.2 Council Directive of 20.03.1978 on toxic and dangerous waste (78/319/EEC)

Article 7

Member States shall take the necessary steps to ensure that:

- toxic and dangerous waste is, where necessary, kept separate from other matter and residues when being collected, transported, stored or deposited;
- the packaging of toxic and dangerous waste is appropriately labelled, indicating in particular the nature, composition and quantity of the waste;
- such toxic and dangerous waste is recorded and identified in respect of each site where it is or has been deposited.

Article 16

1. Every three years, and for the first time three years following the notification of this Directive,

Member States shall draw up a situation report on the disposal of toxic and dangerous waste in their respective countries and shall forward it to the Commission. The Commission shall circulate this report to the other Member States.

2. The Commission shall report every three years to the Council and to the European Parliament on the application of this Directive.

1.3 Council Directive of 16/6/1975 on the disposal of waste oils (75/439/EEC).

Article 4

Member States shall take the necessary measures to ensure the prohibition of:

- a) any discharge of waste oils into inland surface water, ground water, territorial sea water and drainage systems;
- b) any deposit and/or discharge of waste oils harmful to the soil and any uncontrolled discharge of residues resulting from the processing of waste oils;
- c) any processing of waste oils causing air pollution which exceeds the level prescribed by existing provisions.

1.4 Council Directive of 12.06.1986 on the protection of the environment and in particular of the soil, when sewage sludge is used in agriculture (86/278/EEC).

Article 1

The purpose of this Directive is to regulate the use of sewage sludge in agriculture in such a way as to prevent harmful effects on soil, vegetation, animals and man,

thereby encouraging the correct use of such sewage sludge. (see Annex I)

The directive sets up limit values for concentration of heavy metals in the soil and in sludge and the maximum quantities of cadmium, copper, nickel, zinc and mercury, which may be added to the soil.

1.5 Council Directive of 17.12.1979 on the protection of groundwater against pollution caused by certain dangerous substances.

Article 1

1. The purpose of this Directive is to prevent the pollution of groundwater by substances belonging to the families and groups of substances in lists I or II in the Annex, hereinafter referred to as 'substances in lists I or II', and as far as possible to check or eliminate the consequences of pollution which has already occurred.

2. For the purposes of this Directive:

a) 'groundwater' means all water which is below the surface of the ground in the saturation zone and in direct contact with the ground or subsoil;

b) 'direct discharge' means the introduction into groundwater of substances in lists I or II without percolation through the ground or subsoil;

c) 'indirect discharge' means the introduction into groundwater of substances in lists I or II after percolation through the ground or subsoil;

d) 'pollution' means the discharge by man, directly or indirectly, of substances or energy into groundwater, the results of which are such as to endanger human health or water supplies, harm living resources and the aquatic ecosystem or interfere with other legitimate uses of water.

Lists I and II see Annex II.

1.6 Council Directive of 27.06.1985 on the assessment of the effects of certain public and private projects on the environment. (85/337/EEC)

Article 1

1. This Directive shall apply to the assessment of the environmental effects of those public and private projects which are likely to have significant effects on the environment.

Article 3

The environmental impact assessment will identify, describe and assess in an appropriate manner, in the light of each individual case and in accordance with the articles 4 to 11, the direct and indirect effects of a project on the following factors:

- human beings, fauna and flora,
- soil, water, air, climate and the landscape,
- the inter-action between the factors mentioned in the first and second indents,
- material assets and the cultural heritage.

2. The significance of the 4th Environmental Action Programme (1987 - 1992) for soil protection.

The first three Environmental Action Programmes concentrated on pollution problems as these arise in the different media: air, water, soil and the approach to control pollution has been a sectoral one. "One inevitable consequence of the sectoral approach to pollution is that, as standards are tightend in one area, so the pressures may increase in another area." /1/.

The global approach of the Fourth Action Programme changed the environmental strategy of the Community to a multi-media and multi-sectoral pollution control. As the soil is a very complex biosystem and as there are many different types of soils and pollutants the comprehensive approach to soil protection will aim:

- to reinforce the arrangements for coordination between policies to ensure that soil protection is more effectively taken into account in particular in the Community's agricultural and regional development policies,
- to reduce the damage caused by agriculture to the ecological infrastructure by proposing measures (within the context of the reform of the common agricultural policy) to encourage less intensive livestock production

systems; to reduce the use of agricultural chemicals; and to ensure the proper management of agricultural waste (especially from intensive livestock units)

- to prevent soil erosion and rapid run-off of water (including the identification and mapping of rapidly erodable soils in the Community),

- to identify and clean up polluted waste disposal sites; to encourage the recovery and re-use of contaminated or derelict land (e.g. old industrial sites, mining land, etc.); and to reduce the hazard to soil from current waste disposal practices,

- to encourage the development of innovative soil protection techniques and the transfer of available know-how.

3. Resolution of the European Parliament on the waste disposal industry and old waste dumps (19.06.1987). PE DOC A 2-31-/87

The Committee on the Environment, Public Health and Consumer Protection has adopted on 19.01.1987 a working document on the waste disposal industry and old waste dumps (Doc. B 2-1654/85; author: Roelants du Vivier), where the nature and extent of contaminated land, the government responses to the problem and perspectives for the European Community are described.

Following this report the European Parliament adopted a resolution on the waste disposal industry and old waste dumps (PE Doc. A 2-31-/87).
(see Annex III)

III. The fund problem: Financing the clean-up of contaminated land

1. Costs of remedial actions in the EC

"On account of (the) wide variety in local or national circumstances and factors there can hardly be said to be any similarity in the policies of the various Member States with respect to soil contamination problems." /11/

The expenditures for soil protection, in particular for the clean-up of contaminated land differ widely and will, in respect of the internal market of 1992, lead to false competition and to the import and export of highly

polluted soil due to the different approaches of the Member States.

It might be very difficult to set up international standards (reference values, trigger values) because of the variety of soil types, soil structure, intended after use etc., but it seems that this is, for the long term, the only solution to the problems connected with contaminated land.

The listed expenditures of the Member States are based on published literature and reports 2/12/13. It is not possible to give exact data for all Member States.

Important Note:

The figures of the number and type of sites in the table cannot be compared with each other because
- the definitions of contaminated or derelict land differ widely

- only in some Member States a systematic survey of contaminated land has been completed

- the reference year of the inventories is different

2. Comparison of costs for some of the existing remedial and containment techniques

TECHNIQUES	COST
Thermal techniques	± 75-175 ECU/t
Extraction techniques (physico-chemical)	± 75-100 ECU/t
Microbiological techniques	± 50-125 ECU/t
Surface sealing (synthetic material)	± 10-18 ECU/m ²
Seal walls	± 18-175 ECU/m ²
Bottom liners Horizontal barriers	± , 200-1000 ECU/m ²

3. Financing models

The estimated expenditure required for the reclamation of contaminated land in the EC Member States (EC 10) amounts up to 1.350×10^4 ECU per annum for the next 15 years /2/. (1 ECU = 1.25US\$, 2.07DL, 0.66£, 2.32DFL, 7.03FF.)

Despite the urgent need for remedial measures and the restoration of contaminated soils, especially in urban areas, there is a lack of funds to finance the new decontamination techniques.

Since the Community's First Action Programme the "polluter pays principle" (P.P.P.) has always been the cornerstone of the EEC environmental policy.

In theory, the PPP seems to be a simple solution, but practise has shown that several difficulties have to be overcome to execute this principle, because in many cases:

- the polluter is unknown
- the polluter is insolvent
- the initial polluter is known but has no legal successor

Therefore, a different approach was developed in several Member States. The experience in the Netherlands shows that law-suits to retrieve the high costs for the reclamation measures can take a long time, but in certain cases of severe soil and groundwater pollution it is necessary to act very fast. So the central Dutch government finances 90%, the municipality 10% of the clean-up costs and tries to recover the money from the responsible parties. In this way, 40 law-suits have recovered 300×10^6 Dfl., and in more than 400 cases agreements were settled with companies to cover the expenses of clean-up operations /14/.

The practical experience of this approach seemed to be quite successfull as the threat of a law-suit convinced many companies to start voluntarily reclamation of the contaminated land.

The USA established in 1980 a cleaning fund which is financed from tax on organic and inorganic chemicals and crude oil. This "Superfund" is administrated by the EPA (Environmental Protection Agency) and has spent 1,6 Billion \$ in the last 6 years. /15/. With the aid of the Superfund 25 000 potential hazardous sites were identified and 888 sites were listed on the NPL (National Priority List) for remedial action.

In Germany several attempts have been made to solve the liability problem. The introduction of a voluntary cooperation between the state and industry at the federal level and also a compulsory legal solution similar to the Superfund failed because it was controversial as to the way in which the fund should be divided to the Länder and because industry wanted to have a say what should be done with the money they had to contribute /16/.

In consequence of these problems the federal Länder developed their own different liability regulations.

In conclusion and to simplify matters, it can be said that the following possibilities have been considered to finance the clean-up of contaminated land:

1. Polluter Pays Principle: direct application, suing the polluter
2. Public fund of the government: costs of reclamation are paid by the government. Later retrieval of the cost from the polluters (Netherlands)
3. Joint liability programme: compulsory taxes on industrial products. Administration of the fund by the government (Superfund, USA)
4. Combined industry/government fund: voluntary co-operation between the industry and the government. Funds are raised together and the distribution of the expenditures is coordinated.

IV. Community action concerning point source contamination

1. Research and demonstration

1.1 Existing studies and reports

Until now four major studies have been ordered and/or financed by the Commission to analyse the extent and the problems of soil contamination in the Member States.

a. TNO Study (1986)

Contract number 85-86 600-11-042-11-N

"Prospective action with regard to soil contamination in view of a common policy"

The TNO-study defines the state of the art and essential developments in the field of soil contamination. The national policies and programmes for soil protection in the EC Member States are summarized and some recommendations for the European Commission are given.

b. ECOTEC-Study (1986) commissioned by DG XII

"Land Recycling and Renewal: A prospective analyses of industrial land contamination and Remedial Treatment"

The ECOTEC report focuses on the required expenditures to clean-up contaminated sites in the EC, gives an assessment of the scale, nature and location of future land contamination and reviews the available technology for remedial actions and includes priorities for R + D and legislative controls.

c. Dornier-Study (1987)

Contract number 85-B 6632-11-006-11-N

"Contaminated Land in the EC"

The Dornier-study gives a comprehensive survey of state laws, the structure of the administration, the registration of contaminated sites and financing models in the EC concerning soil pollution.

d. Mickan-Report (1987)

"Parameters characterizing toxic and hazardous waste disposal sites. Management and monitoring".

The criteria for toxic and hazardous waste disposal sites are summarized and the advantages and disadvantages of landfills, underground disposal sites and deep well disposals are discussed. The common field and laboratory tests are described in an annex.

1.2 ACE Programme

In the framework of the ACE-programme (Action by the Community relating to the Environment), Council regulation N° 2242/87 of 23 July 1987, the Community will make financial support available to demonstration projects relating to:

a) new clean technologies, i. e. technologies which cause little or no pollution and which may also be more economical in the use of natural resources

b) techniques for recycling and reusing waste, including waste water

c) techniques for locating and restoring sites contaminated by hazardous waste and/or hazardous substances

d) methods for measuring and monitoring the quality of the natural environment.

Demonstration means the operation of a full scale installation and is the link between the R + D phase and the later investment/production phase.

A call for tenders for the items 1.c) and 1.d) of the Council Regulation will be launched at the end of 1989. The third amended version of the fields of application for item c) is enclosed in Annex IV.

1.3 Research areas

1. The research programme STEP (Science and Technology for the Environmental protection) carried out by DG XII is the continuation and extension of the ongoing 4th Environment Protection Research Programme (1986 - 1990).

The objective of the research area 5: soil and groundwater protection is to develop a scientific basis for the protection of soil and the prevention of groundwater pollution. The protection against organic pollutants will include research about the throughflow from waste disposal sites.

The research area 8: Technologies for environmental protection focuses on waste research.

In respect of soil protection against point-source contamination the following items of the waste research are of special interest:

- specific treatment processes to facilitate disposal such as solidification of waste
- Environmental impact assessment for waste disposal sites
- Risk assessment and reclamation of abandoned disposal sites

1.4 Recommendations for research:

Contaminated land:

- a) Behaviour and impact of organic and inorganic contaminants on soil ecosystems
- b) Overlapping effects of a wide variety of contaminants in the soil
- c) Dose-response relations to low dose levels of soil contamination (long-term effect)
- d) Research for cost-effective reclamation techniques for abandoned waste disposal sites.

COUNTRY	S I T E S			N° of cleaned-up sites	Present annual expenditure (1984) x10 ⁶		Estimated future annual expenditure* x10 ⁶		% of GDP
	Number	Type	Ref year		ECU	National currency	ECU	Nat.currency	
BELGIUM	Flanders: 70 Wallonia	industrial/waste	1985	Insufficient data.			62	2772 BFR	0,08
DENMARK	3115	industrial/waste	1980-2	Insufficient data.	5	44 DKR	13	101 DKR	0,03
GERMANY	35000 44000	5000 industrial 30000 waste	1985 1987	Insufficient data.	North-Rhine Westphalia 48	106 DM	377	829 DM	0,07
FRANCE	800		1982	Insufficient data.	Nord pas de Lorraine, 13	Calais, Rhône-Alps 87 FF	214	1468 FF	0.04
IRELAND**	7	gasworks/mines	?	Insufficient data.			10	7 £	0,06
ITALY	5433	abandoned waste	?	Insufficient data.			134	198190 LI	0,06
GREECE	5000	uncontrolled disposal	?	Insufficient data.			11	1456 DR	0,04
LUXEMBOURG	142	municipal waste	1986	Insufficient data.			3	189 FRS	0,07
NETHERLANDS	6060	Contaminated: 6000 small/60 big	1986	Insufficient data.	88	215 DFL	56	140 DFL	0,04
PORTUGAL	69 ± 1800	toxic or hazardous waste industrial (estimate)	1986	Insufficient data.					
SPAIN	(Catalonia 400) 916	industrial waste uncontrolled spillways urban solid waste uncontrolled spillways		Insufficient data.					
UK	Wales 703 45600 Ha	Contaminated derelict land	1983/4 1982	Insufficient data.			476	280 £	0,1

until the year 2000

* new inventory until end of 1987

Landfills:

- a) Research for the safe disposal of hazardous waste in landfills
- b) Effects of waste disposal on land
- c) Soil vulnerability by dump leachates
- d) Treatment of seepage water from landfills
- e) Longterm surveillance and monitoring for hazardous waste in landfills

2. Preparation of legal provisions
(recommendations, resolutions, regulations, decisions,
directives)

Preventive measures:

- a) Preparation of guidelines and codes for landfill design and operation:

Strategy in landfilling /17/:

- banning of landfilling of organic waste (as far as possible)
- operating of mono-landfills or quasi-mono-landfills
- banning of liquid waste
- treatment of waste before dumping to reach a "final storage quality".
- b) Guidance notes for careful dismantling of disused factories, plants and mining districts

Curative measures:

- a) Guidelines for the risk assessment of contaminated sites
- b) Setting up of uniform trigger and reference values for contaminated soil
- c) Guidelines for sampling and analysis of soil
- d) Definitions for contaminated land

3. Participation in international working groups/technical committees

3.1 Nato/CCMS Pilot Study "Demonstration of remedial action technologies for contaminated land and groundwater".

The purpose of the pilot study is to demonstrate and evaluate new technologies and/or existing systems for the restoration of hazardous waste sites and to promote the exchange of information and data.

After establishing contact with the Nato/CCMS the Commission (DG XI/A-3) was invited to attend the second international experts' meeting in the Netherlands (Bilthoven, November 1988) and to present the activities of the CEC in the field of remedial action technologies.

3.2 International organisation for standardization (ISO) TC 190

The International Organisation for Standardization has established in 1985 a new Technical Committee for soil quality including classification, definition of terms, sampling of soils and measurement and soil characteristics. The Commission (DG XI/A-3) has an observer status and receives all documents.

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(Vol.4, Water)

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ANNEX I A

LIMIT VALUES FOR CONCENTRATIONS OF HEAVY METALS IN SOIL

(mg/kg of dry matter in a representative sample, as defined in Annex II C, of soil with a pH of 6 to 7)

Parameters	Limit values ⁽¹⁾
Cadmium	1 to 3
Copper ⁽²⁾	50 to 140
Nickel ⁽²⁾	30 to 75
Lead	50 to 300
Zinc ⁽²⁾	150 to 300
Mercury	1 to 1,5
Chromium ⁽³⁾	—

⁽¹⁾ Member States may permit the limit values they fix to be exceeded in the case of the use of sludge on land which at the time of notification of this Directive is dedicated to the disposal of sludge but on which commercial food crops are being grown exclusively for animal consumption. Member States must inform the Commission of the number and type of sites concerned. They must also seek to ensure that there is no resulting hazard to human health or the environment.

⁽²⁾ Member States may permit the limit values they fix to be exceeded in respect of these parameters on soil with a pH consistently higher than 7. The maximum authorized concentrations of these heavy metals must in no case exceed those values by more than 50 %. Member States must also seek to ensure that there is no resulting hazard to human health or the environment and in particular to ground water.

⁽³⁾ It is not possible at this stage to fix limit values for chromium. The Council will fix these limit values later on the basis of proposals to be submitted by the Commission, within one year following notification of this Directive.

ANNEX I B

LIMIT VALUES FOR HEAVY-METAL CONCENTRATIONS IN SLUDGE FOR USE IN AGRICULTURE

(mg/kg of dry matter)

Parameters	Limit values
Cadmium	20 to 40
Copper	1 000 to 1 750
Nickel	300 to 400
Lead	750 to 1 200
Zinc	2 500 to 4 000
Mercury	16 to 25
Chromium ⁽¹⁾	—

⁽¹⁾ It is not possible at this stage to fix limit values for chromium. The Council will fix these limit values later on the basis of proposals to be submitted by the Commission within one year following notification of this Directive.

ANNEX

LIST I OF FAMILIES AND GROUPS OF SUBSTANCES

List I contains the individual substances which belong to the families and groups of substances enumerated below, with the exception of those which are considered inappropriate to list I on the basis of a low risk of toxicity, persistence and bioaccumulation.

Such substances which with regard to toxicity, persistence and bioaccumulation are appropriate to list II are to be classed in list II.

1. Organohalogen compounds and substances which may form such compounds in the aquatic environment
2. Organophosphorus compounds
3. Organotin compounds
4. Substances which possess carcinogenic mutagenic or teratogenic properties in or via the aquatic environment⁽¹⁾
5. Mercury and its compounds
6. Cadmium and its compounds
7. Mineral oils and hydrocarbons
8. Cyanides.

LIST II OF FAMILIES AND GROUPS OF SUBSTANCES

List II contains the individual substances and the categories of substances belonging to the families and groups of substances listed below which could have a harmful effect on groundwater.

1. The following metalloids and metals and their compounds :

- | | |
|---------------|---------------|
| 1. Zinc | 11. Tin |
| 2. Copper | 12. Barium |
| 3. Nickel | 13. Beryllium |
| 4. Chrome | 14. Boron |
| 5. Lead | 15. Uranium |
| 6. Selenium | 16. Vanadium |
| 7. Arsenic | 17. Cobalt |
| 8. Antimony | 18. Thallium |
| 9. Molybdenum | 19. Tellurium |
| 10. Titanium | 20. Silver. |

2. Biocides and their derivatives not appearing in list I.
3. Substances which have a deleterious effect on the taste and/or odour of groundwater, and compounds liable to cause the formation of such substances in such water and to render it unfit for human consumption.
4. Toxic or persistent organic compounds of silicon, and substances which may cause the formation of such compounds in water, excluding those which are biologically harmless or are rapidly converted in water into harmless substances.
5. Inorganic compounds of phosphorus and elemental phosphorus.
6. Fluorides.
7. Ammonia and nitrites.

⁽¹⁾ Where certain substances in list II are carcinogenic, mutagenic or teratogenic, they are included in category 4 of this list

Friday, 19 June 1987

6. Waste disposal industry — Water quality objectives for chromium**(a) Doc. A2-31/87****RESOLUTION****on the waste disposal industry and old waste dumps***The European Parliament,*

- having regard to the motion for a resolution by Mrs Schleicher and others on the waste disposal industry and old waste dumps (Doc. B2-1654/85),
- having regard to the motion for a resolution by Mr Tridente on the danger of discharging waste on the outskirts of an environmental protection area (Doc. B2-952/86),
- having regard to its previous resolutions on waste and in particular those of 16 March 1984 ⁽¹⁾ and 11 April 1984 ⁽²⁾,
- having regard to the report by the Committee on the Environment, Public Health and Consumer Protection (Doc. A2-31/87);

Regarding the general objectives of Community policy on waste

1. Calls initially for action to be taken on all its previous requests, and in particular those calling for:
 - (a) the creation, within the Commission, of an administrative unit which is responsible for waste alone and with a bigger staff complement than hitherto (the European Parliament has on several occasions created posts in the budget for the environment sector, but the Commission has not used them for matters concerning waste);
 - (b) the harmonization of systems of statistics on waste;
 - (c) clarification of the Community definition and nomenclature of dangerous waste;
 - (d) the development of a long-term Community strategy on waste management;
 - (e) the organization of campaigns to increase the awareness of the public, waste producers and workers in the industry;
 - (f) the improvement of safety procedures covering movements of dangerous waste, with particular regard to professional training and the information given to haulage firms and drivers;
2. Calls on the Commission, in addition, to put into effect all the measures it has set out in the action programmes on the environment, and in particular:
 - (a) programmes to promote the extended use of products and the recovery of secondary raw materials;
 - (b) recommendations for the policy on clean technologies;
3. Condemns the irresponsible attitude of some Member States regarding the observance of directives adopted on waste, and insists once again that the Commission play its full role in ensuring total compliance with these directives;
4. Calls on the Commission to submit proposals for the establishment of a corps of Community inspectors responsible for monitoring the strict application of Community law on the environment;
5. Criticizes the Commission for its continued failure to fulfil adequately its function of supervising the incorporation into national law of and compliance with the Directives on waste and calls on it, in particular, to ensure forthwith that all Member States comply with their duty to provide information;
6. Calls on the Commission to supplement, at an early date, the measures it has taken with regard to the monitoring of international movements of waste by measures to harmonize the standards applicable to waste disposal facilities (dumps, incinerators) which exist in the various Member States;

⁽¹⁾ OJ No C 104, 16. 4. 1984, p. 147.⁽²⁾ OJ No C 127, 14. 5. 1984, p. 67.

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7. Stresses particularly that the harmonization of standards applicable to waste disposal installations must also cover national regulations setting limit values for the discharge of pollutants into the soil and national regulations designed to protect groundwater;
8. Calls on the Commission to draw up a specific Community strategy on the management of 'small quantities of dangerous waste' emanating from households, research laboratories, small undertakings and the farming industry;
9. Calls on the Commission, as part of its coordinating function in the research sector, to produce a survey of its techniques and pilot projects regarding the treatment, sorting and recycling of waste;
10. Emphasizes that, as a matter of priority, Community policy on waste prevention must progress from rhetoric to practical action, for example by the effective application of a European label for 'clean products';
11. Insists, again as a matter of priority, on the increased importance to be accorded at Community level to the provision of information on waste, beginning with the information which Member States must make available in accordance with the obligations laid down in existing directives;
12. Approves in particular, among the measures planned by the Commission in its Fourth Environment Action Programme the introduction of financial procedures implementing the polluter pays principle;
13. Calls on the Commission to speed up work on new directives on:
 - (a) livestock effluents;
 - (b) batteries;
 - (c) solvents;
 - (d) waste plastic;
14. Strongly advocates that particular attention be paid to waste connected with heavy metals, in view *inter alia* of the alarming figures given by water companies regarding the poisoning of surface water and groundwater as a result of the increasing contamination caused by heavy metals;
15. Urges that, in accordance with the Oslo Convention, immediate measures be taken to put a stop to waste incineration at sea and calls on the Member States to sign both the provisions of the Convention and the annexes and to implement them immediately in national measures and monitoring procedures;
16. Calls for particular attention to be paid by the Community Institutions to waste that drifts from one country to another via cross-frontier rivers, with strict measures based on monitoring at the points where the rivers cross the frontiers to ensure that contamination of surface water in the neighbouring country is properly counteracted in order to protect the drinking water extracted from the surface water, and to prevent contamination of the groundwater via permeation of the pollution which accumulates in the beds of these rivers;

Measures to be taken regarding old waste dumps

17. Draws attention to the extent and seriousness of the potential problems, in particular regarding the quality of groundwater, and consequently also of drinking water, arising from a large number of old waste dumps — more than 10 000 polluted sites to be cleaned up in the Community at an annual cost, over 15 years, of more than one billion ECU;
18. Points out that the United States has produced a response to this problem which includes the establishment at federal level of technical standards and rules governing objective civil liability and a budget funded partly by a tax on chemical and petroleum products;

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19. Points out that in the European Community only a few Member States have so far recognized the nature of the problem and taken certain measures as a result;
20. Points out that this disparity among national responses to the problem of contaminated sites is not only a cause of distortion of competition but has also led to many cases of contaminated soil being exported from one country to another;
21. Recalls that the concept of action at the most appropriate level is one of the principles of the Community's environment policy as contained in Article 130R and that many of the potential problems of old waste dumps are best handled at national, regional or local level;
22. Calls, in the first instance, for the incorporation into the law and practice of all the Member States of the last part of Article 7 of Directive 78/319/EEC, which seeks to ensure that 'toxic and dangerous waste is recorded and identified in respect of each site where it is or has been deposited' ⁽¹⁾;
23. Calls on the Commission, on the basis of information provided under Article 7 of Directive 78/319/EEC, to draw up a list of all dangerous waste dumps in order to identify in particular problematical dumps situated near borders and to call on the Member States to make a survey of all disused industrial sites where dangerous substances were employed;
24. Calls on the Commission, as part of its coordinating function in the research sector, to produce a survey of techniques for cleaning up waste dumps and industrial sites and to ensure that Member States exchange information about existing techniques;
25. Regards the traditional procedures for establishing civil liability as inadequate to guarantee, in certain cases, the compensation of victims and the reparation of damage caused to the environment, and hence calls on the Commission to make proposals generalizing the objective liability of the producer of dangerous waste and establishing obligations on those involved in the management of dangerous waste to take out insurance or an equivalent financial guarantee;
26. Regards as equally essential the creation of public or private funds which would guarantee that a contaminated site would be cleaned up (and any victims compensated) in cases where there were no solvent or identifiable guilty party;
27. Calls on the Science and Technology Option Assessment Office (STOA) to draw up a report on how the 'Superfund' operates in the United States and on the possibility of establishing a similar mechanism in the European Community;
28. Urges that research and development programmes at Community level should exploit the expertise of the Joint Research Centres and should cover:
 - the spread of pollutants emanating from old waste dumps in various types of soil and in water;
 - the refinement of risk-assessment models;
 - the development of emergency methods to combat pollution;
29. Calls on the Commission to release resources from the existing environmental funds for the coordination of research and development and the transfer of technical knowledge essential for the cleaning-up of particular contaminated sites;
30. Calls on the Commission once again to consider whether, in the future, the dumping of certain types of dangerous waste should not be prohibited and the recycling of such waste systematically encouraged, and in this connection, calls on the Commission to study the economic and environmental benefits of recycling certain dangerous wastes as opposed to other forms of disposal;

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*

31. Instructs its President to forward this resolution to the Council and Commission.

⁽¹⁾ OJ No L 84, 31. 3. 1978, p. 45.

TECHNIQUES FOR LOCATING AND RESTORING SITES CONTAMINATED BY HAZARDOUS WASTES AND/OR HAZARDOUS SUBSTANCES

Application fields

1. Location of contaminated sites and risk evaluation:
 - 1.1 Systematic investigation methods for polluted heterogeneous soils, which are contaminated with waste and/or hazardous substances.
 - 1.2 Development of methods for rapid investigation and risk assessment of hazardous waste sites, or in case of emergency.
2. Restoring of contaminated sites
 - 2.1 Remedial action techniques for the decontamination of soils containing clay and humus.
 - 2.2 Cost-saving remedial methods for a large number of small areas with contaminated soils.
 - 2.3 Remedial action techniques for the decontamination of soils with a high content of heavy metals, organic and inorganic compounds.
 - 2.4 Decentralized, mobile, modular designed soil decontamination systems for the clean-up of various combinations of pollutants.
3. Demonstration of microbiological techniques
 - 3.1 Techniques for the supervision of the degradation and displacement of pollutants during microbiological in-situ treatment.
 - 3.2 Improvement of microbiological in-situ remedial action techniques for the removal of hydrocarbon contaminants.
 - 3.3 Techniques for the improvement of the contact reactions between the nutrients, the microorganisms and the contaminated soils.
 - 3.4 Microbiological degradation techniques for concentrated organic contaminants in soil and groundwater.
4. Thermal techniques
 - 4.1 Thermal techniques for the decontamination of soils polluted by halogenated organic compounds.
5. Extraction techniques
 - 5.1 Improvement of extraction methods for soil restoration.
 - 5.2 Combination of extraction methods and biological treatment techniques for the decontamination of oil and other organic compound sludges.

