CLARINET

Remediation of Contaminated Land Technology Implementation in Europe

A report from the Contaminated Land Rehabilitation Network for Environmental Technologies

Umweltbundesamt
Federal Environment Agency – Austria

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- Environment Agency for England and Wales, June 2001: Epidemiology Workshop on Human Health Tools and Techniques - Report; Environment Agency, Rio House, Waterside Drive, Aztec West, Almondsbury, Bristol BS32 4DU
- Land Contamination & Reclamation, Vol. Nine - Number One, 2001; published by EPP Publications, 52 Kings Road, Richmond, Surrey TW10 6EP, UK
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FOREWORD

This report is the result of working group "Remediation Technologies" of the network CLARINET (Contaminated Land Rehabilitation Network for Environmental Technologies), a project funded under the Environment and Climate Programme of the European Commission.

CLARINET provides an interdisciplinary network on the sustainable management of contaminated land in Europe, analysed key-issues in decision-making processes and identified priority research needs on technical, environmental and socio-economic topics. The network brings together the combined knowledge and expertise of academics, national policy makers, government experts, consultants, industrial land owners and technology developers from 16 European countries. Key objective of CLARINET was to identify the means for the effective and sustainable management of contaminated land in order to

ensure the safe (re-)use of these lands

abate caused water pollution

maintain the functionality of soil and (ground-)water ecosystems.

CLARINET focused on the basis of currently applied risk-based procedures for land management in European countries, aiming to evaluate the current state of the art and to stimulate scientific collaboration on identified research needs in Europe.

To yield an integrated approach within the project, several interlinked working groups were identifying problem and solution related aspects for contaminated land management. Following themes have been addressed:

Brownfields Redevelopment

Impacts of Contaminated Land on Water Resources

Remediation Technologies and Techniques

Human Health Aspects

Risk Management and Decision Support

Furthermore, one working group aimed to stimulate collaboration between various R&D Programmes on a European level.

Based on the identified state-of-the-art in these areas, integrative concepts and recommendations for tackling contaminated land problems have be investigated, taking the different approaches in the European countries into account. Needs for further research have been identified.

The individual working group results contributed in developing an overall conceptual framework for sustainable management of contaminated land (Risk Based Land Management). This concept is also available within this series of publications.

Martin Schamann

Federal Environment Agency, Austria

On behalf of the CLARINET Steering Committee and members of the network

CONTENT

1 SUMMARY

Several billion EUROS are spent in the EU each year on the remediation of land affected by contamination. It is an important goal from all perspectives that this money is spent wisely and appropriately. A risk based decision-making process for remediation is now the norm across most EU member states (CLARINET and NICOLE, 1998). In this process, risk assessment and the subsequent step of risk management are intimately related elements that form the basis for a fitness-for-use approach to land affected by contamination. Risk assessment was the focus of CARACAS, the Concerted Action, which was a forerunner of CLARINET (FERGUSON *et al.,* 1998, FERGUSON & KASAMAS, 1999).

CLARINET through its Working Group “Remediation Technologies” has surveyed state-of-the-art of implemented remediation technology in the European countries represented in CLARINET. The survey was based on the use of questionnaires circulated to CLARINET’s national country representatives. The responses to these questionnaires have been compiled and peer reviewed, and are available through this final working group report. This report on remediation technologies presents a State-Of-the Art (SOA) review of implementation of remediation technologies in the different European countries. It comprises a description of the key elements for describing and selecting remediation technologies, and their principle categories. It goes on to provide a detailed inventory, by country, of technology development programmes, pilot scale projects and the use of remediation technologies. As remediation technology is an extensive topic, these country reviews are by necessity overviews. Further information can be obtained by referring to the existing national documents provided for each country (Annex 1), and the references given in the document.

Planned land use, time available for remediation, developers knowledge and understanding and the money available for development, are powerful controlling the remediation solutions. There is a constant pressure for reducing remediation costs, both to improve the economics of brownfield re-use for "hard applications" such as housing or commerce; and for "softer" uses such as nonfood agriculture and recreation. There is growing pressure to develop more cost-effective remediation technologies. Cost effectiveness is not just a product of reducing remediation costs, but also of finding remediation approaches that provide an additional enhancement to the value of the land.

The highest cost reducing potential can be achieved by reducing the volume of soil needing treatment and by increasing the proportion of materials to be recycled and reused. Experienced and professional project management, relevant and adequate site investigations, improved knowledge of the performance and efficiency of remediation processes can significantly enhance the accuracy of forecasting remediation costs. This information needs to be addressed not only from “problem definition” or “solution provision” perspectives, but as interdependent issues. For example, appropriate site investigation not only highlights problems, it also acts as a

guide to the solution. Inappropriate site investigation does neither. All procurement of services needs to be done with a view to value, not cost. In current terms this is “intelligent procurement”, concentrating on value and confidence in achievement of objectives.

There are two further factors that impact on the cost-effectiveness of remediation technologies that are outside the remit of most CLARINET participants. The first is the impact of waste legislation and regulation that, in certain nations, determines the fate of contaminated soil, and the potential for its treatment, disposal, recovery, recycling and reuse. The second is the designated land-use of a remediated site; this has a profound effect on site values and hence the options available for remediation.

There are large differences in practice throughout Europe, and some examples of aspects contributing to these differences can be given:

- In some countries waste licence is needed to treat contaminated soil on site, making time constraints a problem for on site treatment technologies,
- There are large differences in prioritisation of protection of groundwater, very much dependent on the degree of utilisation of groundwater, e.g. in countries like Norway, where only 15% of the groundwater resource is utilised for water supply, remediation is rarely initiated to protect the groundwater.
- The economic framework differs, e. g. differences in landfill taxes in the countries
- The policy framework differs, e.g. some European countries (e.g. Portugal, Greece, and Hungary), have not implemented Risk Based Land Management (RBLM) for decision-making. There are large differences in economic framework, i.e. for supporting innovative technology implementation, sustainable remediation solutions, or remediation of derelict land or brownfields.

Remediation technologies can be defined in accordance to the type of treatment processes taking place, such as:

- Biological
- Chemical / Physical
- Solidification / stabilisation (S / S)
- Thermal

Remediation solutions are also referring to where the action is taking place:

- On site
    - In situ
    - Ex situ
- Off site
    - Ex situ

In general, it can be stated that *ex situ* technologies are by far the most widely applied remediation solution in Europe. *In situ* technologies are currently in the early stage of implementation, and a number of constraints must be resolved before they are readily implemented. Assuming that a remedial approach can be adequately monitored and controlled, there is an increasing desire to promote *in situ* over *ex situ* solutions and on site solutions over solutions based on removal off site. However, there are often conflicting pressures affecting whether or not an on-site or off-site approach is taken. In some cases stakeholders may express a preference for a solution based on removing materials off site. This may be related to concerns over residual liabilities, which in turn are related to concerns over the duration, feasibility or completeness of on site solutions. Conversely, removal of materials off site may be problematic because of the transportation and related problems, or because excavation is not considered technically or economically feasible. Offering previously validated solutions and developing an appropriate verification strategy for the sites in question are key steps in dealing with these concerns.

Technologies are often being referred to as:

- Emerging technology (E);
- Some field applications, but not widely used (FA);
- Widely used (WU).

Emerging technologies have only been applied in laboratory- or pilot scale/demonstration plants. A technology, which has been used in some field applications for solving a particular problem, or addressing a specific type of matrix, could be emerging when it comes to another application. The above categorisation is rapidly changing, and it is not the intention of the working group on remediation technologies to keep this source of information updated, and the reader needs to consider this document as a state-of-the art in present time, and look for updated references in the future. This document describes in short the different technologies, and advices on literature where more detailed information can be found, some of which is readily updated. A summary of the degree of implementation of remediation technology in Europe is given below:

Civil engineering techniques are by far the most widely applied technologies throughout Europe, including:

- Excavation and related materials handling (WU);
- Disposal of contaminated soil (WU); Infilling void (WU); Cover systems (WU); Vertical barriers (WU).

Another important group of remediation technologies are those protecting against development of hazardous gases in the ground, including:

- Barriers beneath buildings (WU); Gas Barriers in the ground (WU); Monitoring systems and gas alarms (WU).

In situ technologies vary more in their degree of implementation and include processes like:

- Soil vapour extraction / bioventing (WU);

- Air / biosparging (WU); Soil flushing, pump and treat (WU); Permeable reactive barriers (E) / (WU); Redox amendments for *in situ* bioremediation (WU); *In situ* oxidation (WU); Electro-remediation (FA);Phytoremediation, (E); Monitored Natural Attenuation (MNA) (WU).

The following group of technologies are predominantly *ex situ* technologies:

- *Ex situ* bioremediation (WU); Soil washing & related *ex situ* techniques (WU); Solidification and stabilisation (WU); *Thermal treatments, (FA); *Vitrification (FA); **Ex situ* groundwater treatments (WU).

  *= Some *in situ* variants exist

The results of the questionnaire illustrated the difficulties in obtaining comparable cost figures for different technologies. Cost figures vary dependent on their origin. General remediation cost figures are high, but when cost figure are taken from bids on large clean-up projects, the figures are generally lower. The cost figures for the same technology varies several orders of magnitude, illustrating these differences, but also illustrating the lack of availability of the technologies in some countries, and the size of a commercial remediation marked in other countries. Differences in technology definitions might also be a source of error to the cost figures. Prior to this investigation, some of the authors had the general feeling that *in situ* technologies would be cheaper than *ex situ* technologies, but the investigations showed that this was not always the case. *In situ* technologies are mostly applied in projects where *ex situ* technologies were not so easy implemented, e.g. difficult clean-up projects (beneath existing buildings etc.). The cost figures for different technologies are only considered to be comparable, and are summarised below:

Predominantly *ex situ technologies*:

- Bioremediation: 20-40 Euros/t, assuming that:
  - Low cost figures are referring to composting, and
  - High cost figures are referring to bioslurry or reactor treatment system
- Soil washing 20-200 Euros/t
- Stabilisation/solidification 80-150 Euros/t
- Incineration treatment 170-350 Euros/t
- Thermal treatment 30-100 Euros/t

In situ technologies:

- 20-60 Euros/t depending on technology and application at site. Many remedial treatments operate over the shorter term and require relatively high cost and energy inputs. These are referred to as "intensive" treatment technologies. Extensive technologies operate over a longer period with low maintenance, cost, and energy requirements. Examples in current use include phytoremediation and monitored natural attenuation (MNA).

In general, concerns over feasibility tend to be greater for innovative remedial approaches, even if these have long standing track records in other countries.

However, there are often these innovative solutions that are seen to offer more in terms of reducing wider environmental impacts and furthering the cause of sustainable development.

A range of pilot scale studies and demonstration programmes are ongoing in Europe. Some of the programs are internationally oriented with partners from outside Europe.

One major international programme is the NATO/CCMS pilot study. In this programme a broad range of countries have been and are demonstrating different technologies. The study covers a broad range of technologies such as remediation of gasoline, phenol, tar, BTEX, metals etc. in different media. The results are reported and discussed in an international context. The study is now in the third phase with demonstrations of 15 different technologies from 10 different countries. The earlier phases have been reported both in paper and electronic format. The other major European programmes include:

1. The TUP (Technology Development Programme) programme sponsored by the Danish EPA;
2. The 4-5 years programme "Tests of polluted soil treatment and technology development" initiated 1998 by ADEME in France;
3. The Dutch NOBIS programme (SKB);
4. The German VEGAS programme;
5. The British CLAIRE and exSite programmes; and
6. The Swedish Coldrem programme.

There is currently interest in Europe in promoting greater consideration of the principles of sustainability in remediation work. Different countries are using different definitions and approaches to measure sustainability, and the principle of investigating sustainability is so far not implemented in any regulatory framework in Europe. United Kingdom is defining sustainable development as consisting of:

- Social progress, which encompasses the needs of everyone;
- Effective protection of the environment;
- Prudent use of natural resources;
- Maintenance of high and stable levels of economic growth and employment.

Three European approaches were illustrated by three different case studies at the Final Clarinet Conference in Vienna, a Dutch approach, a Danish approach used in a Norwegian clean up project, and an approach from United Kingdom:

Denmark: A project was carried out in Denmark supported by EU's Life Programme. Through this project a method for investigating the environmental sustainability of different remediation technologies applied in a clean up project was developed. The total environmental costs and benefits, including any potential negative or positive side effects of remediation solutions were included as decision parameters, together with more traditional parameters, such as time, finances and function. When side effects of remediation technologies are taken into consideration, the decision of technical solution has demonstrated that this often becomes different than initially anticipated. The LIFE approach has been applied in several Danish projects, and so far in one Norwegian project. The most important environmental aspects considered are: climate gas emission, acidification (acid rain), ecotoxicity, persistence (human and ecotoxicity on a regional scale), and waste production. All phases in a clean up project is included; mobilisation, operation and demobilisation.

The Netherlands: A decision support system weighing the various remediation techniques is being used. The term "environmental merit" is used to describe the non-core environmental effects. This enables objective mutual comparison of the different remediation technologies, their contribution to risk reduction, environmental merit and costs. The costs and benefits for the environment are weighed as well. A remediation technology can be chosen using the following strategy: primary risk assessment, take the time (considering natural processes in the ground), use "the self cleaning" capacity of the soil (investigate if it is sufficient), stimulate natural processes (investigating the possibility), intensive *in situ* remediation if necessary (investigate the possibility), and quantifying financial risk of a remediation alternative.

United Kingdom: Groundwork, a federation of more than 40 local Trusts in England, Wales and Northern Ireland, established in 1981, was dedicated to improving the local environment and the quality of life in local communities. The stock of derelict land in the UK had remained constant for over two decades, and a large scale, ecological-informed and community-led programme of land regeneration (Changing Places) was initiated in 1995 on the basis of a grant of £22.1 million from the Millenium Commission's project: "Revitalising Our Cities". During the last 5 years of the 20th century, tracts of neglected industrial areas have been transformed into parklands and conservation areas, play areas and wildlife sanctuaries, urban commons and community spaces. The major difference from the British approach compared to the Danish and Dutch was the community involvement. The communities involved prioritised the following aspects:

- Nature: building diversity;
- People: developing a network of friends;
- Art: Functional and celebratory;
- Learning: developing ownership and responsibility;
- History: Proud pasts, optimistic futures;
- Regeneration: people, places, prosperity.

The review of the implementation of remediation technology and ongoing pilot scale and demonstration programmes show gaps in knowledge, and that R&D throughout Europe in this area still is needed, both on a local scale and in the international scene, and in short, the following items have been identified:

- Comparable cost figures;
- QA / QC systems for performance and total emission;
- Comparable output (demonstration plants);
- Harmonised approaches including wider environmental issues for sustainable technology evaluation;
- Integration of technologies for solving the variety of problems occurring on one site;
- Integration of the planning-, investigation-, remediation- and aftercare process;
- Long-term experiences from pathway / exposure control technologies;
- Decision making on “clean” remediated soil (soil function);
- For some countries, risk based decision making approaches need implementation;
- Further development of more cost / effective technologies;
- Further development of integrated technologies solving mixed problems.

2 INTRODUCTION

The report in hand is the final Report of Working Group “Remediation Technologies”, which considers the various techniques employed to mange the risks of contaminated land. Its specific tasks have been to: inform CLARINET’s recommendations for sound decision making for the sustainable rehabilitation and redevelopment of contaminated sites, review and catalogue the present status on remediation technologies in Europe. It is envisaged the information in this document can also be used as background information for future R&D proposals on technology development through National and EU RTD programmes.

Several billion EUROs are spent in the EU each year on the remediation of land affected by contamination. It is an important goal from all perspectives that this money is spent wisely and appropriately. A risk based decision-making process for remediation is now the norm across EU Member states (CLARINET and NICOLE, 1998). In this process, risk assessment and the subsequent step of risk management are intimately related elements that form the basis for a fitness-for-use approach to land affected by contamination. Risk assessment was the focus of CARACAS, the Concerted Action, which was a forerunner of CLARINET (FERGUSON *et al.,* 1998, FERGUSON & KASAMAS, 1999).

In most countries the control of risk management is based on breaking the pollutant linkage, see Figure 1. This can be done by:

- Reducing or modifying the source (e.g. in situ bioremediation of diesel contaminated soil);
- Managing or breaking the pathway (e.g. by pump and treat or use of a physical barrier);
- Modifying the exposure to the receptor (e.g. by limiting the access to the area, restricting land-use).

To date the majority of contaminated sites that have been dealt with in Europe have been managed by one or more of the following: excavation and removal of contaminated materials for off site disposal, or disposal in on site cells, containment (e.g. barriers, hydraulic containment) and controlling site use. Over recent years there has been a growing emphasis on applying treatment based remedial approaches which destroy contaminants, extract them as some kind of concentrate or stabilise / detoxify them (NATHANAIL *et al.,* 2001). These treatment processes are the *remediation technologies*, which are the focus of this report.

This report presents a State-of-the-Art (SOA) review of implementation of remediation technologies in the different European countries. It comprises a description of the key elements for describing and selecting remediation technologies, and their principle categories. It goes on to provide a detailed inventory, by country, of technology development programmes, pilot scale projects and the use of remediation technologies. As remediation technology is an extensive topic, these country reviews are by necessity overviews. Further information can be obtained by referring to the existing national documents provided for each country.

3 KEY FACTORS IN REMEDIATION TECHNOLOGY SELECTION

3.1 General

There is a number of factors that need to be considered in selecting an effective remediation solution. These include considerations of core objectives such as risk management, technical practicability, feasibility, cost/benefit ratio and wider environmental, social and economic impacts. In addition, it is also important to consider the manner in which a decision is reached. This should be a balanced and systematic process founded on the principles of transparency and inclusive decision-making. Decisions about which risk management option(s) is most appropriate for a particular site need to be considered in a holistic manner. Key factors in decision making include:

- Driving forces to remediate and goals for the remediation objectives;
- Risk management;
- Sustainable development;
- Stakeholders' views;
- Cost effectiveness;
- Technical feasibility.

3.2 Drivers and goals for remediation work

Most remediation work has been initiated for one or more of the following reasons:

- To protect human health and the environment. In most countries, legislation requires the remediation of land, which poses significant risks to human health or other receptors in the environment such as groundwater or surface water. The contamination could either be from "historic" contamination or recent spillage of substances from a process or during transport. Groundwater protection has in many countries become an important driver for remediation projects.
- To enable redevelopment. Remediation of formerly used land may take place for strictly commercial reasons, or because economic instruments have been put in place to support the regeneration of a particular area or region; and/or
- To "repair" problems. In some cases remediation work must be retrofitted to a newly developed site.
- To limit potential liabilities. Remediation can take place as an investment to increase the potential value of land. Owners may perceive that a particular site could potentially have an environmental impact, which might leave them liable to third party actions.

3.3 Risk management

A risk-based approach has been adopted for the management of contaminated land in many countries (CLARINET and NICOLE, 1998, FERGUSON & KASAMAS, 1999). The assessment and management of land contamination risks involves three main components:

- The source of contamination (e.g. metal polluted soils, a leaking oil drum);
- The receptor (i.e. the entity that could be adversely affected by the contamination e.g. humans, groundwater, ecosystems etc.); and
- The pathway (the route by which a receptor could come into contact with the contaminating substances).

A *pollutant linkage* (see Figure 1) exists only when all three elements are in place. The probability that a pollutant linkage exists needs to be assessed. Risk assessment involves the characterisation of such a relationship, which typically includes: delineation of the source, measurement and modelling of fate and transport processes along the pathway, and assessment of the potential effect on and behaviour of the receptor. A consideration of risk must also take into account of not only the existing situation but also the likelihood of any changes in the relationship into the future. From a risk management standpoint, remediation technologies are applied to the control of the source term and/or the management of contaminants along the pathway.

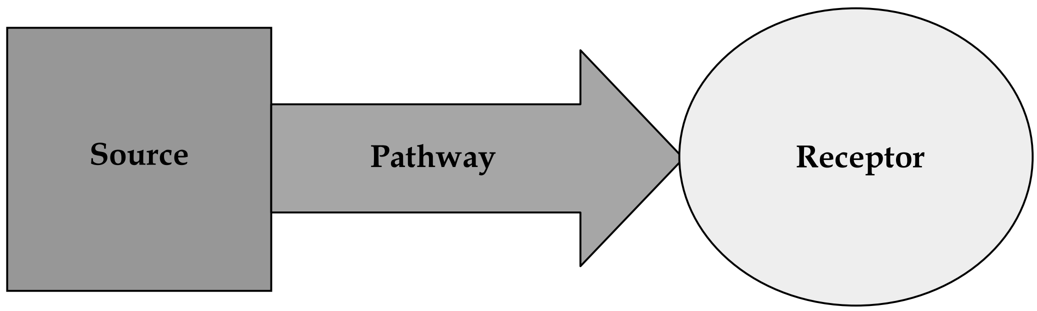

Figure 1: The pollutant linkage (including source, pathway and receptor) analysis needs to be addressed when considering the risk of a contaminated site. Remediation includes any action taken to break the linkage.

3.4 Sustainable development

The concept of sustainable development gained international governmental recognition at the United Nation's Earth Summit conference in Rio de Janeiro in 1992. A number of definitions for sustainable development have been proposed in different countries, for example the Norway and the UK (outlined in Table 1), based on the original concept of: "*Development that meets the needs of the present without compromising the ability of future generations to meet their own needs*" (BRUNDTLAND, 1987). Underpinning all of these approaches are three basic elements to sustainable development: economic growth, environmental protection and social progress.

Table 1. Various definitions and approaches are used for "sustainable development", e.g.:

Norway	**United Kingdom**
Sustainable development requires a broad-based approach, which encompasses both on assessment of environmental problems and possible remedial measures: Economic dimensions, Technological dimensions, Social and cultural dimensions	Sustainable development consists of: Social progress which recognises the needs of everyone; Effective protection of the environment; Prudent use of natural resources; and Maintenance of high and stable levels of economic growth and employment.

At a strategic level, the remediation of contaminated sites supports the goal of sustainable development by helping to conserve land as a resource, preventing the spread of pollution to air, soil and water, and reducing the pressure for development on Greenfield sites. However, remediation activities themselves have their own environmental, social and economic impacts. On a project-by-project basis, the negative impacts of remediation should not exceed the benefits of the project. At present there are no generally agreed means of carrying out sustainability appraisal for remediation projects. Although approaches to assessing the wider impacts of individual elements of sustainability (e.g. wider environmental effects) are under development in several countries - see Box 1, a truly integrated approach has yet to be found. There is some way to go before an international consensus can be reached in the way that agreement has emerged about the principles of risk assessment and risk management. This is hardly surprising given the complex interplay of economic, environmental and social factors that affect and are affected by a remediation project.

Remediation objectives typically relate to environmental and health risks and perhaps performance of geotechnical / construction measures. These may form part of a larger regeneration project with social and economic aims, such as attracting inward investment. What is realisable, and the approaches that can be taken, will be subject to certain site/project specific boundaries, for example the time and money available for the remediation works, the nature of the contamination and ground conditions, the site location and many more. Hence the objectives that can be realised by remediation works represent a compromise between desired environmental quality objectives and these site-specific boundaries. This compromise is reached by a decision making process involving several stakeholders (see Section 3.5.). This decision making process is often protracted and costly. Its conclusions can be said to represent the *core* of the remediation project. While achieving environmental quality objectives will normally underpin any project dealing with contaminated land, desired quality objectives may be driven by a combination of technical criteria and third party non-technical perception of risk.

From a broader perspective remediation processes will achieve these core objectives, by:

- Helping to conserve land as a resource;
- Preventing the spread of pollution to air and water;
- Reducing the pressure for development on green field sites.

In a broader perspective, a number of questions must also be addressed, such as:

- How justified is it to excavate ground materials and put them somewhere else?
- How justified is it to burn huge amounts of fossil fuel to treat ground containing grams of hydrocarbon per kilogram?
- How justified is it to strip VOC to atmosphere?

The grand question is therefore, should the remedial regime also be sustainable? If the undesirable impacts of these remediation processes exceed the desired benefits of the core objectives, the core objectives may need to be re-evaluated. If proper risk management procedures have been followed, along with a thorough cost benefit analysis and stakeholder consultation, the risks of such a situation arising should be minimised, depending on the remediation approach selected. Different remediation approaches will vary in their wider environmental impacts, as illustrated in Table 2; and perhaps also their wider social and economic effects. For example, the acceptability to local residents of different processes can differ. It is therefore useful to consider the route taken to affect the remediation, as well as the core objectives of the remediation project. Assuming an overall "sustainability value" of the core objectives these "non-core" considerations help determine the remediation approach, which detracts least from this overall value.

The wider consequences of a particular remedial project are site-specific in their nature. Some may be temporary (e.g. lorry movements; traffic problem, noise), other permanent (e.g. loss of soil function). The significance of these consequences also depends on the location of the site being remedied. The importance of "nuisance" issues (e.g. odours, dust, and noise) associated with remedial options, may, for example be less for a remote site than for a site in a city neighbourhood. The relative significance that attaches to any particular wider effect of remediation will itself vary at a local, regional and / or national level, for example as a result of cultural differences, differences in population density, use of resources etc.

Box 1: Assessment of Non-Core Effects: Case Studies, i.e.:

In Denmark, the Danish Railroad Systems AS has in a EU financed project (LIFE-program) supported by the Danish EPA, the environmental element of sustainability further developed into a computer model suitable for optimising the environmental and economic aspects when selecting remediation strategy (Deigaard, 2000). The environmental costs involve the work process throughout the whole life cycle of the remediation. The work process includes the consumption of materials, fuel and energy consumption (including emissions to air, soil and water), and effects on man (noise, odour), as well as waste and accidential issues. The Danish approach of evaluating sustainable clean-up solutions has recently been used to evaluate clan-up measures in single sites within a large remediation project of the old airport of Oslo, Fornebu (Ellefsen, 2001).

In the Netherlands the term "Environmental merit" is used to describe non-core environmental effects, and a decision support system involving the weighting of the various remediation alternatives, is being used (Nijboer, 1998), [NOBIS 1995a & b]. This enables objective mutual comparison of the different remediation technologies, their contribution to risk reduction, environmental merit and costs. The costs and benefits for the environment are weighed as well. A remediation technology can be chosen using the following strategy.

- Primary risk assessment
- Take the time (Considering natural processes in soil)
- Use the “self cleaning capacity” of the soil (Investigating if this is sufficient)
- Stimulate natural processes (Investigating the possibility)
- Intensive in-situ remediation if necessary (Investigate the possibility)
- Quantify financial risk of a remediation alternative (Hetterschijt *et al*, 1999).

The integrated assessment approach using the Dutch approach, was presented by Okx (2001).

In the UK, social involvement in derelict land remediation became a key-stone in the Changing Places programme, which was initiated in 1995 on the basis of a grant of £22.1million from the Millenium Commission’s project: ”Revitalising Our Cities” (Groundwork, 2000, Barton, 2001). The stock of derelict land in the UK had remained constant for over two decades, and the ecological-informed and community-led programme of land regeneration (Changing Places) was initiated. During the last 5 years of the 20th century, tracts of neglected industrial land have been transformed into parklands and conservation areas; play areas and wildlife sanctuaries, urban commons and community spaces. The major difference from the British approach compared to the Danish and Dutch was the community involvement. The communities involved prioritised the following aspects:

- Nature: building diversity,
- People: developing a network of friends,
- Art: Functional and celebratory

Table 2: Some Examples of the Wider Environmental Effects of Remediation Activities (BARDOS et al., 2000) a. Factors included in the EU project (ScanRail Consult et al, 2000) b.

Negative	Positive
• Traffic ***(a,b)*** • Emissions (e.g. volatile organic compounds) ***(a,b)*** • Noise ***(a,b)*** • Dust ***(a,b)*** • Odour ***(a,b)*** • Loss of soil and groundwater function ***(a,b)*** • Use of material resources (e.g. Aggregates) and energy ***(a,b)*** • Use of landfill resources ***(a,b)*** • Waste production (***b***) • Accidents on personell and machinery (***b***) • Physical surroundings (***b***)	• Restoration of landscape "value" ***(a,b)*** • Restoration of ecological functions ***(a,b)*** • Improvement of soil fertility (e.g. for some biological remediation techniques) ***(a,b)*** • Recycling of materials ***(a,b)***

Good practice in risk management for contaminated land includes the setting of clear risk management goals and a shortlist of potentially feasible remedial techniques as a basis for determining future actions (for example in the UK as set out by the forthcoming "Model Procedures" for managing contaminated land, (DETR, 2001). These are the outputs of the “core” decision-making process.

It is this short-list of potentially feasible techniques that can then be considered more closely, to assess potentially wider, "non-core" effects. Different techniques can be compared with each other against a range of sustainability appraisal criteria, which can be used to *refine* the shortlist of remedial techniques. This includes the:

- Primary (Core) goals and constraints, e.g. risk reduction, time, space and money
    - Cause a decision to act and set the boundaries of what is possible
- “Non-core”: wider environmental effects, wider economic effects, wider social concerns
    - Could shape a sustainable approach once a decision to act is taken

Hence, decision making for contaminated site remediation can be divided across two dimensions: (1) the (three) elements of sustainable development and (2) core/non-core issues. Together these ensure a consistent approach to considering sustainable development for remediation projects across sites. This “core / non-core” model is summarised in Table 3 and Table 4. This conceptual model proposes that the “value” of the project core is fixed, being a function of the risk reduction and redevelopment goals. The non-core “value” of the choice of remedial technique is variable, depending, obviously, on the choice made. The overall “value” of the project is the sum of the core and non-core “volumes” for each sustainability element.

Table 3: The Core/Non-Core Model for sustainable risk management of contaminated sites

Sustainability elements	**Core**	**+ Non-Core**	**=Total (Overall Performance)**
Economic (Include liabilities)	Fixed	Variable	Economic Value
± Environmental (Include risk reduction)	Fixed	Variable	Environmental Value
+ Social	Fixed	Variable	Social Value
= Total (Overall “Sustainability”)	Core *Value*	+ “Efficiency”	Overall Performance in Achieving Sustainable Development

Table 4: Examples of Wider Economic and Social Issues

Economic Consequences	**Social Consequences**
• Impacts on local business and inward investment • Impacts on local employment • Occupancy of the site	• Removal of blight • Community concerns about remedial approach • Amenity value of the site

This conceptual framework is intended to reflect the practical reality of contaminated land management today, in which risk management is a principal basis for action. The range of remedial options available for a particular problem site is fundamentally constrained by: their cost, land requirements, time required and time constraints and the effectiveness of the chosen remedial technique to reduce the risks given site conditions, and the controls imposed over process emissions and wastes etc. Under current conditions, the opportunity for considering wider environmental issues only exists once these matters have been satisfactorily dealt with.

This is a sequential system, which is appropriate when we know what land-use are expected, but this may not always be appropriate, since the risk management goals are doubtful, the site / problem is too big, and we cannot afford the clean-up costs.

The future land-use is not decided, and the value of the land is rather low. In such cases, it is necessary to consider the appropriate solution by striking a balance between core cost / benefits and non-core, see Figure 2.

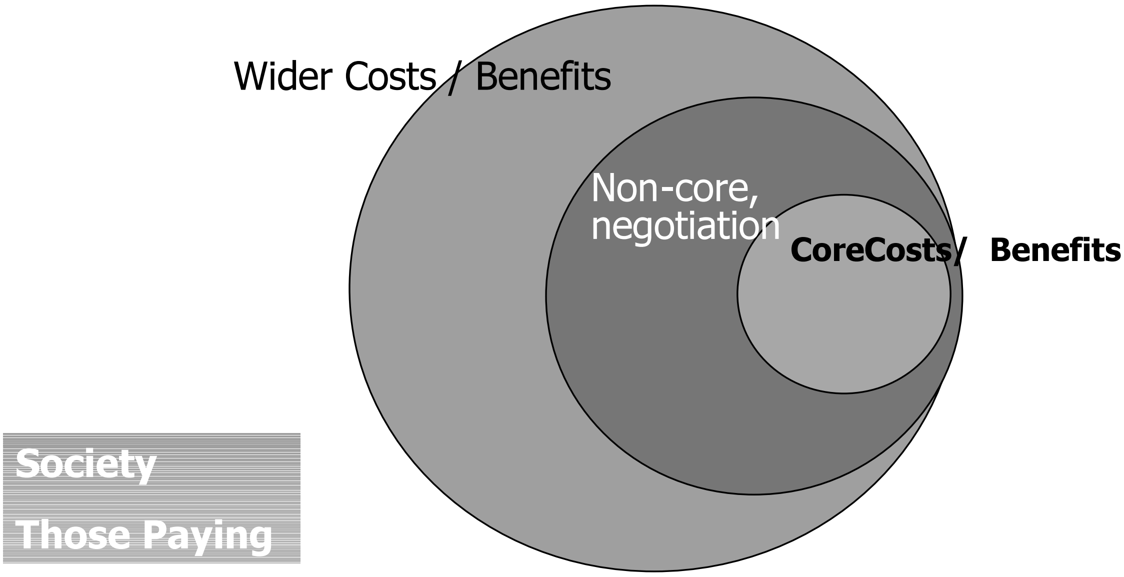

Figure 2: In many remediation projects, striking the balance between core and non-core objectives is needed to fulfil the requirement of the society and those paying.

At present there are no generally agreed means of carrying out sustainability appraisal for remediation projects. Although approaches to assessing the wider impacts of individual elements of sustainability (e.g. wider environmental effects) are under development in several countries, a truly integrated approach has yet to be found. There is some way to go before an international consensus can be reached in the way that agreement has emerged about the principles of risk assessment and risk management. This is hardly surprising given the complex interplay of economic, environmental and social factors that affect and are affected by a remediation project.

Presently there is no European agreement (standard) on how to add or weigh different sustainability factors influencing the selection of remediation technologies for contaminated sites. A number of technical approaches are under development and have been reviewed by the Final Report of Working Group on Decision Support Tools. Box 1 summarises information from three European approaches.

There is currently great interest in Europe in promoting greater consideration of the principles of sustainability in remediation work. The country review (see Appendix 2) shows how some countries have sought to promote the use of process based remediation technologies in place of conventional removal to landfill and containment effects, which are *perceived* to be more sustainable. Of all the technologies available, biological techniques are *perceived* to be the "most sustainable". However, in the absence of agreed and verifiable approaches to sustainability appraisal for remediation projects, it is not possible to categorically support or oppose these assertions.

3.5 Considering stakeholder different views

In this paper, the principal stakeholders in remediation are generally considered to be the "problem owners" (usually the polluter or site owner), and also all those with an interest in the land, its redevelopment, and the environmental, social and financial impacts of any necessary risk management works. Depending on the size and prominence of the site these stakeholders will include several of the following:

- Land owners;
- Problem holders;
- Regulatory authorities;
- Planning authorities;
- Site users, workers, visitors;
- Financial community (banks, founders, lenders, insurers);
- Site neighbours (tenants, dwellers, visitors);
- Campaigning organisations and local pressure groups;
- Consultants, contractors, and possibly researchers.

Stakeholders will have their own perspective, priorities, concerns and ambitions regarding a site. The most appropriate remedial actions will offer a balance between meeting as many of their needs as possible, in particular risk management and achieving sustainable development, without unfairly disadvantaging any individual stakeholder. It is worth noting at this point that for some stakeholders, the end conditions of the site are likely to be significantly more important than the actual process used to arrive at that condition. Such actions are more likely to be selected where the decision-making process is open, balanced, and systematic. Given the range of stakeholder interests, agreement of project objectives and project constraints such as use of time, money and space, can be a time consuming and expensive process. Seeking consensus between the different stakeholders of a decision is important in helping to achieve sustainable development.

Risk communication and risk perception issues need special considerations. Arguments and decisions need to be communicated in a balanced form to all stakeholders. A diverse range of stakeholders may need to reach agreement before specific remedial objectives can be set, for example, site owner, regulators, planners, consultants, contractors, site neighbours and perhaps others. Unsurprisingly once these remedial objectives are set it may be hard to renegotiate them.

In most practical situations, the members of the decision making team who are finally responsible for the choices of technology are the landowner, the funder, the regulator and the service provider. All other stakeholders are in a position of influence but in most cases their input does not control the decision. Landowners provide finance to execute projects. Regulators ensure compliance with acceptable environmental quality standards. Service providers apply their expertise to deliver results for both parties.

3.6 Costs

3.6.1 Indicative Costs of remediation

Costs of remediation depend on many factors and may be broken down into mobilisation, operation (per unit volume or area treated), demobilisation, monitoring and verification of performance. Although data can only be tentative, comparisons of indicative equivalent costs may be a useful exercise in the early stages of consideration of different remediation options. A range of indicative unit price costs is provided from one Member State in Table 5 (NATHANAIL, 2000). However, it is essential that site-specific factors be considered when estimating remediation costs for a particular site.

Table 5: Indicative Costs of Remediation, UK experience (NATHANAIL, 2000)

Remediation technology	Indicative unit price
Engineering capping	£ 15-£30 / m^2
Excavation and disposal to landfill	£ 50 / m^3
Encapsulation (shallow cut-off wall)	£ 40 - £ 60 / m^2
Encapsulation (deep cut-off wall)	£ 70 - £ 120 / m^2
'Typical' landfill gas control system	£ 200,000 per site
'Typical' grout curtain / vent trench	£ 220,000 per site
Bioremediation	£ 35 - £ 45 / tonne
Vitrification	£ 40 / tonne
In-situ vitrification (5t/hr)	£ 150 - £ 215 / tonne
Incineration (special wastes)	£ 750 - £ 1,000+ / tonne
Dechlorination	£ 100 - £ 300 / tonne
Soil vapour extraction	£ 40-60 / m^3 vadose zone
Soil washing	£ 30 - £ 35 / tonne
Enhanced Thermal Conduction	£ 35 - £ 45 / m^3
Six phase heating	£ 20 - £ 30 / m^3
In situ chemical oxidation	£ 40 - £ 80 / m^3

Table 5: Indicative Costs of Remediation, UK experience (NATHANAIL, 2000) (continued)

Remediation technology	Indicative unit price
Pump and treat	£ 20 - £ 30 / m^3
Free product recovery	£ 10 - £ 20 / m^3 vadose zone
Air sparging	£ 45 - £ 55 / m^3 groundwater
Oxidation of cyanide	£ 400 / tonne
Solvent extraction and incineration	£ 400 / tonne
Thermal desorption (including excavation and pre treatment)	£ 35 – £ 150 / tonne

3.6.2 Cost effectiveness

Any good practice approach to the selection process for the remediation of contaminated sites needs to consider the costs and benefits attributable between different options. Many protocols have been developed, as decision support tools, to make such considerations, systematic, transparent and to a lesser or greater extent, reproducible. These have been discussed in more detail in the Final Report of CLARINET Working Group "Decision Support Tools". Generally the techniques employed fall into two broad categories:

- Multi-Criteria Analysis (MCA): A structured system for ranking alternatives and making selections and decisions, that incorporates selection of key variables to be compared, valuations for those variables, weightings for the valuations, and an algorithm for combining this data. REC and the Danish LIFE approach is an example of a MCA system.
- Cost benefit analysis (CBA): A form of economic analysis, also an MCA, in which costs and benefits are converted into monetary values for comparison.

Sometimes an intermediate approach is adopted in which the findings of an MCA are compiled as a numeric index, which is then divided by the projected remediation costs of an option to provide a "cost effectiveness analysis". Cost effectiveness is subjective, in that different stakeholders perceive it differently. It is important that this is recognised by decision makers. CBA, MCA and allied techniques are very useful as a tool for option appraisal, by providing a common framework for stakeholders to examine and compare their perceptions of costs and benefits. However, the monetary or other values of these outputs are rarely meaningful data in their own right, at least not given the current state of the art (OKX, 2000)

Typically these analyses must consider a diverse range of impacts that not only vary from site to site but which may also differ from one proposed solution to another. In many instances, it is difficult to attach a strictly monetary value to many environmental effects, hence assessments - particularly of benefits, can involve a combination of qualitative, formal Cost Benefit Analysis (CBA) and MCA methods (CRUMBLING, 2000, Environment Agency, 1999, NOBIS, 1995a & b). It is also useful to perform a sensitivity analysis to identify the most important cost driving factors, particularly where this encourages decision-makers to question their judgements and assumptions through the eyes of other stakeholders.

Contaminated land management in Europe is a component of the wider European economy. It exists within a competitive market and is subjected to the same commercial constraints and opportunities as other land. It is, in addition, subject to multiple regimes imposed by those responsible for land quality, water quality, air quality, spatial planning and economic/social/environmental regeneration. This creates a complex scenario within which the evaluation and use of technology must fit.

Figure 3 illustrates the positions of these three key stakeholder groups. Even these can find it difficult to define a common understanding:

- Landowners may define a project (and hence the technology employed) as cost effective, if negative equity relating to the land was eliminated at a cost of less than the negative value. Conversely, they may seek to employ specific technologies that delivered “cleaner” land than was required by the regulator, in order to maximise the value of that land. It depends entirely on whether the land is a liability or an opportunity and it reflects the basis on which the decision is made whereby Directors of public companies are obliged to make decisions that are 1) legal and 2) in the best interests of the company’s shareholders. They are not obliged or necessarily authorised to consider any other factors.
- A Regulator’s perspective in the same circumstances may be significantly different. Other than in special cases (e.g. financial hardship etc), project economics is not a priority. It is quite conceivable that either or both of the project scenarios could be regarded as non-cost effective in terms of environment and public health issues, as well as considerations such as: amenity, road safety, noise etc. This is an interesting parallel to the landowner’s position as it reflects a superficially similar set of constraints. Regulators are obliged to make decisions that are 1) legal (same rules as landowners), 2) in the best interests of their shareholders (the public), and 3) to ensure environmental protection. “Best interests” begs the questions: whose interests, which interest, whose costs, which costs?
- Service providers operate within a highly competitive arena, reacting to priorities set by Landowners and Regulators. They make decisions on technology selection, but only insofar as translating the landowners’ defined needs into action that delivers projects on time, within budget, to a specified quality and within regulatory constraints. This usually represents the complete obligation. There is often no consideration of other factors. Cost effectiveness is measured in exclusively economic units.

Consensus among stakeholders can be difficult to achieve for reasons that are many and diverse but are centred often on conflicts of (best) interests that legal and regulatory systems find difficult to reconcile. For this reason, clear and inclusive decision support tools are vital to enable informed choices that do not over-compromise stakeholder(s).

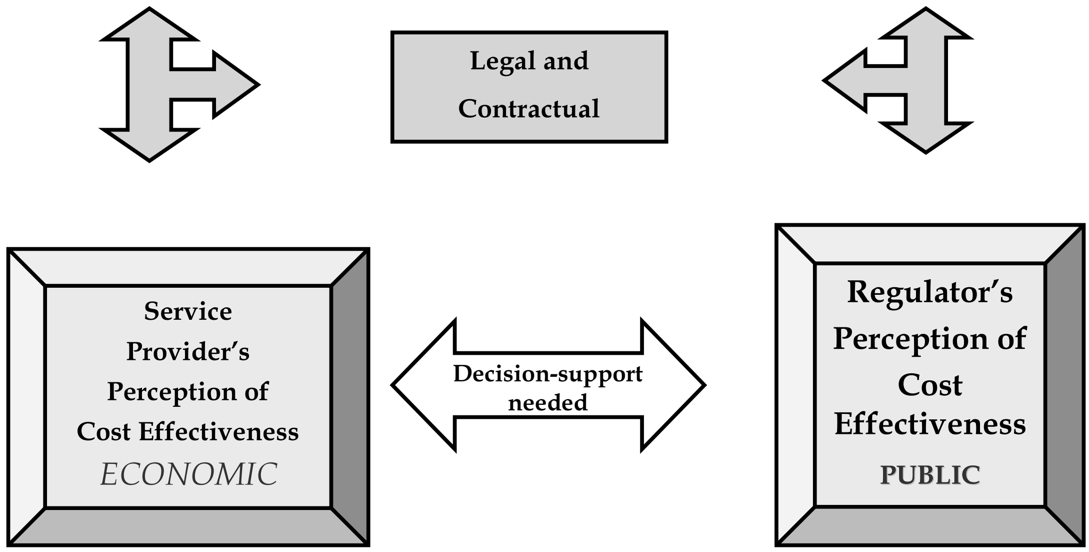

Figure 3: Elements of Cost Effectiveness

A significant amount of remediation takes place as a result of the redevelopment of brownfield sites, either as a private commercial venture or as part of a wider regeneration initiative often supported by public funds. Brownfields remediation is discussed as a specific topic in the Final Report of CLARINET Working Group "Brownfields Redevelopment". Typically brownfields regeneration aims at stimulating wider economic regeneration by the attraction of new industries or other commercial activities. However, regeneration projects can also be suitable for "softer" end uses, for example "country parks" in areas where the commercial drivers for redevelopment are less. There is an emerging view that opportunities for attracting industrial regeneration are likely to diminish in Western Europe as a result of changes in the world economy (BARTON, 2000). This implies that alternative end uses for brownfield land may need to be considered. Some are obvious, for example the need for housing in areas such as Southeast England. However for other areas some innovation may be necessary to restore land to a beneficial re-use, without creating a management burden for the Public Sector, particularly for extensive tracts of land such as former mining locations. One possibility might be the re-use of land for non-food crops, for example energy from biomass (see www.exsite.org).

In the context of brownfield remediation a large amount of effort has been placed in the past to redevelop areas with high land reuse value, and/ or areas, which have been prioritised for remediation through the use of public funding. The future challenge will be to establish a full range of reliable technologies, which can be selectively implemented in any circumstances, and for all land reuse options. However, in many European countries public sector funding has supported regeneration for "softer" end uses, for example "country parks" in areas where commercial drivers for redevelopment are less. Limited resources are available for this, and these might go further with lower input, lower cost approaches to remediation. Such low input approaches are a key area of current remediation technology and demonstration.

Planned land use, time available for remediation, developers knowledge and understanding and the money available for development, are powerful controlling the remediation solutions. There is a constant pressure for lower remediation costs, both to improve the economics of brownfield re-use for "hard applications" such as housing or commerce; and for "softer" uses such as nonfood agriculture and recreation. There is growing pressure to develop more cost-effective remediation technologies. Cost effectiveness is not just a product of reducing remediation costs, but also of finding remediation approaches that provide an additional enhancement to the value of the land.

The highest cost reducing potential can be achieved by reducing the volume of soil needing treatment and by increasing the proportion of materials to be recycled and reused. Experienced and professional project management, relevant and adequate site investigations, improved knowledge of the performance and efficiency of remediation processes can significantly enhance the accuracy of forecasting remediation costs. This information needs to be addressed not only from “problem definition” or “solution provision” perspectives, but as interdependent issues. For example, appropriate site investigation not only highlights problems, it also acts as a guide to the solution. Inappropriate site investigation does neither. All procurement of services needs to be done with a view to value, not cost. In current terms this is “intelligent procurement”, concentrating on value and confidence in achievement of objectives.

There are two further factors that impact on the cost-effectiveness of remediation technologies that are outside the remit of most CLARINET participants. The first is the impact of waste legislation and regulation that, in certain nations, determines the fate of contaminated soil, and the potential for its treatment, disposal, recovery, recycling and reuse. The second is the designated land-use of a remediated site; this has a profound effect on site values and hence the options available for remediation.

3.7 Technical feasibility

Remedial approaches can be categorised in a way that makes it easier to compare their suitability in general for particular problems, and their feasibility for more specific site circumstances.

A *suitable* technology is one that meets the technical and environmental criteria for dealing with a particular remediation problem. However, it is also possible that a proposed solution may appear suitable, but is still not considered *feasible*, because of concerns about:

- Previous performance of the technology in dealing with a particular risk management problem (in the countries);
- Ability to offer validated performance information from previous projects;
- Expertise of the purveyor;
- Ability to verify the effectiveness of the solution when it is applied;
- Confidence of stakeholders in the solution;
- Cost; and
- Acceptability of the solution to stakeholders who may have expressed preferences for a favoured solution or have different perceptions and expertise.

In general, concerns over feasibility tend to be greater for innovative remedial approaches, even if these have long standing track records in other countries. However, it is often these innovative solutions that are seen to offer more in terms of reducing wider environmental impacts and furthering the cause of sustainable development.

4 DEALING WITH CONTAMINANTS

Remediation is initiated to reduce the concentration of contaminants or to extract, immobilise, or transfer them into less toxic or harmful substances or to interrupt a pathway. Remediation processes are typically used to treat contaminants in groundwater, soil, made ground, construction and demolition waste, non-aqueous liquids, tars, sediments or sewage sludges. The type of treatment and the likely success of any particular technique will depend upon the nature of the material treated as well as the type of contamination. Contaminant properties and chemical structure affecting treatment include not just the chemical types present, but also their concentration range, their phase distribution, and their origin.

Different historical activities on the site might have caused different types of contamination. Typical contaminants related to such activities and sources of contamination are summarised in Table 6. Identification of contaminants must be determined on a site-by-site basis, in a thorough and careful manner. Studying the historical activities of the site, generally provides a good indication of potential sources and types of contaminants likely to be found on site.

Table 6: Typical contaminants found related to past activities on a site (U.S. EPA, 1999 with European additions)

Past activities conducted on the site	**Typical contaminants**
Agriculture	VOCs, arsenic, copper, carbon tetrachloride, ethylene dibromide and methylene chloride, pesticides, insecticides, herbicides, grain fumigants
Automobile refinishing and repair	Some metals, metal dust and metal sludges, various organic compounds, solvents, paints and paint sludges, scrap metal, waste oils, acids and alkalis
Battery recycling and disposal	Heavy metals (Pb, Cd, Ni, As, Cu, Hg, Cr, At, etc.) and metals, and acids
Chloro-alkalis manufacturing	Chlorine compounds, mercury
Coal gasification	PAHs, BTEX, creosote, phenolics, sulphur compounds, chloride compounds, cyanide, aluminium, iron, lead, nickel, chromium, arsenic
Cosmetic manufacturing	Heavy metals, dusts, different type of solvents, acids
Dry cleaning activities	Chlorinated aliphatics, such as chloroform and tetrachloroethane, various solvents, spot removers, fluorocarbon, perchloroethylene and its dechlorination break down products
Dye facilities	2-naphthylamine, 4-aminobiphenyl, benzedrine and other organic solvents, aromatics, phosphates, sulphates, nitrites, chromium, zinc

Table 6: Typical contaminants found related to past activities on a site (U.S. EPA, 1999 with European additions) (continued)

Past activities conducted on the site	**Typical contaminants**
Electroplating operations	Metals such as cadmium, chromium, copper and nickel, cyanide, chlorofluorcarbons and other solvents
Glass manufacturing	Arsenic and lead, acids and alkalis
Herbicide manufacturing and use	Dioxin, metals, herbicides (dangerous halogenated organic compounds and others)
Hospitals	Formaldehyde, radionuclides, photographic chemicals, solvents, mercury, ethylene oxide, chemotherapy chemicals, pathogens
Incinerators	Dioxins, various municipal and industrial waste, ash and slags with dangerous compounds, ordnance compounds, metals, sulphuric acid and waste from cleaning gas system
Landfills- municipal and industrial	Metals, VOCs, PCBs, ammonia, methane, household products and all kind of detergents, pesticides, diversified wastes, hydrogen sulphide, batteries, medicines, photo-chemicals, acids and alkalis
Leather treatment and manufacturing	BTEX and other solvents, paints and dyes, chromium and sludges with chromium
Machine shops/metal fabrication	Metals, VOCs, dioxins, beryllium, degreasing agents, solvents, waste oils, metal wastes
Marine maintenance industry	Solvents, paints, cyanide, acids, VOC emissions, heavy metal sludges, degreasers, waste oils, acids and alkalis
Munitions manufacturing	Lead, explosives, copper, antimony, mercury, unexploded ordnance (UXO), sludges with heavy metals and solvents
Paint/ink manufacturing	Meatls (such as chromium, cadmium, lead, and zinc), VOCs, chloroform, ethylbenzene, other solvents, paints, inks, waste paints and sludges
Pesticide manufacturing	VOCs, arsenic, copper, pesticides, insecticides, herbicides, fungicides, xylene, chlorinated organic compounds, solvents, acids and alkalis
Petroleum refining and use	Petroleum hydrocarbons, PAH's, BTEX, fuels, oil and grease, acids, sludges with hydrocarbons and dangerous substances
Pharmaceutical manufacturing	Heavy metals (essentially lead), various organic chemicals, organic solvents
Photographic manufacturing and uses	Silver, bromide, methylene chloride, solvents, photographic products and residues from this industry

Table 6: Typical contaminants found related to past activities on a site (U.S. EPA, 1999 with European additions) (continued)

Past activities conducted on the site	**Typical contaminants**
Plastic manufacturing	Polymers, phthalates, cadmium, solvents, resins, chemical additives, acids and alkalis, oils, waste additives and sludges with dangerous substances
Printing industry	Silver, solvents, acids, waste oils, inks and dyes, toner, photographic chemicals, waste etching solutions, contaminated sludges
Railroad yards	Petroleum hydrocarbons, VOCs, PAH's, BTEX, solvents, fuels, oil, and grease, lead, PCBs
Research and educational institutions	Inorganic acids, organic solvents, metals and metal dust, photographic waste, waste oil, paint, heavy metals, pesticides
Scrap metal operations	Various metals and heavy metals (such as Pb and Ni), PCBs, PCT, dioxin, transformers, oil filters, asbestos, brake and antifreezing fluids, explosive components
Semiconductor manufacturing	Metals, VOCs, carbontetrachloride, degreasing agents, solvents, phosphoric acid??
Smelter operations / mining activities	Metals and heavy metals (such as Pb, Cu and As), dust, ash, slag, metal sludges, mineral oils, acids and alkalis
Underground storage tanks	Solvents, metals, POLs, BTEX, gasoline, diesel fuel
Wood pulp and paper manufacturing	Chlorinated organic compounds, dioxins, furans, chloroform, acid resins, mineral oils
Wood preserving	Creosote, PCP, arsenic, chromium, copper, zinc, PCBs, PAHs, beryllium, dioxin, wood preservatives, solvents, mineral oils
Inorganic chemical processes	Acids and alkalis, solutions and sludges with heavy metals, wastes with asbestos, solutions and slags with dangerous substances
Organic chemical processes	General organic chemicals (halogenated and not halogenated solvents, washing liquids, mother liquors)

5 REMEDIATION APPROACH

5.1 Classification of Remedial actions

In general remedial options fall into one or more of the following broad categories (NATHANAIL *et al.,* 2001):

- Excavation and containment (Removal to landfill: the disposal of material to an engineered commercial void space; Deposition within an on-site engineered cell, generally with a view to combining the disposal of waste with the reclamation of land area from the void space; Engineered land-raising and land forming, where materials are deposited on the land surface to make a hill or mound above the natural surface level suitably contained.)
- Engineered systems (*In situ* Physical Containment: designed to prevent or limit the migration of contaminants left in place or confined to a specific storage area, into the wider environment. Approaches include in-ground barriers, capping and cover systems; Hydraulic containment and pump-to-contain approaches.)
- Site rehabilitation measures are those used to bring back some measure of utility to a site whose contamination cannot be treated or contained for technical or economic reasons. Examples include growth of grass cover tolerant of contaminants, covering with soil or soil substitute, liming and other cultivation measures.
- Treatment based approaches destroy, remove or detoxify the contaminants contained in the polluted material (e.g. soil, ground water etc). Using treatment technologies in contaminated land remediation is encouraged by agencies in many countries, because they are perceived as having added environmental value compared with other approaches to remediation such as excavation and removal, containment or covering / revegetation. The "added" environmental value is associated with the destruction, removal or transformation of contaminants into less toxic forms.

Treatment based approaches can be further described as (MARTIN & BARDOS, 1996):

- Biological Processes (Bio): contingent on the use of living organisms;
- Chemical processes (Chem): destroy, fix or concentrate toxic compounds by using one or more types of chemical reaction;
- Physical processes (Phys): separate contaminants from the soil matrix by exploiting physical differences between the soil and contaminant (e.g. volatility) or between contaminated and uncontaminated soil particles (e.g. density).
- Solidification and stabilisation (S/S): processes immobilise contaminants through physical and chemical processes (Solidification processes are those which convert materials into a consolidated mass. Stabilisation processes are those in which the

chemical form of substances of interest is converted to a form which is less available).

- Thermal processes: exploit physical and chemical processes occurring at elevated temperatures.

Ex situ approaches are applied to excavated soil and/or extracted groundwater. ***In situ*** approaches use processes occurring in unexcavated soil, which remains relatively undisturbed. **On site** techniques are those that take place on the contaminated site. They may be *ex situ* or *in situ*. **Off site** processes treat materials that have been removed from the excavated site (*ex situ)*.

Table 7 lists some examples of *in situ* process based remedial treatments, Table 8 examples of *ex situ* process based remedial treatments.

Table 7: Examples of in situ remediation technologies (NATHANAIL et al*, 2001)*

Technology	**Description**	**Type**
Biopiles	Excavated soil is built into a heap within which is a network of perforated pipes to aerate the soil.	Bio
Bioreactors	Soil (dry or slurried) is treated in a enclosed reaction vessel to which nutrients, air water and microbes are added as necessary. Bioreactors are also used to treat groundwater.	Bio
Biological treatment beds	shallow cultivation, where contaminated soil is cultivated in a contained treatment bed on a specially prepared area of a contaminated site	Bio
Chemically enhanced soil washing	Physical processes are integrated with chemical processes such as leaching or extraction.	Chem/ phys
Chemical Leaching/ Chemical extraction	Transfer of contaminants from the soil into an aqueous solution. The soil is dewatered and the aqueous solution plus contaminants is further processed.	Chem
Groundwater treatments (non-biological)	Various including: airstripping, carbon adsorption, chemical oxidation, filtration, ion exchange, neutralisation, precipitation, reverse osmosis, steam stripping.	Chem/ phys
Incineration	High temperature destruction of contaminants (eg in rotary kiln incinerators or fluidised bed systems). Main pre-treatment is to obtain suitable particle size. Thermal desorption occurs during incineration. An *ex situ* process.	Thermal
Soil washing	Primarily a physical technique involving size separation and washing of contaminants using aqueous based solutions.	Phys
Solvent extraction	Uses non-aqueous solvent to transfer contaminants from soil into solution.	Chem

Table 7: Examples of in situ remediation technologies (NATHANAIL et al, *2001) (continued)*

Technology	Description	Type
Stabilisation / Solidification	Mixing of chemical agents into the soil to solidify the ground or otherwise reduce mobility of contaminants.	S / S
Thermal desorption by combustion of organics in vapour phase	Two stage process comprising low temperature transfer of contaminants from soil to vapour phase via volatilisation followed by destruction or removal of contaminants from gas stream. *Ex situ* process needs extensive pre-treatment e.g. screening, de-watering, neutralisation, blending. Partial combustion often occurs during process.	Thermal
Thermal desorption by condensation	Heating of soil to volatilise volatile metals (so far principally mercury), which is then condensed from exhaust gases downstream.	Thermal
Vitrification	Excavation of soil, transport to (usually off site) facility. Soil plus other materials used for glass making (silica, fusing agents) are placed in a smelter, which heats to about 1500°C. Molten material is continuously removed and cooled to produce granular solids or monolithic mass.	S / S & Thermal
Windrow turning	Piles of contaminated soil often mixed with organic materials such as bark are turned on a regular basis to aerate the soil and improve the soil structure.	Bio

Table 8: Examples of in situ remediation technologies (BARDOS et al *2000, NATHANAIL* et al, *2001)*

Technology	Description	Type
Bioremediation	Remediation by altering *in situ* conditions, typically by *in situ* flushing (see below) to optimise biodegradation rate. Examples include the addition of nutrients, oxygen, etc.	Bio
Biosparging / Air sparging	Injecting air (or other gases) into the saturated zone to strip volatile contaminants and / or stimulate biodegradation. The latter process is often termed “biosparging”.	Bio / Phys-chem
Bioslurping	Multiphase extraction of groundwater, free-phase contamination and soil gas to achieve bulk contaminant removal and supply oxygen for enhanced biodegradation.	Bio & phys
Bioventing	Movement of air or other gas through soil to stimulate biological destruction of contaminants, possibly in combination with their removal in the gas phase (c.f., soil vapour extraction)	Bio & phys

Table 8: Examples of in situ remediation technologies (BARDOS et al., 2000, NATHANAIL et al., 2001) (continued)

Technology	**Description**	**Type**
Chemical destruction	Use of highly reactive reagents to convert contamination to environmentally acceptable end-products *in situ*. An example is the use of Fenton's reagent (iron-catalysed hydrogen peroxide).	Chem
Electro-remediation	Use of electric fields to move or contain contaminants.	Phys-chem
Flushing	Enhanced pump and treat to remove contaminants, for example addition of surfactants or solvents to re-circulated water.	Phys-chem
Hydrofracture	Hydraulic or pneumatic techniques to induce fracturing of subsurface zones to increase permeability for other remediation treatments.	Phys
In situ heating	Use of steam or microwaves (radio-frequency heating) to heat the soil, for example to increase the range of contaminants recoverable by soil vapour extraction.	Thermal
Landfarming	Cultivation of surface soils (typically the top 50cm) to stimulate biodegradation. Usually includes the addition of various amendments (e.g., fertiliser) - unlikely to easily find regulatory approval under current circumstances.	Bio
Natural attenuation	Monitored use of naturally occurring *in situ* processes to remediate contamination without enhancement. Often, and more accurately, called monitored natural attenuation (MNA).	Bio, Phys & Chem
Permeable reactive barriers	A single or combination of biological, chemical or physical process(es) in a specific portion of the subsurface that treats a carrier as it passes through but does not unacceptably impede flow.	Bio / Chem / Phys
Phyto-remediation	Use of plants to recover contaminants and/or stimulate *in situ* biodegradation/stabilisation.	Bio
Pump and treat	Treatment mediated by the pumping of groundwater. The term "Pump and Treat" is sometimes specifically used to mean technologies where groundwater treatment is undertaken above ground. However, in practice the term is also used to refer to true *in situ* processes involving groundwater pumping.	Phys
Soil vapour extraction (SVE)	Movement of air or other gas through unsaturated soil to remove contaminants through enhanced volatilisation. Sometimes called "venting " or "stripping".	Phys

Table 8: Examples of in situ remediation technologies (BARDOS et al., 2000, NATHANAIL et al., 2001) (continued)

Technology	**Description**	**Type**
Stabilisation / Solidification	*In situ* mixing (e.g., by augering) of chemical agents into the soil to solidify the ground or otherwise reduce mobility of contaminants.	S / S
Vitrification	Use of high temperature to melt subsurface minerals. Organic contaminants are thermally destroyed; inorganic contaminants are immobilised in the glassy residue.	S / S & Thermal

5.2 Suitability of remedial technologies

A *suitable* technique is one, which meets the technical and environmental criteria for dealing with a particular remediation problem. The choices that affect the suitability of a remediation technology for a particular situation are (BARDOS *et al.,* 1999), as illustrated in Table 9:

- Risk management application
- Treatable contaminants and materials
- Remedial approach
- Location
- Overall strategy
- Implementation of the approach
- Legacy

Table 9: Factors Affecting the Suitability of a Particular Remediation Technology (Adapted from NATHANAIL et al., *2001)*

Risk management application	• *Source control,* remedial action either to remove, or modify the source of contamination • *Pathway control*; remediation to reduce the ability of a given contaminant source to pose a threat to receptors by inhibiting or controlling the pathway by modifying its characteristics • *(Receptor control*)
Treatable contaminants and materials	• Contaminant(s) • Concentration range • Phase distribution • Source and age • Bulk characteristics • (geochemistry, geology, microbiology)

Table 9: Factors Affecting the Suitability of a Particular Remediation Technology (Adapted from NATHANAIL et al., 2001) (continued)

Remedial approach	• Type of remediation (containment, treatment: biological, chemical etc) • Strengths and weaknesses of remediation solution
Location	Where the action takes place (e.g.: *in situ* or *ex situ*, on site or off site);
Overall strategy	For example: • Integrated / combined approaches • Active versus passive measures • Long term / low input (”extensive”) versus short term / high input (”intensive”) • Use of institutional measures (such as planning controls combined with long term treatments)
Implementation	Implementation encompasses the processes of applying a remedial approach to a particular site and involves: • Planning remedial operations • Site management • Verification of performance • Monitoring process performance and environmental effects • Public acceptability and neighbourhood relationships (risk communication and risk perception) • Strategies for adaptation in response to changed or unexpected circumstances, - i.e. flexibility • Aftercare These activities are significantly different for different choices of remediation technique, and are likely to be a significant cost element for a remediation project
Outcome	**Destruction** may be result of a complete biological and / or physico-chemical degradation of compounds, for example at elevated temperatures by thermal treatments. **Extraction** of contaminants may be brought about by (a) excavation and removal (b) some process of mobilisation and recapture or (c) some process of concentration and recovery. **Recycling** might be the "ultimate" form of removal. **Stabilisation** describes where a contaminant remains *in situ* but is rendered less mobile and or less toxic by some combination of biological, chemical or physical processes.

Table 9: Factors Affecting the Suitability of a Particular Remediation Technology (Adapted from NATHANAIL et al., 2001) (continued)

Outcome	**Containment** where the contaminated matrix is contained in a way which prevents exposure of the surrounding environment. • Destruction may be incomplete, emissions and wastes are an outcome of all approaches, hence consideration of the fate of compound should be included as part of both remedy selection AND evaluation of risk management. • Extraction implies a need for further treatmnent and/or subsequent disposal Stabilisation and containment both leave contamination in situ, which means that their performance in the long term requires thorough assessment

The use of a treatment based approach to remediate contaminated land is often the approach most favoured by agencies in many countries, because they are perceived as having added environmental value compared with other approaches such as: excavation and removal, containment or covering and revegetation. The added environmental value is associated with the destruction, removal or transformation of contaminants to less toxic forms thereby reducing the long term potential to cause harm to the environment and human health.

5.3 *In situ* versus *ex situ* approaches

Ex situ techniques are used in most clean-up operations throughout Europe. Long-term experiences exist in most European countries on most of the technologies discussed in paragraph 5.4. The principal advantages of *ex situ* technologies versus *in situ* technologies are:

- Clean up operations on site are fast;
- Liability discussions can be limited;
- Practical operational experience are available for the technologies;
- Process optimisation and final results can be easily controlled;
- Nearly independent of geology.

Principle disadvantages include:

- Working labour and surrounding environment are likely to be exposed to higher concentrations of the contaminants;
- Not easily applicable to contaminants located deep in the ground;
- Difficult to use when existing infrastructure is complex or need special precautions;
- Can have extensive negative influence on a natural environment;

- Can be very costly since larger volumes of soil often need to be treated. It is often difficult to limit the volumes of soil to be removed due to time constraints.
- Negative side effects (non-core issues) can be extensive.

In situ technologies are in an early stage of implementation in Europe, and a number of constraints must be resolved before they generally are considered on an equal basis as ex situ technologies. Assuming that a remedial approach can be adequately monitored and controlled, there is an increasing desire to promote *in situ* over *ex situ* solutions and on site solutions over solutions based on removal off site. However, there are often conflicting pressures affecting whether or not an on-site or off-site approach is taken. In many cases stakeholders may express a preference for a solution based on removing materials off site (*ex situ* technologies). This may be related to concerns over residual liabilities, which in turn are related to concerns over the duration, feasibility or completeness of *in situ* solutions. Conversely, removal of materials off site may be problematic because of the transportation and related problems, or because excavation is not considered technically or economically feasible. In many cases, the limitations to *in-situ* techniques are the heterogeneities naturally occurring at the sites, giving magnitudes of differences in hydraulic conductivities, which prevent delivery of air, chemicals or release of vapours from the soil. This leads to situations where >90% of the transport can occur through <5% of the ground, even if the contaminants are equally spread. In many cases these problems cannot be overcome by engineering, and significantly more research is needed. Offering previously validated solutions and developing an appropriate verification strategy for the sites in question are key steps in dealing with these concerns. A special technology development program (TUP) was initiated in 1996 in Denmark. This program is presently focusing on co-financing expenditures in projects developing cheaper technological solutions for clean up operations in areas with difficult infrastructure. The last few years' focus has been on *in situ* technologies. Experience has shown that *in situ* techniques in general can be considered most suitable when:

- The contaminants are located under existing buildings, parking lots, roads, railroads etc.;
- The contaminants are located deep in the ground;
- Both soil and groundwater need to be treated;
- Large volumes are contaminated;
- The contaminated volume contains coarse types of soil;
- Treatment time is not so important;
- Minimum site disturbance is required.

The principal advantages of *in situ* treatment include:

- Working labour and environment are in some cases less exposed to the contamination than when *ex situ* techniques are used;
- Not In My Back Yard (NIMBY) discussions are reduced;

- The costs for excavation, transport, and landfilling / off site treatment are reduced or avoided;
- Risk of accidental spillage causing environmental pollution during transport is removed.

The principal disadvantages of *in situ* treatment include:

- Typically they are of longer duration than *ex situ* processes;
- Techniques may require greater knowledge of the ground environment (geology) than techniques following excavation;
- Process containment, optimisation and control is difficult compared with *ex situ* approaches;
- Techniques are limited by the accessibility of contamination in the ground;
- Concern for residual liability is higher;
- Concern on feasibility of completeness is higher.

5.4 Remediation technology

5.4.1 Introduction

Remediation technology can be divided according to types of treatment or categorised according to how the technologies are applied. Five categories of treatment technologies have been identified: biological, chemical, physical, solidification / stabilisation, and thermal, as discussed in paragraph 5.4. Different technologies have proved useful to treat different contaminants.

Table 10 summarises which types of technologies are appropriate for specific types of contaminant groups. This information is based on U.S. EPA sources.

Table 10: Examples of technologies suitable for treating different types of contaminants (U.S. EPA, 1999)

Contaminants treated	**Suitable Remediation Technologies**
	Soil, sediments and sludge
VOCs	*Ex situ* bioremediation; *In situ* bioremediation; *In situ* soil flushing, SVE, Thermal Desorption, *In situ* Vitrification
SVOCs	Thermally Enhanced SVE; Soil washing; Solvent Extraction; Thermal Desorption
Inorganic compounds	Soil flushing; Soil washing; Electrokinetic Separation; Solvent Extraction; Chemical treatment and Phytoremediation.
Petroleum Fuel Oil	*Ex situ* bioremediation; In situ bioremediation; Soil washing; SVE; Thermal Desorption
Explosives	*Ex situ* bioremediation; In situ bioremediation; Soil washing; Solvent Extraction; Thermal Desorption

Table 10: Examples of technologies suitable for treating different types of contaminants (U.S. EPA, 1999) (continued)

Contaminants treated	**Suitable Remediation Technologies**
Groundwater, surface water and leachate	
VOCs	Air sparging; Dual-Phase Extractiom; Fluid / Vapor Extraction; *In Situ* Bioremediation; Bioreactors; Permeable Reactive Barriers
SVOCs	*In situ* bioremediation; Bioslurping; Permeable Reactive Barriers; Phyto Remediation
Inorganic compounds	Adsorption; Permeable Reactive Barriers; Phytoremediation
Fuels	Air sparging; Dual-Phase Extraction; *In Situ* Bioremediation, Bioreactor; Bioslurping; Fluid / Vapor Extraction
Explosives	Bioreactor; Permeable Reactive Barriers; Phytoremediation

VOC= Volatile Organic Compounds; SVOC= Semi-Volatile Organic Compounds; SVE= Soil Vapor Extraction

5.4.2 Biological treatment

Biological treatments exploit one or more basic processes to treat contaminated soil and water; either *in situ* or *ex situ*:

(a) Degradation. Aerobic and anaerobic biochemical decomposition of a compound through the action of soil microorganisms (bacteria, fungi and actinomycetes);

(b) Transformation. Biochemical conversion of a contaminant to a less toxic and / or less mobile form;

(c) Accumulation. Accumulation of organic and inorganic contaminants within plant or algal tissues;

(d) Mobilisation. Biochemical mediated mobilisation of contaminants into a solution that is then separated from the contaminated soil and the contaminants recycled, treated, or disposed of.

(e) Immobilisation. Transformation of a compound less mobile and bioavailable in a given matrix.

In general, established commercial processes are limited to those based on biodegradation, which is sometimes further subdivided into biostimulation or bioaugmentation. Biostimulation involves the addition of nutrients, oxygen, and moisture to stimulate natural indigenous bacteria in contaminated soils and so biodegradation. Bioaugmentation involves the addition of specifically accumulated cultures of communities of organisms, either from a natural source such as sewage sludge, from laboratory cultures developed from a contaminated site, to supply biological functions, such as specific biodegradation steps, which appear to be absent in the indigenous microflora.

In most cases the indigenous microflora is already competent (i.e. capable of carrying out the desired biodegradations), but is limited by environmental factors. Hence typically, biostimulation only is required. While bioaugmentation is unlikely to be detrimental, it has been hard to categorically demonstrate its effectiveness, except in special cases, such as for DNAPL degradation under anaerobic conditions (BARDOS *et al.,* 2000).

Ex situ application of biological processes allows better process control, in particular the breaking down of ground into small particles, for example by cultivation, grading or conversion into a slurry. This overcomes one of the major limitations of *in situ* processes, which is ensuring the accessibility of the contaminant to the treatment. *Ex situ* processes can be divided into four basic groups (BARDOS & NATHANAIL, in prep).

- Where contaminated soil is cultivated in a treatment bed or *in situ* by cultivation of the surface layers of a specially prepared area of a contaminated site;
- Windrow turning (where piles of contaminated soil often mixed with organic materials such as bark are turned on a regular basis using processes akin to green waste composting);
- "Biopiles” where static piles of contaminated soil are vented and irrigated using processes akin to static pile waste composting; and
- Bioreactors where groundwater or soil slurry is treated in a reaction vessel.

Treatments employing cultivation

Landfarming has been used to describe these processes, but is avoided here to avoid confusion with the treatment of oily sludges by cultivation on land, which is also known as landfarming. Methods vary from quite simple to rather advanced techniques, which are all largely based on agricultural practice. At its simplest, contaminated soil is spread over a surface, typically to a thickness of about 0.5 m. The soil is regularly mixed and tilled to improve soil structure and oxygen supply. Water can be supplied to adjust the moisture content and supply inorganic nutrients to the system. In general the treatment bed is placed over an impermeable membrane to ensure complete collection of leachate. Spray irrigation / recirculation of leachate are also common practice.

Treatment of windrows

Treatment techniques based on windrows are very similar to approaches used for waste composting, for example of urban wastes and agricultural wastes (Figure 4). Soil is placed in thicker layers or heaps. Furthermore, materials such as wood chips, bark or compost are often added to improve the soil structure and increase aeration. Regular turning and tilling is still carried out to improve aeration. Specialised equipment is often used for this purpose, typically technology borrowed from the waste composting industry. In most cases true composting (i.e. a controlled aerobic, solid-phase thermophilic process) does not take place. Amendments tend to be added to condition the soil rather than as part of an integrated waste management approach, which perhaps remains an under-exploited opportunity.

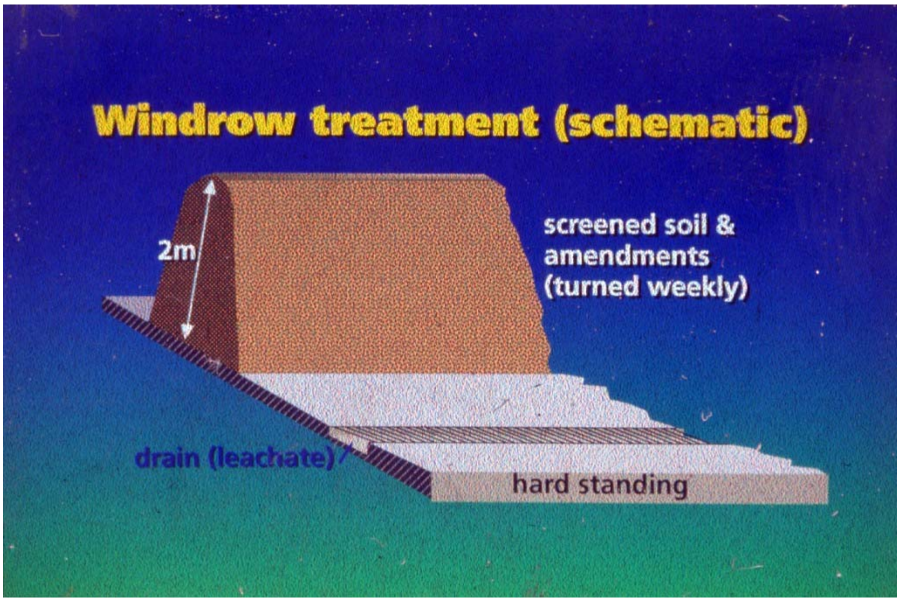

Figure 4: Windrow treatment schematic (BARDOS, 2002)

Treatment using biopiles

Excavated soil is placed in a static heap (i.e. no mechanical turning or tilling is carried out). Nutrients are added to the contaminated soil by percolation or along a network of internal galleries. The conditions in the piles are monitored and optimised through aeration and water supply. The principal distinction between "biopiles" and windrow-based systems is the use of active aeration and irrigation. Biopiles are closely allied to the aerated static pile technique for waste composting (STENTIFORD, 1996), although refinements such as feedback control based on temperature, moisture and/or O_2 are less frequent in soil treatment than in aerated static pile waste composting, see Figure 5. The technology has a longer history for composting of waste and there is still a potential for technology transfer to soil treatment.

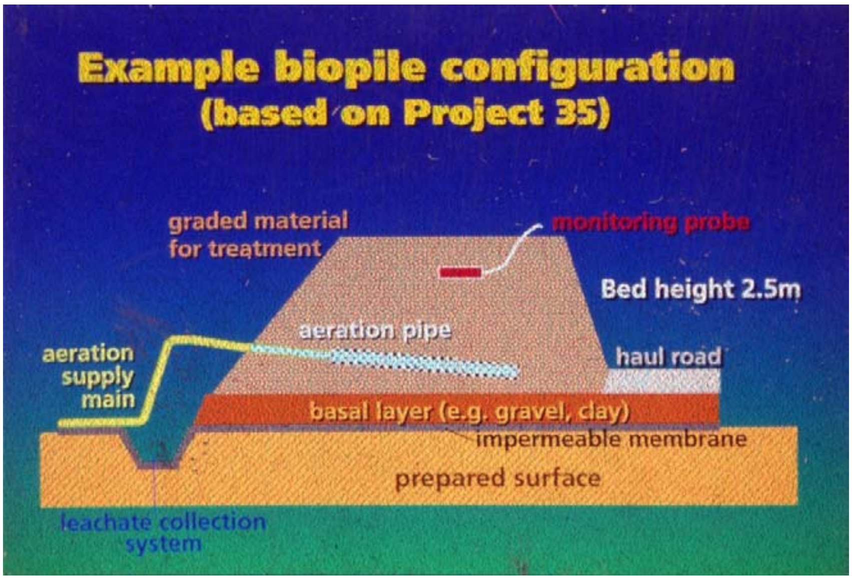

Figure 5: Biopile example schematic - configuration (BARDOS, 2002)

Treatment using bioreactors

Pre-treated soils (usually with particles >4-5mm removed) in a slurry with water are treated in a purpose built reactor system with a mechanical agitation device. Within the reactor controls on temperature, pH, nutrients and oxygen supply can be amended to gain the maximum contaminant degradation rates, using either microorganisms indigenous to the soil or specially added cultures.

In Situ approaches include systems based on the *in situ* movement of air (bioventing), air and water (biosparging) and water (using passive amendments or via in situ flushing).

Bioventing

Movement of air through the vadose zone often stimulates in situ biodegradation of organic contaminants, see Figure 6. Bioventing is an application of SVE or soil venting (outlined in Section 5.4.4), where the movement of air is controlled so that the rate of in situ biodegradation is minimised. Ideally this enhancement of biodegradation should be accompanied by a minimisation of VOC content in the exhaust air from the process. However this is not always the case. Bioventing extends the range of contaminants treatable by venting to include "semivolative" contaminants as well.

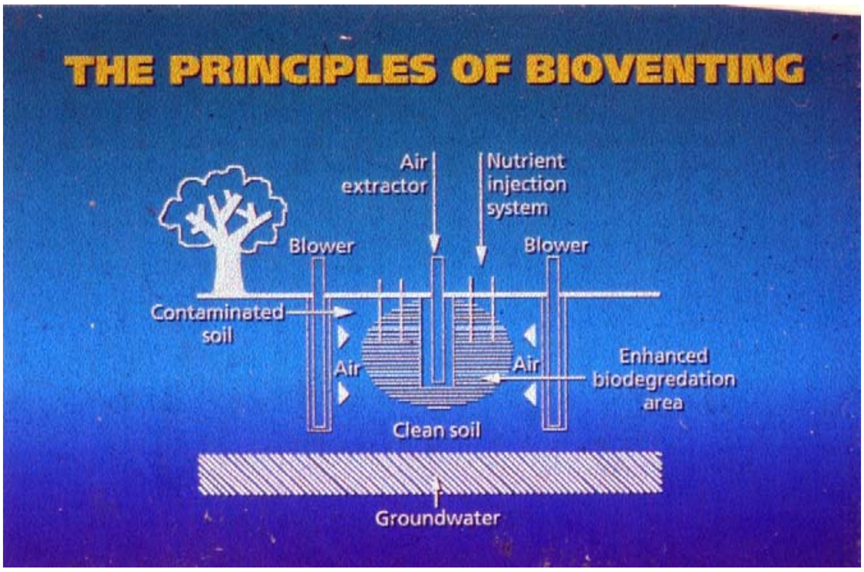

Figure 6: Diagram - bioventing concept (BARDOS, 2002)

Biosparging

Biosparging is the analogous optimisation of air sparging to optimise biodegradation in the saturated zone.

Passive amendments for enhanced bioremediation

Changes in *in situ* redox conditions are affected when using materials that release oxygen (creates oxidizing /aerobic conditions) or that stimulates microbial removal of oxygen (creates anaerobic conditions). These materials are added to the subsurface to treat contaminated groundwater or soil in place. The desired effect is to enhance aerobic or anaerobic bioremediation, respectively. Aerobic bioremediation converts many organic contaminants to carbon dioxide, water and microbial cell mass. Anaerobic bioremediation is typically used for solvent contamination through dehalorespiration (BARDOS *et al.,* 2000). The redox control amendments can be placed into the subsurface by injection of fluids, or a powder and water mix (slurries), as a direct mass reduction treatment or as a barrier containment approach.

In situ flushing

In situ flushing is often applied as a means of "delivering" a biological treatment to the saturated zone, for example by supplying (hopefully) the saturated zone with electron acceptors or donors, depending on whether enhancement of aerobic and anareobic biodegradation is the goal. As a method it has strict limitations, it is an attempt to use actove pumping to accelerate the dispersal of nutrients, redox amendments etc in the saturated zone.

5.4.3 Chemical treatment

Chemical treatments degrade, immobilise or concentrate toxic compounds in contaminated soil or water by:

(a) Oxidation. Includes addition of chemicals donating electrons to the contaminant.

(b) Reduction. Includes addition of chemicals accepting electrons from the contaminant.

(c) Immobilisation. Precipitating as insoluble complexes, by adsorbing to a solid matrix, or by amending soil conditions; reduces the mobility of contaminants.

(d) Extraction. Using chemical extraction processes such as solvent flushing to transfer the contaminant from the soil to a leachate, which can be collected, concentrated and treated. Leachates include: acids, alkalis, surfactants, and organic solvents.

(e) Substitution. Replacement of functional groups of a contaminant, for example, progressive dechlorination of chlorinated solvents.

(f) Hydrolysis includes addition of chemicals leading to hydrolysis (degradation) of the compounds.

(g) Leaching. Enhancing leaching of the contaminants to groundwater.

In situ applications include: chemically enhanced soil washing, chemical leaching/extraction, and chemical destruction. *Ex situ* applications include: soil washing combined with chemical water treatment and groundwater treatment using various chemicals (pump and treat).

5.4.4 Physical treatment

Physical treatments separate contaminants from the soil matrix by exploiting differences in physical properties between the soil and contaminant (e.g. volatility or magnetism) or between contaminated and uncontaminated soil particles (e.g. particle density or particle size). Typically physical treatments result in contaminant-enriched residues, which require further treatment or disposal.

Physical processes also include those based on electrolysis, electro-osmosis, and electrophoresis, which are known collectively as electro-remediation, although more accurately these are mediated by a combination of chemical and physical effects. Electric fields can also be used to induce heating in situ, for example the "six Phase" heating technology (www.clu-in.org/thermal) and even *in situ* vitrification.

In situ applications include: soil vapour extraction, air sparging, dual phase extraction, steam stripping, heating, pump and treat, *in situ* flushing and electro-remediation. *Ex situ* applications include: screening, soil washing, venting and filtration, air stripping and sorption for air and liquids.

Soil vapor extraction (SVE)

SVE involves the application of a vacuum via extraction wells to soil pore air in the vadose zone of the soil. This vacuum stimulates a movement of air through the soil, with air entering the soil via the surface as it is extracted. Often recharge is controlled using injection wells (passive or active = soil venting) and an impermeable cap on the surface of the soil. The movement of air causes volatilise contaminants to evaporate, and are removed by the circulating air (i.e. by stripping). Air recovered at the extraction well then requires treatment if transfer of VOC contamination to the atmosphere is to be avoided, for example by sorption to activated carbon, or catalytic oxidation.

Air sparging

Air sparging is injection of air into the saturated zone. It operates in two ways: Firstly it encourages aerobic biodegradation because it adds air to the system, and secondly it strips off volatile contaminants. As a result, it needs to be operated in conjunction with SVE to ensure adequate capture of volatiles as they migrate from the saturated zone to the unsaturated zone. In a physical treatment context this removes VOCs by stripping, see Figure 6.

Dual phase extraction

Dual phase extraction involves different technical solutions. Induced surfactant enhanced aquifer remediation (SEAR) is used to enhance the removal of residual nonaqueous phase liquids (NAPL) from the subsurface by lowering the interfacial tension between NAPL and aqueous surfactant solution. Increasing the solubility of NAPL with surfactants substantially enhances the removal of NAPL. 2-PHASE™ extraction process was developed as an alternative to conventional pump-and-treat technology, particularly in lower conductivity media such as silt and clays that are impacted by volatile organic carbon. The technology uses a high-vacuum source applied to an extraction tube within a water well to increase groundwater removal rate and to volatilise and extract the portion of contaminant from the sorbed or free product.

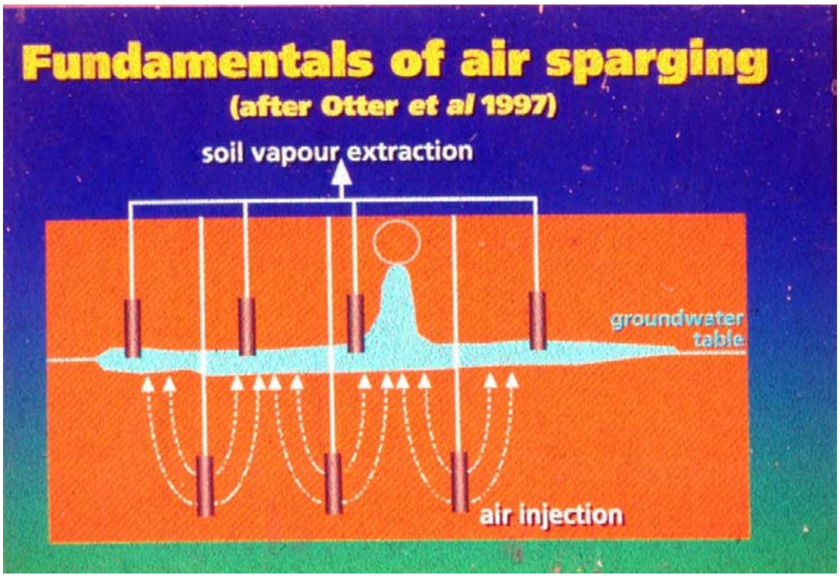

Figure 7: Fundamentals of air sparging (BARDOS, 2002)

Steam stripping

When steam stripping is applied, the soil is "loosened" by two opposite directed rotating drilling devices while damp and compressed air is forced through the well into the soil. Volatile compounds are stripped from the soil to the air and are volatilised on the surface. The method can be rather energy intensive.

Pump and treat

Pump and treat usually refers to the extraction of groundwater, followed by some form of treatment. Depending on regulatory requirements, the treated groundwater may then be discharged to surface water, sewers or re-infiltrated. It may also be tanked and transported off site. Typical treatments include air stripping and sorption to activated carbon. Pump and treat also describes processes where free phase NAPL (principally LNAPL) is extracted for subsequent treatment and disposal.

In situ flushing

In situ flushing applies Pump and treat techniques to circulating water through the ground. The water that is reinjected may be conditioned in some way to stimulate physico-chemical processes (such as desorption at lower pH), or in situ biodegradation in the saturated zone. *In situ* flushing was one of the first remediation technologies to enter widespread use. However, its ability to affect a treatment, in particular one that is a source removal, is limited (TEUTSCH *et al.*, 2001, MACDONALD & RITTMAAN, 1993). Typically its effect is to act as a hydraulic containment.

Electro-remediation

Electrokinetic remediation is particularly suited for treating fine grained matrices. The process has been used successfully to treat soil contaminated by metals and organics. The heavy metal contaminations are driven out of the soil by electrokinetic processes taking place when an electric field is set on the soil. Organic contaminants are secondary removed by electro osmosis.

Soil washing

Soil washing applies mineral processing techniques such as attrition scrubbing, flotation, settlement and cylones to separate contaminant particles according to size, shape, density and or surface characteristics. Typically contamination is concentrated in a "fine" fraction, with snady and larger particle size fractions reused, e.g. as fill material. Soil washing may also include chemical steps such as use of surfactants or leachates to desorb contaminants into a liquid phase, for subsequent collection as a concentrate.

Bioventing

Bioventing is a process which results in aerobic biodegradation of organic contaminants in the unsaturated zone by addition of oxygen or air. A number of bioventilation filters are installed in the unsaturated zone. The method is best suited for treating lighter, biodegradable organic contaminants (not chlorinated solvents) in permeable types of soil.

5.4.5 Solidification and stabilisation (S/S)

Solidification and stabilisation treatments immobilise contaminants through physical and chemical processes. Solidification is the encapsulation of contaminated soil within a solid monolithic mass, and stabilisation is the chemical transformation of contaminants to reduce their mobility, for example precipitation of heavy metals as insoluble hydroxides.

Solidification technologies add chemical agents to contaminated soil to make a mixture, which sets as a firm mass with enhanced structural integrity and reduced permeability or use high temperatures to melt soil until it forms a strong and impermeable glassy matrix.

Stabilisation technologies use chemical agents to react with soil contaminants to convert them into a less toxic and/or mobile form. Stabilisation does not necessarily result in solidification and *vice versa*. However they are commonly used in tandem.

Solidification and stabilisation treatments require the addition of amendments, for example pozzolans, to cause the solidification, binders and agents to facilitate setting. Examples of pozzolans include cements, lime and incinerator ash. Examples of binders include zeolites, silicates, and bentonites. While chemical fixation of many organic species, particularly cations, is a well-established class of technologies, stabilisation of organic contaminants is not straightforward, although some degree of physical immobilisation may take place in solidified matrices. For pozzolan based systems an amendment is necessary for their chemical sorption, which in tern is physically bound in a solidified matrix. Technologies aimed at the stabilisation of organic compounds include amendments such as organophilic clays or activated carbon.

Pozzolan based systems can be applied *ex situ*, using conventional mixing approaches, *or in situ*, for example via a hollow stem auger. Alternatives to pozzolan based systems include the use of asphalt.

In situ applications include *in situ* vitrification, where the soil is heated by electricity and a glass-forming additive is mixed with the soil. Vitrification is also carried out on site producing a molten glass product, which is subsequently disposed.

For S/S technologies, there are problems assessing the long term performance, and presently the lack of an agreed protocol for long term weathering assessment of the stabilised product and thus the inability to test the long term effect of the process, limits the possibility for regulators in approving the technology.

5.4.6 Thermal treatment

Thermal treatments use elevated temperatures to remove and destroy or to immobilise contaminants in soil particles through physical and chemical processes such as volatilisation, combustion, and pyrolysis. Thermal systems are most commonly used to treat soils contaminated with toxic organic compounds, which are then destroyed at high temperatures. Thermal treatments can also be used to remediate soils contaminated with asbestos (decomposition of blue asbestos takes place at about 900^{O}C). Volatile heavy metals, such as mercury, may also be removed from soils by thermal processes, although they are not destroyed and have to be recovered downstream of the process. Established thermal treatments are *ex situ*-based, however, a number of *in situ* systems are under development.

Thermal treatments are often described as either one stage destruction or two stage destruction processes. However, the exact distinction between these approaches can often be difficult to distinguish. For example, **incineration** is commonly described as a one-stage process where organic contaminants are combusted within the soil matrix by heating the soil to high temperatures. However, such systems often include a secondary chamber to treat volatilised contaminants in the off-gases. In two-stage systems, such as **thermal desorption**, organic contaminants are volatilised from soil at lower temperatures (up to 600^{O}C) and are then treated in a second chamber (i.e. thermal or catalytic oxidation processes). Some relatively volatile inorganic contaminants (in particular mercury) may be recovered by thermal desorption systems, which use condensation to treat the off-gases produced by heating. One possible categorisation is that **incineration** processes are those which produce a slag or ash as a treatment residue while **thermal desorption** processes produce a residual material, which is still soil-like. Thermal treatments are not applicable for most inorganic contaminants, which remain in treatment residues such as fly ash.

Thermal processes use a variety of heat sources such as heated air, open flame and liquid heat-transfer, which can be in direct or indirect contact with the contaminated soil.

Most known organic contaminants can be destroyed, but dioxins require high incineration temperature. Furthermore, for any thermal process, dioxins can be formed when chlorinated organic are incinerated at low temperatures, and the reformation of dioxins in exhaust gases is also a possibility without rigorous process control. Many incineration plants are large, see Figure 8.

The two most commonly *Ex situ* applications of Incineration methods are:

Rotating oven

Incineration occurs at the temperature interval of 1200-1400^{o}*C.*

Fluidised bed

Air is blown through the bed containing the soil to be incinerated, sand and calcium (material not incinerating). The incineration residues are separated from the residue using a cyclone. Normal temperatures 800-900^{o}*C, but can be run at 1200-1400*^{o}*C depending of type of contaminant.*

Figure 8: View of the Boran Thermal Treatment Plant, Berlin - NATO pilot study 1996 (BARDOS, 2002)

5.5 Strategic approaches

Over recent years combined or strategic approaches have become increasingly used as means of dealing with contamination problems, particularly as a means of reducing costs and facilitating in situ treatments. This selection outlines some of the most important of these approaches:

- Process integration
- Active containment / *in situ* treatment zones
- Extensive approaches

5.5.1 Process integration

Contaminated sites frequently cannot be remediated by application of a single technology. Complex contamination problems often require the combination of different technologies to deal with either different contaminated areas on the site or for a specific material, carrying complex mixtures of contamination. Process integration is the combined use of two or more remediation technologies. The main objective of process integration is to enhance treatment by extending the potential application of individual methods beyond that where they would normally be used as a single, stand-alone treatment. Figure 9 illustrates the process integration used to treat a soil contaminated by a mixture of heavy metals and PAH.

Process integration tends to be used to describe specific technology linkages being used to resolve a specific contamination / material mixture. On almost all sites a variety of remedial operations may be going on in parallel, for example on different sections of a site, or linking treatment with excavation, which require careful management to achieve best effectiveness along with minimum cost and environmental impact. It may be useful to distinguish this latter activity as an implementation issue: managing operations.

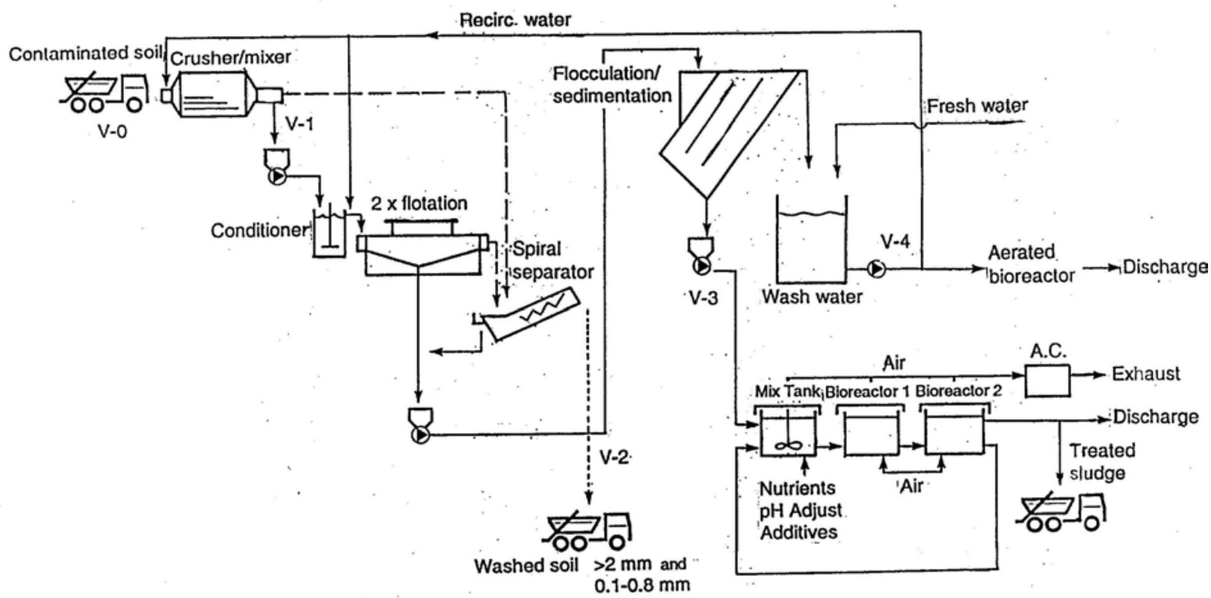

Figure 9: An example of remediation of a site (on site treatment) containing high content of heavy metals and high concentration of PAH. Remediation includes soil washing and biological treament of fines (Aquateam, 1999).

5.5.2 Active containment / *in situ* treatment zones

Treatment zones aim to improve in situ remediation by treating contamination in a smaller more clearly defined and better optimised sub-surface volume to address typical limitations of in situ remediation such as process and emission control, and ensuring contaminant availability and accessibility. Treatment zones employ groundwater or vapour as a "carrier" for the contamination. Active containment is a special case of an in situ treatment zone with the aim of treating migrating contaminants, usually dissolved in groundwater or in the vapour phase, where the source cannot be treated (for example for reasons of cost). Active containment targets treatment of contaminants in the plume/pathway rather than the source. Active containment deals with migrating contaminants. At its most elegant active containment does not contain the carrier fluid (i.e. groundwater), but contains the contamination by destroying it or removing it from the groundwater. Examples include:

- Permeable Reactive Barriers / Treatment walls
- Funnel and Gate™
- Sparge curtains

Permeable reactive barriers (PRB)

A permeable reactive barrier (PRB) is a passive *in situ* treatment zone of reactive material that degrades or immobilizes contaminants as groundwater flows through it. Natural gradients transport contaminants through strategically placed treatment media. The media degrade, sorb, precipitate or removes dissolved organic carbon, metals, radionuclides and other pollutants. These barriers may contain reactants for degradation of volatile organic carbon, chelators for immobilizing metals, nutrients and oxygen for microorganisms to enhance bioremediation or other agents. Permeable reactive barriers are used as a pathway management technique to prevent contaminants from spreading, typically through an aquifer. A range of physical, chemical and/or biological processes can be exploited within the barrier to prevent contaminants from spreading further, such as: reductive declorination with iron, inorganic-sorption or substitution barriers, inorganic-precipitation barriers, inorganic-degradation barriers and organic-sorption barriers PRBs have been applied to the treatment of chlorinated aliphatic (TCE, PCE, TCA, etc.), heavy metals, Arsenic, VOC, hydrocarbons, TCE and BTEX. The method is limited to approximately 8 m in depth and costs become prohibitive at greater depth. The hydraulic behaviours of the two major permeable treatment wall design types – funnel and gate systems or continuous reactive walls are based on the hydraulic permeability of filter layers, screens and the treatment media itself. The system permeability of the wall construction should at least be a factor of 2 higher than the natural permeability, but it will be better to use a factor of 10 due to the factors, which will change permeability over time. Limiting factors are expected to be:

- Transport and settling of fine-soil particles reducing permeability over time
- Precipitation of carbonates such as calcium and magnesium, ferrous oxides/hydroxides or other metal precipitates in the filter layer reducing permeability
- Uncontrolled growth of micro organisms such as bioclogging
- Unknown processes.

Funnel and gate™

Natural groundwater gradients is required to move groundwater through the treatment zone. Pumping may be used in some cases where the natural gradient may be too low to generate sufficient volumetric flux. In a continuous reactive wall, the conductivity of the wall is the sole design criterion, where the permeability of the system must be higher than in the natural ground. In the case of the funnel and gate system the design depends on a number of factors, including number, position and size of the gates, length and angle of the funnel and hydraulic conductivity of the reactive material within the gates. From a practical point, the major criterion is the width of the capture zone (treatment zone) for a given length of the funnel and gates. The width of the capture zone can be approximated from the flow rates through the gates. Another aspect that needs to be considered is the heterogeneity of the aquifer.

5.5.3 Extensive approaches

Many remedial treatments operate over the shorter term and require relatively high cost and energy inputs. These are referred to as "intensive" treatment technologies. Extensive technologies operate over a longer period with low maintenance, cost, and energy requirements. Examples in current use include phytoremediation and monitored natural attenuation.

Phytoremediation

Phytoremediation is the term used for a process that use specific plants, i.e. hyperaccumulation, extract/accumulate or enhance degradation. The technique is mostly applied to treatment of surface soil contaminated with heavy metals, soils but some demonstration projects with treatment of organic contaminants have been carried out as well (i.e. Batelle Europe, hydrocarbons; Limburgs Univ, Belgium, BTEX). Potential obstacles to large-scale application of phytoremediation technologies include the time required for remediation, the pollutants levels tolerated by the plants used, and the fact that only the bioavailable fraction of the contaminants are removed, while regulations often still are based on the total amount. Another obstacle is the problem of how to dispose of the plants which have accumulated high concentrations of contaminants in their tissue and are themselves hazardous materials. These problems are addressed when considering harvesting and disposal. Research is studying ashing the vegetation and recycling of the ash through a metal smelter. VAN DER LELIE *et al.* reported results from nine successful field projects in Europe (2001).

Monitored natural attenuation (MNA)

Monitored natural attenuation is the combination of all the naturally occurring processes that act without human intervention or enhancement, and is used with the objective of managing risks posed by contamination in soil and groundwater. Natural attenuation comprises a series of naturally occurring processes that can be shown to be protective of critical receptors. The processes include biodegradation, sorption, dispersion, dilution, volatilisation, chemical and biological stabilisation, transformation or destruction of contaminants. A high standard of site characterisation and considerable monitoring is required to document the loss of contaminant and demonstrate an adequate understanding of the processes causing that contaminant loss. This is necessary in order to develop and maintain confidence that natural attenuation will continue to protect critical receptors.

Natural attenuation is sometimes wrongly viewed as acceptance of a “do-nothing” approach. Monitoring and recording are essential and MNA is often combined with *in situ* techniques to speed up the natural processes. Monitoring and detailed site characterisation is essential. Furthermore natural processes can be enhanced or can act in parallel with other technologies, for example, source removal can be coupled with MNA of dissolved contaminants.

6 TECHNOLOGY IMPLEMENTATION IN EUROPE

To provide a picture of how different soil remediation technologies are implemented across Europe, each CLARINET country representative was asked to respond to a survey on the use of remediation technologies in their countries. The obvious conclusion that can be drawn from this survey is that there is a huge difference in the way technologies are used in the different countries of Europe. Several countries have well-established markets for soil remediation while others have barely begun. It should be pointed out that the actual data in these responses should be regarded as tentative, indicating trends, rather than categorical.

Table 11 through 14 summarise European information on different technologies. Table 15 – 16 summarise cost information.

Table 11: Degree of implementation of ex situ biodegradation technologies in Europe

Country	**Tech-nology**	**Contami-nant**	**Degree of imple-mentation**				**Costs**	**Limitation**	**Comments**
			R&D	**Pilot**	**Dem**	**Com**			
Austria	Do not specify					X			Four projects funded by government using biological treatment
Belgium / Flandres	Do not specify	Hydro-carbons				X	20-40 Euros / tonne		Several companies are involved in biological treatment. At least 10 sites treated with success.
Denmark	Composting	Oil / petroleum or not specified				X	25-35 Euros / tonne Average		Five companies
France	Composting	Oil / PAH / Halogens / PCB	X			X	5-40 Euros / tonne	Usually combining treatment technologies	Biological treatments were used in 29% of contaminated sites, but it is not specified if it is applied *in situ* or *ex situ*. Thirteen companies are prepared to treat biologically contaminated soils *ex situ*.
	Biopile					X	40-90 Euros / tonne		

Table 11: Degree of implementation of ex situ biodegradation technologies in Europe (continued)

Country	**Tech-nology**	**Contami-nant**	**Degree of imple-mentation**				**Costs**	**Limitation**	**Comments**
			R&D	**Pilot**	**Dem**	**Com**			
Finland	Composting Biopiles Bioreactors	Oil products, less common Creosotes and Chloro-phenols				x X	8-60 Euros/ tonne 60-200 Euros/ tonne	Pretreatment for heavy contamination, with repercussion on costs	Many *ex situ* biological treatment are used to remediate contaminated soils. At least two companies are prepared to treat contaminated soils by composting methods. But there are 54 locations where is possible to compost soils contaminated by oil based compounds and other compostable substances. For oil products the time treatment is 1-1.5 years, but for other contaminants time needed for treatment, will increase.
Germany	Composting Bioreactors Biopiles	Hydro-carbons Chlorina-ted Hydro-carbons PAH Phenols Nitro-phenols TNT	 X			X	No cost figures avail-able		Many companies exist for ex situ treatment, some companies perform on site treatment. Significant progress has also been achieved in the field of bioremediation. More than 30 projects are running. More information in electronic addresses.
Greece	Composting	Oil-products Heavy metals and metalloids	 X			X	20-65 Euros/ tonne		Mobilisation and recovery of heavy metals and metalloid using sulphate- and heavy metal reducing bacteria

Table 11: Degree of implementation of ex situ biodegradation technologies in Europe (continued)

Country	Technology	Contaminant	Degree of implementation: R&D	Pilot	Dem	Com	Costs	Limitations	Comments
Ireland	Composting	Oil-products				X	40-100 Euros/tonne		
	Biopile					X	32-140 Euros/tonne		
Italy	Composting	Petrol Hydrocarbons				X	<low-90 Euros/ tonne		Nine different treatment sites Only one soil treatment plant has been recently installed (20,000 tonnes/year). Several bioremediation projects have been carried out on site
	Bioreactor						<240 Euros/tonne 75-600 Euros/tonne		
	Biopiles	Other contaminants		X					
Netherlands	Composting	Oil PAH				X	Sandy soil 20-30 Euros/tonne Claye soil 35-45 Euros/tonne		
Norway	Composting	Oil				X	e.g. 20-120 Euros/ tonne		~100,000 tonnes of contaminated soil per year 18 locations, 6 companies
		PAH Gasoline				X	200 Euros/ tonne		
Spain	Composting	Oil/petrol				X	40 Euros/ tonne > 2,600m^3 300 Euros/ tonne ~ 285 m^3		Costs depending on soil volume and the main enterprises are related to the construction sector

Table 11: Degree of implementation of ex situ biodegradation technologies in Europe (continued)

Country	Technology	Contaminant	Degree of implementation				Costs	Limitations	Comments
			R&D	Pilot	Dem	Com			
Sweden	Composting Bioslurry Composting in sanitary landfills	Oil PAH PCB Hydro-carbons				X X X	Min-max.16-320 Euros/tonne Average 33-120 Euros/tonne 26-91 Euros/tonne		Private companies ; 9 composting and 1 bioslurry. Municipal facilities for composting (32 sites)
Switzerland		Small fraction of organic pollutants				X			No data available on *ex-situ* biotreatment. A few companies offer these services.
United Kingdom	Composting Biopiles					X	50-60 Euros/tonne		

Table 11 summarises the degree of implementation of *ex situ* biodegradation technologies in Europe and shows that remediation by *ex situ* biodegradation by composting is available in all European countries. The costs vary, with the lowest price given from France (5 Euros/ton) and the highest from Norway and Sweden (120 Euros/ton). Hydrocarbon is by far the contaminant mostly treated by composting. Biological treatment seems to be a commonly used treatment method in Europe, when considering number of units. France reports that as much as ~30% of contaminated sites are applying biological treatment technologies. Municipal composting plants are in some countries used to treat contaminated soil. Bioreactors/bioslurry are reported used by Germany, Finland, Italy and Sweden to treat chlorinated organics. Several countries report using biopiles (France, Finland, Germany, Ireland, Italy and United Kingdom). The variation in reported information from the different countries may, however, reflect that the different countries use different definitions (biopile, composting). Difference in the degree of implementation of biological treatment for contaminated soil, and difference in cost figures in different countries may reflect different regulations, such as requirement for monitoring and controlling treatment effectiveness and residual concentrations. High natural background concentrations of metals and arsenic (particulate bound but not necessary bioavailable), have in some countries limited the use of biodegradation as a sole treatment technology.

Table 12: Degree of implementation of physical/chemical treatment technologies in Europe

Method	Contaminant	R&D	Demo	Commercial	Price
Soil washing				Austria	
	Oil, PCB, PAH			France	30-90 Euros/tonne
				Finland	
	Organic, inorganic			Germany	
	Acids			Greece	60-235 Euros/tonne
				Italy	
				Netherlands	20-35 Euros/tonne Up to 60 Euros/tonne if removal of residues is included
	Oil, PAHs, metals			Norway	40-250 Euros/tonne
	Oil, PAHs, metals			Sweden	45-320 Euros/tonne
				Switzerland	135 Euros/tonne
				UK	
Electrodialysis	Heavy-metals		Den-mark		
Electro-oxidation				France	
Flotation	Mercury		France		
Stabilisation/				France	
Solidification/			Belgium	Austria	
Immobilisation				Finland	
	Acids, organic			Greece	60-230 Euros/tonne
	Inorganic			Ireland	
				Italy	
				Norway	60-250 Euros/tonne
	Heavy metals, hydrocarbons, chlorinated organics			Spain	
				UK	
	Oil, PAH			Sweden	

Table 12: Degree of implementation of physical/chemical treatment technologies in Europe (continued)

Method	Contaminant	R&D	Demo	Commercial	Price
Solvent extraction				France	75-150 Euros/tonne
				Spain	
Chemical extraction	Organic, inorganic	Swe-den			
Photo oxidation	Cyanide, metallic ions, Ag, Cr			France	
Landfill				France	150-230 Euros/tonne
				Greece	470-700 Euros/tonne
Ex situ soil venting				Finland	
Chemical dehalogenation	Chlorinated organics	Nor-way			
Molecular bonding	Cr6+			UK	

Physical/chemical treatment includes numerous different technologies (Table 12). Soil washing and stabilisation/solidification/immobilisation are commercially available in many European countries. Electro oxidation, solvent extraction and photo oxidation are reported commercially available in France. Solvent extraction is also reported available in Spain. Finland is reporting that *ex situ* soil venting is commercially available. Reported cost figures for soil washing vary from 20-320 Euros/tonne. Netherlands reports the lowest costs. Stabilisation / solidification / immobilisation cost figures varies from 60-250 Euros/tonne.

Table 13: European implementation of thermal treatment technology

Technology	Conta-minant	Commercial Scale	Cost per tonne	Comments
Thermal stripping & desorption	Org.	AT 4 Plants	-	-
Thermal	Org.	BE 3 Plants	50-60 Euros	On site
Thermal	Org.	DK 2 Plants	95-220 Euros	
Thermal + Incinerators	Org.	FR 7 Plants	35-205 Euros	Both thermal desorption + inc. Applied at 29% of sites

Table 13: European implementation of thermal treatment technology (continued)

Technology	**Conta-minant**	**Commercial Scale**	**Cost per tonne**	**Comments**
Thermal + Incinerators	Org.	SK 3 Plants	-	1 incinerator 2 thermal
Thermal + Incinerators	Org.	IT 3 Plants	240-700 Euros	2 thermal 1 incinerator
Thermal + Incinerators	Org.	IE -	520-1300 Euros	No thermal or incinerators - Ireland
Thermal + Incinerators	Org.	NL 4 Plants	30-80 Euros	Costs for thermal
Thermal +Incinerators	Org.	NO 2 Plants	380 Euros	Costs for incineration 1 thermal plant
Thermal +Incinerators	Org.	PT -	-	Not available
Thermal +Incinerators	Org.	ES -	590 Euros	Costs for incineration No details given
Thermal +Incinerators	Org.	SE 5 Plants	540 Euros 48 –80 Euros	Incinerator Thermal
Thermal +Incinerators	Org.	CH -	-	Has thermal. No details given
Thermal +Incinerators	Org.	UK 3 Plants	1600 – 1920 Euros	2 incinerators 1 thermal
Thermal +Incinerators	Org.	SF 1	95-220 Euros	One incinerator are thermal plant also, but no details given

Table 13 summarises the use of thermal treatment for remediation of contaminated soil. More than 30 commercial scale plants are reported available in Europe. The cost varies from 30 – 1920 Euros/tonne, probably reflecting the variation between thermal treatment and incineration. Lowest costs figures are reported for The Netherlands where cost are reported varying between 30 and 80 Euros/tonne, but the costs are for thermal. Austria reports thermal stripping and desorption technology available in commercial scale. No cost figures are reported.

Table 14: Implementation of in situ technologies in Europe

Technology	Scale and degree of implementation			
	R&D	Pilot	Demonstra-tion	Commercial/ full scale
Bioventing	DK, NL, UK		DK, SF	DK, B, F, G, EI, I, N, UK
Soil Vapor Extraction (SVE)	DK, NL	UK, F, A	DK, D	A, DK, B, F, SF, G, EI, I, N, E, S, UK
Air sparging / biosparging	NL, UK		DK	DK, B, F, EI, I, N, S, UK
Dual phase extraction				DK, NL, F, EI, I, UK
Bioslurping			NL, D	EI
Steam stripping		D	DK	DK, NL, F, SF
Biostimulation	DK, NL, D, A, UK	DK, NL, D, A	NL, D, A	D, B, SF, EI, N, CH, UK
HRC				DK
ORC	UK	DK, D, EI		DK, UK
Soil washing / flushing	UK	D, I		DK, F, G, UK
Electro kinetics	DK, NL,UK	DK, NL, SF	DK, NL, S	D, NL, F
Electrical heating		DK		
Phytoextraction	A, DK, NL, B, UK, F, D	DK, F, B, SF, UK, EI	DK, UK	F, EI
Phytostabilization	DK, NL, UK	N	DK	
Permeable Reactive Barriers (PRB)	DK, D, UK, A	D, NL, SF, G, N	A, DK, D, NL, I	A, DK, D, F, EI, CH, UK
Encapsulation / containment	D	D, A	D, E	A, DK, D, F, B, SF, EI, I, E, CH, UK
Solidification	UK	UK, EI	UK	D, SF, G, UK
Stabilisation / stabilisation	UK	D, F, A, B, G, EI	NL, I, UK	D, B, F, SF, G, UK
Biostabilisation	D			

Table 14: Implementation of in situ technologies in Europe (continued)

Technology	Scale and degree of implementation			
	R&D	**Pilot**	**Demonstra-tion**	**Commercial /full scale**
Chemical oxidation	DK, D, SF	F, I, EI	DK, S	DK, D, EI, N, UK
Thermal desorption			DK	F, UK
Hydraulic fracturing	DK		DK	D, UK
Hydraulic containment	UK			UK
Pump an Treat	DK, NL, D, UK		DK	DK, D, B, SF, EI, S, CH, UK
Monitored Natural Attenuation (MNA)	DK, D, NL,	UK, EI	DK, NL, I	DK, NL, F, EI, S, UK

More than 20 different *in-situ* technologies are reported available in Europe, see Table 14. Electrical heating is only reported available in pilot scale in Denmark, and biostabilisation only available in R&D scale in Germany. There is a growing interest for *in-situ* methods because the material treated in situ is not considered waste unlike ex situ treatment. The use of i*n situ* technologies has traditionally been used in areas where traditional "dig and treatment" technologies are not easily implemented.

Table 15: Summary of costs in Euros per tonne of soil treated in ex situ treatment units

Treatment	Countries									
	EI	**Be (Flan ders)**	**DK**	**SF**	**GR**	**I**	**NL**	**N**	**S**	**UK**
Biological	40-100	20-40 low on s.				<240	20-45			50-65
Landfarming	30-200			8-60		low-90				
Composting	30-95		25-35	8-60				20-200	25-350 10-100 Municipal landfill.	
Biopile	32-140			60-200		75-600 high				
Solvent extraction	500-890			75-150		>240				565

Table 15: Summary of costs in Euros per tonne of soil treated in ex situ treatment units (continued)

Treatment	**Countries**									
	EI	**Be (Flan ders)**	**DK**	**SF**	**GR**	**I**	**NL**	**N**	**S**	**UK**
Soil washing	30-150			30-90	43-171	med-high 80-240		40-250	25-350	
Thermal desorption	60-330			40-205		med-high 80-240			55-90	50-210
Incineration	[4] 520-1300			305-1065		240-700 med-high		380	590	1055-1410
Thermal	-	50-60 on s.	95-220				25-80			
Physico / Chemical	30-110	30-50								
Landfilling	30-110			152-230	340-515	100-400				70 / m^3
Stabilisation / Solidification	-				45-170			40-250		55 vitrif.

Notes:

1. In preparation of the table, it has been assumed that treatments occur off site unless stated otherwise
2. Some countries have probably used different terminology for the same treatment: e.g. thermal treatment and incineration might perhaps be on the same line. Same might be for physico / chemical and stabilisation / solidification
3. M.C. = composting by Municipal Company
4. . There are no incinerators for contaminated soil in Ireland. Prices quoted are for export from Ireland for incineration.

Table 16: Costs in Euros per ton of soil (or m³ water or m² area) of in situ remediation

Treatment technology	Countries						
	EI	**BE (Flanders)**	**DK**	**F**	**GR**	**I**	**UK**
Air Sparging	60-120	moderate		25-45		70 med-high	65-75 / m^3
Soil Vapor Extraction	60-140	moderate			20-40	65-80 low	55-85 / m^3
Bioventing	25-80	moderate			20-50	25-80 low-med	
Landfarming	48					low	
Biodegradation	25-160			15-75		80-240 med	
Bioslurping	30-90					85	
Biosparging	50-110					40	
Pump and treat	30-120			15-75		30 med-high	30-40 / m^3
Dual phase extraction	90-160						
Vacuum extraction	30-130			15-30			
Venting / Stripping	90-130			25-45			
Soil washing	25-80			30-90	35-155		
Stabilisation / solidification	50-130			25-30			
Encapsulation	90-280						55-170 / m^2
Active barriers	25-410					high	
Confinement	20-70			30-75 / m^2			20-40 / m^2 eng. cap
Chemical oxidation	70-400						55-110 / m^3
Free-product recovery	20-40					50	10-20 / m^3

It seems as if only a few countries have adapted *in situ* treatment technologies as an alternative to excavation and ex situ disposal in a larger scale. The *in situ* methods most frequently are soil vapour extraction (SVE), air sparging, bioventing and biostimulation. Permeable reactive barriers, encapsulation / containment are also widely applied *in* situ. These technologies are available or are in use in most countries, the rate of use may be low though because of issues such as concerns over their ability to remove liabilities. Costs of *in situ* technologies are in the same range as *ex situ* technologies. Some of the reported information in Table 16 might reflect on site treatment, but not necessarily *in situ* technologies.

For a detailed description of the implementation of different technologies on the national level please see Appendix 2. The data quality is likely to have some limitations, due to lack of reported figures from different countries and availability of comparable figures. References given by each country in appendix can provide updated information.

7 PILOT SCALE AND DEMONSTRATION PROGRAMMES

A range of pilot scale studies and demonstration programmes are going on in Europe. Some of the programs are international with partners from outside Europe.

One major international programme is the NATO/CCMS pilot study. In this programme a range of countries are demonstrating some technologies each. The study covers a broad range of technologies for different purposes such as remediation of gasoline, phenol, tar, BTEX, metals etc. in different media. The results are reported and discussed in an international context. The study is now in the third phase with demonstrations of 15 different technologies from 10 different countries. The earlier phases have been reported both in paper (EPA/542/R-98/002) and electronic format (http://www.nato.int/ccms/pilot-studies/pilot007/).

The other major programmes include the TUP programme sponsored by the Danish EPA, the 4-5 years programme "Tests of polluted soil treatment and technology development" initiated 1998 by ADEME in France, the Dutch NOBIS programme (SKB), the German VEGAS programme and the British CL:AIRE and exSite programmes. CL:AIRE is a UK programme for demonstrating both remediation research and commercial scale technologies on contaminated sites throughout the UK. Established in 1999, it has approved 9 projects as of January 2001. In additional 8 to 10 projects are expected to approve over 2001. Reports on three technology demonstration projects and one research project are expected to be published during 2001.

The aim of the French programme is to propose an inventory of tests in order to choose an appropriate remediation technology. For this purpose eight different technologies and eight different types of contaminated materials have been selected for studies.

The Dutch research programme In situ Bioremediation (NOBIS) started in 1995. It is a collaborative venture between public and private parties. About 100 projects are ongoing with an annual budget of 4 million dollars. Since The Netherlands abandoned the uniform risk assessment a search for more cost efficient methods started. NOBIS has focused on cost efficient remediation technologies in relation to location-specific circumstances. A new Dutch programme called "soil knowledge development and transfer" will use the same approach.

A German research facility for subsurface remediation, VEGAS, was founded in 1995. At this facility, remediation methods are tested in large-scale tanks ranging from 30 – 790 m^3. The main research projects are methods for hydraulic remediation techniques, treatment of non-aqueous liquids in the vadose zone, remediation of PAHs and reductive contaminant transformation.

The Danish TUP programme for development of technology, soil and groundwater contamination started 1996 in Denmark. The technology programme has focused mainly on remedial technologies for chlorinated solvents and oil, heavy metals and petroleum contaminations. In the next year a more specified assessment of air sparging, modified stripping, geo-oxidation, fracturing permeable reactive barriers, and phytoremediation will be published.

For a detailed description of the different programmes please see appendix 1.

8 RTD NEEDS

There is currently great interest in Europe in promoting greater consideration of the principles of sustainability in remediation work. The country review (see Appendix 2) shows how some countries have sought to promote the use of process based remediation technologies in place of conventional removal to landfill and containment, which are *perceived* to be more sustainable. Of all the technologies available, biological techniques are *perceived* to be the "most sustainable". However, in the absence of agreed and verifiable approaches to sustainability appraisal for remediation projects it is not possible to categorically support or oppose these assertions. Integration of the principles associated with sustainability; environmental, social and economic, taking wider environmental effects into consideration is an overall R&D need.

The review of the implementation of remediation technology, and ongoing pilot scale and demonstration programmes shows that there still are many gaps in knowledge on remediation technology, and that R&D throughout Europe in this area still is needed, both on a local scale and in the international scene, and that coordination of these efforts are needed. In short, the following items have been identified as needs:

- Comparable cost figures
- QA / QC systems for performance and total emissions
- Comparable output (demonstration plants)
- Harmonised approaches including wider environmental issues for sustainable technology evaluation
- Integration of technologies for solving the variety of problems occurring on one site
- Integration of the planning-, investigation-, remediation- and aftercare process
- Long-term experiences from pathway / exposure control technologies
- Decision making on “clean” remediated soil (soil function)
- For some countries, risk based decision making approaches need implementation
- Further development of more cost / effective technologies
- Further development of integrated technologies solving mixed problems
- Developing remediation goals based on bioavailable fraction of contaminants rather than total concentration

For *in situ* technologies, examples of some detailed R&D are given:

Permeable Reactive Barriers:

- Effect of changes in permeability with time as a function of bioclogging / growth, precipitation, bubble formation etc.
- Biodegradation kinetics and pathways, including metabolite accumulation, under different redox conditions in bioscreens.
- Biodegradation enhancement by addition of primary substrates, electron acceptors, nutrients etc. or inoculation with starter cultures in bioscreens.

Phytoremediation:

- Control of enhanced leaching of heavy metals as a result of addition of chelating agents to stimulate heavy metal solubility and uptake in plants in phytoextraction schemes.
- Use of plants to affect longterm stabilisation, while at the same time yielding revenue.
- Identification and / or construction of fast growing hyperaccumulators able to effectively translocate contaminants from roots to leaves.
- Environmental risks connected with bioavailability of heavy metals accumulated in plants.

SVE / Bioventing:

- Prediction of treatment time in case of presence of free phase contaminants in the soil / groundwater.
- Kinetics of phase transfer processes at microscale governing availability (desorption, dissolution, evaporation) in a multiphase complex medium.
- Spatial airflow control in a medium with variabilities of permeability in time (growth, precipitation) and space.

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ANNEX 1

Remediation of Contaminated Land Technology Implementation in Europe – State-of-the-Art

Content

1 PROJECTS INCLUDED IN NATO/CCMS PILOT STUDIES

Table 1 summarises the pilot studies included in phase II of NATO/CCMS Pilot Studies.

More details are given in EPA (EPA 1998): Evaluation of Demonstrated and Emerging Technologies for the Treatment of Contaminated Soil and Groundwater (Phase II, NATO/CCMS Pilot Study). 1998 Annual Report No 228. EPA/542/R-98/002, May.

Table 1: Listing of NATO/CCMS Pilot Study technical projects according to sponsoring country showing their status and technology type (Technical Status May 1996)

Sponsoring Country	Project Title	Status /Type
Australia	Trial of Air Sparging of a Petroleum (Gasoline) Contaminated Aquifer	I, P
	Bioremediation of Phenol Contaminated Soils on Coode Island	I, B
	Bioclogging of Aquifers for Containment and Remediation of Organic Contaminants	I, B
	Remediation of Methyl Ethyl Ketone Contaminated Soil and Groundwater	I, P
Austria	Technical and Economic Aspects of In Situ Bioremediation	W, B
Canada	*In Situ*/On Site Bioremediation of Industrial Soils Contaminated with Organic Pollutants: Elimination of Soil Toxicity with *Daramend*™	F, B
	Biopile Technology for the Treatment of Organic Contamination in Soil	F, B
	Integrated Treatment Technology for the Recovery of Inorganic and Organic Contaminants from Soil	I, In
	Demonstration of Thermal Gas-Phase Reduction Process	F, T
	Field Demonstration of an *In Situ* Treatment for Hydrocarbon Contaminated Sites Using Well Points	A, In
Czech Republic	Sobêslav, South Bohemia Wood Treatment Plant	A, Mx
Denmark	Biodegradation of PAHs at Frederiksbergs Gasworks	I, B
	Groundwater/Soil Remediation at a Former Manganese Suphate Plant	I, Mx
	Rehabilitation of a Site Contaminated by Tar Substances Using a New On-Site Technique	F, T
France	Ozone Treatment of Contaminated Groundwater	F, In
	Soils of Garbage Dumps of Coal Tar and Petroleum Tar Distillation Plants	A, B
	Innovative *In Situ* Groundwater Treatments System	I, P
	Treatment of Polluted Soil in a Mobile Solvent Extraction Unit	I, C

Table 1: Listing of NATO/CCMS Pilot Study technical projects according to sponsoring country showing their status and technology type (Technical Status May 1996) (continued)

Sponsoring Country	Project Title	Status / Type
Germany	Assessment of a Biological *In Situ* Remediation	F, B
	Cleaning of Mercury-Contaminated Soil Using a Combined Washing and Distillation Process	I, In
	Mobile Low Temperature Thermal Treatment Process	I, T
	Permeable Treatment Beds	A, Mx
	Fluidised Bed Soil Treatment Process – *BORAN*	A, T
Hungary	Environmental Problems at Tököl Airbase and Other Former Soviet Military Bases in Hungary	F, Mx
Italy	Application and Development of Ground Penetrating Radar System for the Determination of Pollutants in Contaminated Areas	W, Mx
	Forced Soil Washing Using UV and Hydrogen Peroxide	W, C
	Biological Treatment of Soil Contaminated with Aromatic Hydrocarbons	A, B
The Neth-erlands	Combined Remediation Technique *FORTEC*™	F, In
	Slurry Decontamination Process	I, B
	Modelling and Optimisation of *In Situ* Remediation	I, Mx
	In Situ Bioremediation of Chloroethene Contaminated Soil	A, B
Norway	Treatment of Creosote Contaminated Soil	I, In
	Use of White Rot Fungi for Bioremediation of Creosote Contaminated Soil	I, B
	Soil Washing and DCR Dehalogenation of PCB Contaminated Soil	I, In
Sweden	Treatment of PAH and PCB Contaminated Soil in Slurry-Phase Bioreactors	A, B
Switzerland	Re-use of Bioremediated Soils / Long Term Degradation of Hydrocarbon Residuals	A, B
Turkey	Sorption / Solidification of Selected Heavy Metals and Radionuclides from Water	I, S
UK	*CACITOX*™ Soil Treatment Process	F, In
	In-Pulp Decontamination of Soils, Sludges and Sediments	F, In
	Using Separation Processes from the Mineral Processing Ind. for Soil Treatment	F, P
	In Situ Soil Vapour Extraction within Containment Cells Combined with *Ex Situ* Bioremediation and Groundwater Treatment	F, Mx
	Enhancement Techniques for *Ex Situ* Separation Processes Particularly with Regard to Fine Particles	F, In
	Chemical Fixation of Soils Contaminated with Organic Chemicals	I, S
	Decontamination of Metalliferous Mine Spoil	F, In

Status: A (Accepted), I (Interim), F (Final), W (Withdraw); B (Biological), C (Chemical), P (Physical), T (Thermal), S (Solidification / Stabilisation), In (Integrated), Mx (Mixed)

Table 2 summarises the pilot studies included in phase III of NATO / CCMS Pilot Studies. More details are given in EPA (2000): Evaluation of Demonstrated and Emerging Technologies for the Treatment and Clean Up of Contaminated Land and Groundwater. NATO / CCMS Pilot Study Reports, 1985-2000. EPA 542-C-01-002, CD ROM.

Table 2: Listing of Pilot Studies included in NATO/CCMS Pilot Studies Phase III (Updated 2000) (EPA, 2000)

PROJECT	**COUNTRYS**	**MEDIUM**		**CONTAMINANT**					**NOTES**
		Soil	**Groundwater**	**VOCs**	**SVOCs**	**Pesticides/PCBs**	**PHCs**	**Inorganics**	
1. Bioremediation of Loamy Soils Contaminated with Hydrocarbons and Derivatives	Belgium	❼			❼		❼		PAHs, munitions chemicals
2. Mercury-Contaminated Spolchemie Plant	Czech	❼	❼		❼			❼	Hg, metals, PAHs, TPH
3. Permeable Treatment Beds	Germany		❼	❼	❼		❼	❼	PAHs, BTEX, TCE, PCE
4. Rehabilitation of Land Contaminated by Heavy Metals	Greece	❼						❼	Pb, Zn, Cd, As, H*, $SO_4^{=}$
5. Application of BioWalls / BioScreens	Netherlands		❼	❼	❼	❼	❼		Chlorinated pesticides, BTEX, TPH, HCH, PCE, TCE
6. Rehabilitation of a Site Contaminated by PAH Using Bio-Slurry Technique	Sweden	❼			❼			❼	PAHs, cyanides, metals, ammonium compounds
7. Risk Assessment for a Diesel-Fuel Contaminated Aquifer Based on Mass Flow Analysis During the Course of Remediation	Switzerland		❼				❼		PHC
8. Obstruction of Expansion of a Heavy Metal / Radionuclide Plume Around a Contaminated Site by Means of Natural Barriers Composed of Sorbent Layers	Turkey	❼	❼					❼	Pb, As, Cr, Cu, Cd, Hg, Ni, Zn; ^{137}Cs, ^{90}Sr, ^{238}U
9. Solidification / Stabilization of Hazardous Wastes	Turkey	❼			❼	❼		❼	PCBs, AOX, metals
10. Metals Biofilms Interactions in Sulfate-Reducing Bacterial Systems	UK		❼					❼	Metals (Cu, Zn, Cd), radionuclides (Labscale)

Table 2: Listing of Pilot Studies included in NATO/CCMS Pilot Studies Phase III (Updated 2000) (EPA, 2000) (continued)

PROJECT	COUNTRYS	MEDIUM		CONTAMINANT					NOTES
		Soil	Groundwater	VOCs	SVOCs	Pestcides/PCBs	PHCs	Inorganics	
11. Predicting the Potential for Natural Attenuation of Organic Contaminants in Groundwater	UK		❼	❼	❼		❼	❼	Coal tars, phenols, creosol, xylenols, BTEX, NH_4^*
12. Treatability of Enhenced *In Situ* Anaerobic Dechlorination	USA		❼	❼	❼				TCE, DCE. VC, PCE
13. Permeable Reactive Barriers for *In Situ* Treatment of Chlorinated Solvents	USA		❼	❼				❼	PCE, TCE, DCE
14. Dynamic Underground Stripping	USA	❼	❼		❼				PAHs, PCP
15. Phytoremediation of Chlorinated Solvents	USA		❼	❼					TCE, TCA, DCE, PCE, xylene, methyl chloride, TMB
16. In-Situ Heavy Metal Bioprecipitation	Belgium		❼					❼	TCE, TCA, DCE, PCE, Xylene, methyl chloride, TMB
17. GERBER Site	France	❼	❼	❼	❼	❼		❼	Chlorinated solvents, BTEX, PCBs, phenols, phthalates, Pb, Zn
18. SAFIRA	Germany		❼	❼					Omplex contaminations, Chlorobenzenes
19. Successive extraction Decontamination of Leather Tanning Waste Deposited Soil	Turkey			❼				❼	Tanning waste
20. Interagency DNAPL Consortium Side-by-Side Technology Demonstrations at Cape Canaveral, Florida	USA	❼	❼						DNAPLs
21. Development and Use of s Permeable Reactive Barrier System for Ground Water Clen-up at a Chromium-Contaminated Site	Switzerland		❼					❼	Chrom (VI)
22. Thermal In-Situ Using Steam Injection	Germany	❼		❼					TCE, BTEX
23. Bioremediation of Pesticides	USA	❼				❼			Hlordane, DDT, DDD, DDE, Dieldrin, molinate, toxaphene

Table 2: Listing of Pilot Studies included in NATO/CCMS Pilot Studies Phase III (Updated 2000) (EPA, 2000) (continued)

PROJECT	COUNTRYS	MEDIUM		CONTAMINANT					NOTES
		Soil	Groundwater	VOCs	SVOCs	Pestcides/PCBs	PHCs	Inorganics	
24. Surfactant-Enhanced Aquifer Remediation	USA		❼	❼					PCE
25. Liquid Nitrogen Enhanced Remediation	Netherlands		❼	❼					Chlorinated Hydrocarbons
26. SIREN: Site for Innovative Research on Monitored Natural Attenuation	UK		❼	❼					Organic solvents
27. Hydro-Biological Control on Transport and Remediation of Organic Pollutants for Contaminated Land	UK	❼	❼	❼	❼				PAH, Phenols, substituted benzenes
28. Demonstration of as Jet Washing System for Remediation of contaminated Land	UK	❼					❼		Tars,
29. Automatic Data Acquisition and Monitoring System for Managing Polluted Sites	Italy	❼	❼	❼					TPH,BTEX

KEY:
AOX = adsorptive organic halogens
BTEX = benzene, toluene, ethylbenzene, and xylenes
DCE = dichlorethene
HCH = hexachlorocyclohexane
PAHs = polycyclic aromatic hydrocarbons
PCBs = polychlorinated biphenyls
PCE = tetrachloroethene
PCP = pentachlorophenol
PHCs = petroleum hydrocarbons
SVOCs = semivolatile organic compounds
TMB = trimethylbenzene
TCA = trichloroethane
TCE = trichloroethene
VC = vinyl chloride
VOCs = volatile organic compounds

Additionally to the NATO CCMS pilot studies, U.S EPA has prepared a good overview of innovative technologies. (EPA, 2000) evaluates the superfund innovative technology evaluation program. Most of the technologies described are the same as provided in Europe, while the companies delivering the technologies can be different.

2 TECHNOLOGY DEVELOPMENT PROJECTS BY COUNTRIES

2.1 France – IRH

A 4-5 years programme was inititated in 1998 by ADEME in France. This programme aims at proposing an inventory of tests for main available technologies in order to choose a technique of treatment according to the degree of pollution in soil. Eight types of contaminated soils and eight different technologies have been selected for the study. These are:

Types of contaminated soil:

- Former gas works
- Petroleum storage
- Surface treatment
- Non-ferrous metallurgy
- Wood preservation contaminated site
- Mining activities
- Solvent regeneration
- Accidental contamination by PCB

Treatment technologies:

- Physical separation of pollutants
- Chemical extraction- washing by organic solvents
- Pressure extraction –venting
- Stabilisation
- Thermal treatment
- Biological treatment (biodegradation of organic compounds, and leaching and immobilisation of heavy metals)
- Washing by use of surfactants
- Phytoremediation of heavy metals

A co-ordinator is in charge to provide the different kinds of polluted soils corresponding to each type of contaminated soil to the different laboratories involved in the research programme. Characterisation tests will be conducted and each specialised laboratory will apply their treatment technology. All test protocols and methodologies will be presented in parallel with treatment results. This first phase of the programme will be followed by a second phase validating the results. This will be assured in collaboration with soil treating industries in France.

2.2 Germany

2.2.1 German demonstration projects on remediation of contaminated sites

An 8 years program started in 1990 by the German Federal Ministry of Education and Research (BMBF). The objective was to test and evaluate new remediation technologies on site under the harsh conditions encountered in daily practice, using them separately or in combination. This was to give impetus to the effective use of the techniques developed and generate experience about their behaviour in long-term use and their effectiveness.

Altogether, 13 demonstration projects were realised. The total expenses summed up to 125 million €.

Types of contaminated sites

- Former gas works
- Mercury-electrolysis plant
- Painting - and solvent production site
- Ferrous metallurgy site
- Non-ferrous metallurgy site
- Armament sites
- Petroleum sludge landfill
- Chemical residue deposit

Improved remediation and treatment technologies:

Washing/chemical-physical separation	dioxins, furanes, heavy metals PAH's, TNT, Mercury
Thermal Treatment	PAH, Dioxines, Mercury, TNT
Biological treatment	Mineral Hydrocarbon, PAH's
Soil venting	Chlorinated hydrocarbons

Additionally, several combinations of treatment technologies have been demonstrated.

The ways of performing cost-effective, environmentally appropriate and use-oriented remedial measures are documented and published as a compendium.

2.2.2 The research Facility for Subsurface Remediation – VEGAS

The German Federal Ministry of Education and Research and the Ministry of the Environment of Baden-Württemberg founded the facility in 1995. It is linked with the hydraulic laboratory of the institute of hydraulic Engineering of the University of Stuttgart. The facility includes several large -scale experimental tanks of various sizes with volumes of between 30 and 790 m³. The various test set-ups are filled with partially contaminated soils and aquifer materials thus simulating contaminated sites without the risk of uncontrolled spreading into the natural environment.

Advantages of experiments with contaminants in large-scale closed containers:

- Possibility of controlling and modifying the experimental conditions
- Possibility of determining accurate mass balance
- Experiments with hazardous substances without the danger of contaminating the natural environment
- Variable subsurface structure
- Experimental residence times similar to nature
- Possibility of applying and testing technical equipment for remediation

Participating German institutions are universities, research institutions, industrial companies and engineering consultants.

Main research projects

- Optimisation and further development of hydraulic remediation techniques
- Non-aqueous phase liquids (NAPL) in the vadose zone
- Improvement of the remediation efficiency of soils contaminated with PAH
- Contaminant transformation by reduction for *in situ* remediation of soils and aquifers

International co-operations

- University Louis Pasteur Strasbourg
- University of Waterloo Ontario,Canada
- French geological survey B.R.G.M., Orleans, France
- University of California at Berkeley ,USA

Further information: http://www.iws.uni-stuttgart.de/vegas/uebersicht.html

Bioremediation

Since 1994 sponsored the BOMB, a research project "Biological soil decontamination methods", consisting of more than 40 single projects. This activity is concerned with exploring the use of bacteria and fungi as well as of ligneous and herbaceous plants for the destruction or removal of such organic compounds as e.g. TNT, hexagon, nitrophenols, aromatic amines, phenols, and dioxins. The methods developed are currently being tested on a commercial scale; this includes testing for degradation of explosives-typical compounds at the site "Tanne" near Clausthal-Zellerfeld.

2.3 Dutch research Programme In Situ Bioremediation (NOBIS)

2.3.1 Background

Local cases of contaminated sites have often hampered the planning and the economic development of urban areas (for example textile cleaning companies and former gas works sites), industrial areas (often large-scale, the sites are being sold, the user is not the owner) and natural areas (dump sites in the countryside, filling in waterways).

Meanwhile, the 'classical' ***uniform*** risk assessment of soil contamination based on concentrations has been abandoned in the Netherlands. This was necessary in order to achieve the desired cost reduction and to improve the functioning of the market. Presently the costs of soil remediation in the Netherlands are estimated at about $25 billion (formerly about $50 billion).

Apart from abandoning the uniform risk assessment, cost reduction is also related to the *available* means (not only money, but also time and space) and cheaper research methods and remediation techniques. NOBIS has focused on the latter aspects and used the actual risks in location-specific circumstances as the basis for technology development.

2.3.2 NOBIS

The Dutch Research programme In situ Bioremediation (NOBIS) started in 1995. NOBIS is a collaborative venture between public and private parties. The present extent of the programme can best be described by the following key data:

- number of projects: about 100, subdivided into about 25 research projects, 50 feasibility projects and 25 implementation projects;
- number of participating parties: about 100 (industry, authorities, consultants, contractors, technological institutions and universities);
- financing: about 20 million € for projects, half of which is financed by the government and the other half by private parties;
- turnover: about 4 million dollars annually and a programme duration of 5 years.

A market study has shown that in situ bioremediation may be an important *part* of the solution in 70% of the cases of soil remediation. In 15% of the cases, in situ bioremediation offers the *total* solution. This implies that combinations of techniques are usually required. The in situ technology mainly focuses on mobile contaminants.

Finally, new techniques for biological remediation of contaminated dredging sludge have also been developed within the NOBIS framework.

NOBIS is expected to supply the technical and scientific products that facilitate a problem solving method to tackle soil contamination. The products have to meet the knowledge requirements of the new government policy, as well as help get around the obstructions all other parties involved are confronted with in practical situations. Concentrations of contaminants are no longer the central issue, but rather the *actual* risks of the contaminants in *location-specific* circumstances.

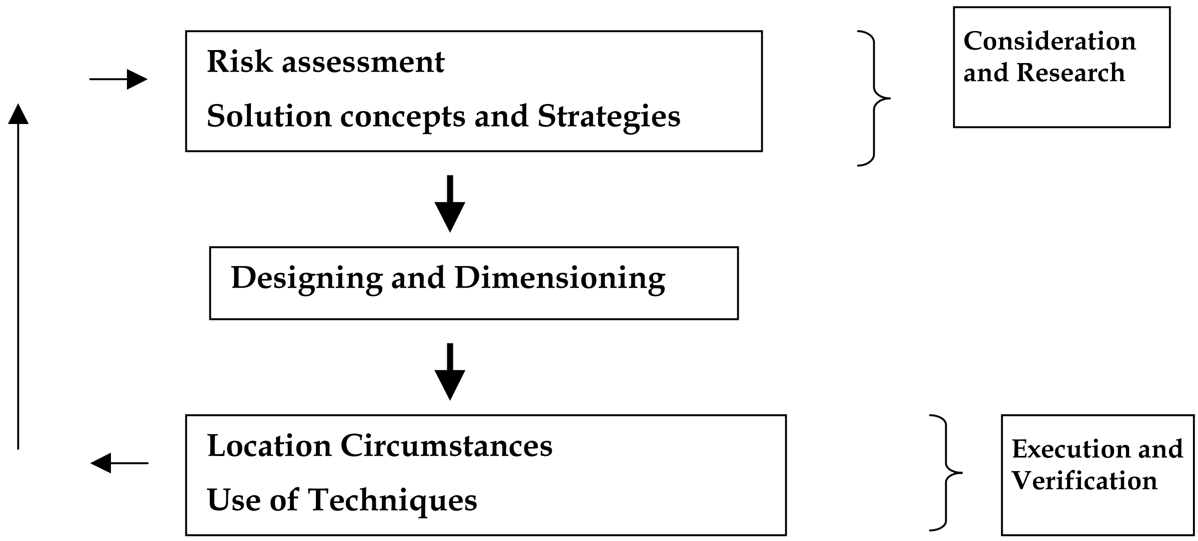

Figure 1: The soil remediation cycle. The basis for soil remediation is the reduction of risks. This is what the results of the efforts are tested against.

The developments in the field of technology will be discussed briefly on the basis of the cycle shown in figure 1. According to this schematic representation, basically any case of soil contamination can be tackled step by step. This cycle was not a basic principle for the research programme, but it has been derived from the methods used in the various projects. This paper will focus on the first three items mentioned in figure 1.

Risk assessment.

The actual risk assessment as well as the establishment of priorities regarding the remediation are and will remain policy matters. However, the existing frameworks for weighing the pros and cons had little support from the soil remediation market. There appeared to be a need for *new* weighing methods based on technological principles that: A) expressed the balance between the risk reduction, the environmental merit and the costs of the remediation alternatives [1] and B) included a strategy for handling potential risks [2].

Moreover, (C) soil remediation often leads to lengthy groundwater purification projects that hardly ever achieve the intended remediation objectives. For these so-called stagnating groundwater purification projects, a method of weighing has been developed that allows for an interim assessment of whether continuation is still worthwhile [3].

So, the contamination of the soil is no longer assessed solely on the basis of concentrations. Risks have been linked to the intended use of the soil. This has created more room for new concepts and strategies and allows time and space to be more efficiently used.

Concepts and strategies.

New concepts and strategies for remediation integrate planning development, water systems and intended function. The development of a new concept only results from good communication between all parties involved. Examples of such concepts are:

The remediation of dredging sludge in combination with the cultivation of willows as biomass. The advantages of this concept are shared use of the land, significant reduction of the costs of dredging sludge remediation, proceeds in the form of biomass [4]. At a test farm in the north of the Netherlands this concept is being put into practice. It involves PAH contaminated dredging sludge. The sludge is spread among the willow fields. Critical factors are the possible spread of the contaminants to ground and surface water and eco-toxicological risks. So far, the monitoring data assembled over a period of about one and a half years show no signs of any spread. Bioassays with earthworms show no negative consequences for the worm population. Current plans are to apply the concept at a regional scale.

Application of natural degradation as a remediation alternative for (former) textile cleaning company sites. The remediation of the contamination of the soil at textile cleaning companies stagnated because of the high costs of the traditional remediation alternatives. Many of these companies are situated in inner city areas. Moreover, they are frequently small family businesses. Obviously, the financial resources of these companies are insufficient to cover the costs of soil remediation. Therefore, a simple and fast strategy has been developed to assess natural degradation as a remediation alternative. This has created new possibilities for the realisation of an approach geared to a specific branch [5].

As a final example, the management of former dumpsites can be mentioned. In the Netherlands are about 3000 closed dumpsites. New monitoring methods using sensor technology for the analysis of macro parameters and contaminants coupled with telemetric data transmission offer possibilities for a substantial reduction of the costs [6].

Other concepts involve the remediation of former gas works sites in combination with urban development [7].

The development of natural areas in the countryside at and around former dump sites in combination with the processing of dredging sludge from the same area [8].

Incorporation of closed oil extraction in the countryside in combination with less intensive land farming [9].

The weighing of remediation alternatives.

A decision support system has been developed for weighing the various remediation alternatives. This system enables objective mutual comparison and optimisation of the alternatives. These are assessed with regard to their contribution to Risk reduction, Environmental merit and Costs [1]. The costs and benefits for the environment are weighed, as well. For mobile contaminants a system has been developed, that determines the cost effectiveness of a measure [10]. Apart from the primary risk assessment, the following points are involved when choosing a remediation alternative:

1. *Take the time.* Natural processes in the soil are slow. This implies that the time factor is of vital importance for biological remediation options. Therefore, it is important to take the time in order to be able to use the advantages of in situ degradation. Taking the time means attacking a contaminated situation at an early stage, so that, when another application for the soil arises some years later, the location is suitable for that new purpose. Taking the time also implies that the in situ degradation process is in progress while the (new) company activities continue as usual.
2. *Use the 'self cleaning capacity' of the soil.* All sorts of biological degradation processes take place in the soil. Generally, it is worthwhile to investigate whether the natural degradation process *as such* will be sufficient to obtain an acceptable risk reduction over time [11]. A number of factors play a role in this assessment, including the natural 'rate of disappearance' of the contaminants, the geochemical characterisation in relation to the degradation products, the capacity (potential) of the soil to remove a certain quantity of contaminants over a period of time, the 'global' modelling of the geohydrology, the compound behaviour to obtain an overall impression of the location and to determine the dominant processes [11].
3. *Stimulate natural processes.* A high return on investments can be obtained by stimulating the biological degradation processes that are already present. Limited injection of nutrients, oxygen, other electron acceptors or donors and a subtle control of the groundwater flow may be sufficient to stimulate the degradation processes to such an extent that the requirements for acceptable risk reduction will be met. This less intensive remediation can sometimes be combined with control measures that have already been taken or will be taken anyway. As mentioned before, the time factor is very important in this approach. The term within which the risk reduction will have to be realised will usually have to be weighed against the technological interventions.
4. *Intensive in situ remediation if necessary.* Despite all efforts, the previously described line of thought may lead to the conclusion that the stimulation of natural degradation will not sufficiently reduce the observed risks. In that case, a more intensive approach is required [12].

Apart from the previously mentioned REC method [1], the application of a method to quantify the financial risks of a remediation alternative is also being worked on.

[13]. Insurance companies are expected to play an increasingly important role in this matter, as well [14].

Research and characterisation.

Remediation alternatives on the basis of natural processes require new methods and techniques for research and characterisation of the soil matrix. The concentrations of contaminants are not the central issue here, but rather the biological and chemical processes that are responsible for the degradation of contaminants. The risk reduction that has to be achieved in relation to the desired development of the location (concept) determines what remediation alternatives are possible. Thus the research and the characterisation are at the service of the intended solution. This is in contrast to the past, when soil research was organised around defining the problem. NOBIS has generated a wide range of new and / or improved research methods. Strategically these methods all aim at efficiently mapping the processes in the soil. For VOCl-compounds, this mainly involves concentration contour analysis of degradation products in relation to the geochemistry supported by geohydrological modelling. In addition to the previously mentioned approach in the textile-cleaning branch, this method was developed and tested at various locations [15, 16, 17]. Measuring hydrogen as the ultimate electron donor plays a central role here. [18]. Based on this research approach, various pilot tests have been started which will lead to a full-scale application [15, 16]. For volatile aromatics (BTEX), a similar approach has been realised. However, it has to be noted that the intrinsic degradation of benzene is a significant bottleneck in the field characterisation [19]. This has still not been well demonstrated, although the degradation of benzene under denitrifying circumstances has been proven in the laboratory [20]

A major aspect of the research into biodegradation of mineral oil is a new method to characterise mineral oil. This involves the development of a methodology to distinguish in advance what part of the oil can be removed by biodegradation, stripping or flushing [21]. This method also fits in well with the risk assessment of mineral oil. On the basis of this method of analysis, it is also possible to state in advance what residual concentrations are feasible. Another important development is the direct link between analysis data and soil structure in the design and dimensioning of air sparging systems [22].

Pilot tests may often play an important role in establishing the feasibility of remediation projects [23, 24].

Location, circumstances, implementation and monitoring.

In the implementation of a technique, measuring and monitoring is of crucial importance. The design has to be flexible to such an extent that improvement on the basis of monitoring data is allowed for. Monitoring on the basis of gauging observations is generally not very reliable. The use of sensor-technology simplifies the monitoring, leads to more reliable results and is cost-effective. Sensors for the measurement of the pH, temperature, EC and oxygen values have been developed. Sensors for the measurement of BTEX and VOCl are still being developed. The first BTEX prototypes will enter the testingphase in the spring of 1999. All sensors can be assembled in to one instrument suitable fore monitoring in one-inch gauges [25].

2.3.3 Retrospective

Based on 3.5 years of NOBIS, the following conclusion can be drawn:

A programme in which research is executed on the basis of bottlenecks experienced in practice and in which all other parties involved collaborate on a solution, offers excellent opportunities to efficiently and effectively develop methods and techniques for soil remediation.

The NOBIS approach will be continued by a new foundation: soil knowledge development and transfer (SKB). This programme started in January 1999 and has an intended duration of 10 years. The programme has been budgeted at € 7,5 million a year.

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2.4 The United Kingdom – exSite and CLAIRE

2.4.1 exSite

exSite has been established to fund the field scale demonstration of sustainable solutions to bring Brownfield sites back into use. It operates as an applied research organisation and includes within its membership Lattice Property, Shell, VHE, Corus, the Welsh Development Agency, Parkman Environment, Shanks Waste Solutions, the Environment Agency, DETR, UKAEA and TRL. These organisations are interested in the recovery and reuse of brownfield land. The reuse of such land is also a major priority area for the UK and other European governments.

exSite has been formed to support and fund projects that promote the sustainable reclamation of redundant land assets. To tackle the recovery of sites either for which there is no commercial end-use or which have been contaminated or impaired by industrial activity, ***exSite*** focuses its activities on three primary aims:

- restoration of brownfield sites through minimisation of reliance on landfill disposal.
- rehabilitation of such sites via reduction, re-use or recovery of redundant waste materials; and
- Undertaking cross sector work e.g. market characterisations, strategic planning, economics and risk management.

In meeting these aims ***exSite*** concentrates on technologies and approaches, which:

- enable the beneficial recycling of recovered materials;
- enable the productive re-use of land as part of the brownfield development process; and
- minimise reliance on landfill.

exSite provides opportunities for demonstrating innovative Brownfield site regeneration approaches, processes and technologies. Such alternatives will be focused on the promotion of any or all of the following objectives:

- Reducing landfill disposal volumes.
- Reducing natural aggregate consumption.
- Increasing the sustainable reclamation of land.
- exSite helps successful proposers to demonstrate innovation by offering:

- Sites.
- Financial assistance.
- Partners with expertise, plant and labour resources to carry out site activities.
- exSite exists to bridge the confidence gap that is evident between research innovation and commercial site practices. Examples of successful project outputs are:
- Full - scale utilisation of innovation in the commercial market.
- Small project results that inspire large and compliant exemplar project proposals.
- Creation of strategies and management approaches for generic adoption.

exSite is focused on innovation in Brownfield Regeneration. This requires a multi-disciplinary and multi-sectoral approach, particularly for large projects. This provides an opportunity for organisations with diverse interests to collaborate to create holistic projects.

exSite projects include:

- Scoping Study for the reuse of marginal land
- Characterisation of bulk materials
- Jetpump soil washing
- The Road to Recovery.
- Markham Willows.
- MARS **-** Manufactured Aggregates for Reclamation Sites.

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2.4.2 CLAIRE (Contaminated Land: Applications In Real Environments)

CLAIRE was established as a public/private partnership in March 1999, to facilitate the field demonstration of remediation research and technology, including innovative methods for site characterisation and monitoring, on contaminated sites throughout the UK. The results of project demonstrations are published as research or project demonstration reports and disseminated throughout the contaminated land community.

CLAIRE is an incorporated company, limited by guarantee, and is a registered charity and an environmental body. Public/private organisations provide the legal guarantee for CLAIRE and along with others have provided funding to cover overhead costs. Whilst CLAIRE was not set up with project funding, CLAIRE has attracted some project funding and additional funding sources are continually being sought.

CLAIRE's six operational objectives are to:

- establish a network of characterised, contaminated sites throughout the UK
- demonstrate the application of remediation technologies which may offer improved site investigation, monitoring or remediation solutions
- develop a strategy for remediation technology research in the UK
- disseminate information related to research and technology demonstrations on contaminated land
- prepare and provide educational materials related to contaminated land for school children and the general public
- procure funding to support CLAIRE's activities

CLAIRE Sites

The CLAIRE network of sites are representative of industrially contaminated land in the UK. The majority of contaminated sites and contaminants can be found within coalfields, manufactured gas plants, railway lands, petrochemical facilities and solvent contamination sites, although other types of sites containing other contaminants such as pesticides and explosives are considered.

Ideally, sites have been characterised to the degree that the general nature and extent of contamination is known. CLAIRE meets with the site owner, obtains information about the site and incorporates that information into a site database. A contract is signed between CLAIRE and the site owner, and an appropriate project is then matched to the site.

CLAIRE Projects

Applications for projects are submitted to CLAIRE and reviewed by the CLAIRE Technology and Research Group (TRG) which approves projects for ratification by the CLAIRE Board. Once a project is approved, the project operator is required to enter into a contract with CLAIRE. Projects are of two types: Technology Demonstrations (TDP) and Research Projects (RP). As of May, 2001, CLAIRE has ratified 4 technology demonstration projects and 5 research projects. A summary of projects is provided below in Table 3. A further 4 projects are before the TRG for review and a further 2 projects are before the Board for ratification. CLAIRE approved 1 project in 1999, 5 projects in 2000 and it is expected that at least 10 new projects will be approved in each of 2001 and 2002.

CLAIRE is involved with two major demonstration programmes in the UK. The first is Avenue Coking Works, which is a former coke works located in the East Midlands, south of Sheffield. The site has been decommissioned and contains predominantly polynuclear aromatic hydrocarbons (PAHs), volatile organic compounds(VOCs), coal tars and heavy metals. Six different types of technologies will be demonstrated at both laboratory and field scale, including: solid phase bioremediation, slurry phase bioremediation, soil washing, solidification / stabilisation, low temperature thermal, and incineration. Technology demonstrations are expected to get underway by summer 20001. The second programme is SIREN, which is utilising a well characterised operating petrochemical site to carry out research into monitored natural attenuation.

Table 3: CLAIRE Projects

Project	**Description**
TDP 1	Low Temperature Thermal Desorption
TDP 2	Soil Washing
TDP 3	Permeable reactive barrier (prb) project to remediate groundwater contamination
TDP 4	Fieldscale demonstration of Bioslurry reactor technology
RP 1	Predicting Spatial Uncertainty in Pollutant Movement from Contaminated Land
RP 2	Hydro-biological controls on transport and remediation of organic pollutants for contaminated land
RP 3	Processes controlling the natural attenuation of fuel hydrocarbons and MTBE in Chalk
RP 4	Optimised contaminated land investigation using uncertainty as fitness for purpose criterion
RP 5	Stabilisation of metal contaminants using phosphate derived from bonemeal.

Project reports are being prepared for TDP1, TDP2 and TDP3 and the first report is expected to be published in June / July 2001.

Research Strategy

CLAIRE has developed a research strategy for remediation research. The document is circulated to research funding organisations throughout the UK and is updated on an annual basis. The document is posted on the CLAIRE Web site.

Dissemination of Information

CLAIRE disseminates information through two main vehicles: the CLAIRE Web site at www.claire.co.uk and a quarterly newsletter *CLAIRE view*. The Web site contains information on CLAIRE activities; project updates, and contains links to other organisations with an interest in contaminated land. The Web site is updated regularly.

CLAIRE view is circulated to more than 3700 contacts. It provides information on CLAIRE activities, and contains articles on a broad range of issues related to contaminated land. In addition there are regular reports on various sectors involved in contaminated land both within the UK and internationally.

CLAIRE is in the process of producing its first technology demonstration and research reports, which provide details on CLAIRE projects. The first reports are expected out in April/May 2001 and will be available for a nominal fee. Summary factsheets of each project will be prepared and posted on the CLAIRE Web site and posted with the newsletter. In the future, CLAIRE will present the results of its demonstration projects in workshops and seminars.

Education

In areas where demonstration projects are being carried out, CLAIRE will develop poster board presentations for display in local public areas, and where possible, will arrange to make demonstration sites available for public visits.

Funding

CLAIRE will continue to search for new sources of funding to support its overheads and projects.

2.5 Denmark – Programme for Development of Technology, Soil and Groundwater Contamination

In 1996 a special programme for development of technologies for cleanup and remediation of soil and ground water contamination was established. The annual budget for the programme amounts to DKK 15 million.

Pursuant to the Act on Soil Contamination a Contaminated Sites Council has been set up for the purpose of advising the Minister on general matters in relation to soil contamination including technology development. The appropriation is administered by the DEPA (Danish EPA), which presents proposals for principles and programme areas to the Contaminated Soils Council.

The objective of the appropriation is to gather experience in soil contamination, develop tests for new technologies, develop and test methodologies, amongst others those aimed at setting criteria, risk analyses and employment analyses, as well as documenting, assessing, and comparing the effectiveness, cost, and environmental effects of remediation techniques. Furthermore, the appropriation may be applied to co-financing expenditure on development and testing aspects of remediation projects, which county councils prepare, and finance, provided they include a development aspect.

The ‘Program for Development of Technology (TUP), Soil and Ground-Water Contamination, December 1996 describes the contaminant areas, which the Programme for Development of Technology should aim at over the next 2-5 years.

The areas for efforts are as follows:

1. Soil and / or ground water contaminated with chlorinated solvents.
2. Soil contaminated with heavy metals.
3. Soil and ground water contaminated with oil / petrol
4. Soil contaminated with tar / PAH
5. Composite contamination
6. Landfills and leakage of landfill gas

The technology programme has primarily focused on remedial technologies for chlorinated solvents and oil and petrol contaminations. The projects have resulted in a number of new technologies for chlorinated solvents, among others thermally-assisted remediation and reactive walls. In addition the programme has lead to a cheap method for treatment of chromium(VI) contaminated groundwater.

Within the next year a more specified assessment of the methods air sparging, modified stripping, detoxification and fracturation will be published.

A number of phytoremediation projects have been initiated. So far, it has not been possible to clean inorganic composite contamination with plants. A number of phytoremediation projects with the objective of cleaning oil and PAH contamination has been established. The result of these projects will be available within 3 to 4 years.

The programme has given a useful overview of remedial technologies for MTBE and heavy metals. Specific methods like vacuum ventilation, thermally assisted remediation and natural degradation has been assessed and described in detail.

2.6 Sweden - COLDREM

The national research program COLDREM – Soil Remediation in a Cold Climate – is a Swedish effort to find solutions to soil remediation problems in a cold climate. Research groups from several universities cooperate in this endeavor. The Foundation for Strategic Environmental Research (MISTRA) funds the program.

COLDREM has developed for some years and has gathered a lot of knowledge on PAH as well as mercury and dioxin-contaminated soils, and the problems relating to the remediation of such soils. The broad interest and large number of participants at the COLDREM symposium in Göteborg in August 2000 confirms that the programme now constitutes an important and accepted qualified forum for society and industry.

As expected, COLDREM has achieved most success in the development of analytical tools. Much work remains, however, to adapt these to real life remediation processes. A number of remediation methods are at development stage, where it becomes important to start investigating the effects on a pilot scale. Contacts with stakeholders have intensified in order to find suitable ways of carrying out tests in realistic conditions. Pilot plant studies at Husarviken have, so far, been focused on site geohydrology.

This year has seen the appointment of a technology co-ordinator, and a model for evaluation of the various methods is now being discussed within the programme. The model will take into account possible remediation results, costs, and time for remediation, and will be used both in the initial studies and in subsequent evaluations. COLDREM has also during 2000 focused on clarifying goals and results for the various projects within the programme.

COLDREM's web site – www.umu.se/coldrem - has information in both Swedish and English.

ANNEX 2

State-of-the-Art in the European Countries
(as of 2001)

Content

BELGIUM/FLANDERS

Ex situ remediation

Table 4. Companies with permanent discharge permit for treating contaminated soil and sediments in Belgium/Flandern.

Company	Treatment address	Treatment technology	Capacity
Bioterra NV	Nijverheidslaan 1527 3660 Opglabbeek	biological fysico-chemical	40.000 tonne/yr 20.000 tonne/yr
Bosatec NV	Koolmijnlaan 201 3582 Beringen	biological	20.000 tonne/yr
Bremcon NV	Kruibeeksesteenweg 154 2070 Zwijndrecht (Burcht)	biological fysico-chemical	17.500 tonne/yr 17.500 tonne/yr
De Paepe NV	Haven 4410 J. Kennedylaan 52 9042 Gent	biological fysico-chemical	60.000 tonne/yr 100.000 tonne/yr
Ecotechniek Soil Remediation NV	Westvaartdijk 83 1850 Grimbergen	biological fysico-chemical	75.000 tonne/yr 80.000 tonne/yr
Envisan NV	Scheepszatestraat 3 9000 Gent	biological fysico-chemical	40.000 tonne/yr 30.000 tonne/yr
GRC Kallo NV	Haven 1562 St-Jansweg 10 9130 Kallo	biological fysico-chemical	100.000 tonne/yr 120.000 tonne/yr

Costs/tonne

- Biological : 20 ECU - 40 ECU/tonne
- Physic-Chemical : 30 - 50 ECU/tonne

Type of contaminants treated

- Hydrocarbons
- Heavy metals
- PAH's
- Cyanides
- Chlorinated hydrocarbons

Table 5: Technologies used to remediate excavated soil on site, and treatment efficiency

Technology	No of sites treated	Costs	Type of contaminants treated	Treatment efficiency
Biological	10 sites	Low	Hydrocarbons	High efface.
Thermal	3 sites	50-60 ECU / tonne	Hydrocarbons	Not yet started

Choice of technology is directed by the BATNEEC-principle. The policy allows for all technologies.

In situ remediation

Table 6: In *situ technologies in use or implemented in Belgium/Flanders*

Technology	No of sites treated	Costs low-high	Types of contaminant treated	Experience
Air Sparging	± 15 sites	Moderate	Hydrocarbons	GW-table / soil
SVE	± 50 sites	Moderate	Hydrocarbons	GW-table / soil
Bioventing	± 15 sites	Moderate	Hydrocarbons	GW-table / soil

Innovative technology

Pilot scale projects:

- Pilot scale experiments for soft remediation techniques for heavy metal polluted soils:
  50% funding by EFRO, 50% by the OVAM. Three techniques were tested in pilot scale: immobilisation, phyto-extraction and bio-extraction.
- Life project 'On site remediation of a MPG site' (Lier, Belgium) Following technologies were demonstrated: Clean Soil Process, extraction followed by biodegradation, biodegradation by landfarming after inoculation with specific micro-organisms.
- To be started in 2000: '*In situ* remediation of Hg polluted soils

DENMARK

Ex situ remediation

Table 7: Summary of companies having a "permanent discharge permit

Company/ localisation or similar info	Treatment technology	Capacity (tonne/year)	Price (tonne- 1999) low-high	Type of contaminants treated
Bioteknisk Jordrens	Composting, Electro	200,000	200 DKr and more	Oil / petrol
Hovedstadens Jordrens	Composting	40-60,000	App. 250 DKr	Oil
Dansk Jordrens	Composting, thermal	175,000 (total)	From 170 DKr Up to 845 DKr	Oil
KK Miljøteknik	Composting, Soilwash Thermal	75,000 10-15 / hour	200-250 DKr 700-1,000 DKr	Oil Coal tar Coal tar
Soil recovery	Thermal	1-2.5 / hour 10,000 / year	1,650 DKr	Coal tar
Marius Pedersen	Composting	60,000	From 200 DKr	Oil
Various Powerstations	Combustion			Oil

In situ remediation

Denmark has no policy on what type of technology should be preferred. Tax is laid on landfilling in order to limit the amount of soil deposited in landfills. But there is not a proper policy e.g. recommending that soil should be cleaned instead of landfilled. A statutory order on reuse of soil will be issued in the near future. The statutory order will include limit values for what soil can be reused for based on the contamination content.

Various in situ treatment technologies have been applied on a commercial scale in DK. The funding for their clean-up are either the counties, private enterprises or a special fund for clean up of contaminations from far gasoline stations.

The technologies applied in full scale include (either finished or on-going), some of them are demonstration projects, such as:

- Bioventing, (10-15 sites) most gasoline compounds (BTEX), petroleum compounds.
- SVE (25-30 sites), BTEX and chlorinated aliphatics (TCE, PCE, TCA etc.)
- Air sparging (5-10 sites) BTEX, chlorinated aliphatics
- Permeable Reactive walls (4 sites) chlorinated aliphatics, chromium
- Biostimulation (5-10 sites) BTEX, petroleum

- Soil flushing (2 sites) BTEX
- Chemical oxidations (5 sites) BTEX
- Phytoremediation (4 sites) heavy metals, PAH's
- Steam stripping (5 sites) TCE, BTEX

Monitoring remediation performance

Denmark has no special requirements for monitoring the performance or the quality of treated soil. For biologically treated soil, there exist a set of accept criteria for when soil can be used without restrictions :

- Petrol: 25mg/kg (total hydrocarbon), 0.5mg/kg BTEX, 1.5mg/kg PAH (5 specified components)
- Gas oil: 50mg/kg (total hydrocarbon), 0.5mg/kg BTEX, 1.5mg/kg PAH (5 specified components)

There will in the near future be published corresponding requirements for other types of contaminants.

FRANCE

Background

The French policy on treatment and rehabilitation of polluted sites has been presented in the CARACAS publication Risk Assessment for Contaminated Sites in Europe (vol. 2). This policy can be summarised in three steps: inventory; prevention; treatment.

A combination of methodologies has been developed in France last years to apply this policy, and especially for investigations and risk assessment (simplified and detailed). For unacceptable risk, remedial objectives depend on the land use allocated to the site and its surrounding. These objectives are determined on a case-by-case basis using a site-specific risk assessment approach.

The French Ministry of Environment published in 1996 the last register of contaminated sites, which need a remediation action in France, which is available on: http://www.environnement.gouv.fr/basol/. This register is completed by statistical information about treatment technologies applied in these sites. Due to the number of concerned sites and due to emergent technologies, it can be considered that these data are probably quite different today. It can be noticed that in some cases, a combination of several treatments has been used.

Treatment	% Of site concerned
Landfill	44
Biological treatment	29
Soil washing	10
Thermal treatment	29
Confinement	60
Ventilation	17
Natural degradation	15
Stabilisation	12
Other	33

In parallel with this register, an inventory is in progress on the whole territory based on historical research of former industrial sites. This second approach allows identifying potentially contaminated sites and to collect the minimum information on the location, nature and extend of activities and the environmental context. A national database, BASIAS (Base des Anciens Sites Industriels et Activités de Service) has been developed:

- to provide an archive for data gathered during inventory compilation,
- to use these data in a geographical information system and inform all partners of the results,
- to be sure that everyone concerned is informed of previous use of a site, especially when a change of use is decided.

This database is available on: http://basias.brgm.fr:

Concerning existing active industrial sites, a ministerial directive, dated 3 April 1996, describes categories of priority sites based on polluting activities such as chemical and petroleum industry, metallic industry, petroleum storage, wood, tannery and textile industry, ceramic and crystal industry, and installations bound to industrial special waste (recycling, valorisation and elimination). Preliminary investigations and simplified risk assessment are carried out for these sites.

Companies and technologies

Identification of companies from each European country is quite difficult because most of them belong to international groups, with national contact in many countries. Moreover, several collaborations have been established between companies in Europe and even in North America to improve and to widen competence field. Another kind of difficulties concerns companies from the same group. Indeed, the same equipment can be presented several times, by each company. In this case, only the owner of the process is presented. Moreover, mobile plant can naturally be displaced from site to site. For instance, a French orphan site is currently treated by a Belgium company with a treatment unit of soil washing from the Netherlands and supervised by a French consultant. Then, to propose a rational description of French technologies in matter of soil treatment, only companies with own permanent equipment and a real experience in the considered technology are presented in this paper. About 20 companies can be inventoried in France on these criteria. However, most of them are specialised in some specific techniques. Then, the list of techniques presented in the following table is not exhaustive and only the more current techniques for each company are presented. Many information presented in the following table come from CD ROM ASTRES proposed by the CNRSSP (Centre National de Recherche sur les sites et sols pollués) in collaboration with the Pôle de Competence sur les sites et sols pollués from the Nord – Pas de Calais.

Table 8: Registered French Companies for treating contaminated soils

Company	Treatment technology	Comments from the company (usual pollutants, experiences…)
AMDE	Biodegradation in situ Biopile Composting Venting, sparging Vacuum extraction Pomp and treat Confinement	
APINOR	Landfarming, biopile Stripping Confinement	
APROCHIM	Soil washing	PCB: 15 000tonne/an (soil) and 2 000t/an (oil)
APSR	Biodegradation in situ	Micro-organisms selection
ATE	 Biodegradation Biopile Phytoremediation Reactive barriers Electro-oxidation In situ soil washing Pomp and treat venting, sparging, stripping dual phase extraction vacuum extraction	(Priority for in situ technologies) Fungus; aeration/non aeration HC Organic + metallic compounds CC, nitrate; in progress (collaboration with Soletanche Bachy) Organic compounds difficult to treat Surfactants
ATI	 Biodegradation in situ Venting, stripping, sparging Soil washing in situ Pomp and treat	(Specialised in organic compounds) can be associated with other techniques HC HC HC
BIOGENIE EUROPE SARL	Biopile Bioreactor Pomp and treat Flotation Sparging, venting	HC, HC, PAH (in specialised centre) Pilot scale for soil polluted by mercury
BREZILLON	Thermal desorption	Mobil treatment unit

Table 8: Registered French Companies for treating contaminated soils (continued)

Company	Treatment technology	Comments from the company (usual pollutants, experiences…)
CECA S.A.	Biodegradation in situ Composting Bioreactor Venting, stripping Stabilisation Confinement Soil washing Pump and treat	Main experience in biological treatment Concrete and lime Encapsulation process Experience in Australia Recovery of oil by oilphilic system
COLAS ENVIRONNEMENT ET RECYCLAGE	Thermal desorption Confinement	Mobile treatment unit (12 – 35 tonne/h) COLETANCHE (membrane)
D2E	Pomp and treat Vacuum extraction Stripping Thermal desorption	
ENVIRO SERVICES France	Venting, sparging, stripping Vacuum extraction Pump and treat Incineration Confinement	 PH
GEOCLEAN	Biodegradation in situ, Bioreactor, Landfarming, Composting, Solvent extraction, Vacuum extraction, Venting, sparging, stripping, Pump and treat Dual phase extraction	Name of the patent: BIOVAC Solvis: (6 – 15 tonne/h)
GESTER	Biodegradation in situ Landfarming, biopile Venting Soil washing Vacuum extraction Pomp and treat Confinement	

Table 8: Registered French Companies for treating contaminated soils (continued)

Company	Treatment technology	Comments from the company (usual pollutants, experiences…)
GROUPE SECHE Réalisation	Biopile	
GRS VALTECH	Biodegradation in situ Bioreactor Landfarming Composting Vacuum extraction Venting Stripping Pomp and treat Dual phase extraction In-situ soil washing Photo oxidation H2O2/UV Thermal desorption Confinement Stabilisation/solidification	PH Used with stripping, activated carbon PH, PCB PH PH Used with air vacuum extraction PH, HC, PH Solvent, used with stripping to treat water Can be used with hot water, HC Cyanide, metallic ions (Ag, Cr) Mobil treatment unit Sludge polluted by PH and confinement
ICF	Biodegradation in situ Biopile Venting, stripping, sparging Soil washing in situ Pomp and treat Thermal desorption Confinement	 PAH, CC HC Mobile treatment unit (10 t/h)
INTERA/ DE&S	Pomp and treat Confinement Venting, sparging Soil washing Soil washing in situ	
MEURTHE ET MOSELLE SERVICE BIOCENTRE	Biopile Stabilisation	
POLLUTION SERVICE	Biodegradation in situ Pomp and treat Stripping, sparging Biopile Bioreactor, Venting, sparging, stripping Vacuum extraction	Diesel oil

Table 8: Registered French Companies for treating contaminated soils (continued)

Company	Treatment technology	Comments from the company (usual pollutants, experiences…)
SERPOL	Biopile	HC
	Venting, stripping	HC, solvents
	Stabilisation	
	Soil washing	PAH
	Thermal desorption	MOBITHERM (mobile unit)
	Pomp and treat	
	Vacuum extraction	
	Confinement	
	Stabilisation	Patent: Fixpol
SOLETANCHE BACHY	Pomp and treat	
	Confinement	Patent: GEOLOCK, PANELJET
	Reactive barriers	Patent: Ecosol
	Stabilisation / solidification	Patent: COLMIX

PH: Petroleum hydrocarbons; HC: Halogen compounds; CC: chlorinated compounds

Ex situ versus in situ remediation

There is no statistic on the volumes of soil being treated in France, but the market can be evaluated around 100 millions of Euro (including studies and investigations) (UPDS). For most of contaminated soil, several techniques can be used for remediation. Because there is no national procedure to support choosing, planing and / or designing remedial approaches for polluted sites in France, some guides have been proposed latterly. For instance, the French company ATE has published a guide to identify available techniques, according to the contamination (pollutants and soil properties) and even according to activity at the origin of the pollution. Many techniques are also described in this guide. Other preoccupations are taken into account in this guide such as economic and time aspects in order to help the decision-maker.

The ADEME, which is in charge of management of orphan sites, has worked about the utilisation of a method based on multi-criteria analysis. Indeed, it is necessary to take into account all concerns to select the more adapted technique. Criteria used for it are presented below:

- Technique (feasibility and reliability),
- Economy (cost of implement, cost of maintenance, possible subsidy and possible compensation),
- Psycho-sociology (visual, sonorous and olfactory discomfort),
- Administrative (administrative difficulties to implement the solution, insurance).

The aim of this methodology is to assist the decision making, but the administrative representatives are finally the main decision-makers for all steps of management of polluted sites. However, the responsible of the pollution (or the ADEME for orphan sites) participate to the decision making in collaboration with consultants and companies of treatment.

Table 9: ex situ technologies

Technology	**Costs (€/tonne-1999) low-high**	**Comments**
Landfarming	8 – 60	
Composting	8 - 60	
Bioreactor		
Biopile	600 – 200	5 specialised centres in France
Solvent extraction	75– 150	1 unit
Soil washing	30 – 90	
Thermal desorption	40– 200	6 treatment units in France
Incineration	300 – 1100	
Landfill	150 – 230	13 sites in France: an authorisation is needed which depend on the kind and the degree of contamination.

Table 10: In situ technologies

Technology	**Costs (€/tonne) low-high**	**Comments**
Biodegradation	15 – 75	
Pump and treat	15 – 75	
Dual phase extraction		
Vacuum extraction	15 – 300	Time: 4 to 8 months
Venting Sparging Stripping	20 – 40	
In situ soil washing	30– 90	
Stabilisation / solidif.	20 – 200	
Confinement	300 – 4500 €/m² 300 – 75€F/m²	For a cover with gas collector With geomembrane

Innovations

During the eighties and in the beginning of the nineties, most of the techniques used were isolation and treatment or disposal in the installations of waste system. It appeared soon that waste treatment plants (incineration) were often technically inappropriate and very expensive and, because of recent regulations, including restrictions of use and technical constraints, landfilling has become more and more difficult and costly. These circumstances create a positive evolution for the use and development of specific soil treatment techniques.

The techniques that have been and are still the most frequently used to clean soils are microbiological degradation. Biodegradation is most of the time carried out on site by the mean of composting or bio-piles. Contaminants degraded are petroleum compounds, light and heavy oils, and even polyaromatic hydrocarbons. Most of companies proposed these techniques in their competence. In term of research, an important target consists in identification and selection of microorganisms to degrade as much as possible recalcitrant compounds like PAH or PCB.

Soil venting, which is also a frequently used technique, addresses volatile hydrocarbons and chlorinated solvents in the unsaturated zone. It is sometimes associated with in situ biodegradation (bio venting). To remediate the saturated levels, (groundwater) venting is combined with air sparging.

More recently, new treatment capabilities have been made available either by specific own development or by technology transfer. Until now in France, in term of treatment unit, the trend has been rather to develop thermal desorption equipment. Then, it can be notice that soil washing technology is not really developed by French companies, excepted in one case (solvent extraction), by opposite with The Netherlands where these techniques are frequently applied due in particular to soil nature and texture.

According to the present situation, it can be estimated that the R&D programs are mainly oriented to develop more economical and efficient equipment and processes to characterise and to treat the pollution. Two possibilities are simultaneously developed:

- Improvement of existing techniques: a typical example is bioremediation with many projects trying to extend its application to recalcitrant pollutants (PAH, PCB, etc.).
- Development of new treatment techniques: reactive walls, supercritical extraction, electromigration. Moreover, due to important gaps, more and more experiments are focused in treatment of metallic compounds like arsenic or lead.

Monitoring treatment performance

There are no special requirements for monitoring performance of a technique and the quality of treated soil. However, the ADEME has published states of the art for each family of soil treatment technique (biological, confinement). Guides about thermal and physicochemical techniques are in progress. In parallel with description of techniques, methodologies to control the efficiency of the treatment are presented. Another guide, published by the BRGM can be used for monitoring quality of water around a landfill or a polluted site. Concretely, requirements are worked out on a case by case basis but can be assisted by these guides.

In term of selection of appropriate technique according to the site, an important research program is in progress currently in France. This 4 - 5 years programme, called " test of polluted soil treatment and technology development", has been initiated last year by the ADEME. This programme aims to propose an inventory of tests for main available technologies in order to choose a technique of treatment according to criteria such as pollution, soil, etc. Eight soil typologies and height techniques have been selected to conduct this study.

<u>Site typologies:</u>

- former gas factories - petroleum storage site
- surface treatment - non ferrous metallurgy
- site concerned by substances used in wood treatment - mining activities
- accidental contamination by PCB - solvent regeneration

<u>Treatment technology:</u>

- Physical separation of pollutants
- Stabilisation
- Chemical extraction - washing by organic solvents
- Pressure extraction – venting
- Washing by use of surfactant
- Phyto-remediation of heavy metal
- Thermal treatment
- Biological treatment (degradation (organic compounds), leaching and immobilisation (heavy metals))

A co-ordinator is in charge to provide the different kinds of polluted soils corresponding to each site typology to the different laboratories implied in this research program. Then, characterisation tests will be conducted and each laboratory will apply their treatment technologies. All protocols and methodologies will be presented in parallel with treatment results. This first phase of the program will be completed by a second phase of validation of results, which will be assured in collaboration with industrials of soil treatment.

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http://basias.brgm.fr:

http://www.environnement.gouv.fr/basol/

FINLAND

To remediate contaminated sites and clean up contaminated soil needs always a permit given by a regional environment centre. In Finland there are 13 such centres. In some urgent cases the permit can also be given by the municipal authorities. The permit defines the remediation method and how to classify contaminated soil. This can be done using for instance guideline values which are unofficial so far.

Ex situ technologies

Soil material which is classified as slightly contaminated can be disposed of in a landfill. This is done case by case. Masses should be utilized if possible in landfill constructions where there is no risk for the environment. There is no tax if the masses can be utilized on landfill.

Soils contaminated by inorganic substances are treated mainly in two ways which are used to an equal degree. Soil can be either physically or hydraulically encapsulated on site or, in most cases, off site on the permitted location. This is the case when there is a big amount of contaminated soil and when the proportion of the covering material is not very high. If the masses to be treated are relatively small or treated masses can be utilized on site or somewhere else, stabilisation or solidification is commonly used technology. Cement, bentonite and bitumen are used as binders. Small amounts of heavily contaminated soils are also burned in high temperatures and after that disposed of in a special landfill.

The technologies which were mentioned above are well known but the quality assurance of the remedial actions must be improved. Also the criteria and places for the utilization of the treated masses should be defined more precisely than up till now.

There is only one full scale soil washing plant in Finland but soil washing is an interesting technology for instance for cleaning up shooting ranges.

Many ex situ technologies to remediate soils contaminated by organic substances are used. The most common method is biological treatment by composting which is mainly used for oil products and chlorophenols. There are numerous and often quite large sawmill and wood impregnation sites which are contaminated with phenols. Composting itself is carried out either on site or off site on specially made composting grounds where there is a possibility to control environmental impacts. If there are VOCs in soil the compost must be covered or made in a container or a hall.

The results of composting have recently been rather good but there are still many compounds, which are difficult or even impossible to treat in composts. Especially wood impregnation product KY 5 which is a mixture of different phenols contained as an impurity also small amounts of dioxines and furans and although phenols can be degradated dioxins remain in soil mass and it makes difficult to utilize treated mass.

Activated carbon is used for adsorbing harmful substances from the groundwater when pump-and -treat is the selected method to remediate contaminated groundwater. Activated carbon is commonly used also for adsorbing substances from pore air in soil venting technologies or when contaminated soil is removed into the hall in order to vent it there. Activated carbon is very efficient and easy to use but the choice of the right type of carbon is important for achieving cost-beneficial results.

Catalytic burners and biofilters are also used to some extent in treating harmful substances of vented pore gases.

There is only one full-scale bioreactor in Finland which is used to degrade chlorophenols in groundwater. The advantage of the reactor is that the degradation happens at normal groundwater temperature, which is 6-8 ^{o}C.

In Finland there is one incineration plant where all kinds of difficult contaminants like dioxins and furans can be treated in high, over 1200 ^{o} C, temperatures. Also thermal stripping is possible in this plant. There are also some other plants, which are using thermal stripping technology.

Table 11: Finnish companies with permitted stationary plants or using proven clean up technology

Company	**Plant/ technology**	**Capacity**	**Contaminants treated**	**Comments**
Ekokem Oy	Thermal treatment, stabil/solid., ventilation techniques	20 tonne/h (700 ^{o}C) 2 tonne/h (1300 ^{o} C)	All kinds of contaminants	Incineration plant for hazardous waste, mobile equipments
Lohja-Rudus	Stabil./ solidification, washing, composting	80 000 tonne/a (plant)	All kinds of contaminants	Stationary plant, mobile equipments
Greensoil Oy	Thermal stripping	30 000 tonne/a	Oil based contaminants and solvents	Stationary plant
Lemminkäinen	Stabilization (bitumen)	"sufficient"	All kinds of contaminants	Mobile
Nordic Envicon Oy	Ventilation techniques, biodegradation, "pump and treat"		Organic substances	Mobile units
Merinonita Oy	Composting	30 m^3/unit (container)	Oil based contaminants	Movable containers
Doranova Oy	Activated carbon solutions			Mobile units
Nobar Oy	Thermal stripping	40 tonne/h		Mobile plant

In addition there are 54 (1998) permitted locations where it is possible to compost soils contaminated by oil based compounds and case by case also other substances which are verified to be compostable.

There are 5-7 consultant enterprises which offer case by case services to manage contaminated sites combining different technologies.

In situ remediation

Soil ventilation is the most common technology to treat sites in situ when contaminants are deep in soil or otherwise located in difficult places. Venting can be organised in many ways but it is always very important to know the soil characteristics of the particular place. Pore-gases are commonly treated by activated carbon, but catalytic burners and biofilters can also be used.

Bioventing and biostimulation have been used only in some places, which have been contaminated by oil products. Pilot scale trials to stimulate degradation of chlorophenols *in-situ* have also been made with promising results.

Natural attenuation (NA) as a technology or a procedure has not established itself in Finland. Of course in many cases there has been no other alternative than to manage more or less like in the natural attenuation procedure. It means that processes are monitored on the site in order to avoid sudden risks and to decide whether there is still a risk left, or what measures to take if the conditions on the site will change. However there is a need to harmonize practices to make the whole procedure more consistent. Possibilities to monitor natural attenuation are improving because many active *in situ* technologies need also advanced monitoring systems and same methods can be used in connection with NA.

Innovative technology

In situ bioremediation technology is highly interesting. Using different mathematical models efforts are made to find and optimise parameters, which improve remedial processes in particular cases involving different pollutants and soil conditions. Pilot-scale tests have also been made to speed up *in situ* biodegradation of chlorophenols and some solvents like ethenes deep in soil.

Promising results in laboratory scale have also been achieved in no biological degrading of chlorinated dioxins and furans. Pilot test are under consideration.

Good results have been achieved using sea containers as composting units for soils that are contaminated by oil products. The containers are equipped with devices to speed up and monitor the composting process.

The use of ground penetrating radar linked to computer technology has been developed and used on regular basis in characterizing contaminated areas.

Mobile thermal treatment plant using indirect heating is under construction. It will reduce significantly dust emissions and make it easier to handle residues.

Ashes from power plants and sludges from the paper industry are problematic in many ways. Good results have been achieved in using them in making barriers and isolating layers for instance at old landfills and contaminated areas which need to be covered with no permeable layers. Further R&D-activities are going on.

Reactive barriers constitute an interesting technology. Some case studies are going on and it is obvious that in the near future such barriers can also be used in the Finnish conditions.

The use of phytoremediation and electrokinetic solutions could be beneficial in certain cases. Both technologies have been deliberated and even tested to some extent. No breakthrough has occurred until now.

Monitoring remediation performance

In Finland there are no general national specifications concerning the monitoring of remedial performance. However all remedial actions must be permitted and in the permit there are conditions about how to monitor that particular case and how to verify and document the performance. The authorities check the final reports and decide whether to approve the results or require further actions.

To assure high quality in the remediation of contaminated areas, guidebooks have been published or are under preparation. The guides deal with among other things the use of risk assessment, work protection, the use of field monitoring, the performance of barrier structures, quality assurance and the general context of the remediation plan.

In the near future personnel taking environmental samples need a certification. Analyses must be done in a laboratory, which has an approved quality assurance system and uses standardized or otherwise verified analytical methods

GERMANY

General

The enforcement of contaminated site remediation which generally includes the steps (a) registration (b) remedial investigation (c) risk assessment and (d) remediation is with the 16 Federal States (Laender) of Germany. The Federal Soil Protection Act (FSAP), which has been enacted on March 1st, 1999, includes precaution issues as well as remediation of contaminated soils and sites.

The two terms "harmful changes in the soil" and "contaminated sites" in the FSAP cover all burdens of the soil, which cause hazards for human beings and the environment.

Nation-wide are more than 300.000 of suspected contaminated sites registered by the Leander.

According to the definitions of the FSAP remediation are measures

(1) for the removal or reduction of contaminants (decontamination measures)

(2) which prevent or reduce the spreading out of contaminants on a long term basic without removing contaminants (safeguarding measures)

(3) for the removal or reduction of harmful changes of the physical, chemical and biological nature of the soil.

The decision on whether to use prevention or decontamination measures for remediation is a complex procedure determined by a multitude of factors (remedial investigation).

For more information see http:/ www.bmu.de or www.umweltbundesamt.de.

Ex situ technologies

Generally, the technological standard for the treatment of contaminated soil is high. Public funding has contributed significantly to the development of soil treatment technologies. Expenses on R&D spent by the Ministry for Research and Development are estimated to 100 million € within the last 20 years for about 70 projects aiming at the testing of equipment and technologies.

Industry investments in the range of approximately 450 million € have been taken place only for the installation of soil decontamination facilities. Meanwhile, there are more than 100 soil treatment plants in operation providing a total treatment capacity of almost 4 million tons per year.

The technologies available for field application cover a broad range of on- and off-site techniques by means of soil washing, thermal treatment and biological treatment.

As regards soil contaminated with organic and highly volatile inorganic substances there are direct combustion technologies using rotary kilns and fluidised beds available. Furthermore, indirect heating systems using vacuum, steam distillation and steam extraction are best demonstrated and available.

Concerning soil washing technologies for organic and inorganic contaminated soil, the use of the principles flotation, hydro cyclone separation, high pressure washing are best demonstrated and available.

Significant progress has also been achieved in the field of bioremediation.

A Joint Research Group „Processes for the Bioremediation of Soil„ comprises seven joint projects with more than 30 single projects. This interdisciplinary group is working on the development of innovative processes for the bioremediation of contaminated soils. After the laboratory phase, not only their effectiveness is tested under application-oriented conditions, but also their success is monitored by a complex control system that goes far beyond a conventional chemical analysis of pollutants. A comprehensive handbook on the results will be published this year. It is expected that the results of the research project will contribute significantly to the wider application of bioremediation technologies in Germany. According to the results, the treatment of short and long chain mineral hydrocarbons and chlorinated hydrocarbons, lower monocular PAH's, phenols and nitrophenols are regarded as state of the art now. Furthermore, biological treatment of TNT contaminated soil by heap piles and reactor technology, has been demonstrated successfully.

The Federal Environmental Agency has conducted a survey on soil management in Germany arising from contaminated land. 85 soil treatment plants, out of 108 plants written to, took part in the survey; this correspondents to a response rate of approx. 80 %.

During the period covered by the study - 1993 - 1997 - the input quantities (quantities actually treated in the plant) of the plant participating in the study rose from approx. 409.000 tons to more than 1,8 million tons (see table 12).

Table 12: Development of the capacities, treated, cleaned and recycled soil quantities from 1993 to 1997 for the soil treatment units covered by the study.

	1993 (tonne/a)		**1997 (tonne/a)**
Industrial capacity	1,460,800	===>	3,224,700
Soil accepted	539,120	===>	1,843,030
Plant input	408,586	===>	1,791,890
Plant output	341,396	===>	1,574,287
thereof recycled	335,306	===>	1,567,610

Of that, in 1993 approx. 335.000 tonnes was recycled. Thus the recycling rate almost reaches 100% (see Figure 2).

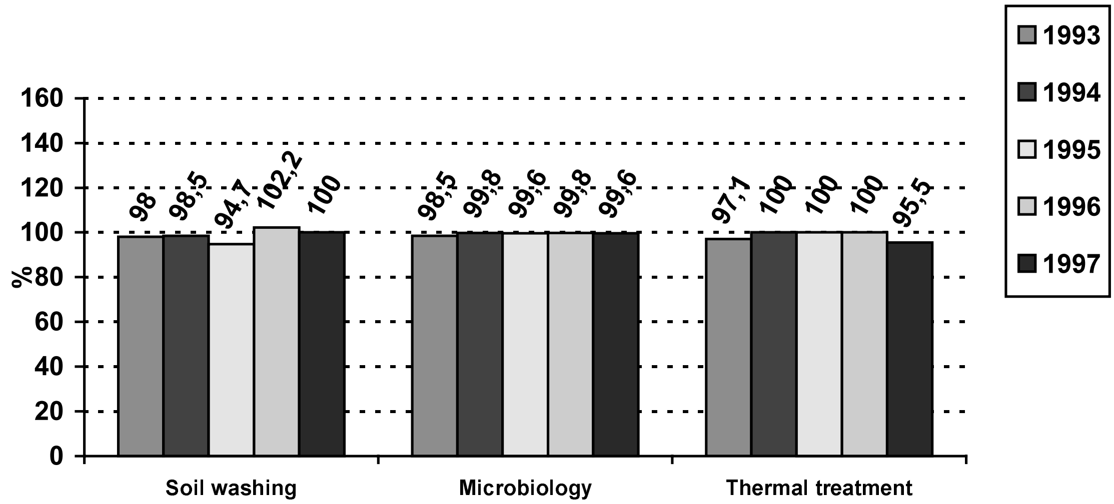

Figure 2: Recycling rate for all soil treatment measures

The most comprehensive overview on remediation technologies is provided by an electronic databank system, which has been developed under the contract of the Federal Environmental Agency from 1996 to March 2000. The databank TERESA 2.1 (GERMAN acronym for *„Register on Contaminated Land Remediation Technologies")* includes detailed information on approx. 110 companies in Germany who are offering services in the field of contaminated land clean up. The technologies offered are described in detail according to their individual performance criteria like substances and subsoil conditions and their effectiveness. Furthermore, references on the application of the technologies from about 680 field applications and 75 substances are made.

The databank can be obtained free of charge at the Federal Environmental Agency. It will be available only in German. However, an English version of the handbook is available. It was designed to enable the use of the databank also by foreigners. It is attached to this document.

In situ remediation

In situ technologies have been tested and applied at more than 100 sites in Germany:

- Pneumatic measures
- Hydraulic measures
- Biological soil treatment
- Elektrokinetic technologies
- Immobilisation

In situ technologies are frequently applied in combination with on or off site soil treatment measures. Most common and state of the art is the injection of specific agents into the soil (NO_3 O_2, H_2O_2) aiming at the initiation respectively maintenance of biological degradation processes.

Due to cost constrains also safeguarding measures like encapsulation, surface sealing or excavating and disposal became more meaningful in the last few years.

It is estimated that about 50% of the remedial action in Germany are done by safeguarding measures.

A specific topic has been the development and adoption of techniques and procedures for contaminated sites in lignite mining areas in the new Federal States. Work on this is almost completed.

It has been focussed on new containment techniques capable of safely isolating deposits of contaminants from chemical plants in this region under extreme conditions. There is, in particular, the need to provide effective sealing systems to a depth of up to 100 metres which are stable for the long term even under acidic groundwater conditions (pH at around 2).

Innovative developments

The high standard of available soil treatment facilities being reached in Germany is particularly due to the funding policy of the Federal Ministry for Education and Research (BMBF) in the past.

This, of course, is also the reason that the focus for future research and development moved to optimisation of available solutions in terms cost-effective technologies and strategies. In this context, bioremediation techniques for soil, groundwater treatment walls including permeable reactive barriers and natural attenuation strategies have to be mentioned.

Another important focus of research and development are in situ technologies aiming at the controlled mobilisation and extraction of substances. Steam injection, in situ washing using tensides, radiofrequency and microwave technologies have been tested so far. Furthermore, alternative capping technologies and in situ immobilisation techniques are subject of examination.

Valuable and significant input regarding such processes is made by the testing facility VEGAS in Stuttgart (see 3.2.2)

In January 1999 the pilot plant SAFIRA has been erected on a site in Bitterfeld for the examination of chemical, physical and biological groundwater in situ treatment technologies. Bitterfeld was the heard of the chemical industry in former East Germany. The aquifer is contaminated with a mixture of pollutants, especially chlorinated hydrocarbons. The operation of the pilot plant is with the Environmental Research Centre Leipzig-Halle in co-operation with the University of Tübingen, Kiel, Dresden and Leipzig and the TNO Institute in the Netherlands. The pilot plant consists of five vertical underground shafts, which are 30m in depth. Each of the shafts is accessible. Altogether, eight different reactors have been installed in the shafts. They are designed for research purposes regarding the destruction of contaminants in the groundwater with different chemical / physical properties, such as:

- A combination of red ox reactors (aerobic reactor with Oxygen releasing compound / ORC, reactor with activated carbon, reactor with metallic iron)
- Micro aerobic reactor and anaerobic reactor for use the anaerobic microbial degradation of pollutant
- Reactor filled with zeolite-supported palladium catalysts,
- Reactor with membrane-supported palladium catalyst
- Plant for ultrasound-based catalytic oxidation

Public funds in the range of 12,5 million € for the construction of the pilot plant and the conduction of the research activities are provided by BMBF. It is expected that the results will improve the database for the design, construction and installation of effective funnel and gate systems for the treatment of contaminated groundwater.

In addition to the Bitterfeld pilot plant a joint research project on the "**Application of Treatment Walls for the Remediation of Contaminated Sites**" has started in June 2000. Research activities will be focussed on 10 selected industrial sites (see Table 13).

Table 13: Overview of joint projects on application of treatment walls for the remediation of contaminated sites.

Sites	Contaminants	Principle	Research Institution
Wiesbaden / Hessen	Arsen	A-Kohle	TU H.-Harburg
Offenbach / Hessen	BTEX, PAK	Fe(0)	HIM ASG Wiesbaden
Bernau / Brandenburg	TCE	Fe(0)	BBG mbH Waldstadt
Dresden / Sachsen	Schwermetalle	A-Kohle	TU Berlin
Denkendorf / Baden-W.berg	CKW	Zeolithe	GeoRisk Stuttgart
Edenkoben / Rheinland-Pfalz	LCKW	Fe(0) und A-Kohle	Rochmes&Pechla GmbH
Braunschweig / Niedersachsen	LCKW	Fe(0)	Stadt Braunschweig
Rheine / NRW	LHKW	Fe(0)	Mull & Partner mbH Rheine
Dassel / Niedersachsen	CKW	A-Kohle und Fe(0)	Teleflex Inc. Dassel

The financial contribution of the BMBF will be in the range of 5 million € They cover a broad range of application purposes and technical principles. The final objective of the joint research project is the elaboration of a handbook on the selection, design, planning and effective use / control of permeable treatment walls to be used by problem owners, consultants and administration.

A further joint research project in the field of **monitored natural attenuation** is in preparation for beginning in September 2000. It will consist of about 50 single projects. The total amount of public funding is estimated to 25 - 30 million € for 5 years.

The focus on the intended research activities regarding natural attenuation will be the following fields:

(1)Lignite- and ore mining, ore smelting and manufacturing

(2)Refineries and tank storage facilities

(3)MTBE

(4)Gas work sites, wood impregnation

(5)Chemical and textile industries, arsenic

(6)Landfills and dump sites

(7)Abandoned armament sites

(8)Military sites

(9)Agricultural sites

(10)Sediments

The main objectives of this joint project are:

(1)Identification of frame conditions for environmental and economic useful natural self-cleaning processes (Note: Within the scope of the project the term "natural Attenuation" is considered to encompass both, dilution and reduction processes like absorption and/or degradation of pollutant in soil or groundwater)

(2)Identification of substances that can be accessed by natural attenuation or enhanced natural attenuation

(3)Assessment of the behaviour of pollutant in soil or groundwater regarding natural self cleaning processes

(4)Requirements on soil and groundwater schemes regarding the application of natural attenuation

(5)Design and conduction of long term monitoring measures to quantify the reduction of contamination and to predict the long term behaviour of the contamination under the aspects of future use options.

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http://www.lfu.baden-wuerttemberg.de/lfu/abt5/altlasten/index.html (AlfaWeb)

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GREECE

Ex situ remediation

In Greece there is *no company with fixed facilities*, i.e. a stationary treatment plant, *for ex situ treatment* of contaminated soils. In some cases, soils contaminated with hazardous substances are excavated and transferred to other EU countries, where they are treated as hazardous wastes, in plants operating in France, West Germany, etc. There are today 4 companies, which are specialised in hazardous waste management (including contaminated soils) and have the relevant permits.

The current Greek policy related with the management of hazardous wastes, including contaminated soils, is covered by the Joint Ministerial Decision (J.M.D.) 19396/1546/1997 ("Measures and provisions for hazardous waste management"). This JMD sets that incentives may be granted to installations, which deal with the reuse/recovery of hazardous wastes or contaminated soils. More specific policy tools will be included in the "Framework of Technical Specifications for Hazardous Waste Management", which is today in preparation and is expected to be issued before the end of year 2000.

In specific cases, the Ministry of Environment may grant permit to the cement industry to treat contaminated soil in the rotary kiln. Such a permit was granted in 1996, for the treatment of 150 tons of soil contaminated with creosols and phenols. For the thermal destruction of those organic pollutants, the soil was mixed with the fuel (coal) at a percentage of 2% and fed to the rotary kiln.

Table 14: List of technologies used to remediate excavated soil

Technology	Tons/year treated	Costs (€/tonne-1999) low-high	Type of contaminants treated	Treatment efficiency/ limitations	Comments/ special conditions
Off-site landifilling	500 – 1000	400 - 600	Organic volatile and semi-volatile components	High	Depends on the local regulations
Bioventing	2000 – 3000	25 - 75	Organic volatile and semi-volatile components	High	Depends on the type of the treated material
Stabilisation and solidification	100 – 500	50 - 200	Acids, organic volatile and semivolatile compounds	High	Depends on the type of contaminants
Soil washing	50 – 200	50 -200	Acids	High	Depends on the type of contaminants

Available information for full-scale soil remediation projects using *on-site* or *in situ treatment* technologies is very limited. The data presented in tables 14 and 15, were provided by INTERGEO Ltd, a company with established experience in soil remediation projects and are simply indicative of the technologies currently applied in Greece.

In situ remediation

Table 15: In situ technologies in use or implemented

Technology	**m³/year treated**	**Costs (€/tonne-1999) low-high**	**Type of contaminants treated**	**Result/ experience/ limitations**	**Comments/ special conditions**
Soil Vapour Extraction	3000	25 - 50	Organic volatile and semi-volatile components	Satisfactory	Depends on the geological conditions and the type of contaminants
Bioventing	1500	25 - 60	Organic volatile and semi-volatile components	Satisfactory	Depends on the geological conditions and the type of contaminants
Soil flushing	100	40 - 180	Acids, metals, organic volatile and semi-volatile compounds	Satisfactory	Depends on the geological conditions and the type of contaminants

Innovative technology

Innovative technologies, which are currently under development by Greek Universities and Research Organisations, are summarised in Table 16.

Table 16: Innovative technologies under development

Technology	**Type of contaminants treated**	**Development stage**	**Details of application**	Result / **experience/ limitations**
In situ chemical stabilisation	Heavy metals	Pilot scale, 1000m² treated in-situ to a depth of 0.4m	Stabilisers tested: phosphates, biological sludge, fly ash, compost	Reduction of Pb, Zn, Cd solubilty by 60 to 95%. Reduction of phytotoxicity, development of vegetation on treated soils. Costs ~15-60 Euro / m³, depending on materials availability
Soil washing with chemical extraction	Heavy metals	Bench scale, 10 kg treated in columns	Reagents tested: acidic chloride solutions, chelators	Removal of Pb, Zn, Cd up to 95%, depending on speciation and soil matrix. Costs more than 100 Euro / m³
Biological treatment	Heavy metals and metalloids	New project EU 5th FW	Use of metal reducing bacteria	
Permeable reactive barriers	Heavy metals and metalloids Removal from GW	New project EU 5th FW	Development of new sorptive materials	

During the development and pilot scale evaluation of *stabilisation* and *chemical extraction* techniques the following regulatory and technological gaps were identified:

For stabilisation techniques:

- Establishment of regulatory limits and standard procedures to evaluate the stabilisation techniques based on the bioavailability of contaminants. Existing guidelines based on total concentrations are not applicable for this category of technologies.
- Development of efficient mixing equipment to increase the depth of application for the *in situ* treatment of soils.
- For soil washing - chemical extraction techniques :
- Identification of reagents and / or conditions, which will ensure protection of soil matrix and soil multifunctionality
- Further development of proposed barrier technologies to allow a safe *in situ* application of washing techniques, e.g. construction of horizontal impermeable barriers to avoid the vertical spreading of contaminants and leaching reagents.

A list of EU funded projects with Greek participation is given below:

1. Prediction, protective and remedial action against acid mine drainage. CEC, Brite-Euram II, 1992, *(NTUA (GR) Imperial College (UK), Hellenic Chemicals and Fertilizers (GR), Knight, Piesold and Partners (UK)).*
2. Biorehabilitation of the acid mine drainage phenomenon by accelerated bioleaching. EC Environment Programme, 1992, *(NTUA(GR), University of Dublin (IR), etc.)*.
3. Soil rehabilitation in the municipality of Lavrion. EC LIFE Programme, 1993, *(Municipality of Lavrion (GR), NTUA (GR), IGME(GR)*).
4. Marine pollution in the Black Sea due to mining activities: risk assessment, development of preventive and remedial action. EC COPERNICUS Programme, 1996. *(NTUA (GR), Univ. of Mining and Geology Sofia (BG), Burgas Copper Mines (BG), Institute of Marine Biology (RO)).*
5. Innovative industrial technologies for the rehabilitation of land contaminated from polymetallic sulphide mining and processing operations. EC Brite-Euram III Programme,1996 *(NTUA (GR), EMSA (IT), KP (GB), ISQ (PT), QUIMIGAL (PT), DEAL (GR), TVX HELLAS (GR)).*
6. Implementation of local environmental policy in the residential development, EC LIFE Programme, 1997, *(Municipality of Evosmos (GR), University of Thessalia (GR), IGME(GR)*). Project involving demo scale applications of SVE and bioventing techniques for petroleum contaminated soils.
7. Long-term performance of permeable reactive barriers used for the remediation of contaminated groundwater. EC Environment and Sustainable Development Programme, 1999. *(NTUA (GR), UNIKARL (DE), BAM (DE), UNIVLEEDS (UK), MEC (HU), MISKOLC (HU), GUT (A)).*

8. Development of technologies using the activity of sulphate and metal-reducing bacteria to remove heavy metals and metalloids from ground waters and soils. EC Environment and Sustainable Development Programme, 1999. *(NTUA (GR), DEAL (GR), BRGM (FR), CNRS (FR), IRD (FR), VITTO (BE), GEOS (DE), MUNTERS (DE), PROPLAN (CY), UOC (CY))*

Monitoring remediation performance

In Greece there is neither specific legislation nor official guidance on monitoring requirements regarding the quality of treated soil, *in situ* treatment and natural attenuation.

In the J.M.D. 114218/1997 ("Framework of Specifications and general solid waste management programmes") some general provisions are included, concerning the monitoring of the rehabilitation works at solid waste disposal sites.

More specific monitoring requirements will be included in the "Framework of Technical Specifications for Hazardous Waste Management", mentioned above.

For further information on national policy, soil remediation projects and research activities

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IRELAND

General

Examples of most of the common types of soil contamination being dealt with throughout Europe may be found in Ireland, including old gas works sites, old waste disposal sites, old mining sites and associated tailings ponds, and leaking underground storage tanks. To-date no specific national survey has been carried out to identify and register contaminated sites in Ireland however, in 1998 the Environmental Protection Agency (EPA) estimated that there were somewhere between 1900 to 2300 industrial activities that may pose a risk to soil and groundwater.

Ireland lacks specific legislation for dealing with and remediating contaminated sites. However, some existing legislation does provide a considerable range of powers to the EPA and Local Authorities to deal with contaminated land including its remediation. Existing legislation of particular importance include the Waste Management Act, 1996 and the Environmental Protection Agency Act, 1992 and associated regulations. Remediation of historical waste disposal or recovery sites may require a waste licence from the EPA or a permit from local authority. Under the EPA Act 1992, the integrated pollution control licensing system may require remediation of contaminated soil on sites subject to a licence. The current approach used in the licensing system for waste and industrial activities encompasses pollution prevention, polluter pays principle, the precautionary principle and the use of risk assessment in relation to contaminated land. Where soil contamination has been identified, the type of licence required and remediation required is determined on a site by site basis taking into account fitness for use. There are no statutory or non-statutory guideline values for contaminants set in Ireland at present although non-statutory guideline values for groundwater and soils are currently being developed by the EPA. Decisions on clean-up requirements to date are determined on a site by site basis using risk assessment as the main decision tool supported by existing international guidance from various countries such as the Netherlands and the USA.

The EPA has to date issued two waste licences for on-site remediation of old gas-works sites which are under redevelopment. Integrated pollution control licensing of industrial activities commenced in Ireland in 1994. Since then 452 licences have been issued. To date, a total of 55 have indicated that there is a possible soil and or groundwater contamination problem on site, which may require remediation. Risk assessment is the main tool which is used to determine if remediation is required taking into account fitness for use. Both in situ and ex situ technology are used on these sites. On some sites where deep sub-soil/groundwater contamination has been identified with difficult contaminants e.g. DNAPLs, monitored natural attenuation can be the preferred remediation technology in such circumstances.

Information on ex situ and in situ treatments of contaminated soils in Ireland is not compiled. However, the EPA has information on soil remediation undertaken under their waste and IPC licensing system and also information received from consultants and practitioners in the field of soil remediation. This information although incomplete indicates the types of technologies currently being used in Ireland.

Ex situ remediation

The most common form of soil remediation to date in Ireland has been to excavate and transport off site for disposal to landfill or exported from the country. Since the introduction of the waste licensing system in 1997 under the Waste Management Act, 1996, more stringent controls over waste acceptance into landfill have been imposed. All landfills which have been licensed by the EPA to date (21) do not accept hazardous waste thereby requiring most of contaminated soil which is considered hazardous to be exported from Ireland. The export of waste from Ireland is controlled under Council Regulation on the supervision and control of shipments within, into and out of the European Community (93/259/EEC) and Waste Management (Transfrontier Shipment of Waste) Regulations, 1998 (SI No. 149 of 1998).

In 2000, the EPA granted an Integrated Pollution Control Licence (IPC) to a company to operate a soil bioremediation facility to treat soils contaminated with petroleum products. It is expected that this facility will be able to remediate up to 20,000 m^3 of contaminated soil on an annual basis. In addition, new regulations have been implemented (i.e. Waste Management (Licensing) Regulations, SI No. 185 of 2000) which will provide for the licensing of mobile plant used for the recovery and disposal of waste at more than one site. It is envisaged that these regulation will apply to mobile units used for the remediation of contaminated soils.

From the limited information available in Ireland on ex situ treatments for soil contamination, it would appear that most of the commonly used techniques in Europe are also used in Ireland. These include biological treatments such as land farming, chemical/physical such as physical encapsulation and solidification and thermal treatments such as thermal stripping and incineration (abroad).

In situ remediation

The selection of the most appropriate in situ treatment option for soil remediation is normally determined on a site by site basis taking into account various factors including fitness for use. The main types of in situ treatment being used for contaminated soil in Ireland include in situ bioremediation, vacuum extraction and bioventing. Remediation technologies may be subject to licensing requirements under the Waste Management Act, 1996 or the Environmental Protection Act, 1992 as detailed above.

A summary of some of the companies currently involved in soil remediation, both in situ and ex situ in Ireland (including Northern Ireland) are given in the Table 17 below.

Table 17: Some of the main companies involved in the remediation of contaminated sites in Ireland

Company	Treatment technology
Alpha Environmental Systems Ltd. *Contractor*	Vacuum extraction Bioremediation (land farming) Bio-injection Excavate and export Partner in joint venture for soil bioremediation facility recently established in Ireland
Atlas Environmental *Contractor*	Bioremediation ex situ (landfarming). Specialised facility set up to remediate soils contaminated with petroleum fuel
Bio-Logix Environmental Limited *Contractor*	In situ bioremediation using pump and treat technology Treat mostly hydro-carbon soil contamination. Also involved in odour control.
Dames and Moore *Consultant &* *Contractor*	Bioremediation Soil vapour extraction Bioslurping Bioventing Landfarming Thermal treatment / desorption UV oxidation (groundwater – pilot test) Excavate and landfill Groundwater remediation
Environmental Engineering Research Centre, Queens University, Belfast *Consultant &* *Contractor*	Monitored Natural Attenuation Permeable Reactive Barriers Source Oxidation / Reduction techniques Focus on in situ methods of dealing with organic contaminants. Involved in pilot scale and full scale remediation
GeoDelft Environmental *Consultant &* *Contractor*	Soil washing and flushing Biochemical remediation Bioremediation Air sparging / vacuum extraction Physical barriers Soil mixing and blending Landfarming Low temperature thermal desorption

Table 17: Some of the main companies involved in the remediation of contaminated sites in Ireland (continued)

Company	**Treatment technology**
Geotechnical and Environmental Services *Consultant*	In situ bioremediation Vacuum extraction Dual phase extraction Bioremediation Pump and treat for groundwater Phyto-remediation for heavy metals and some organics
K.T. Cullen *Consultant & Contractor*	Bioremediation Soil vapour extraction Landfarming Excavate and landfill Groundwater remediation Involved in in situ and ex situ bioremediation. Ex situ treatment in Ireland - landfarming Excavate and export to Netherlands and Germany for thermal treatment. In situ bioremediation with addition of nutrient and air.
Micro-Clean Environmental *Contractor*	In situ bioremediation of petroleum contaminated sites both residential and industrial
O'Callaghan Moran & Associates *Consultant & Contractor*	Bioremediation Soil venting Soil washing Pump and treat Physical encapsulation Excavate and landfill or incinerate (abroad)
Greensunrise Holdings Ltd. *Contractor*	Ex situ Excavate and landfill Thermal desorption Landfarming Work mainly with petroleum contaminated soils. Proposals to establish thermal desorption plant and bioremediation landfarm in Ireland.
S.M. Bennet & Co. *Consultant*	Biological treatment Chemical treatment Physical treatment Vacuum extraction Air venting Air sparging Dilution

Table 17: Some of the main companies involved in the remediation of contaminated sites in Ireland (continued)

Company	Treatment technology
Spillclean Limited *Contractor*	In situ anaerobic bioremediation of soils. Use nutrient source which stimulates indigenous soil micro-organisms to biodegrade hydro-carbon contaminants Use gravity feed system rather than traditional pump and treat

Innovative technologies

Some of the latest innovative technologies emerging world-wide are currently being used and evaluated in Ireland both at pilot and full scale. The types of remediation technologies include:

- Use of propriety oxygen release compounds (ORCs) to remediate diesel range organics (DRO) in groundwater. OCRs are lowered into wells and suspended in a 'sock' into the groundwater where it intersects with the zone of contamination. Oxygen is slowly released into the groundwater to stimulate the natural biodegradation of the diesel.
- Permeable reactive barriers (PRB) – contaminated groundwater passes through an in situ reactive material that either biotic or abiotic degrades the contaminants. A zero-valent iron reactive barrier has been installed in Northern Ireland to degrade chlorinated solvents. This PRB was one of the first of its kind to be installed in Europe and world-wide.
- Monitored natural attenuation (MNA) – relies on the indigenous microbial population and aquifer nutrients to biodegrade contaminants in groundwater. The application of MNA can be limited by nutrient availability and/or high risks associated with contaminant movement. There is considerable interest in MNA as a remediation option for contaminated groundwater.
- Phyto-remediation – research work is being undertaken to evaluate the effectiveness of phyto-remediation to enhance natural degradation rates of hydrocarbons and provide mechanisms for the remediation of metals from soils and shallow groundwater.
- Solidification and stabilisation – use of cement to chemically stabilise and solidify inorganic contaminants.

Monitoring remediation performance

Where soil remediation has been undertaken as part of either a waste licence (i.e. in the case of waste disposal or recovery activities) or an IPC licence (i.e. for an industrial activity) monitoring the effectiveness of the remediation would be a condition of the licence issued. Remediation performance would be determined on a site specific basis and assessed by the EPA supported by international guidance.

ITALY

General

The following data refer to a preliminary survey carried out by interviewing 7 major companies (approximately 400 sites remediated nationwide) and the Province of Milan (120 sites in the Province territory). Data are summarized in Tables 18, 19, 20 and 21, 22, 23 respectively. Some of the data might be overlapping, and they cannot be merged for the time being. Collection of further information is necessary.

Physical immobilisation barriers as impermeable barriers, capping and hydraulic barriers are listed under 'ex situ' treatments.

On some sites, more than one treatment technology might have been applied.

The interviewed companies that provided the data are Golder, Aquater, Dames & Moore, ITCorp, ERM, FosterWheeler, SET Srl. Data are updated to year 2000.

It should be underlined that if containment, and excavation/landfilling for heavy metals, are still the most frequent solutions, hydrocarbons, aromatic and chlorinated compounds are more and more being treated by in situ and on site technologies. Bioremediation technologies, such as bioventing, biosparging and composting as well as physical techniques, as soil vapor extraction, are frequently applied.

Ex situ remediation

In Italy basically off site biological treatment plants do not exist (only one soil treatment plant has been recently installed for a capacity of 20,000 t/year). Nevertheless several full-scale bioremediation experiences have been carried out on site.

Table 18: Off site treatments operated by the interviewed companies

Treatment technology	**No. of treatments**	**Costs** **low-high**	**Type of contaminants treated**	**Comments**
Physical barriers	205			might include some landfilling
Soil washing	3	Medium-high	hydrocarbons	Large quantities of water to be treated
Incineration	3			Concerns with air emissions
Hydraulic barriers	24			

Table 19: Off site treatments (Province of Milan)

Company/ localisation or similar info	**Treatment technology**	**No. of sites**	**Costs €/tonne- 1999)**	**Type of contaminants treated**	**Comments**
No companies holding discharge permit	Landfilling Incineration	43	100-400 -700	Shallow contamination, small volumes	no reuse of soil

Table 20: List of technologies used to remediate excavated soil on site, and degree of re-use of soil operated by the interviewed companies

Technology	**No of treatments**	**Costs low-high**	**Type of contaminants treated**	**Treatment efficiency/ limitations**
Immobilization / stabilisation	2			
Thermal desorption	2			
Landfarming	18	Low-medium	hydrocarbons	good
Bioreactor / Biopile	9			

Table 21: List of technologies used to remediate excavated soil on site, and degree of re-use of soil (Province of Milan)

Technology	**No of sites and tons treated**	**Type of contaminants treated**	**Comments/ special conditions**
Landfarming	2 sites (45000 tonne / each)	Petrol hydrocarbons	Reuse of soil on site
Bioreactor in water	1 site (small volume)	Petrol hydrocarbons	Reuse of soil on site
Biopile	1 site (69000 tonne)	Petrol hydrocarbons	Reuse of soil on site

In situ remediation

Table 22: In-situ technologies in use or implemented operated by the interviewed companies

Technology	**No of sites**	**Costs low-high**	**Types of contaminant treated**	**Result/ experience/ limitations**
Pump&treat	19	Medium-high	Chlorinated. Aromatics, solvents	
Soil vapor extraction / soil venting	88	Medium-high	Aromatic, chlorinated hydrocarbons, solvents	Often associated to pump & treat
Bioslurping	3		Hydrocarbons	
Vacuum enhanced recovery	5	Low-medium	Hydrocarbons	good
Vacuum dewatering system	5	Low	Hydrocarbons	good
Bioventing / Bioremediation / Air sparging	74	Low-medium	hydrocarbons	Good results
Dual phase extraction	49			
Active barriers	4	High	hydrocarbons	Good results
Natural attenuation	4	Very low	hydrocarbons	Good results

Table 23: In situ technologies in use or implemented (Province of Milan)

Technology	**No of sites or volumes treated**	**Types of contaminant treated**	**Comments**
Pump and treat	>10 sites		
Soil vapour extraction and / or air sparging	>10 sites		
Reactive barrier	1 site	Petroleum hydrocarbon	
Stabilisation	I site	chromium	Concrete injection
Bioventilation	5-10 sites		

Monitoring remediation performance

At present there are no regulations about requirements for monitoring treatment performance. A monitoring protocol is normally defined for each site when the remediation permit is given by the competent public body.

Innovative technologies

The largest program for research and development of remediation technologies has been launched by the Ministry for Scientific and Technological Research under National Research Program n. 15 (PNR15). Main contractor is AREA / Ravenna, partners are the Center for Environmental Research Montecatini, the University of Bologna and the Institute for Cancer Research. The program started in 1997 and is expected to last till end of 2001. The program includes the following subprograms:

- R&D for bioremediation techniques in situ and on-site
- R&D for vitrification techniques in situ

The Ministry is supporting a number of other individual research projects for the Environment and the Ministry presently funds others for Scientific and Technological Research and by the ANPA. In this context, bioremediation and phytodepuration deserve particular attention. A number of research projects are carried out in order to test biological and chemical / physical methods able to degrade / remove persistent PAH from soil (Politecnico di Milano). Isolation and characterisation of bacterial strains capable of degrading condensed sulfur-containing heterocycles in soil and groundwaters are being studied (University of Verona).

An innovative project aims at integrating phytodepuration and biodegradation processes in order to achieve synergic effects for the degradation of Pb, Zn and Se in soil (National Research Institute, University of Verona).

Other research activities on technology development are carried out within international and EU funding programs or by research investment and by specific initiatives from the national holding for hydrocarbons. One important EU funded project (under ESPRIT program) deals with the implementation of models to simulate bioremediation processes in contaminated soils.

NETHERLANDS

General

In the Netherlands, there is a general picture of the extent of the existing soil pollution situation, which is based on (a limited number of) studies and estimates made by extrapolation. A priority system is used in order to determine whether decontamination is necessary (the level of seriousness) and when (the level of urgency). There are three basic categories: **not serious** (decontamination not required), **serious** (decontamination required in due course), **serious and urgent** (decontamination required in the near future).

Prognoses relating to the costs of soil pollution indicate figures in the order of € 45 billion. Table 24 gives an overview of the most important groups of pollution cases with figures for the category "serious and urgent". Around 60,000 cases are involved, the costs of which amount to almost € 30 billion. According to the same estimates, the "serious" cases number more than 26,000. It is thought that the costs of these cases, including the costs of the serious and the urgent diffuse cases of soil pollution, could be as high as € 20 billion.

Table 24: Overview of pollution groups and costs of urgent cases

Groups (urgent)	**Number**	**Cost in € million**
1. Gasworks	234	1500
2. (Former) waste dumps	950	4500
3. Filled-in canals, ditches etc.	1250	310
4. Former industrial sites	33600	5000
5. Current industrial sites	19200	9500
6. Petrol stations	2500	140
7. Ministry of Defence sites		200
8. Netherlands Railways sites	410	1700
9. Fuel tanks	1000	13
10. Extreme cases	286	130
11. Other government# cases	PM	PM
Total	**59430**	**23000**

In 1999 approximately € 0,5 billion is to be spent on soil decontamination. Businesses and private persons will pay about one third of this, one-third by central government and one third by other public bodies.

Despite these considerable efforts, central government is of the opinion that soil decontamination is not progressing rapidly enough. As a reaction to this, the cabinet has published a policy document in which renewal of the soil decontamination policy is proposed. This policy document sets out the following two objectives:

1. The extent of the soil pollution must be mapped for the whole country by 2005.
2. There should be permanent management of the soil, and within the framework of such management, efforts are to be made to get this problem under control in the next 25 years or so. These efforts are to be assisted with increased private investment. The cabinet has promised extra finance until 2010 to help achievement of these goals.

The ultimate objective is to double the speed of execution of the entire soil decontamination operation whilst halving the costs as compared with those of the current prognoses. The principle that the pollution should be entirely removed from the soil is to be abandoned except in cases where it is imperative that the principle be applied (as determined by fixed criteria). The principle is to be replaced with that of decontamination matched to the function i.e. the extent of decontamination will be determined on the basis of hazards for (future) use.

This new policy proposal is now being elaborated and is to be implemented in the near future. Procedures for granting of approval are also being simplified. In future, an even greater emphasis is to be placed on an integral approach to soil decontamination which combines it with area development and other work.

Ex situ remediation

The fact that, in the Netherlands, soil decontamination is included as an integral part in many other activities means that nearly all contractors have the capacity and expertise to perform soil decontamination work. There are no comprehensive lists with overviews of companies that perform soil decontamination work or of the quantities of decontaminated soil excavated, removed and treated or dumped. For a long time, dumping was considered a good alternative to cleaning. In the present situation, however, very little contaminated soil is taken to waste dumps. Dumping of soil that could be decontaminated is prohibited, and there is sufficient processing and cleaning capacity.

Tables 25, 26 and 27 contain overviews of existing and planned capacities for cleaning of contaminated soil by means of respectively thermal methods, wet methods (sedimentation and washing) and biological methods.

Thermal methods can be used for treatment of all types of organic contaminants. The concentrations influence the level of treatability only in extreme cases. Heavy metals may, however, be present only in small quantities (as indicated in the application standard).

In the case of the wet methods, if separation is involved, the proportion of sand should preferably be higher than 50%. Virtually all types of contaminants can be treated with these methods. The manner in which the contaminants are bound to the soil matrix plays a significant role in the washing process. A number of installations that use wet cleaning methods have been set up especially for treatment of dredging mud. With minor adaptations, existing separation installations for soil can also be used for separating dredging mud. There are also a number of mobile installations for on-site treatment of dredging mud. The capacity of these are, however, very low in comparison with that of off-site installations. The biological cleaning companies concentrate primarily on soil and dredging mud contaminated with oil and polycyclic aromatic hydrocarbons.

Table 25: Overview of existing thermal cleaning methods

Company	Installation site	Hourly capacity (tonnes)	Annual capacity (tonnes)
ATM bv	Moerdijk	33	244,000
Ecotechniek	Botlek	27	200,000
Ecotechniek	Utrecht	19	150,000
Broerius bv	Voorthuizen	12	89,000

Thermal methods can be used for treatment of all types of organic contaminants. The concentrations influence the level of treatability only in extreme cases. Heavy metals may, however, be present only in small quantities (as indicated in the application standard).

In the case of the wet methods, if separation is involved, the proportion of sand should preferably be higher than 50%. Virtually all types of contaminants can be treated with these methods. The manner in which the contaminants are bound to the soil matrix plays a significant role in the washing process. A number of installations that use wet cleaning methods have been set up especially for treatment of dredging mud. With minor adaptations, existing separation installations for soil can also be used for separating dredging mud. There is also a number of mobile installations for on-site treatment of dredging mud. The capacity of these are, however, very low in comparison with that of off-site installations. The biological cleaning companies concentrate primarily on soil and dredging mud contaminated with oil and polycyclic aromatic hydrocarbons.

Table 26: Overview of existing wet cleaning methods for soil and dredging mud

Company	Site of soil cleaning installation	Current annual capacity (tonnes/year)	Planned capacity (tonnes/year) after development
NV Afvalzorg	Nauerna (Zaanstad)	75,000	330,000
BSN	Weert	125,000	140,000
Boskalis Dolman	Schiedam	100,000	150,000
De Groot Boskalis VOF	Heiloo	40,000	100,000

Table 26: Overview of existing wet cleaning methods for soil and dredging mud (continued)

Company	**Site of soil cleaning installation**	**Current annual capacity (tonnes/year)**	**Planned capacity (tonnes/year) after development**
Arcadis • Soil • Dredging mud	Moerdijk	 125,000 20,000	200,000 (incl. mobile)
Heimans Milieu	• Rosmalen • Moerdijk • Nunen • Wijster	25,000 80,000 25,000 --	25,000 80,000 25,000 25,000
HWZ Milieu		125,000	300,000
Jaartsveld G & M	Steenbergen	70,000	104,000
Jansma en Mosman	Drachten	35,000	35,000
Mosmans Bodem bv	Oss	25,000	25,000
Pouw Recycling	Utrecht	360,000	360,000
Smink Boskalis Dolman	Amersfoort	40,000	100,000

Further companies	**Mobile separation installations**	**Known : 4 installations**	**Per installation 30 - 40 tonnes/hour**

Company	**Site of installation/ facility for treatment of dredging mud**	**Type of treatment**	**Annual capacity (m^3/year)**
V.O.F. het Oost	Den Helder	Sedimentation basin, hydrocycloning and digestion	250,000 – 500,000
RWS – Port of Rotterdam	Maasvlakte (Slufter)	Sedimentation basin, primary classifier, hydrocycloning	250,000
ORTI Zeeland bv	Dekkerspolder, Westdorpe	Hydrocycloning, flotation, dewatering	30,000
Pecos den Haag	Dordrecht / 3e Merwedehaven	Hydrocycloning and dewatering	150,000
DWR, Municipality of Amsterdam / Boskalis Dolman	Van Riebeeckhaven in Amsterdam	Hydrocycloning, upflow column, dewatering and secondary digestion	50,000

Table 26: Overview of existing wet cleaning methods for soil and dredging mud (continued)

Company	**Site of installation/ facility for treatment of dredging mud**	**Type of treatment**	**Annual capacity (m^3/year)**
Roelofs den Ham	mobile	Hydrocycloning and dewatering	50,000
BVNN/Boskalis Dolman vof	Skinkeskâns, Leeuwarden	Primary classifier, hydrocycloning, upflow column and dewatering	30,000

The current commercial price of wet soil decontamination in the Netherlands is in the region of € 18 to 34 per tonne of processed soil (excluding removal of residues). If removal is included, the price can be as high as € 57 per tonne of processed soil.

Table 27: Overview of existing biological cleaning installations (intensive and extensive landfarming unless otherwise indicated)

Company	**Site of installation**	**Current capacity (tonnes/year)**	**Planned capacity (tonnes/year)**
NV Afvalzorg	Nauerna - Zaanstad, Dordrecht, Halfweg, Nieuwegein, Zoetermeer	20,000	60,000
Biograp bv	Anna Paulowna	25,000	
Bion Overijssel bv	Almelo	24,000	
Biowier	Middenmeer	65,000	
Arcadis	Dordrecht, Europoort, Veendam	105,000	160,000
Heijmans Milieu	Rosmalen, Vlagheide	25,000	
Mourik Groot Ammers bv	Groot Ammers	25,000	80,000
NBM Milieu bv	Moerdijk	13,000	24,000
NV VAM	Wijster	20,000	
Stuurwiel grondreiniging bv	Oudehaske, Drachten, Heerenveen, Hoogeveen, Groningen	95,000	
CVI Westdorpe	Sas van Gent	12,000	
Arcadis	Moerdijk	20,000 **(Slurry reactor)**	80,000 **(slurry reactor)**

In the Netherlands the commercial price of biological soil decontamination, including the disposal of the cleaned product, is currently in the region of € 18 to 45 per tonne. The price of processing is dependent on the type of soil and the type of contamination. In the case of sandy soil with "slight" oil contamination the price will be low (€

18to27), and in the case of clayey soil with severe oil contamination the price will be high (€ 36 to45).

In the Netherlands, the facilities required for on-site treatment of contaminated soil are often unavailable. Due to the relatively small scale of the operations and the fact that the sites requiring decontamination are situated in built-up areas and often in the vicinity of residential areas, there is now a definite preference for off-site treatment at locations specially set up for the purpose. Due to the relatively large number of available installations and facilities and the fact that they are fairly well spread out through the country, the transport distances and costs are not such that on-site treatment will be given preference for cost reasons. Annoyance to the surroundings and obtainment of the required permits are much more important factors when a choice is to be made between on-site and off-site treatment.

In situ remediation

The policy for the future is aimed at "functionally oriented decontamination", in which removal of the contaminants from the soil must be done in a cost-effective manner. A period of 30 years after the start of the actual decontamination work has been allocated for this. As a result of these policy developments, the opportunities for in situ methods have increased enormously in the Netherlands. Between 50 and 100 in situ decontamination operations have been prepared, commenced or completed in the last 5 years. Plans are being developed for many more. The in situ methods in use can be divided into the following methods and treatment principles.

- Removal by transport via the groundwater
  - Extraction of contaminated groundwater and infiltration (developed to "smart pump and treat");
  - In situ extraction;
  - Electroreclamation.
- Removal by transport via the air;
  - Ground air extraction and bioventing;
  - Compressed air injection and biosparging;
  - Steam stripping.
- Removal by conversion
  - In situ biorestoration, both for substances that are broken down in aerobic conditions (aromatics, mineral oil, polycyclic aromatic hydrocarbons and the like) and substances that can be broken down under anaerobic conditions.

In Dutch practice, increasing use is also being made of combinations of methods. In-situ methods can form part of an isolation variant in which as many mobile substances as possible are removed or contaminated substances are controlled by (bio)screens with stimulation of the breakdown of substances by in situ methods. The reinstatement variant can also be formed by combinations of in-situ methods. Practical examples are:

- A combination of ground air extraction and in situ biorestoration;
- A combination of compressed air extraction and ground air extraction;
- Compressed air extraction in combination with ground air extraction and biorestoration;
- In situ extraction to increase bioavailability and removal by biorestoration or electroreclamation;
- Excavation of hotspots and in situ methods for the pollution spread area;
- Etc.

According to a market survey performed in 1998, in the Netherlands, on the basis of the new soil decontamination policy, biological in situ decontamination could provide a total solution for over 15% of all locations. In approximately 70% of the locations, biological in situ decontamination can be applied in combination with other methods for tackling contaminants that are difficult to break down and for eliminating unacceptable risks. The net market share of biological in situ decontamination, which, at the end of the market survey, was less than 5%, could be increased to 40% under the new policy. It should be noted, however, that the total scope of the market for soil decontamination will decrease severely as a result of the new policy. Much practical research is now being conducted within an incentive programme intended to promote work in the field of in-situ soil decontamination methods, which is being organized by various government departments and public bodies (NOBIS).

Innovative developments

New developments in practical application of in situ decontamination include:

- A phased approach in which several methods are combined. The methods can be applied simultaneously or in a phased manner;
- Natural attenuation, in which use is made of the self-cleaning ability of the soil;
- Phased anaerobic breakdown of chlorinated hydrocarbons;
- Bioscreens as a component of a management variant;
- Multiphase vacuum extraction (bioslurping);
- Chemical or biological fixation;
- C-sparge technology for removal of chlorinated and aromatic hydrocarbons by a combination of in situ stripping and chemical conversion;

Dual-gas technology, includes a gaseous mixture being pumped into the soil. The air bubbles comprise an oxidizing gas (inter alia an ozone / air mixture), which facilitates breakdown of the contaminants.

In addition, mention should be made of the development of various decision-assisting systems that are aimed at enabling reasoned decisions to be made when solutions are being chosen. The rapid development that in situ methods are currently undergoing in the Netherlands can be attributed primarily to the new policy in the field of soil decontamination and to the existence of an incentive programme concerned specifically with this area. Within the framework of the Dutch Research Programme Biotechnological In Situ Decontamination (Nederlandse Onderzoeksprogramma Biologische In situ Sanering (NOBIS)), more than 65 research and development projects have been conducted in the last five years. As a result of this enormous success, a broader programme within the framework of the newly established Foundation recently followed NOBIS for the Development and Transfer of Knowledge of Soil (Stichting Kennisontwikkeling en –transfer Bodem (SKB)).

In the coming years, this foundation will turn its attention to soil decontamination around local pollution sources and to the following subjects:

- Urban development and renewal in relation to soil decontamination;
- Redevelopment of urban areas in relation to (diffuse) soil pollution;
- Management of water systems;
- Post-project assistance and management.

The first invitation for tenders at the start of 1999 resulted in the submission of over 85 ideas for research.

Monitoring

In the Netherlands, monitoring is conducted with various objectives:

- For adjustment of installed (in situ) systems;
- For control and maintenance,
- For checking whether the decontamination objectives are being achieved and for checking progress;
- In connection with discharge and emission standards in the operation of sewage treatment plants;
- To gain an understanding of the possibilities and/or the mechanisms of natural breaking-down processes.

The interest in extensive decontamination concepts means that there is a growing need for knowledge regarding the processes that (can) take place under various conditions in the soil. It is consequently very important that a better understanding be gained of reliable monitoring and prediction methods.

References

Mention should be made of the Stichting Kennisontwikkeling en kennisoverdracht Bodem (SKB), PO Box 420, 2800 GOUDA, The Netherlands, tel +31 (0)182 540690; E-mail: skb@cur.nl. This foundation has the most up-to-date knowledge on the developments in in situ soil decontamination methods in the Netherlands.

In addition, mention can also be made of the Executive Organization for the Manual of Soil Decontamination Methods project. Within the scope of the project, method descriptions have been drawn up for all soil decontamination methods in operation or in development in the Netherlands, and practical evaluations have been performed on a very large scale for determination of the mechanisms and performance, under practical conditions, of the methods used. Executive organization: BOdemBeheer bv, PO Box 25, 3998 ZR SCHALKWIJK, The Netherlands; E-mail: j.gun@tip.nl

The Service Centrum Grond (SCG) has a large amount of knowledge and experience concerning the treatability of soil. The SCG is the organ which, on the basis of the above-mentioned ban on dumping of cleanable soil, issues the statements to the effect that the soil cannot be cleaned. In addition, it assists the government departments in matters such as tendering procedures, cost / quality assessment and cleaning specifications. It also plays a part in the quality assurance in soil research, decontamination and the quality of the removed soil.

NV SCG, PO Box 19, 3990 DA HOUTEN, The Netherlands; E-mail: info@scg.nl

NORWAY

General

The national authorities (State Pollution Control Authorities, SFT) have established a priority list for handling of contaminated soil. The priority list is based on the general principles for waste disposal, and is as follows:

- First priority: Regeneration / Re-use, energy recovery
- Second priority: Treatment / detoxification
- Third priority: Disposal

Moving contaminated soil to landfills is considered to be the least wanted alternative, but the largest volumes are still going to landfills. To prevent landfilling to be the ultimate “treatment” alternative of contaminated soil, it was agreed to implement an environmental tax (1999) on all contaminated soil delivered to landfills. Due to political reasons the tax has been postponed, partly because landfill disposal is more inexpensive, and a highly prized earning for the municipally kept landfills.

Ex situ remediation

No statistic exists on the volumes of contaminated soil being treated in Norway. An approximate amount of 100,000 tons per year is assumed being handled, most of which is petroleum-contaminated soil. The amounts vary, highly influenced by the building activities in city areas. These activities are steering the amount being handled every year. In 1997, more than 3,350 contaminated sites had been registered, and in 750 of these, investigations had started. On about 350 of these sites, remediation is ongoing or completed.

The largest volumes of contaminated soil is presently being treated on sanitary landfills using biological composting, most of the time by putting the soil on a layer of bark, but sometimes by mixing bark into the soil. Presently (1999) there exists 18 places where contaminated soil can be delivered located in 9 different municipalities. This solution is still available due to market pricing, and lack in knowledge of alternative and better technological solutions. Bark mixing is mainly a way of contaminant stabilisation, and thus part of the traditional landfill disposal.

An overview of treatment technologies for contaminated land in Norway shows that the following technologies are commercially available through Norwegian companies:

- Bioventing
- Vacuum Extraction
- Air Sparging
- Pump and Treat

- Biopiles
- Landfarming
- Ex Situ Soil Washing
- Thermal Oxidation
- Solidification / Stabilisation
- Incineration

In Situ and Ex Situ / On Site bioremediation technologies are mainly conducted by consultancies. In total 5 to 10 consulting companies have experience with these technologies. In addition to the consultancies about 3 to 5 companies have specialised in treatment of contaminated soil in Norway as their major activity. They have so far concentrated on solidification / stabilisation, soil washing, land farming and partly incineration. The small number of sites in the ”remediation phase” together with easy access to and low prices on landfills are major reasons for the limited development and accessibility of treatment technologies on the market.

SFT has started projects on national and local scale to develop guidelines for management of excavated contaminated soil. The guidelines will be administrative tools for local, regional and national authorities and support the existing legislation on contaminated land. A more consistent assessment by the authorities is of great importance to society.

Table 29 describes ex situ treatment plants presently operating with acceptance from SFT in Norway.

Table 28: Registered Norwegian companies with treatment plants and permanent discharge permits for treating contaminated soil and sediments

Company	Plant	Capacity (tonnes)	Cost (NOK/tonne)	Contaminants treated	Comments
NOAH	**Stabilisation** Solidification Deposition	30,000 / year 15 / hour metals	500-2000 1500		22000tonne / year
NOAH	**Composting** **Soil washing**	10.000(96-97) 20000 PAH 5000metals	1000-2000	Hydrocarbons Oil, PAH and metals	Capacity 20-30.000tonne / year
Deconterra as	**Soil Washing (mobile)** Thermal Oxidation 3 regional Senters for varying storage and treatment / regeneration	20,000 30,000 30,000	500-900 400-1200 350-1200	Hydrocarbons oil, gasoline, PAH, PCB, metals, CN	
Øijord & Aanes	Composting Soil washing Solidification	4-5000 (95-98) 1000 PCB 60000 (93-98)	150-950 300-2000 300-2000	Hydrocarbons Oil, PAH, metals Metals and CN	

Table 28: Registrered Norwegian companies with treatment plants and permanent discharge permits for treating contaminated soil and sediments (continued)

Company	**Plant**	**Capacity (tonnes)**	**Cost (NOK/tonne)**	**Contaminants treated**	**Comments**
Den-tor/Norcem	Incineration		3000		
NETT	Composting Soil washing (mobile) Thermal (mobile)	25000tonne /yr	700-1200	Hydrocarbons (aliphatic and aromatic) PAH Metals	
Grønmo Waste Landfill	Composting	10000tonne /yr	1600	Oil contaminated soil/sludge	
Kirkenes Airforce	Composting			Gasoline	
Oslo Airport	Composting	~25000 tonne (97-99)		Gasoline	Internal
Frantzefoss Gjenvinning	Thermal			Oil contaminated sediments	Only for high contamination levels

In additionthere are numerous plants (10-20) operating or having completing soil and water treatment on site in connection to larger development projects.

In situ remediation

The following in situ technologies are presently available through Norwegian companies:

- Air sparging
- bio-venting
- vacuum extraction
- bioremediation (air sparging + nutrient addition). This method has been applied in full scale at Haakonsvern in Bergen. Remediation started in 1996
- chemical oxidation and reduction

Innovative technology

Presently there is limited amount of innovative technology development taking place. In the second phase of the NATO/CCMS Pilot Study program Norway had several pilot studies running (1996). The environmental authorities were at that time supporting technology demonstration project. Presently there is one R&D programme supporting technology development, the GRUF Programme. This programme completed its activities in 1999, and there is uncertainty to whether the technology developing activities will continue. The following technology developing projects have been supported:

- Use of white rot funghi for bioremediation (1997-1999)
- Treatment of chlorinated organics by chemical dehalogenation (1997)
- Binding and degradation of priority pollutants using reactive barriers (1997-1999)
- Funnel and gate technology for treatment of CCA (Creosote, Cd and Arsenic) contaminated groundwater
- Testing of filter material for treatment of CCA contaminated groundwater
- Use of white rot fungi for bioremediation (1997-1999)
- In-situ biological treatment of creosote (1997-2000). The method was tested in field.
- Sorption and degradation of organic priority pollutants (creosote components) in reactive barriers (1998-2001). The project included a pilot scale installation.

The latter project combines phytoremediation and the permeable barrier technology. The pilot scale barrier consists of two filter materials in series, where the first is planted with grass.

Other projects:

Various filter materials have been tested for sorption of copper, chromium and arsenic (CCA), and in 1999 a funnel and gate system was installed (full scale) on an abandoned wood preservation site contaminated with CCA.

Monitoring remediation performance

There exist no detailed guidelines on monitoring requirements for documentation of treatment performance, neither with respect to documentation of the efficiency of natural attenuation processes. Requirements are worked out on a case by case basis.

References

RASMUSSEN, G. (2001): Vegetated permeable reactive barriers treat cresosote contaminated groundwater. Proc. Of the first European Bioremediation conference, Chiania, Greece July 2-5.

SFT (1995): Disposal of contaminated soil. A handbook for selection of the right method for final disposal of contaminates soil and used sorbents after remediation actions. (In Norwegian).

SNV (1998): Technology for treatment of contaminated soil in the Nordic countries. Report 4856 (In Swedish)

SNV (1995): Remediation of oil contaminated sites. Report 4445 (In Swedish)

SFT (1995): Experiences on windrow composting. Report 95:23 (In Norwegian)

The Norwegian Research Council (1999): Progress Reports – GRUF projects (In Norwegian)

SFT (1999): Risk assessment guidelines for contaminated sites. SFT 99:01(Under translation to English).

PORTUGAL

Ex situ remediation

With EXPO 98 the first action of remediation in Large scale started. The solution proposed was excavation of contaminated soil and its deposition in a landfill, where its isolation is allowed. Then a part of the soil has been be submitted to bioremediation.

The quantity of contaminated soil for deposition has been about 220 000 m^3. The soil was contaminated with hydrocarbons. The degree of remediation was a problem because no national criteria exist. On this framework it was agreed to adapt the Canadian guidelines.

Other projects

In the area of the Chemical Complex of Estarreja, called “Methodlogies of remediation of groundwater and soil” a study with the aim to evaluate the degree of contamination in the area was developed. Different measures for the control of the pollution were proposed.

Some projects / studies were submitted to a funding:

Project of recovery of “Lagoa da Palmeira”. This project is actually in the phase of evaluating the degree of contamination. Oil contaminated waste, chemical sludges, and municipal sewage were dumped in this lagoon over a period of more than thirty years.

Recovery project of Petrogal. The project includes an evaluation of the contamination from two refineries, 5 storage tanks, and other areas.

The Metalimex project. This project includes an evaluation of the contamination on an industrial site where 32 000 tons of aluminium slag produced in Switzerland and illegally imported during almost 10 years. After the removal of these slag (treated in a special plant in another EU country), and based on the evaluation, a decision will be made regarding remediation of the site.

SPAIN

General

This chapter describes the state-of-the art of remediation processes in Galician soil. An amount of 287 industrial sites potentially contaminated are shown in the second step of the Operative Program on Contaminated Soils. The criteria used for ranking these sites are pollution potential of the industrial activity, potentially contaminated area, environment and its probability of affection, use of land and social issues related with industrial activity. This ranking is used by Xunta de Galicia in order to priorize actions.

Beside of keeping a close watch about uprising of new pollution focuses which, in many times, needed fast actions the regional government promotes characterisation of pontentially contaminated soils beginning with higher ranking values. When sites are characterizated, the decision on actions is taken and, in affirmative case, the industries are suggested by Xunta de Galicia about the more suitable technologies for the remediation. Xunta de Galicia keeps a flexible attitude about chosen technology, keeping an eye on remediation objectives fixed.

This administrative work also keeps promotion of good practices of environmental management.

Ex situ remediation

Even though in Galicia there are cases in which more than one single model of remediation is applied in an integrated frame, a great deal of processes are exclusively ex situ treatments.

Soils contaminated with ashes from pyrites toasting were used in cement plants or dumped in hazardous waste landfills.

Soils with high concentrations in heavy metals, hydrocarbons or chlorinated organic compounds were disposed in accurate sites too, carrying out previous stabilisation procedures when needed.

Acid soils in absence of other pollutants were separated, neutralizated and dumped in inert waste landfills.

In places contaminated with organochlorinated compounds areas including both building and non-building zones have been found, combining ex situ actions for non-building zones (mainly solvent extraction or bioremediation) and in situ bioremediation for building zones.

Some of these treatments include dumping in hazardous waste landfills. Xunta de Galicia, looking forward a solution for industrial waste produced in Galicia, promoted the creation of a treatment centre with capacity for this dumping. This centre, named SOGARISA, is able to stabilizate 250 tonnes per day and its landfill capacity is 800.000 m^3.

Also, PMA S.L. has authorisation for treating of hydrocarbon-polluted soils.

In situ remediation

Enclosing of contaminated soils using concrete baffles encrusted in bedrock were used for great volumes of soil contaminated with lindane residues. Multiple factors led this choice. Mainly, pollutant dispersion through this great volume results in unacceptable cost for ex situ treatment, and it is very difficult to assume risk of exposure of inhabitants at the probable diffusion of pollutants during remediation works in a highly populated site. The latter reason makes necessary an urgent action.

Also, after the hydrologic modelling of the site, the complicated behaviour of the aquifer, existing layers with different permeability, over altered granite, and the discharge to different superficial streams, recommended isolation of the contaminated zone from subterranean streams that act as transport media for the pollutants. The chosen solution deletes pollutant diffusion through the surroundings and keeps open the possibility for future application of in situ remediation techniques.

Impermeable baffles made of bentonitic materials also immobilise metals polluting the soil that active industrial activities occupy.

Where organochlorinated volatile compounds are present, affecting the aquifer, hydraulic barriers have been set to avoid pollutant diffusion and aeration techniques are applied before re-injection of water in the aquifer.

in situ bioremediation techniques

Gasoline contaminated soils were treated using hydraulic barriers, eliminating the supernatant organic layer. High vacuum extraction for volatile pollutants for non saturated zone and water, adsorbing the extract on activated carbon, implies venting the soil, therefore increasing biodegradation of gasoline components. Keeping hydraulic barriers to avoid pollutant dispersion, it takes a few months that natural bioremediation will decrease pollutant concentration to acceptable levels.

Innovations

Even though we cannot refer innovative advances in remediation technologies, Xunta de Galicia promotes research in this field, through agreements and keeping contacts with research groups. In this moment, efforts are directed to bioremediation, affecting a great volume of soil.

SWEDEN

General

The Swedish Environmental Protection Agency (Swedish EPA) (http://www.environ.se) has estimated the number of contaminated sites in Sweden to approximately 22 000. Currently the municipalities and the counties are trying to locate and investigate the contaminated sites in their regions. The worst contaminated sites are put on a priority list for each county. The Swedish EPA have the possibility to finance inventories, investigations and remediations upon request from the counties. When it comes to investigations and remediations it has to be orphan sites.

Since 1999 there is a new environmental legislation in Sweden. According to this legislation the companies having business activities on a site are primarily responsible for remediation if the pollution happened 1969 or later. A landowner can be secondarily responsible for remediation if he has acquired the property after 1 January 1999. If several companies have been involved they have an impartial responsibility.

According to the new legislation essentially all remediation projects need a permit from either the municipality, the county council or the environmental court depending on the size of the remediation.

Ex situ remediation

Much of the remediation in Sweden is still excavation and land filling, but some companies and methods have been established on the Swedish market the last years. A problem on the Swedish market has been the high prices for remediation, which has led to the extensive use of land filling. With the establishment of more remediation companies on the Swedish market the prices are going down. Companies offering ex situ treatment of contaminated soil are presented in Table 30. It should be stressed that several of the methods offered by these companies are on-site methods, which need environmental permits for each new object. The Swedish legislation is very strict since contaminated soil in general is regarded as hazardous waste, which means that an extra permit to handle this will be necessary. Another factor in favour of land filling is that the new Swedish tax on land filled material does not include contaminated soil.

Table 29: Swedish contracting companies offering ex situ treatment of contaminated soil

Company	**Plant**	**Capacity (tons)**	**Cost (SEK/tonne)**	**Contaminants treated**	**Comments**
Aurex Reci AB	Soil washing	5-20 tonne/hour	400-900	Metals	
Banservice Bamab Weiss AB	Thermal desorption	60 000 tonne/year	450-650 (excl. establishing costs)	Oil, PAH, PCP	Joint venture with German company

Table 29: Swedish contracting companies offering ex situ treatment of contaminated soil (continued)

Company	**Plant**	**Capacity (tonnes)**	**Cost (SEK/tonne)**	**Contaminants treated**	**Comments**
Biologisk miljöåterställning	Composting	Depending on on-site permits	800-1000	PAH	
EkoTec	Composting, Bioslurry	Totally for all methods 50 000 tonne / year	500-1 500 (oil-tar) total contracting cost	Hydrocarbons, oil, PAH, PCP	
GHM Marksanering AB	Composting Bioslurry Soil washing	30 000 tonne / year - 20-40 tonne / hour	350-400 - 500	Hydrocarbons Oil, PAH Oil, PAH and metals	Joint venture with Dutch company
Götaverken Miljö AB	Thermal desorption	-	-	Hydrocarbons Oil, PAH, PCP	
Marksanering I Sverige AB	Composting	8 000 tonne / year	500	Hydrocarbons, oil	
Markåtervinning I Norden AB	Soil washing	10-12 tonne / hour	500-1000	Oil, PAH and metals	
Ragn-Sells specialavfall AB	Composting Thermal desorption	20 000 tonne / year -	200-1200 750	Hydrocarbons Oil, PAH, PCP	Agreement with Dutch company
RECI AB	Composting Solidification	2 000 tonne / year -	300 -	Hydrocarbons Oil, PAH	
Råd I Sverige AB	Soil washing	30-60 tonne / hour	-	Oil, PAH and metals	
SAKAB	Composting Soil washing Incineration	Totally for all methods 50 000 tonne / year	300-600 - 5 000	Hydrocarbons, oil, PAH Oil, PAH and metals All types of contaminants	
Soil Restore Technology AB	Soil washing	-	-	Oil, PAH and metals	
Stabilator AB	Soil washing	1500-3000 tonne / week	-	Oil, PAH and metals	
Storfors miljö AB	Soil washing Thermal desorption	Totally for all methods 50 000 tonne / year	- -	Oil, PAH and metals Oil, PAH, PCP	
Terrameck AB	Composting Soil washing	Totally for all methods 15 000 tonne / year	200-3000 200-3000	Hydrocarbons, oil, PAH Oil, PAH, metals	

Data from Swedish EPA report 4856

A range of Swedish construction companies are offering soil remediation through collaboration with soil remediation companies inside and outside Sweden. Among those are NCC, SKANSKA, JM-bygg and PEAB.

The local landfills in some municipalities can take care of oil-contaminated soil. Most of them treat the soil in a composting system, see Table 31. Some other landfills treat the soil just by putting it in heaps and collect the free-floating oil before the final placement of the soil in the landfill.

Table 30: Swedish municipalities offering composting of contaminated soil

Municipal Company	Capacity (tons)	Cost (SEK/tonne)	Contaminants treated
Affärsverken Karlskrona	-	500	Oil
Ale kommun	-	650 SEK / m^3	Oil
ASSY	3 500 t at the same time	700	Oil, PAH
Bälinge avfall	-	448	Oil
Eksjö energi	-	-	Oil
Gatukontoret Kramfors	-	600	Oil
Gatukontoret, Renhållningsverket Falun	-	250-800	Oil, PAH
Gästrike avfallshantering	-	470	Oil
Halmstad Renhållning AB	-	300	Oil
Hyllstofta Landfill Klippan	-	850	Oil
Kalmar vatten och renhållning AB	400 tonne / year	95	Oil
Katrineholms Miljö- och återvinnings AB	-	800	Oil
Laxå kommun	-	350 SEK / m^3	Oil
Nordvästra Skånes Renhållnings AB	-	-	Oil
Nyköpings kommunteknik	-	300-400	Oil
Nässjö Affärsverk AB	-	-	Oil
Reko Sundsvall AB	-	600	Oil
Söderhamns Renhållning	-	528	Oil
SÖRAB	6 000 tonne / year	-	Oil
Tekniska förvaltningen Boden	500-1 000 tonne / year	-	Oil
Tekniska förvaltningen Kristinehamn	-	328-492	Oil
Tekniska kontoret Malung	50 m^3 / year	77 SEK / m^3	Oil
Tekniska kontoret Oskarshamn	400 tonne / year	450	Oil
Tekniska kontoret Jönköping	4 000 tonne / year	625	Oil
Tekniska kontoret Ulricehamn	-	150	Oil

Table 30: Swedish municipalities offering composting of contaminated soil (continued)

Municipal Company	Capacity (tonnes)	Cost (SEK/tonne)	Contaminants treated
Tekniska kontoret Älmhult	-	220	Oil
Tekniska verken Linköping	-	400-1000	Oil
TRAAB	-	460	Oil
VAFAB	-	490	Oil
Västblekinge Miljö AB	2 000 tonne / year	432	Oil
Växjö kommun	-	450	Oil
ÖKRAB	-	520	Oil

Data from Swedish EPA report 4953

In situ remediation

In situ methods have just recently been established on the Swedish market and only a few full-scale remediations have been performed. The most commonly used methods are pump and treat and vacuum extraction. A range of Swedish contracting companies are offering in situ remediation of contaminated soil and ground-water. Most of them have a range of methods such as: pump and treat, air sparging, vacuum extraction and natural attenuation. These contracting companies are listed in Table 32. Also a range of consulting companies are offering in situ treatments, some of these treatments are performed by the consulting companies themself and others by contracting companies.

Table 31: Swedish contracting companies offering in situ treatment of contaminated soil

Company	**Comments**
Däldehög AB	Joint venture with Danish company
EkoTec	
Götaverken Miljö AB	Collaboration with German company
I. Krüger	
MB Envirotech	American technology on license
Marksanering i Sverige AB	
RECIRK	
Stabilator AB	
United drilling contractors	Owned by Danish company
VYRmetoder AB	
Ö-viks pump & mätarservice AB	Collaboration with Danish companies

Data from Swedish EPA report 4856

Innovative technology

Research for new technologies is going on at several Swedish universities and research institutions. Several of the projects are organized in two research programs funded by the Swedish Foundation for Strategic Environmental Research, MISTRA. One of the programs, Mitigation of the Environmental Impact from Mining Waste, MiMi, (http://www.mimi.kiruna.se) is directed towards sustainable solutions for handling of mining wastes. The other program, Soil Remediation in a Cold Climate, Coldrem, (http://wwwnt.umu.se/coldrem) is directed towards remediation in a cold climate of soil contaminated with organic pollutants and metals.

Several demonstration remediations have been carried out during the last years with funding from the Swedish EPA. Among these projects can be mentioned a large remediation of a lake contaminated with PCB and mercury and another remediation of an old gasworks site.

Just recently two large pilot demonstrations have been performed in collaboration between the Swedish EPA and the Swedish Delegation for Sustainable Technology (http://miljoteknik.nutek.se). One of them was a comparison of eight different technologies for remediation of soil and sediment at an old creosote manufacturer site. Here five methods was performed in pilot scale at the site while three methods was demonstrated in full scale in stationary plants in the Netherlands and Finland. This project was funded by the Delegation for Sustainable Technology and the City of Stockholm. Another ongoing project funded by the Delegation for Sustainable Technology is demonstrating three different methods in the field for remediation of soil and groundwater contaminated with chlorinated solvents.

Monitoring remediation performance

The Swedish EPA has published a range of reports and guidelines about methodology for environmental investigation of soil, inventories of contaminated sites and sampling and analysis for risk classification and remediation performance. Most of these are in Swedish and for more information about English literature contact the Swedish EPA (http://www.environ.se).

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Swedish EPA (1998): Facilities taking care of contaminated soil. Report 4953 (In Swedish)

SWITZERLAND

Ex situ remediation

No exact statistics exist in Switzerland about the volume of material treated ex-situ. Most of the excavated material deriving from the remediation of contaminated sites falls into the “dig and dump” category. Dug out material which does not meet Swiss landfill criteria is often exported to German salt mines.

A considerable amount of the material is nonetheless treated in thermal treatment plants (e.g. high temperature incineration, cement factories, incineration plants for special wastes). Also of this type of material a large proportion is being exported to Germany (e.g. to Berzelius Environmental Services in Duisburg).

Switzerland has only a small number of companies specialised in the treatment of contaminated excavation material. There are two soil washing facilities. One is a stationary installation (Eberhard Recycling AG in Kloten with a capacity of ca. 120'000 t/a. The cost per ton is about 200 Sfr.). The other one is a mobile plant with a considerably lower capacity (NUVAG Umweltschutz AG, Winterthur).

Besides this there exists a small number of companies offering ex situ bio-treatment (e.g. EBIOX AG, Kloten). No exact data are availbale on these treatment facilities.

As far as the treatment of specific contaminants is concerned two distinct ways of treatment can be identified:

Contaminations with organic pollutants such as mineral oil are mostly treated in thermal treatment facilities. Only a small proportion of this type of contaminations is treated by soil washing or bioremediation processes.

Contaminations with organic pollutants such as chlorinated/halogenated solvents are often treated by in situ pump and treat methods or reactive barrier systems (e.g. funnel and gate technology). Another part is treated in high temperature incineration plants.

Contaminations with heavy metals are partly treated by thermal methods (e.g. recycling of lead), partly washed in soil washing plants or exported to underground storage sites in Germany.

Switzerland is currently about to create an electronic information system on companies offering service with relation to the remediation of contaminated land. This database will be available by the end of the year 2000.

In situ remediation

There is no specific policy with respect to this aspect. Swiss legislation defines certain remediation targets which have to be met. The way the remediation targets have to be reached is left to those who are in charge of the remediation of the site. I.e. there is no preferred way of treatment defined by legislation. The best available solution has to be evaluated based on a site specific remediation project.

Note: remediation solutions are only acceptable if the remediation targets can be reached within a certain time frame after which the site may be left unattended.

There are no precise statistics on the number of remediated sites and the technologies used for their remediation. This type of information should be made available by a computerised database within the next year.

The following in situ technologies are currently in use in Switzerland:

- barrier walls (confinement) – contaminants treated: various (organics and metals);
- reactive barrier systems (e.g. funnel and gate systems) – contaminants treated: halogenated solvents and Cr6+ (project);
- various pump and treat technologies - contaminants treated: mainly halogenated solvents;
- bioremediation (e.g. stimulation of microbial activity by the addition of nutrients and oxygen) - contaminants treated: mainly mineral oil.

Innovative technologies

Development of new filler materials for the treatment of Cr6+ contaminated groundwater with funnel and gate system. Project is under development and will be implemented and tested in a specific field case within the next three years.

Development of a control method for determining the microbial activity in *in situ* bio-remediation of sites contaminated by mineral oil. The findings of this research project will be used for the development of a monitoring systems for the evaluation of naturally ongoing attenuation processes in sites contaminated by mineral oils.

In Switzerland it is recognised that natural attenuation processes contribute to the remediation of certain contaminated sites. Nonetheless natural attenuation is not considered as being a “remediation technology” as such although its effects should be taken into consideration during the evaluation of a site.

Waste treatment technologies need further development. The treatment of hazardous waste deriving from the remediation of contaminated sites (such as material from landfill sites containing a mixture of industrial waste) poses big problems with respect to separation, treatment / elimination in an environmentally sound manner.

Switzerland currently has no specific technology development programme with respect to contaminated sites.

Those who are in charge of the treatment of individual sites have to prove by adequate measures that the remediation targets defined by the local authorities are met. Monitoring programmes are defined on an individual basis.

UNITED KINGDOM

General

UK legislation on contaminated land is contained primarily in the

a) Section 57 of the Environment Act 1995 which introduces Part IIA of the Environment Protection Act 1990,

b) Town and Country Planning Act, and

c) Planning Policy Guidance No. 23.

Part IIA was implemented in England and Scotland in 2000 on 1st April and 14th June respectively. It will be implemented separately in Wales and Northern Ireland, following on from devolution. For England, its operation is outlined in a statutory guidance document, available from: *www.defra.gov.uk*. Regulation will largely take place at the local authority level with the Environment Agency also having a role (state of the land report and regulation of Special Sites). The Environmental Agency of England and Wales has published a guide to regulatory procedures for implementation of Part IIA, available from: *http://www.environment-agency.gov.uk/gwcl/LC_Policy.htm*.

The implementation of Part IIA is being accompanied by a raft of technical guidance publications and training, being published by the Department of the Environment Food and Rural Affairs (DEFRA), the regulatory agencies, and other bodies such as CIRIA (The Construction Industry Research and Information Association).

A 'Handbook of Model Procedures for the Management of Contaminated land' is in preparation by the DEFRA and the Environment Agency. The *model procedures* will set out good practice for the overall process for managing contaminated land. They combine the tasks carried out when dealing with land, which is, or may be, contaminated into a sequence of risk based steps. This framework incorporates existing good technical practice for assessing and managing the risks associated with contaminated land into a systematic process for identifying, making decisions about and taking appropriate action to deal with the contamination in a way that is consistent with UK legislation. The three primary model procedures are:

- Risk assessment
- Evaluation and selection of remedial measures
- Implementation of risk management actions.

These primary procedures are part of a hierarchy of documents, which increases in complexity and technical detail at each tier. They are to be supported by supporting secondary model procedures (e.g. Verification of remedial treatments for contaminated land) and technical guidance/reports. Taken together this comprehensive package of guidance will constitute a complete decision support system, linking individual decision support tools. Procedures will be summarised in a series of flow diagrams within these publications. These *model procedures* will not be mandatory, nor a substitute for appropriate specialist experience. The procedures assist in the integration of both technical and non-technical issues to optimise the management of land. Further information is available from the CLARINET report on Decision Support Tools.

Remediation Activity and Remediation Technology Use

Land contamination has been subject to increasing remediation activity in the UK during the 1990s. In 2000, the Environment Agency undertook a survey1 of land contamination remediation activity in England and Wales since January 1996. The survey was designed to establish a baseline understanding of the implementation of a range of remedial techniques so as to provide the Agency with a factual database of activity. An additional objective was to understand the key factors influencing the choice of technique.

The survey involved:

(i) A scoping study to ascertain the nature and potential extent of available information

(ii) A questionnaire survey of a sample of local authority environmental health and planning officers with visits to some offices to conduct interviews with relevant officers and to review case site records

(iii) A questionnaire survey of a sample of major landowners, developers and other organisations including the National House-Building Council (NHBC)

In total, 367 sites subject to remediation during the period January 1996-December 1999 were identified. In addition NHBC has provided information collated from the notification by builders of 1189 sites to the Council. The data confirm that the majority of remediation activity involves small sites less than 5 hectare in size;

- prior industrial land uses;
- the protection of human health risk;
- soil (as opposed to water) remediation;
- development-led remediation; and
- civil engineering-based remediation techniques.

However, there is evidence that multiple remediation techniques are being used on sites to match contaminant distribution patterns, end-use layout and the drive to minimise costs. Although only a minority of sites are subject to formal options appraisal there is evidence that cost, while being a key consideration, is not the only factor taken into account: the effectiveness of the techniques in reducing contaminant risk, applicability to contaminants and the availability of the techniques are also important factors influencing selection. Whilst cost is an important selection factor, cost

1 Petts J., Rivett M., Butler B. .Environment Agency R&D Technical Report P401

data are extremely difficult to collect. Remediation objectives are increasingly site-specific and risk-based, although reference to generic criteria dominates. Only a minority of sites are subject to post-remediation monitoring.

Overall, civil engineering techniques have been used on 94% of sites, *in situ* on 16% and *ex situ* on 5%. *In situ* methods each represented less than 3% of reported site use apart from dual vacuum extraction which is reported for 31 sites (9%). There was no reported use of phytoremediation or reactive walls. Since this report was published, application of Reactive Barriers at least two UK sites has been proposed. A Funnel and Gate™ project is also in existence in Northern Ireland. The only *ex situ* processes reported were *ex situ* bioremediation (11 sites, 3%) and soil washing (7 sites, 2%). However, it is important to note that the survey excluded vendor based information. The survey found that only 8 sites (2%) reported the pilot use of a process based remediation technique. However, anecdotal evidence from technology vendors and consultants -indicates a higher and increasing use of process based technologies, i.e. , hundreds of incidences of SVE or dual phase extraction. Table 33 lists some examples of treatment process based remediation projects that have taken place in the UK. This only represents a proportion of the process based remediation projects that have taken place in the UK. Most are not reported in the open literature.

The survey found that a quarter of the site remediations identified have costs over £1m, including 4 over £5m and 3 over £13m, with the Millennium Dome component of the Greenwich Peninsula site being the largest at £147m. As expected the cost data as presented include not only the remediation activity itself (95% of the data) but also 63% of the reported data relate to site investigation costs, 52% to desk study costs and 38% include post-remediation monitoring costs. The survey did not present cost data comparing the various techniques available. Table 34 provides a list of INDICATIVE UK remediation costs for various techniques, taken from a recent paper by NATHANAIL, 2000.

The Millennium Dome component of the Greenwich Peninsula site cost £147m, which involved the following:

- Special waste to landfill - 200000m^3
- Hazardous waste to landfill - 50000m^3
- Gravel washing - 8000m^3
- Re-used alluvial clay - 4000m^3
- Soil washing - 15000 m^3
- Crushing and screening - 80000m^3
- Screening alone -70000m^3

This project is one of the largest to have taken place in the UK, and is reported in more detail in Annex B which is an extract of a paper by BARRY, 1999. There is anecdota; evidence that the large landfill requirement for this project stimulated the development of the landfill service industry, who opened up additional void space. While the project has been completed, the additional landfill services are still available, depressing proces for soil disposal from contaminated sites, at least in the South of England. This has further tightened the competitive situation for remediation technology providers in the UK.

Ex Situ versus *In Situ* Remediation

There is no specific policy preferring one remediation approach to another. There is a desire to reduce use of landfill for dealing with materials produced by site restoration. There are no dedicated central soil treatment facilities per se. However, hazardous materials from contaminated sites may be sent for treatment / incineration to off site waste management facilities. Additionally, some service providers are contemplating situating treatment plants at landfills.

However, in general, *in situ* approaches are used in relation to contamination either within (or destined for) groundwater via the unsaturated zone. Most non water-related, or immobile, contamination is dealt with by ex-situ means, predominantly involving disposal, either onsite or offsite.

Table 32: Commercial Trials and Use of Treatment Technologies in the UK. 1995-2000 (Modified from MARTIN & NATHANAIL 1998)

Bioaugmentation to reduce Cr^{6+} to Cr^{3+} *in situ*, Glasgow, *Environmental Reclamation Services*
Biopiles, former marshalling yard, University of Lincoln site, *Entec* - petroleum hydrocarbons.
Biopiles, London and Clydebank, *Bio-Logic Remediation Works Ltd* - petroleum hydrocarbons and PAHs.
Bioreactor technology, Advantica, trialed for coking plant site
Biosparging, various sites, *WSP remediation (also use treatment beds, and MNA)*
Bioventing, NW England, *Biotal Ltd* - diesel contamination.
Bioventing, SE England, *Celtic Technologies* - oils and solvents.
Cometabolic bioventing, UK, *Shell*
Immobilisation of organic substances using modified organophillic clays, *Envirotreat Ltd*, various organic contaminants.
In situ bioremediation of DNAPLs using solvents, *Arcadis Gerachty & Miller*
In situ chemical oxidation, *QDS*
In situ funnel and gate, Northern Ireland, *Golder Associates*, chlorinated solvents.
In situ remediation using pump and treat and soil vapour extraction, *MEL Ltd* and *Golder Associates*, DNAPL treatment to remove halogenated hydrocarbons and semi-volatiles.
In situ soil vapour extraction within containment cells combined with *ex situ* bioremediation and groundwater treatment, Gatehead, *MEL Ltd*, petroleum hydrocarbons, BTEX and PAHs.

Table 32: Commercial Trials and Use of Treatment Technologies in the UK. 1995-2000 (Modified from MARTIN & NATHANAIL 1998) (continued)

In situ stabilisation and solidification, south-west Scotland, *Bachy UK Ltd*, low pH waste disposal area leaching heavy metals.
Molecular Bonding to reduce Cr^{6+} to Cr^{3+} *ex situ*, Glasgow, *Beech Solucorps*
Monitored Natural Attenuation, several UK sites
On-site *ex situ* solidification and stabilisation process, *Geodur UK Ltd*, contamination problem not specified.
Oxygen Release Compound, *Arcadis Gerachty & Miller* – petroleum hydrocarbons, several sites
Phytoremediation / reed beds, *various*: landfill caps, acid mine drainage, groundwater management
Phytoremediation using SRC, near Glasgow, *WRC et al*, Cr and metals
Pump and treat, Queensferry, Clywd, *Edmund Nuttall Ltd*, industrial solvents.
Soil washing PCB site, NE England
Soil washing, former armaments site, Woolwich, *VHE*
Soil washing, former MGP, Nottingham, *Bergmann/VHE/Parkman*
SVE, petrol stations, many sites, *QDS and others*
Thermal desorption, *Royal Ordnance*, hydrocarbons.
Treatment beds, gasworks S England, *British Gas Research and Technology*.
Treatment beds, Grassmoor lagoons (coking plant), *Celtic*
Windrow treatment with bioaugmentation, Fuel depot Dorset, *Eco-Environmental Services* – petroleum hydrocarbons.
Windrow treatment, Railways site, Norwich, *Biologic Ltd,* TPH, PAH

Table 33: Indicative Costs of Remediation, UK experience (NATHANAIL, 2000)

Remediation technology	**Indicative unit price**
'Typical' grout curtain / vent trench	£220,000 per site
'Typical' landfill gas control system	£200,000 per site
Air sparging	£45-55 / m^3 groundwater
Bioremediation	£35-£45 / tonne
Dechlorination	£100 - £300 / tonne
Encapsulation (deep cut-off wall)	£70-£120 / m^2
Encapsulation (shallow cut-off wall)	£40-£60 / m^2
Engineering capping	£15-£30 / m^2
Enhanced Thermal Conduction	£35-45 / m^3
Excavation and disposal to landfill	£50 / m^3

Table 33: Indicative Costs of Remediation, UK experience (NATHANAIL, 2000) (continued)

Remediation technology	Indicative unit price
Free product recovery	£10-20 / m^3 vadose zone
In situ chemical oxidation	£40-80 / m^3
In situ vitrification (5t / hr)	£150 - £215 / tonne
Incineration (special wastes)	£750 - £1,000+ / tonne
Oxidation of cyanide	£400 / tonne
Pump and treat	£20-30 / m^3
Six phase heating	£20-30 / m^3
Soil vapour extraction	£40-60 / m^3 vadose zone
Soil washing	£30 - £35 / tonne
Solidification / stabilisation	£30-60 / m^3
Solvent extraction and incineration	£400 / tonne
Thermal desorption (including excavation and pre treatment)	£35 – 150 / tonne
Vitrification	£40 / tonne

Regulation of Remediation Technology Use

To ensure that particular activities do not cause pollution of the environment or harm to human health the Government has enacted a wide range of legislative controls.

- In order to protect the water resources, levels of contaminants in discharges to controlled waters are controlled through discharge consents[2] or Groundwater Regulations Authorisations.
- Where an activity or operation poses an unacceptable risk of pollution of controlled waters, (but no discharge is intended), notices may be served to control or prevent the continued operation[3].
- Emissions from specified major industrial sites are controlled under Integrated Pollution Control Authorisations[4]. This requires certain activities (for example waste incinerators) to operate to a particular standard (Best Available Technique) to reduce the emission of pollutants to air, water and land.
- Operations involving the recovery or disposal of waste are subject to control under the EC Framework Directive on waste[5].

2 Issued under Part III of the Water Resources Act 1991 or the Groundwater Regulations 1998

3 Through the Anti-pollution Works Notice Regulations 1999 and the Groundwater Regulations 1998

4 Issued under Part I if the Environmental Protection Act 1990

5 Council Directive 91/156/EEC of 18th March 1991 amending Directive 75/442/EEC on Waste

The waste management licensing system under Part II of the Environmental Protection Act 1990, and the Waste Management Licensing Regulations 1994, is the main means by which the Directive's requirements have been transposed. Under this system anyone who deposits, recovers or disposes of waste must do so in compliance with the conditions of a waste management licence, or within the terms of an exemption from licensing, and in a way which does not cause pollution of the environment or harm to human health. A number of concepts were introduced including; the requirement for operators of such activities to be fit and proper persons and the requirement for the licence to remain in force until it has been surrendered demonstrating that the land will not cause pollution.

Part II of the Environmental Protection Act 1990 (EPA9O) also introduced the concept of mobile plant licences. This allows the Environment Agency to licence a plant, that by its design is mobile and will not be restricted to one piece of land for a limited number of prescribed waste treatment activities[5]. In addition the Act allows, through regulations containing general binding rules, the regulatory burden to be reduced for activities that promote the recycling and reuse of waste where there is not an unacceptable risk to the environment. The Agency's guidance provides a decision framework for the application of tests, in the form of the flowchart in figure 3 and the accompanying text. When assessing land remediation proposals, Agency officers should work through this framework. However, it is agreed that for in-situ techniques or options, such as Permeable Reactive Barriers or Natural Attenuation, the existing legislation is inadequate as a regulatory mechanism

The degree of risk posed, and the subsequent level of pollution control required by different land contamination remediation activities at different sites, can vary greatly. This variation is due to the fact that:

- different remediation techniques produce different emissions
- different contaminants and levels of contamination are found at different sites.
- organic contamination from a different area might be dealt with by bioremediation.
- different receptors have differing sensitivity to pollutants.

A total of 21 mobile plant licences have now been granted for contaminated land remediation technologies in England and Wales. Six are for *in situ* and 14 for *ex situ* remediation, while one covers a combination of the two.

In detail, 5.56 licences are for ex situ bioremediation in soil treatment beds; one for in situ bioremediation; 3.5 for soil vapour extraction; six for soil washing technologies; one for solvent extraction; three for solidification and stabilisation; and one for chemical treatment.

6 0.5 of a license highlights where a license covered two technologies

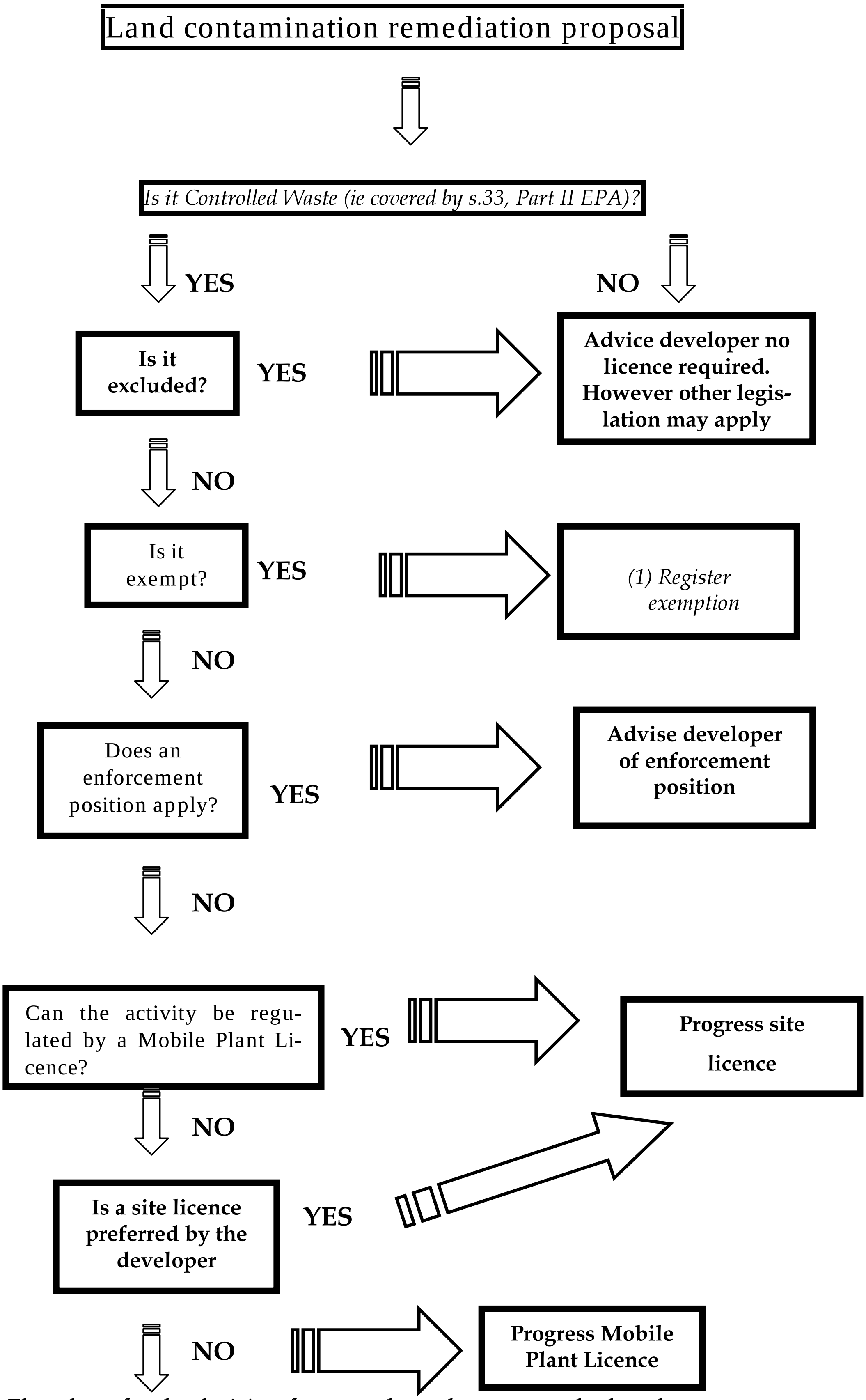

Figure 3: Flowchart for the decision framework used to assess whether the waste management licensing regime applies to a land contamination remediation proposal

Remediation Technology Research and Development

Several organisations have an interest in research, summarised in Table 35. Organisations involved with supporting field scale research, and also technology demonstration are:

- Environment Industries Commission (EIC),
- The Soil and Groundwater Technology Association
- The Construction Industries Research And Information Association (CIRIA)
- exSite Research Limited and CLAIRE (Contaminated Land Applications in Real Environments) - outlined in Chapter 2.4
- The UK DTI (Department of Trade and Industry) may support some bioremediation development through its Biowise programme

Remediation technology R&D needs was reviewed recently by DETR and this year by BBSRC's soil advisory committee (see Section 18.7). The DETR report details are given in Section 18.7. It contains details of the current programmes mentioned in Table 35, and also some recently completed programmes. Web links for these organisations are provided in Section

Table 34: Government funded UK Research programmes

Programme title & acronym	Summary	Sponsor	Duration (years)	Budget/Funding to date	No of projects	Estimated % Contaminated Land R & D	Eligibility	Keywords	Contact
LINK Biological Treatment of Soil and Water (BTSW)	Multidisciplinary programme launched in April 1993, focused on land reclamation and effluent treatment	DTI, BBSRC, EPSRC, NERC, Industry	5	£ 8.3m	15	60	U, RI, PSRE, C, AIR-TOS	Contaminated land, effluents, slurries, bioremediation, biotreatment, monitoring, sensors	DTI - Sue Ellison BBSRC - Ben Sykes
Urban Regeneration and the Environment (URGENT)	In partnership with urban authorities, industry and regulatory bodies: multidisciplinary research programme	NERC (with links to WPM – EPSRC)	7	£ 9.7m	41	60	U, RI	Sub-surface, atmospheric science, chemistry, hydrology, hydrogeology, ecology, environmental monitoring and info systems	NERC – Graham Leeks (CEH Wallingford)

Table 34: Government funded UK Research programmes (continued)

Programme title & acronym	Summary	Sponsor	Duration (years)	Budget/Funding to date	No of projects	% Contaminated Land R &	Eligibility	Keywords	Contact
Waste and Pollution Management (WPM)	Industry-led programme to support engineering and physical sciences research	EPSRC, NERC, Environment Agency	5	£ 8.1m	49	70	U, RI	Contaminated land, landfill practice	EPSRC - Steve Milsom
Environmental Biotechnology	Limited programme launched in 1995, focused on bioavailability of pollutants in soils and liquid effluent treatment	BBSRC	5	£ 3.1m	14	70	U, RI	Bioavailability of pollutants in soils, liquid effluent treatment, biosensors	BBSRC - Ben Sykes
Environmental Diagnostics (ED)	Programme to address a number of fundamental contaminated land issues	NERC	8	£ 7.8m	35	80	U, RI, PSRE, C, AIR-TOS	Chemical transport processes and pathways, biotransformations, effects, detection of contamination, critical loads	NERC - Daniel Osborne
Contaminated Land: Applications in Real Environments	A public/private partnership to establish a UK network of contaminated sites to demonstrate remediation research.	SAGTA, English Partnerships, EA, SEPA, DETR, WDA, DoE (NI)	4+	£ 1.1m	6+	100	open to all	Contaminated sites, demonstration projects, site characterisation, monitoring, risk assessment	CL:AIRE - Paul Beck

Table 34: Government funded UK Research programmes (continued)

Programme title & acronym	Summary	Sponsor	Duration (years)	Budget/Funding to date	No of projects	% Contaminated Land R &	Eligibility	Keywords	Contact
LINK Bioremediation Programme	A bioremediation programme to support pre-competitive research projects between industry and universities and other members of the research base.	DTI, BBSRC, EPSRC, SERAD, MRC, ESRC, Environment Agency, Industry	5	£ 15m	None, first call for proposals 25.04.01	70	open to all inc SME's	- natural attenuation - insitu bioremediation - field conditions - risk assessment - insitu monitoring - integration with other technologies -human health impacts - socio-economic considerations	DTI - Sue Armfield
BIO-WISE	Programme to increase the use of biotechnology in industry	DTI	4	£ 13M	n/a	n/a	open to all inc SME's	- economic benefits - environmental benefits - industrial biotechnology - biotechnology suppliers - grant support	DTI - Bob Brooks

U: Universities
RI: Research Institutes
PSRE: Private sector research establishments
C: Companies
AIRTOS: Association of Independent Research and Technology Organisations
SME: Small to Medium-size Enterprises

Monitoring treatment performance

UK Environment Agency has commissioned research to evaluate the various methods adopted world-wide to assess and verify the effectiveness of soil remediation activities, with the aim of ultimately producing UK guidance which provides a strategy for remedial treatment verification. The main objectives of the guidance are to:

- Address best international practice and further develop these procedures;
- Produce a guidance document that provides clear and transparent procedures for measuring the effectiveness of any given remedial treatment activity against predetermined clean-up objectives;

- Ensure the selected verification approach is practical and consistent with the scope of the remediation exercise;
- Provide clear guidelines for data requirements for regulators and practitioners in the design, running and closure of remediation activities;
- Ensure a consistent approach by all contaminated land practitioners to data evaluation / validation.

As a first step in the production of the Guidance Document the Agency intends to review current international practice to identify the approaches commonly employed to measure the effectiveness of any given remediation solution.

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Sample Web links to the United Kingdom: note this is far from an exhaustive listing

Association of Geotechnical and Geoenvironmental Specialists (AGS)	http://www.ags.org.uk
Biotechnology and Biological Sciences Research Council (BBSRC): Engineering and Biological Systems Committee	http://www.bbsrc.ac.uk/opennet/structur/stg/ebs.html
BIO-WISE	http://www.dti.gov.uk/biowise
British Library on line	http://www.bl.uk/
Changing Places	http://www.changingplaces.org.uk
CIRIA: Construction Industry Research and Information Association	http://www.ciria.org.uk/
CLAIRE: Contaminated Land: Application In Real Environment	http://www.claire.co.uk
Compendium of Pesticide Common Names	http://www.hclrss.demon.co.uk
Department of the Environment for Northern Ireland	http://www.doeni.gov.uk/
Department of Trade Industry-DTI (Biowise Initiative)	http://www.dti.gov.uk/biowise/
DEFRA: Department of the Environment, Food and Rural Affairs	http://www.defra.gov.uk/

EEVL (Edinburgh Engineering Virtual Library)	http://www.eevl.ac.uk/
ENDS	http://www.ends.co.uk/
Environment Agency of England & Wales	http://www.environment-agency.gov.uk/
Environment Industries Commission	http://www.eic-uk.co.uk
Environment Industries Commission Online Guide	http://www.eic-guide.co.uk/guide.html
Environmental Data Interactive Exchange	http://www.edie.net
Environmental Technology Best Practice Programme	http://www.etsu.com/etbpp
exSite	http://www.exsite.org.uk
FOCIL: Forum on Contamination In Land	http://www.nottingham.ac.uk/scheme/research/LQM/Focil/introduction.htm
Her Majesty's Stationery Office: Statutory Guidance, Legislation and other Publications on line	http://www.hmso.gov.uk/
House of Commons all Links and Committees	http://www.parliament.uk/commons/hsecom.htm
Ingenta.com - "the global research gateway"	http://www.ingenta.com
JEMU: Joint Environmental Markets Units	http://www.dti.gov.uk/jemu/main_home.htm
Joint Research Council Review of Bioremediation Research in the UK	http://www.bbsrc.ac.uk/opennet/structur/stg/biores.html
Land Contamination and Reclamation	http://www.btinternet.com/~epppublications/
Land Quality Management	http://www.lqm.co.uk
Land Regeneration Network	http://www.grc.cf.ac.uk/lrn
NERC: Natural Environment Research Council	http://www.nerc.ac.uk/
Network on Natural Attenuation in Groundwater and Soil (NNAGS)	http://www.shef.ac.uk/~nnags/
r^3 Environmental Technology Limited	http://www.r3environmental.co.uk
regeneration-uk.com	http://www.regeneration-uk.com/

Remediation.co.uk	http://www.remediation.co.uk
Safegrounds (a CIRIA network)	http://www.safegrounds.com
SAGTA: Soil and Groundwater Technology Association	http://www.sagta.org.uk/
SEPA: Scottish Environment Protection Agency	http://www.sepa.org.uk/
Sitescope Online / Catalytic Data Limited	http://www.sitescope.co.uk
SNIFFER	http://www.sniffer.org.uk/
The Engineering and Physical Sciences Research Council (EPSRC)	http://www.epsrc.ac.uk
Thomas Telford	http://www.thomastelford.com/
Waste Management Information Bureau	http://www.silverplatter.com/catalog/wsti.htm
Welsh Development Agency	http://www.wda.co.uk

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