Soil and Groundwater
Project No. 21

1996

Barriers to Development and Application of New Remedial Technology

Ministry of Environment and Energy, Denmark
Danish Environmental Protection Agency

Miljø- og Energiministeriet **Miljøstyrelsen**

In 1993 the Danish Environmental Protection Agency initiated a package of projects aiming at developing a set of tools for prioritization of measures towards soil and groundwater pollution, and guidelines for the overall management of groundwater resources. The project budget amounts to a total of 12 million DKK in the project period 1993-1994.

The leading principle underlying the design of projects was to ensure the usability of individual projects to the local and regional authorities. This objective resulted in the formulation of both general projects on the protection of groundwater resources and risk assessment of pollution sources, and inventories/manuals on specific issues. The Danish EPA has found it very important that the regional authorities and the Danish Waterworks Association among others were involved in the execution of the projects, to ensure agreement on the projects and on the methodology used.

Work on the project package was organized in an overall coordination group and five technical groups, acting as steering groups for the projects and dealing with the following subjects: Groundwater Resources, Agriculture, Risk Assesment of Point Sources, Remedial Technology/ Strategy, and Strategy & Actions Plans.

The individual projects were carried out by sectoral research institutions, universities, consultancy firms, and regional authority officials contracted for specific projects.

Soil and Groundwater Project No. 21
Projekt om jord og grundvand fra Miljøstyrelsen

1996

Barriers to Development and Application of New Remedial Technology

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Ministry of Environment and Energy, Denmark
Danish Environmental Protection Agency

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Introduction to the Danish Administration of Contaminated Land

The Danish public sector is divided into three different levels:

- the municipality (local) level
- the county (regional) level
- the central administration (national) level

In total, Denmark consists of 16 counties and 275 municipalities. In the environmental field, the central authority is the Danish Environmental Protection Agency (DEPA) under the Ministry of Environment and Energy.

Regulation

Cleanup of contaminated soil, ground water and surface water is effected at all three levels and is in Denmark governed by three different acts:

* Environmental Protection Act (revised in 1991), /Ref.1/.

* Waste Deposits Act (act on contaminated sites) (revised in 1990), /Ref.2/.

* Act (1993) on Economic Blight to Family Housing etc. on Contaminated Land, /Ref.3/.

The first remedial actions were carried out around 1980, and the original legislation came into force in 1984.

Agreements

In general, as stated in the Environmental Protection Act, the Ministry of Environment and Energy encourages voluntary agreements between authorities and private industry.

The Danish Petroleum Industry Association has made an agreement with the DEPA for the purpose of cleaning up all contamination stemming from the operation of service stations in Denmark. The Danish Oil Industry Association for Remediation of Retail Sites, see /Ref.4/, carries out approximately 150 cleanups a year and is financed by contributions from the oil companies of DKK 0.04 on every litre of petrol sold in Denmark (ECU 0.55/m^3 petrol).

Liability

In theory, the Danish environmental legislation is based on the polluter-pays principle. During recent years, it has, however, in several lawsuits been demonstrated that strict liability within the field of contaminated sites cannot be applied. Thus, the Supreme Court has ruled against the Ministry of Environment and Energy in cases where it could not be proved that the polluter was acting *mala fide* at the time when the polluting activity took place.

A ruling from the Supreme Court in 1992 stated that the normal time limit of 20 years in Danish civil law applies in cases of soil contamination.

Environmental protection

The Environmental Protection Act lays down the framework for operating polluting activities and gives the authorities the right to carry out inspections and the power to enforce orders etc. Investigation and cleanup of contaminated soil and ground water can therefore take place by an administrative order.

It is worth noting that the orders pursuant to the Environmental Protection Act can be addressed to the current owner of the land only. If the owner/leaseholder is not identical with the polluter, the authorities must institute proceedings against the polluter.

Contaminated sites

Definitions

The Waste-Deposits Act makes it possible for the authorities to take and finance action against sites where the contamination took place before the implementation of legislation, e.g. the above-mentioned Environmental Protection Act. It therefore follows that a contaminated site in Denmark is defined as a site polluted with oil and oily waste before 1972 <u>or</u> chemicals and chemical waste before 1976 <u>or</u> is a former landfill site put in operation before 1974 and closed down in 1990 at the latest. It is a condition that the contamination at the site may be a threat to human health and/or the environment (flora, fauna, ground water, surface water).

Sites contaminated after 1972, 1974 and 1976, respectively, represent an unregulated area in so far as they are not owned by the person or company who has caused the pollution.

Identification of sites

Identification of contaminated sites in Denmark consists of the following steps:

Step 1. Mapping of potentially contaminated sites
(Desk studies of present and former land use etc.)

Step 2. Preliminary investigations on sites (in order to demonstrate that the site is actually contaminated)
(Walk over surveys, sampling etc.)

Step 3. Registration with and notification to the Land Registry

Registration of sites

Until the end of the 1980s, step 2 and the notification to the Land Registry were optional. Registrations could be made on "a valid suspicion", e.g. on the basis of a specific land use. Around 1988 the mortgage credit institutions introduced economic blight, and house owners who had (possibly) been incorrectly registered suffered severe losses in their private economy. Politically, this was unsustainable, and a more solid procedure for registration was implemented. Furthermore, the Act on Economic Blight to Family Housing etc. on Contaminated Land (see below) was passed by Parliament.

De-registration

Registration is made by the counties. When a site is fully cleaned up, it can be removed from the registry (de-registration) and the notification to the Land Registry is cancelled.

License for land use

Partly cleaned up sites remain in the registry, and changes in the land use are licensed by the county. A change in the land use to a more sensitive use must again be licensed by the county.

Public spending

Public spending (DDK 280 mio. (ECU 38.5 mio.) in 1995) is only applied in connection with cleanups which neutralize a conflict between the present land use/ground water interests and contamination. Development of contaminated land (voluntary cleanups) can only be effected by private financing. Development projects must have a license if the site is not totally cleaned up and de-registration has taken place.

Act on Economic Blight to Family Housing etc. on Contaminated Land

A special clean-up system for home owners was introduced in late 1993 with the Act on Economic Blight to Family Housing etc. on Contaminated Land. By paying a minor contribution, the home owner can get a publicly financed cleanup. The scheme was introduced to ease the problems for the home owners, an important group, and facilitate operations on the real property market.

Cleanup due to economic blight takes place at registered contaminated sites and sites with younger contamination, but with similar characteristics as those of sites included in the Waste Deposits Act. The idea is that sites with housing affected by minor contamination are cleaned up faster.

In 1995 the scheme has a budget of DDK 81 mio. (ECU 11.1 mio.). Demand for the scheme has so far been relatively low.

Future work

As described above, the system for cleanup of contaminated land in Denmark has undergone changes and budding during the last 10-12 years. Changes in the perception of problems of contaminated sites, uncertainty in the legal framework of liability, a complicated administrative structure and a lack of standard criteria are some of the reasons why the Minister of the Environment and Energy has set up a Commission dealing with the entire area of contaminated sites.

The Commission chaired by the DEPA is working on new and adjusted concepts for contaminated land management and remediation, and will publish a position paper and a draft for comprehensive contaminated land legislation by the end of 1995.

References to the Introduction

/Ref.1/ *Lov nr. 358 af den 06-06-1991 om Miljøbeskyttelse.*

/Ref.2/ *Lov nr. 420 af den 13-06-1990 om Affaldsdepoter.*

/Ref.3/ *Lov of 214 af den 28-04-1993 om en værditabsordning for boligejere m.v.*

/Ref.4/ *Lassen, Ernst V.H. and Andersen, Mette K., 1993. Aftalen om Oliebranchens Miljøpulje. INFONYT nr.4/1993.*

Abstract

In the present report, an analysis of the application of remedial technology in Denmark is carried out and an overview of the technical and non-technical barriers determining the criteria for application of primarily in-situ-/on-site technologies and secondarily application of off-site treatment technologies is provided.

The report, which is strictly limited to technology for application in connection with soil contamination, also includes an account of remedial technology presently applied in the USA and the Netherlands.

List of remedial technologies

Annex 1 provides a list of remedial technology applied in connection with soil contamination in Denmark as well as abroad. The list also indicates the status of implementation of each technology. The listed on-site and in-situ treatment technologies are due to their relatively modest application deemed innovative in Denmark. A possible exception may be soil vapour extraction.

However, several of the on-site and in-situ treatment technologies can hardly be deemed innovative abroad. This is particularly true for:

- on-site,
  - thermal treatment (incineration)
  - thermal desorption
  - soil washing
  - stabilization/solidification (for heavy metals only),
- in-situ,
  - soil vapour extraction

The following technologies are, moreover, applied relatively extensively abroad:

- on-site,
  - windrow composting
  - land farming
- in-situ,
  - biological cleaning
  - bioventing
  - forced soil flushing

Application of technologies

In Denmark, soil contamination is mainly cleaned up by means of excavation followed by off-site treatment and/or disposal. Innovative technologies are, however, applied more frequently in voluntary cleanup operations pursuant to the Waste Deposits Act and cleanup operations in connection with the Environmental Protection Act than in publicly financed cleanup operations pursuant to the Waste Deposits Act.

The innovative technologies which seem to be more and more frequently applied in Denmark are in-situ soil vapour extraction and biological technologies such as land farming.

The application of remedial technology in Denmark is compared with the application of remedial technology under the Superfund programme in the USA. Significant differences can be pointed out. The treatment of contaminated soil through stabilization/solidification and in-situ soil vapour extraction in particular is far more widespread in the USA than in Denmark. Moreover, technologies such as thermal desorption and soil washing are relatively frequently applied in the USA, whereas in Denmark these technologies are not applied today (neither on-site nor off-site).

If the application of remedial technology in Denmark is compared with that of the Netherlands, similar great differences are not observed. In the Netherlands, excavation followed by off-site treatment and/or disposal are just as frequently applied as in Denmark. Soil washing, however, is relatively frequently applied in the Netherlands for treatment of contaminated soil, whereas in Denmark this technology is, as mentioned above, not applied today. With this exception, innovative in-situ/on-site technologies seem to be more frequently applied in Denmark than in the Netherlands. It should be noted that the figures from the Netherlands stem from the period of 1980-90. New developments are therefore not included.

Types of contamination

In terms of type of contamination, cleanup by means of excavation followed by off-site treatment and/or disposal is in Denmark considered to be applicable in connection with almost all types of soil contamination handled in Denmark. For most types of contamination, the experience record of application of on-site and in-situ technologies in Denmark does, however, seem to be relatively limited. The greatest basis of experience seems to be related to application of in-situ soil vapour extraction and biological technologies such as land farming in connection with contamination with petroleum products and BTEXs. With these and other on-site and in-situ technologies it seems to be generally difficult to reach the levels of residual contents of soil contaminants deemed acceptable to sensitive land use in Denmark.

Geological limitations

Treatment of heterogeneous soil and clay, moreover, seems to be a general problem in connection with application of on-site and in-situ technologies. For heterogeneous soil, the problem is not only execution of the treatment, but also the subsequent documentation of the treatment effect as both the concentration of contaminants and the treatment effect vary considerably from area to area. Inhomogeneous geology may thus entail a retention in pockets of residual contamination after treatment.

Barriers

In addition to the geological limitations mentioned above, a more extensive analysis of barriers to development and application of innovative technologies in connection with soil contamination in Denmark has been carried out. The results demonstrate that in addition to barriers of a technical nature, including for instance geology, there are also several non-technical barriers of importance to the criteria for choice of technology in each specific case.

The barriers identified are divided into four groups:

- legislative barriers,
- institutional barriers,
- financial and market barriers,
- technical barriers.

The non-technical barriers, such as for instance the existing registration system pursuant to the Waste Deposits Act, are deemed to be at least just as important as the technical barriers.

Moreover, it is characteristic of the non-technical barriers that they can be eliminated by changing the law or elaborating rules for non-regulated areas. This is not true of the technical barriers, the present technical limitations of which can only be eliminated by technological development.

The non-technical barriers, furthermore, form the basis of a division of the Danish cleanup operations into three reference situations, see figure 1 in which each situation is defined by the requirements and/or desires forming the basis of the decision on cleanup activities and the requirements made for the extent of the cleanup.

Figure 1
Cleanup reference situations in Denmark

Cleanup reference situations in Denmark

Situation A	A1	Waste Deposits Act - very sensitive land use at the time of cleanup
	A2	Act on Economic Blight for Family housing etc. on Contaminated Land
	A3	Order pursuant to the Environmental Protection Act
Situation B	B1	Other cleanup pursuant to the Environmental Protection Act
	B2	Other cleanup pursuant to the Waste Deposits Act
Situation C	C1	Cleanup according to agreement on the Danish Oil Industry Association for Remediation of Retail Sites

With the present technological level there is for each of the above situations a direct connection between the situation and the choice of remedial technology. All cleanup operations in situation A are, for instance, effected by means of excavation followed by off-site treatment and/or disposal, which is due to the requirement and the desire for a subsequent de-registration or the similar rubber-stamp by the authorities of the previously contaminated area.

Scenarios for application of technology

For the purpose of illustrating the connection forming the basis of the choice of remedial technology in a specific case of contamination, three scenarios for application of technology have been set up on the basis of the analysis of barriers to innovative remedial technology:

Scenario 0	: Present application of technology
Scenario 1	: Maximum application of in-situ/on-site technologies
Scenario 2	: Maximum application of off-site technologies

The review of the three scenarios establishes that the present application of technology with an emphasis on excavation followed by off-site treatment and/or disposal will continue for a number of years unless the area is subjected to regulation, see table 1.

Hence, in-situ/on-site technologies in cleanup operations in reference situation A with a very sensitive use of the contaminated area at the time of cleanup are not expected to be applied neither at present nor in the future.

In-situ/on-site technologies

If an emphasis is put on implementing innovative in-situ/on-site technologies, also for cleanup operations in reference situation A, significant changes in the present legislation and administration will be required.

Table 1
Expected future application of technology without public support and control

Cleanup situation	In-situ/on-site treatment	Off-site treatment and/or disposal
A Waste Deposits Act - very sensitive land use Act on Economic Blight to Family Housing etc. on Contaminated Land Environmental Protection Act - orders etc.		
B Waste Deposits Act - other cleanup Environmental Protection Act - other cleanup		
C Cleanup pursuant to agreement on the Danish Oil Industry Association for Remediation of Retail Sites		

Off-site treatment of contaminated soil

Changes are also deemed necessary if maximum application of off-site treatment is aimed at. Here, particulary implementation of stricter rules on disposal and application of contaminated soil at landfills will entail a redirection of contaminated soil to the existing treatment facilities. As an example of a way to regulate this area, the Dutch SCG/TGB system is described.

Development of new remedial technologies

Development of new remedial technology is to some extent restrained by the lack of willingness to invest. The assessment is made that presently great uncertainty as to how the market will develop exists and some hesitation towards large-scaled investments in advanced treatment facilities is prevailing.

Moreover, no platform from where a coordinated research and development effort within treatment of contaminated soil can be made has been established and no forum where innovative technology can be tested and demonstrated is available either.

Thus, development of innovative remedial technologies is not deemed possible without public support and control.

In connection with the review of the three scenarios, a preliminary identification of areas of effort within development and commercialisation of innovative soil treatment methods has been made. It is stated that methods on a bench scale have been developed for the major part of the present types of contamination. Programmes supporting further development of methods for pilot and full-scale implementation are estimated to be required to a larger extent.

With respect to off-site treatment of contaminated soil, more or less advanced facilities for thermal and physicochemical methods have been established abroad, particularly in Germany and the Netherlands. Implementation of such technologies in Denmark is a matter of whether the Danish market is estimated to be sufficiently large. If off-site treatment of contaminated soil is aimed at, investments in programmes for further development of particularly second generation microbiological methods, primarily in closed systems such as reactors, are deemed necessary.

As previously mentioned, it is obvious that the optimum application of technology in Denmark is not either in-situ/on-site or off-site treatment and/or disposal. It naturally follows that both in-situ/on-site and off-site solutions should be possible to implement in an environmentally appropriate way depending on the situation in which the specific cleanup operations are effected.

In this connection, methods and tools for comparison and assessment of the strategy to be applied are deemed to be lacking, thus preventing an environmental as well as an economic optimization of the effort. Hence, an assessment model, possibly based on the principles of life cycle analyses, for assessment and comparison of the sustainability of given remedial measures, including total impact in terms of energy consumption, emissions etc., could be developed.

1. Introduction

This project has been carried out under the supervision of the expert group Remedial Technology in connection with the Priority Project Concerning Contaminated Sites and Ground Water of the DEPA.

The expert group consists of the following participants:

Inge-Marie Skovgård (chairman)	DEPA
Henrik Winther Nielsen (secretary)	DEPA
Trine Nielsen	DEPA
Janne Forslund	DEPA
Poul Clement	County of Aarhus
Leif Christensen	County of Nordjylland
Jørgen Skaarup	Municipality of Copenhagen
Jens Andersen	Copenhagen Water Supply
Pernille Keil	Directorate of the Danish Working Environment Service

The purpose of the project has been to identify the barriers to wider application of already developed remedial technologies in Denmark. Moreover, the purpose of the project has been to provide an overview of the mechanisms and contexts decisive for the choice of remedial action.

The project may thus support elaboration of strategies for development and application of remedial technology as well as the choice of remedial action in each specific situation.

The report begins with an overview of remedial technologies and an assessment of the implementation of the technologies in Denmark, *chapter 2.*

Then barriers to application and development of remedial technology are identified, *chapters 3 and 4.*

The barriers to application and development of remedial technology are analyzed through three scenarios for application of technology, *chapter 5.*

The conclusions of the project appear from each chapter and are summarized in outline in the abstract of the report.

2. Remedial Technology

2.1 Introduction

Below, a systematic overview of remedial technology applied in Denmark as well as abroad in connection with cleanup operations on contaminated sites is provided. Only technologies applied in connection with soil contamination are focused on. Regarding remedial technology applied abroad, special emphasis is put on application of technologies in the USA, the Netherlands and to a lesser extent in Germany due to the fact that in contrast to the situation in the USA and the Netherlands, no total overview of application of technology in Germany is available. The application of technology in Germany is, however, estimated to be similar to that of the Netherlands described below.

Innovative technology

The focus of the project has particularly been application of innovative remedial technology. The following definition of innovative remedial technologies is applied, cf. US/EPA:

- *technologies for which a lack of performance and cost data precludes their routine use to clean up sites*

Quoted from /1/.

Legal framework

The legal framework for execution of cleanup operations on contaminated sites in Denmark consists of:

- Waste Deposits Act,
  - publicly financed cleanups (including delegated industrial sites and gasworks),
  - voluntary cleanups,

- Environmental Protection Act (required by orders etc.),

- Act on Economic Blight to Family Housing etc. on Contaminated Land,

- Agreement on the Danish Oil Industry Association for Remediation of Retail Sites.

Cleanup criteria

It should be noted that the criteria for acceptance of cleanups vary within the above legal framework. Thus, the criteria for acceptance applied in cleanups for de-registration pursuant to the Waste Deposits Act or the Act on Economic Blight to Family Housing etc. on Contaminated Land differ from the criteria of acceptance applied in cleanups for release (related to a specific land use) pursuant to the Waste Deposits Act.

2.2 Remedial Technology

List of remedial technologies

Annex 1 contains a list of remedial technologies applied in connection with soil contamination in Denmark and abroad. The list has been elaborated on the basis of a desk study of literature from particularly Denmark, the USA, the Netherlands and Germany /1-21/.

The remedial technologies on the list are categorized as off-site, on-site and in-situ technologies, respectively.

Off-site technology

Off-site technologies are defined as technologies involving excavation and disposal of contaminated soil from contaminated sites followed by external treatment and/or landfill disposal.

On-site technology

On-site technologies are defined as technologies involving excavation of contaminated soil followed by treatment and possibly disposal on the contaminated site in question.

In-situ technology

In-situ technologies are defined as technologies involving treatment of contaminated soil **without** excavation of the soil.

The list in annex 1 contains the remedial technologies listed in table 2.1 with a brief description of each technology.

Table 2.1
Remedial technologies covered by annex 1 /1-21/.

	Remedial technology
Off-site	External treatment and/or landfill disposal
On-site	Thermal treatment Windrow composting Land farming Bioreactor Soil vapour extraction Thermal desorption Forced soil flushing Soil washing Extraction with acid Extraction with solvents Stabilization/solidification Chemical treatment - dechlorination
In-situ	Bioremediation Bioventing Soil vapour extraction Steam stripping Forced soil flushing Soil flushing with detergents Sealing systems Vitrification Electrokinetics Chemical treatment Pneumatic fracturing

The list in table 2.1 and annex 1 do not cover all present and potential remedial technologies. This is due to the fact that during the elaboration of the list, emphasis has been put on technologies which have been applied in full-scale cleanups in Denmark or abroad.

It should be noted that non-intervention in soil contamination can also be considered an in-situ remedial action (passive remediation) in connection with e.g. contaminations which are naturally degraded. It is a precondition that the contamination in question does not entail an unacceptable hazard following dispersion.

Types of contamination

For each technology, annex 1 states the types of soil contamination in connection with which the technologies in question are deemed suitable. Soil contamination is divided into the types listed in table 2.2.

Table 2.2
Categories of soil contamination applied in annex 1

	I Volatile organic compounds	**II** Heavily volatile organic compounds	**III** Heavy metals
Biodegradable	/	/	
Non-biodegradable	X	X	X

For technologies based on bioconversion of contaminants it is stated that such technologies are suitable in connection with microbially degradable compounds only (indicated by "/" instead of an "X").

Finally, the degree of implementation is assessed for each technology in Denmark as well as abroad.

Degree of Implementation

Various models for illustration of the degree of implementation of technologies (development levels) exist. The following examples can be mentioned:

1)

Bench scale

Pilot scale

Full scale

Quoted from /1/.

2)

Idea

Proof of Concept

Prototype

Pilot

Demo

1st commercial unit

Quoted from /22/.

Grading of full-scale implementation

However, during the elaboration of the list in annex 1 emphasis has as previously mentioned been put on technologies applied in full-scale cleanup operations. It has therefore not been appropriate to operate with the above models for degrees of implementation. Instead, it has been chosen to grade the full-scale implementation of each technology.

In table 2.3 the chosen grading is outlined. As it appears from the table, the gradings for Denmark and for abroad, respectively, differ.

Table 2.3
Grading of full scale implementation of remedial technology in Denmark and abroad (applied in annex 1).

	Number of full-scale cleanups with the technology application in question	Degree of implementation
Denmark	< 10	Tried out on a few sites
	10 - 20	Tried out on several sites
	> 20	Carried out on several sites
Abroad	< 20	Few full-scale cleanups
	20 - 100	Several full-scale cleanups
	> 100	Many full-scale cleanups

In total, all the on-site and in-situ treatment technologies stated in annex 1 are estimated to be innovative in Denmark due to their relatively modest application here. An exception may be soil vapour extraction.

Several of the stated on-site and in-situ treatment technologies can, however, hardly be considered innovative abroad. This is particularly true for the following technologies:

- on-site,
  - thermal treatment (incineration),
  - thermal desorption,
  - soil washing,
  - stabilization/solidification (heavy metals only),

- in-situ,
  - soil vapour extraction.

The following technologies are, moreover, applied relatively extensively abroad:

- on-site,
  - windrow composting,
  - land farming,

- in-situ,
  - bioremediation,
  - bioventing,
  - forced soil flushing.

The above-mentioned assessments are based on the relatively extensive application of the technology in question.

2.3 Application

2.3.1 Implementation

Implementation

As mentioned in section 2.2, different gradings for full-scale implementation of technologies in Denmark and abroad have been applied in connection with the listing of remedial technologies in annex 1.

The need for different gradings is naturally caused by the great difference between the number of cleanups carried out in Denmark and those carried out in the USA, the Netherlands and Germany. Below, the extent of application of different remedial technologies in Denmark, the USA and the Netherlands, respectively, is illustrated.

2.3.2 Denmark

As mentioned in section 2.1, cleanups of contaminated sites in Denmark are carried out within a framework comprising several different acts and schemes (Waste Deposits Act, Act on Economic Blight to Family Housing etc. on Contaminated Land, Environmental Protection Act and the Danish Oil Industry Association for Remediation of Retail Sites).

Publicly financed cleanups

Publicly financed cleanups, in which the expenses for execution of the cleanups (excluding operation) are borne by the DEPA, are carried out in pursuance of the Waste Deposits Act. Such cleanups are given priority in the annual country priority procedure of the DEPA. The country priority procedure is based on recommendations of conceptual projects on cleanups prepared by the counties. The recommendations also include remedial technology proposals for each cleanup operation.

It should be emphasized that the contents of the country priorities may change so that cleanups which according to the priority procedure should be carried out by means of traditional technology may in effect have been carried out by means of innovative technology. This report makes no attempt at quantifying the number of such possible additional cleanups by means of innovative technology.

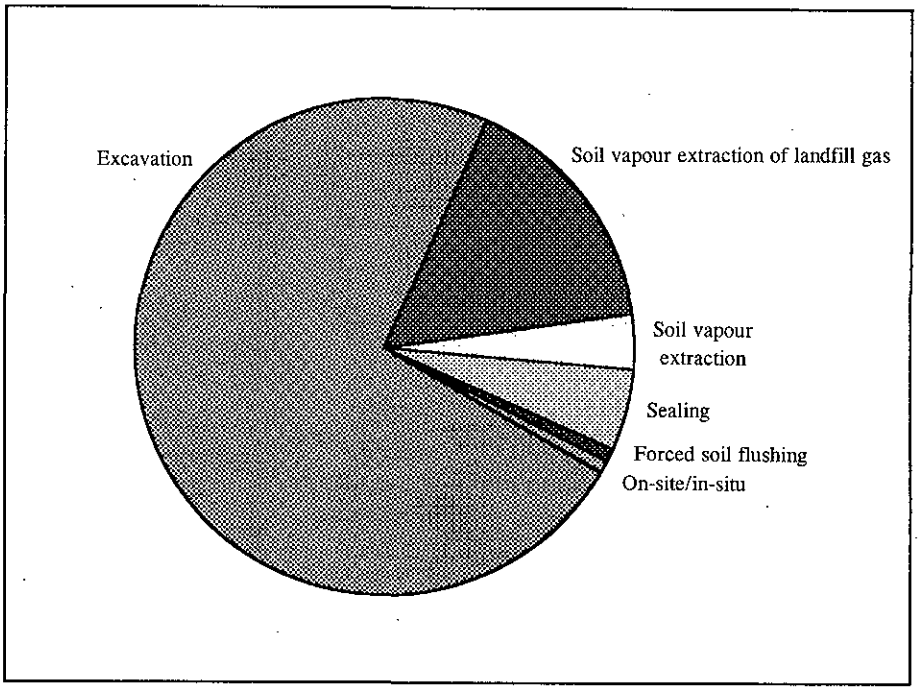
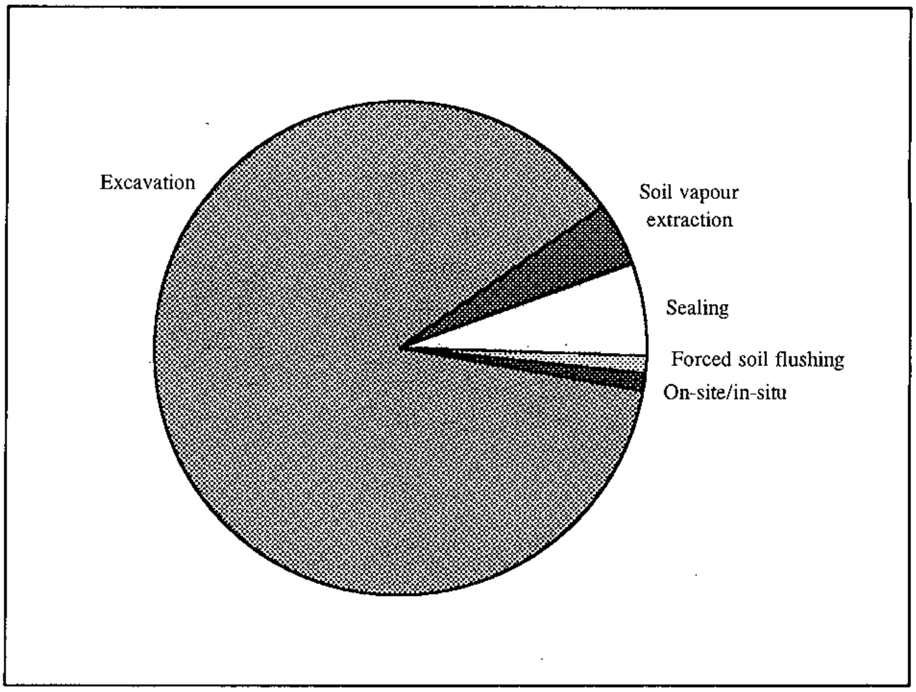


Figure 2.1
Technologies recommended for cleanup of soil contamination in the country priority procedures of the DEPA in 1992, 1993 and 1994 containing 107 proposals for cleanups /16/. Vapour extraction of landfill gas is included.

Figure 2.2
Technologies recommended for cleanup of soil contamination in the country priority procedures of the DEPA in 1992, 1993 and 1994 containing 107 proposals for cleanups /16/. Vapour extraction of landfill gas is not included.



On the basis of the review of the country priority procedures from 1992, 1993 and 1994, the remedial technologies proposed in the recommended cleanups of soil contamination are illustrated in figure 2.1 /16/. The figure illustrates the relative number of recommendations containing each technology. The results in the figure represent 107 proposals for cleanups. It should be noted that the figure is based on proposals for execution of cleanups and that not all these cleanups have in fact been carried out. This fact is, however, not estimated to be of significance to the illustration of the remedial technology application in cleanup operations, cf. the country priorities.

Vapour extraction of landfill gas amounts to a relatively large part of the technologies recommended in the country priority procedures of 1992, 1993 and 1994. If they are omitted, the result will be the distribution of recommended technologies illustrated in figure 2.2.

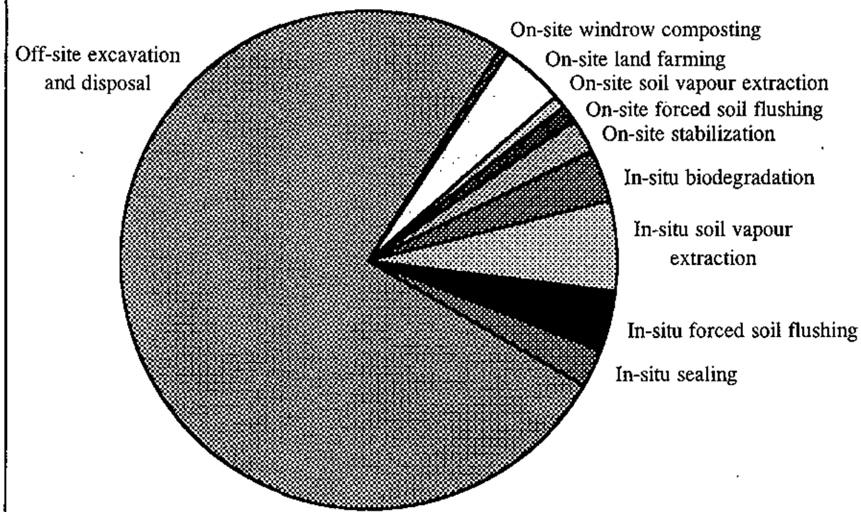
The results in figure 2.2 indicate that publicly financed cleanups pursuant to the Waste Deposits Act are primarily carried out by means of excavation of contaminated soil followed by off-site treatment and/or disposal.

Danish environmental consultants

In connection with this project, information on Danish environmental consultants' application of different remedial technologies in full-scale cleanups of soil contamination has been collected by means of questionnaires /20/. The answers in the questionnaires have been processed together with other information on the number of cleanups carried out in Denmark /17/.

On this basis, figure 2.3 illustrates an estimate of Danish environmental consultants' experience of technology application. The results in the figure are estimated to represent approximately 300 executed cleanups.

Figure 2.3
Danish environmental consultants' application of different remedial technologies in cleanups of soil contamination comprising approximately 300 executed cleanups /20/.



Cleanups in general

Some of the environmental consultants did not wish to participate in the survey, and some of the cleanups indicated in the questionnaires may have been carried out abroad. These facts are, however, not expected to have any significant impact on the illustration of environmental consultants' application of remedial technology in cleanups of soil contamination in Denmark. The results in figure 2.3 are thus deemed to convey a general picture of the application of remedial technology in Denmark.

Similar to the results from the country priority procedures illustrated in figure 2.2, the results in figure 2.3 indicate that cleanups of soil contamination in Denmark are primarily carried out by means of excavation followed by off-site treatment and/or disposal.

Innovative technology, however, seems to be applied more often in cleanups in general than in cleanups pursuant to the country priority procedure. This is estimated to be due to relatively wider application of innovative remedial technology particularly in voluntary cleanups pursuant to the Waste Deposits Act and cleanups in connection with the Environmental Protection Act. Such cleanups are not publicly financed.

The innovative technologies which seem to be more frequently applied in Denmark are in-situ soil vapour extraction and biological technologies such as land farming.

It should be noted that according to the information provided by Danish environmental consultants, no full-scale experience of application of the extraction and soil washing technologies on-site and electrokinetics in-situ in Denmark is available /20/.

Support for development of technology

Development of innovative remedial technology has in Denmark been supported by public funds such as:

- the Landfill Project,
- the gasworks scheme,
- direct support for developers.

Finally, a former manganese sulphate factory in the County of Sønderjylland has conducted bench and pilot-scale tests with both in-situ/on-site biological treatment and chemical treatment. The project is co-financed by the EU.

The gasworks scheme

It should be noted that the development of innovative remedial technology applied in connection with soil contamination only comprised a small part of the projects under the Landfill Project. The projects under the gasworks scheme have in contrast all involved application and development of innovative on-site or in-situ remedial technology. The following projects have been carried out or are being carried out under the gasworks scheme /23/ and /24/:

- Esbjerg gasworks site,
  - experiments with on-site bioremediation (composting) of excavated, tar contaminated soil (the project has been concluded),
- Mørkhøj gasholder station,
  - experiments with in-situ soil flushing with detergents of tar contamination in fissured clay till (the project has been concluded),
- Frederiksberg gasworks site,
  - experiments with on-site bioremediation (composting) of excavated, tar contaminated soil,
- Valby gasworks site,
  - experiments with on-site soil washing followed by treatment of separated, fine soil particle fraction,
- Hjørring gasworks site,
  - experiments with in-situ bioremediation and forced soil flushing.

The project on Valby gasworks site is co-financed by the Commission of the European Community via the LIFE programme.

2.3.3 The USA

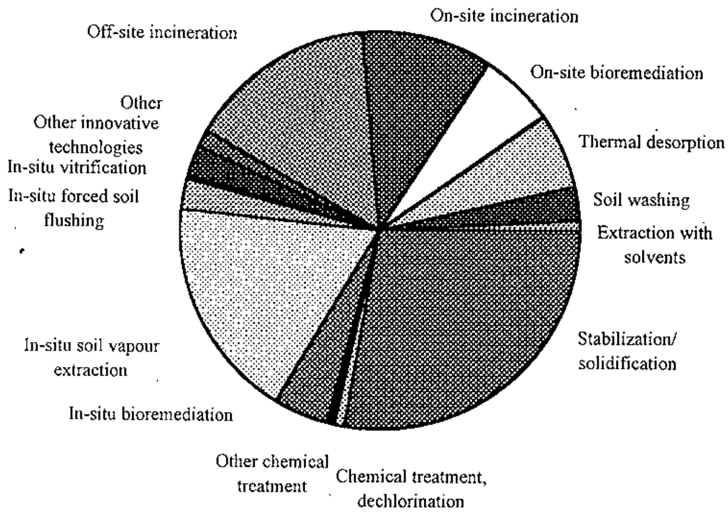
The Superfund programme

In the Superfund programme, enterprises in the USA make payments to a fund. The money is subsequently applied for cleanup of contaminated sites. Under the Superfund programme cleanups of approximately 2000 contaminated sites are expected to be carried out /5/.

This number only amounts to a small part of the expected cleanups of contaminated sites in the USA. For instance, a special programme for cleanup of contamination from underground tanks is expected to include approximately 300,000 cleanups /5/. The extent of each cleanup must, however, be expected to be far smaller for cleanups under this programme than for those of the Superfund programme.

Surveys of the application of different remedial technologies have been elaborated for the Superfund programme. Thus, in figure 2.4 the distribution of technologies applied in cleanups of soil contamination under the Superfund programme is illustrated /6/. The results in the figure represent 686 applications of remedial technology. It should be noted that in any given cleanup of a site several technologies may have been applied. The stated number of applications of technology is therefore larger than the number of sites cleaned up.

Figure 2.4
Application of different remedial technologies in cleanups of soil contamination under the Superfund programme in the USA in 1993 involving 686 applications /6/.



The overview in figure 2.4 includes cleanups in which contaminated soil has been treated only. Cleanups in which contaminated soil has been excavated and simply disposed of off-site without any prior treatment are thus not included, but are expected to amount to less than 20-30% of the cleanups /3/.

Off-site incineration, on-site incineration and stabilization/solidification are considered to be traditional technologies, whereas the other technologies listed in figure 2.4 are deemed innovative /5/ and /6/.

Several of the technologies listed in figure 2.4 include both off-site and on-site treatment of contaminated soil. In this case such treatment includes stabilization/solidification, thermal desorption, soil washing, extraction and chemical treatment. Hence, in connection with thermal desorption, soil washing, extraction and chemical treatment, off-site treatment at central treatment facilities is effected.

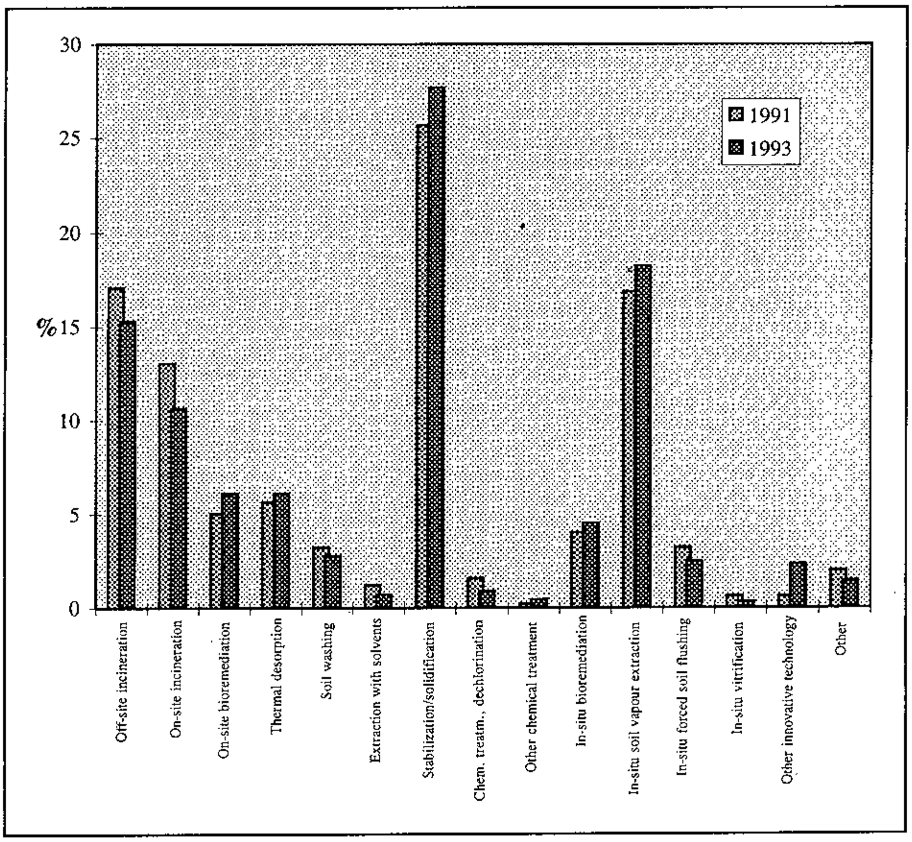
Tendencies

In figure 2.5 the applications of different remedial technologies under the Superfund programme in 1991 and 1993, respectively, are compared /3/ and /6/. The information for 1993 corresponds to that of figure 2.4. The results in figure 2.5 reflect the following tendencies /3/:

- Incineration is becoming less widespread,
- stabilization/solidification is becoming more widespread,
- in-situ soil vapour extraction is becoming more widespread.

It should be noted that the tendencies are relative as the results for 1991 represent 498 applications of remedial technology, whereas, as previously mentioned, the results for 1993 represent 686 applications. Consequently, these numbers indicate that the absolute number of cleanups and thereby the application of remedial technology is on the increase.

Figure 2.5
Application of different remedial technologies in cleanups of soil contamination under the Superfund programme in the USA in 1991 (498 applications) and 1993 (686 applications) /3/ and /6/.



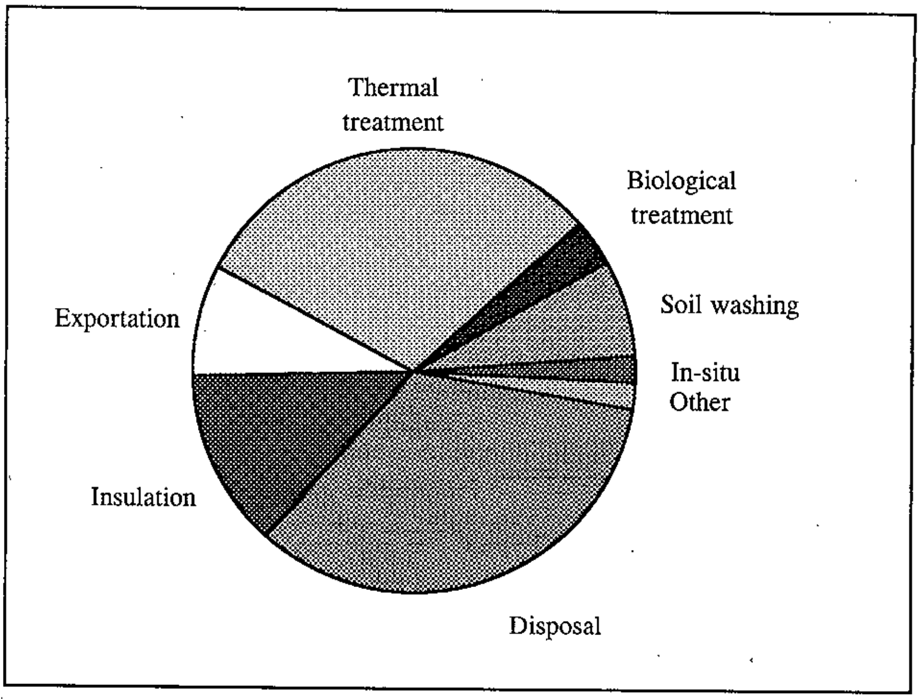
Innovative remedial technology in the USA is to a large extent developed by private companies /2/. The US Environmental Protection Agency (US-EPA) supports the development and demonstration of innovative remedial technology, for instance through the SITE programme (Superfund Innovative Technology Evaluation Program). Moreover, there are several support schemes under the Department of Energy (DOE) as well as the Department of Defence (DOD).

In this connection it can be mentioned that the US Air Force is at the moment carrying out tests with bioventing at approximately 110 jet fuel contaminated locations on their bases. The preliminary results demonstrate that bioventing can be applied almost everywhere. The final report will be published in 1995.

2.3.4 The Netherlands

In figure 2.6 an overview of the application of remedial technology in the Netherlands in the period of 1980-1990 is provided /3/. The overview includes cleanups of approximately 5.5 mio. tonnes of contaminated soil.

Figure 2.6
Application of different remedial technologies in cleanups of soil contamination in the Netherlands in the period of 1980-1990 including cleanup of approximately 5.5 mio. tonnes of contaminated soil /3/.



As it appears from figure 2.6, the application of excavation followed by off-site treatment and/or disposal is widespread, whereas biologically based methods and in-situ methods are less frequently applied.

SCG

For the purpose of discouraging disposal of contaminated soil without prior treatment, the Netherlands set up a state-owned "soil mediator company", SCG (Service Centrum Groundreiniging) in 1989 /18/. The objective of SCG is to ensure that soil which can be cleaned is cleaned and reused, primarily as construction material, whereas soil which cannot be cleaned is disposed of in an appropriate manner.

SCG takes over all land from state cleanups, assesses whether the soil should be cleaned, stored (until cleaning is possible) or disposed of, makes agreements to this effect and sells the cleaned soil.

In 1992, SCG handled 600,000 tonnes of soil, including 360,000 tonnes from state cleanups. Approximately 70% of the soil is cleaned /18/.

The objective for the cleaning of soil is the Dutch target values for soil quality (previous A values) /51/. Soil with these target values has unrestricted application. Soil which can only be cleaned to concentrations of between the target values and 5 times these values is considered to be slightly contaminated and can only be applied for certain purposes /18/.

Innovative remedial technology is in the Netherlands developed by a number of institutes /2/. Support may be obtained from VROM (Ministry of Housing and the Environment) and from a national programme (Netherlands Integrated Soil Research Program).

2.3.5 Comparison

The USA and Denmark

A comparison between the application of remedial technology in Denmark in general (illustrated in figure 2.3) and the application of remedial technology under the Superfund programme in the USA (illustrated in figure 2.4) establishes great differences.

Treatment of contaminated soil by means of stabilization/solidification and in-situ soil vapour extraction in particular is far more widespread in the USA than in Denmark. Stabilization/solidification and in-situ soil vapour extraction must still be considered innovative technologies in Denmark. The application of in-situ soil vapour extraction is, however, estimated to be on the increase in Denmark corresponding to the tendency in the USA.

Furthermore, technologies such as thermal desorption and soil washing are applied fairly often in the USA, whereas these technologies are not applied in Denmark today (neither on-site nor off-site).

It is emphasized again that the stated application of stabilization/solidification, thermal desorption and soil washing in figure 2.4 partly includes off-site treatment.

Some of the differences between Denmark and the USA can probably be explained by the larger number of cleanups carried out in the USA. A larger number of cleanups must be expected to form the basis of a greater research and development effort and thus a greater extent of technology development.

The Superfund sites are, moreover, generally larger than the corresponding Danish sites, which often makes excavation unrealistic.

The Netherlands and Denmark

A comparison between the application of remedial technology in Denmark in general (illustrated in figure 2.3) and the application of remedial technology in the Netherlands (illustrated in figure 2.6) does not demonstrate such great differences. In the Netherlands, excavation followed by off-site treatment and/or disposal is as in Denmark frequently applied. It should also be noted that the Dutch contaminated sites are as in Denmark relatively small, which is why solutions involving excavation are often an attractive alternative.

Soil washing is, however, applied relatively frequently in the Netherlands for treatment of contaminated soil, whereas this technology is as stated above not applied in Denmark today. With this exception, innovative technology seems to be more widespread in Denmark than in the Netherlands. It should, however, be noted that the Dutch figures are from the period of 1980-1990.

Denmark internally

A comparison of the application of remedial technology in Denmark within the framework of the various statutes (Waste Deposits Act, Act on Economic Blight to Family Housing etc. on Contaminated Land etc.) forms the basis of the assessment made in section 2.3.2 that innovative technology is particularly applied in voluntary cleanups pursuant to the Waste Deposits Act and in cleanups in pursuance of the Environmental Protection Act.

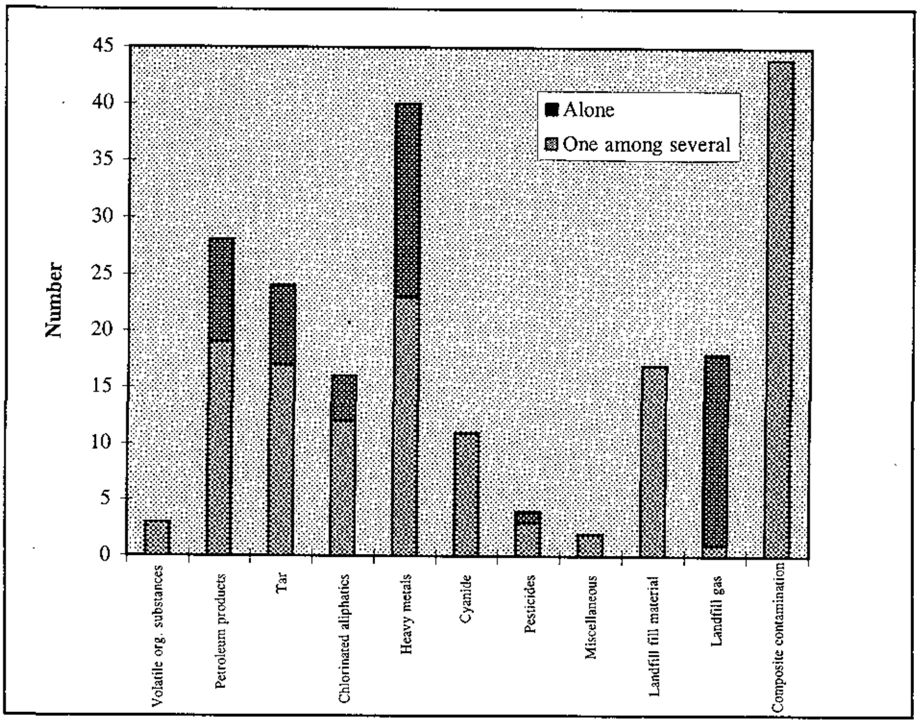
In connection with publicly financed cleanups, of which the expenses (excluding operation) are borne by the DEPA, excavation of contaminated soil followed by off-site treatment and/or disposal is prevailing.

2.4 Types of Contamination

Country priority procedure

Based on information from the review of country priorities from 1992, 1993 and 1994 mentioned under section 2.3.2, figure 2.7 illustrates the types of soil contamination which have brought about the proposals for cleanup /16/. The figure indicates the frequency with which contamination with volatile organic compounds, oil products, tar etc. has given rise to proposals for cleanup.

Figure 2.7
Types of soil contamination which have brought about proposals for cleanup in the country priority procedures of 1992, 1993 and 1994 /16/.



Types of soil contamination

As it appears from figure 2.7, a division of the types of soil contamination from the country priority procedures into the following types has been deemed appropriate: Volatile organic compounds, oil products, tar, chlorinated aliphatic compounds, heavy metals, cyanide, pesticides, landfill fill material and other substances. Furthermore, landfill gas is included as a significant amount of proposals for cleanups have focused on remedial action against dispersion of landfill gas.

Composite contamination

Figure 2.7 furthermore states whether the types of contamination in question have been found alone or as one type of contamination among several (composite contamination). The composite contamination types involve the simultaneous presence of e.g. tar and cyanide or oil products and heavy metals. It should be noted that landfill fill material in figure 2.7 is solely defined as a composite contamination type.

In figure 2.7 the total number of proposals for cleanups involving composite contamination is indicated by "Composite contamination". Excluding cases involving landfill gas, composite contamination has been identified at approximately 50% of the sites represented by the proposals for cleanup in figure 2.7 (about 40 cases of a total of approximately 80).

Thus, the proposals for cleanup focus to a great extent on handling of composite contamination and not just on handling of single-type contamination.

The choice of remedial technology is consequently often based on the fact that several types of contamination typically with very different physico-chemical properties have to be handled in the specific cleanup operation, see also section 3.3.3 below.

Danish environmental consultants

In the questionnaire survey, Danish environmental consultants were asked to indicate in connection with the remedial technology applied the types of contamination remediated by the technologies in question /20/. The review of the answers is provided in table 2.4.

The results in table 2.4 are estimated to convey a general picture of the application of remedial technology in connection with different types of contamination in Denmark. It should be noted that the technologies listed in table 2.4 have been applied in full-scale cleanups.

Table 2.4
Types of contamination cleaned up by means of different remedial technologies applied by Danish environmental consultants.

	Remedial technology	Types of contamination cleaned up
Off-site	Excavation followed by treatment/disposal off-site (externally)	Petroleum products, BTEXs, tar (PAHs etc.), chlorinated aliphatic compounds, phenol, chlorophenol, pesticides, water mixable solvents, cyanide and metals (incl. Hg)
On-site	Windrow composting	Petroleum products, BTEXs, chlorinated aliphatic compounds and water mixable solvents
	Land farming	Petroleum products, BTEXs, tar (PAHs etc.) and water mixable solvents
	Venting	BTEXs, chlorinated aliphatic compounds and water mixable solvents
	Forced soil flushing	Petroleum products, BTEXs, cyanide and metals
	Extraction	Not applied
	Soil washing	Not applied
	Stabilization/solidification	Tar (PAHs etc.), cyanide and metals
In-situ	Biodegradation	Petroleum products, BTEXs and cyanide
	Venting	Petroleum products, BTEXs, tar (PAHs etc.) and chlorinated aliphatic compounds
	Forced soil flushing	Petroleum products, BTEXs, tar (PAHs etc.), chlorinated aliphatic compounds, phenol and water mixable solvents
	Sealing systems	Petroleum products, BTEXs, tar (PAHs etc.) and cyanide
	Electrokinetics	Not applied

BTEXs: Benzene, toluene, ethylbenzene and xylene
PAHs: Polyaromatic hydrocarbons

Off-site technologies

The types of contamination indicated in connection with cleanup of contaminated soil by excavation followed by treatment and/or disposal off-site are estimated largely to cover all types of soil contamination handled by Danish environmental consultants. The stated types of contamination include:

- petroleum products (petrol, diesel, turpentine, petroleum and similar substances),
- benzene, toluene, ethylbenzene and xylene,
- tar (naphtalene, anthracene, fenanthrene, chrysene, pyrene, benz(a)pyrene, fluorene etc.),
- chlorinated aliphatic compounds (1,1,1-trichlorethane, trichlorethylene, tetrachlorethylene etc.),
- phenole (phenol, cresol, xylenol etc.),
- chlorphenol (2,4-dichlorphenol, tetrachlorphenol, pentachlorphenol etc.),
- pesticides (atrazine, dinoseb, simazine etc.),
- water mixable solvents (acetone, methanol, ethanol, propanol etc.),
- cyanide,
- metals (arsenic, lead, chromium, copper etc.).

Off-site technologies are thus considered to be applicable to by and large any type of soil contamination.

On-site and in-situ technology

In figure 2.3 in section 2.3.2 the extent of Danish environmental consultants' application of different remedial technologies is illustrated. A comparison between the results in table 2.4 and those in figure 2.3 demonstrates that the experience record of application of on-site and in-situ technologies is rather limited for most types of contamination. The most comprehensive basis of experience seems to be related to application of in-situ soil vapour extraction and biological technologies such as land farming in connection with contamination with petroleum products and BTEXs.

As it appears from table 2.4, no full-scale experience of application of on-site extraction and soil washing and in-situ electrokinetics is available in Denmark.

It should be noted that one environmental consultant stated that chlorinated aliphatic compounds had been treated by means of on-site windrow composting. It seems unlikely that actual biological treatment of the soil has been effected for the purpose of removing the chlorinated aliphatic compounds as these are generally not biodegradable under normal aerobic conditions. Several US suppliers of remedial technology have also stated that chlorinated aliphatic compounds can be degraded by means of biological methods, whereas this claim is rejected by other suppliers /1/.

At a special deposit established during the remedial action at Skrydstrup in Sønderjylland in Denmark, anaerobe degradation of chlorinated aliphatic compounds has been demonstrated, whereas it has not been possible to provide documentation of aerobe degradation /4/. The special deposit is designed with two sections, one with a liner surface (anaerobe) and one without (aerobe). For several years, recirculation and monitoring of leachate above each of the two sections have been carried out.

Criteria for acceptance of cleanups

As previously mentioned, the greatest Danish basis of experience relating to application of on-site and in-situ technologies seems to be within in-situ soil vapour extraction and biological technologies such as land farming. It should be noted that generally, it seems difficult to reach the levels of residual contaminants in soil acceptable to sensitive land use in Denmark both in connection with the above-mentioned technologies and other on-site and in-situ technologies /25/ and /26/. Moreover, relatively comprehensive documentation proving that acceptable levels of residual contaminants in the soil have been reached during the execution of on-site or in-situ cleanup operations is typically required.

2.5 Geological Limitations

Heterogenous soil and clay

Experience of application of most of the on-site and in-situ remedial technologies listed in annex 1 involves relatively homogenous, sandy soil. Treatment of heterogeneous soil and clay is a general problem for these technologies.

With heterogenous soil the problems do not only concern execution of the treatment, but also the subsequent documentation of the treatment effect, as both the concentration of contaminants and the treatment effect vary considerably from area to area. Inhomogeneous geology may thus entail a retention in pockets of residual contamination after treatment.

On-site technologies

On-site technologies applied in Denmark include, cf. table 2.4 in section 2.4, windrow composting, land farming, soil vapour extraction, forced soil flushing and stabilization/solidification. In windrow composting and land farming, structural materials such as wood or bark chips are applied in an attempt to minimize the problems of heterogeneous soil and clay. With stabilization/solidification the problems of heterogeneous soil and clay are estimated to be less significant. It should be noted that the Danish experience relating to application of on-site technologies is relatively limited.

In-situ technologies

In-situ technologies applied in Denmark include, cf. table 2.4 in section 2.4, biodegradation, soil vapour extraction, forced soil flushing and sealing systems. Biodegradation, soil vapour extraction and forced soil flushing applied for in-situ treatment of contaminated soil are problematic in relation to heterogeneous soil and clay. Sealing systems are not considered to be an actual treatment method. As a remedial technology for prevention or minimization of contamination dispersion the method is, however, not particularly problematic in relation to heterogeneous soil and clay.

Pneumatic fracturing

For the purpose of implementing in-situ technology in the treatment of contaminated clay in particular, pneumatic fracturing is applied abroad. In pneumatic fracturing the permeability of the soil is increased so that air or oxidized water with nutrients can penetrate the soil. Pneumatic fracturing is typically applied in connection with cleanups involving in-situ soil vapour extraction.

2.6 Summary

List of remedial technology

Annex 1 provides a list of remedial technology applied in connection with soil contamination in Denmark and abroad. On the list the degree of implementation of each technique is indicated. The assessment is made that the listed on-site and in-situ treatment technologies must due to their relatively modest application be considered to be innovative technologies in Denmark. A possible exception may be soil vapour extraction.

Several of the on-site and in-situ treatment technologies, on the other hand, can hardly be considered innovative abroad. This is particularly true for the following technologies:

- on-site,
  - thermal treatment (incineration)
  - thermal desorption
  - soil washing
  - stabilization/solidification (for heavy metals only),

- in-situ,
  - soil vapour extraction

The following technologies are, moreover, applied relatively extensively abroad:

- on-site,
  - windrow composting
  - land farming

- in-situ,
  - biological cleaning
  - bioventing
  - forced soil flushing

Application of technology

In Denmark, soil contamination is mainly cleaned up by means of excavation followed by off-site treatment and/or disposal. Innovative technologies are, however, applied more frequently in voluntary cleanup operations pursuant to the Waste Deposits Act and cleanup operations in connection with the Environmental Protection Act than in publicly financed cleanup operations pursuant to the Waste Deposits Act.

The innovative technologies which seem to be more and more frequently applied in Denmark are in-situ soil vapour extraction and biological technologies such as land farming.

The application of remedial technology in Denmark is compared with the application of remedial technology under the Superfund programme in the USA. Significant differences can be pointed out. The treatment of contaminated soil through stabilization/solidification and in-situ soil vapour extraction in particular is far more widespread in the USA than in Denmark. Moreover, technologies such as thermal desorption and soil washing are relatively frequently applied in the USA, whereas in Denmark these technologies are not applied today (neither on-site nor off-site).

If the application of remedial technology in Denmark is compared with that of the Netherlands, similar great differences are not observed. In the Netherlands, excavation followed by off-site treatment and/or disposal is just as frequently applied as in Denmark. Soil washing, however, is relatively frequently applied in the Netherlands for treatment of contaminated soil, whereas in Denmark this technology is, as mentioned above, not applied today. With this exception, innovative in-situ/on-site technologies seem to be more frequently applied in Denmark than in the Netherlands.

Types of contamination

In terms of type of contamination, cleanup by means of excavation followed by off-site treatment and/or disposal is in Denmark considered to be applicable in connection with almost all types of soil contamination handled in Denmark. For most types of contamination, the experience record of application of on-site and in-situ technologies in Denmark does, however, seem to be relatively limited. The greatest basis of experience seems to be related to application of in-situ soil vapour extraction and biological technologies such as land farming in connection with contamination with petroleum products and BTEXs. With these and other on-site and in-situ technologies it seems to be generally difficult to reach the levels of residual contents of soil contaminants deemed acceptable to sensitive land use in Denmark.

Geological limitations

Treatment of heterogeneous soil and clay, moreover, seems to be a general problem in connection with application of on-site and in-situ technologies. For heterogeneous soil the problem is not only execution of the treatment, but also the subsequent documentation of the treatment effect as both the concentration of contaminants and the treatment effect vary considerably from area to area. Inhomogeneous geology may thus entail a retention in pockets of residual contamination after treatment.

3. Barriers to Application of Innovative Technology

3.1 Background

This chapter provides an identification and description of barriers to application of innovative technology in Danish remedial actions.

Definition

Barriers are defined as conditions determined by legislation, regulations, administrative practices, technologies etc. making the application of innovative technology unattractive in any specific situation. Thus, the individual barriers are not necessarily qualitatively or quantitatively comparable.

An identification of barriers should be regarded as a tool for a more profound understanding of the mechanisms preventing a more widespread application of innovative technology in Denmark, as demonstrated in section 2.3.2. Barriers are therefore also regarded as the background for elaborating realistic criteria for the choice of remedial technology in cases of soil contamination.

The identification is partly based on a literature review and partly on interviews with relevant persons, cf. /21/. Moreover, experience from the provision of consultancy services in connection with the choice of cleanup concepts in specific cases has been taken into account.

3.2 Barriers in Denmark

Identified barriers to the application of innovative technology are illustrated in figure 3.1.

Annex 2

Annex 2 provides an outline description and assessment of each barrier shown in the figure. Moreover, the effect of each barrier and the possibilities of removing the barriers within the framework of present legislation and administration are described in outline.

Potential and present barriers

In the review of Danish and foreign literature, it was established that some of the barriers under consideration are more significant abroad than in Denmark and vice versa. This is true for, for instance, *approval pursuant to the Environmental Protection Act* for on/off-site treatment facilities where it is relatively easy to obtain an approval of heavily polluting enterprises in Denmark as compared with the valid requirements for similar facilities in Germany.

The situation is reversed when the barrier of *cleanup due to economic blight* is assessed, as Denmark is so far the only country with special legislation on cleanup due to a financial loss on a property.

Figure 3.1
Overview of barriers to application of innovative technology.

LEGISLATIVE BARRIERS Cleanup for de-registration due to economic blight Recourse pursuant to Waste Deposits Act Approval pursuant to Environmental Protection Act
INSTITUTIONAL BARRIERS Diverging authority objectives Cleanup criteria Documentation of cleanup Guarantee in connection with application of technology Neighbour relations and surroundings Landfill disposal of contaminated soil
TECHNICAL BARRIERS Inhomogeneous geological conditions Time consumption of the cleanups Composite contamination Extent of contamination
FINANCIAL AND MARKET BARRIERS Cost-benefit with the alternative of cost-effectiveness

In the literature review an attempt at including the most essential barriers and an assessment of the importance of the barriers in Denmark have been made, see section 3.3 below.

Division

As shown in figure 3.1, the barriers under consideration have been divided into four groups:

- legislative barriers
- institutional barriers
- technical barriers
- financial and market barriers

The division is not universal, see e.g. /22/, /36/ and /48/. However, the assessment is made that the above four groups represent a division corresponding to the conditions presently prevailing in Denmark.

Legislative barriers

The first group of barriers includes the so-called legislative barriers, which are barriers determined by the present legislation. An example of a legislative barrier to the application of innovative technology in-situ or on-site is the legislation on economic blight. For cleanup operations in this situation, it is required that a de-registration must be effected afterwards and the cleanup has to be carried out within a short period of time, preferably soon after the submission of the request by the property owner. Today, no in-situ or on-site technologies fulfilling these criteria are available, which is why cleanup in connection with the Act on Economic

Blight to Family Housing etc. on Contaminated Land is in most cases carried out by means of excavation followed by off-site treatment or disposal of the contaminated soil.

Institutional barriers

The group of institutional barriers is characterized by being barriers arisen as a consequence of administrative practice, which in several cases has resulted in guidelines issued by the DEPA. Examples of institutional barriers to application of innovative technology are cleanup criteria and various conditions for documentation.

Technical barriers

The technical barriers are based on the physical conditions of contamination such as the extent and nature of a specific case of contamination. For each case of contamination, the extent and dispersion on the location of contamination may, for instance, be a barrier to application of innovative technology, cf. section 2.5 below.

Financial and market barriers

Finally, the application of innovative technology may be prevented by a group of financial and market barriers. This group is in Denmark assessed to be more significant in connection with the development of technology than in the application of technology, cf. chapter 4.

Self-invented barriers

In a survey carried out by ICI Engineering, cf. /37/, of the conditions of soil contamination within the chemical industry and the paper industry in ten countries, it was established that the choice of remedial technology is affected by criteria which may be self-invented. An example is that a specific technology is chosen, almost independently of the cost involved, because it is believed that an environmental approval will be easier to obtain with this solution.

Moreover, the survey established that some extent of inertia is connected with the introduction of new technology.

This project does not make any attempt at identifying self-invented barriers, but this type of barrier naturally has some impact on the choice of remedial technology in each case.

3.3 Primary and Secondary Barriers

The assessment of the impact or significance of the barriers identified in figure 3.1 is based on whether the barrier is deemed to be of primary or secondary importance to the application of innovative technology.

The primary barriers are indicated in figure 3.2 and briefly described below.

3.3.1 Legislative Barriers

The purpose of cleanups in connection with cases of soil contamination in Denmark is usually to remove a conflict between the contamination and the present land use. Cleanups of soil contamination solely for the purpose of protecting the ground water make up a minor part of the total number of cleanups, cf. /16/.

Cleanup for de-registration

For much sensitive land use such as permanent housing, child care centres and similar land use, an attempt at creating a code of practice requiring that contamination on such properties is cleaned up for de-registration has been made within the framework of the Waste Deposits Act, cf. /32/.

Figure 3.2
Overview of primary barriers.

LEGISLATIVE BARRIERS

Cleanup due to economic blight

INSTITUTIONAL BARRIERS

Cleanup criteria
Documentation of cleanup
Landfill disposal of contaminated soil

TECHNICAL BARRIERS

Inhomogeneous geological conditions
Time consumption of the cleanups
Composite contamination
Extent of contamination

FINANCIAL AND MARKET BARRIERS

Cost-benefit with the alternative of cost-effectiveness

The requirement for cleanup for de-registration of properties applied for permanent housing was intensified in connection with the debate on economic blight and is laid down in the Act on Economic Blight to Family Housing etc. on Contaminated Land, cf. /31/.

The psychological effects of contamination on a property, moreover, entail that the property owner usually prefers a physical removal of the contamination as excavation of soil alone is considered to be sufficient "proof" of the removal of contamination.

Furthermore, excavation followed by external treatment or disposal is by the authorities considered to be an easy solution in terms of administration, cf. /21/.

Finally, the assessment is made that so far there is no specified criteria for the time when it is intuitively considered financially more attractive to prefer a solution with excavation. The general attitude it that with small and minor cases of contamination it is not worth while taking other technologies than excavation into consideration.

3.3.2 Institutional Barriers

Cleanup criteria

Requirements for cleanups for de-registration, which are included in the present soil quality criteria, cf. /25/, are estimated to be a significant barrier to the application of in-situ technology as it is doubtful whether the technology available can clean the soil to the levels required.

If the cleanup criteria are eased, as in for instance the draft guidelines for the Danish Oil Industry Association for Remediation of Retail Sites, the in-situ technologies are expected to become more widespread, cf. /21/.

Experience gained by a major Dutch consultancy company may be interpreted to mean that as soon as the requirement for cleanup to the level of "multifunctionality" (the previous Dutch A values) was changed from being a requirement to being an objective, a practice was developed to the effect that cleanups were carried out to the previous B levels. This promoted biological in-situ technologies, particularly in cleanups of industrial sites where the time factor is not decisive, cf. /43/.

Documentation of cleanup

No general guidelines for the documentation of the quality of cleanups are available, neither in the actual cleanup phase or at the termination of a cleanup operation.

In connection with specific cases, the documentation requirements upon termination of in-situ cleanups have involved investigations at a level corresponding to preliminary investigations with borings etc. /21/.

Uncertainty concerning documentation of cleanups as well as varying requirements across the country are generally considered to be a significant barrier to the application of innovative technology, see also chapter 4.

Landfill disposal

No uniform guidelines for landfill disposal of contaminated soil are available. The concentrations of contaminants allowed are regulated through the environmental approvals of the landfills, and some variation is observed from county to county.

Moreover, if the soil is disposed of as waste, a waste tax has to be paid, whereas this is not the case if the contaminated soil is applied as an operating material, e.g. applied for covering.

Landfill disposal and other disposal of contaminated soil at landfills are estimated to be a significant competitor to the established central treatment facilities. Similar conditions have been observed in both the Netherlands and the UK, cf. /35/.

3.3.3 Technical Barriers

An overview of specific technical barriers to the innovative technology dealt with in the SITE programme of the US-EPA is provided in /22/. As far as Danish conditions are concerned, the following general technical barriers are deemed significant:

Inhomogeneous geological conditions

Denmark's typically inhomogeneous geology is estimated to be a significant barrier to the application of innovative remedial technology. This is particulary due to difficulties in connection with treatment of an inhomogeneous medium both in-situ and on-site as well as subsequent difficulties relating to the documentation of treatment.

The clay content is very important for in-situ methods as the success of the operation often depends on reasonably permeable conditions. Moreover, soil with a high content of clay may be physically difficult to treat on-site; e.g. transportation in spiral conveyor etc. may be extremely difficult.

It is, however, estimated to be possible to adjust foreign technology to the Danish conditions, cf. /21/. In the assessment of both Danish and foreign cleaning results, information on the clay content with which the results have been achieved should be obtained.

Time consumption of the cleanups

In-situ and on-site treatment technologies naturally imply an operating phase which is longer than that of excavation. As previously mentioned, an operating phase is not desirable in connection with cleanups carried out due to economic blight.

It is the general impression that it is administratively easier to handle cleanups without an operating phase, cf. /21/. This is also true for cleanups which are not publicly financed as such cleanups should in principle be subject to an authority procedure pursuant to the Environmental Protection Act, cf. annex 2. Generally, there is therefore a tendency to prefer cleanups which can be carried out in a very short period of time.

For cleanups carried out by the Danish Oil Industry Association for Remediation of Retail Sites time consumption is an essential parameter. The Danish Oil Industry Association for Remediation of Retail Sites typically handles the same interest as those of cleanups pursuant to the Act on Economic Blight to Family Housing etc. on Contaminated Land. Thus, the Danish Oil Industry Association for Remediation of Retail Sites gives a high priority to the property owner, who wants his property de-registered as quickly as possible, cf. /21/.

Composite contamination

In approximately half of the cleanups given public priority in the period of 1992-94 contamination with more than one substance has been involved /16/. Typical examples are:

- Oil contamination in fill material with slag containing heavy metals,
- Gasworks sites (tar, gas purification mass etc.),
- Landfill fill material.

In an international study of innovative remedial technology, cf. /4/, composite contamination is considered to be difficult to handle by means of innovative technology. However, the Danish Oil Industry Association for Remediation of Retail Sites does not regard the number of cases involving composite contamination within their field to be so great that they give rise to special problems, cf. /21/.

In Denmark at present, no in-situ technologies capable of treating composite contamination are available. A development of technology for this type of contamination must be expected to consist of on/off-site "treatment trains", known from e.g. water treatment.

The extent of contamination

The extent and accessibility of contamination are a barrier to in-situ technology. What with documentation and possible preceding bench scale and field tests, it is not estimated to be financially viable to try to apply innovative technology in connection with minor contamination.

The extent of contamination also determines the application of on-site technologies. Thus, it is estimated, cf. /21/, that on-site technologies are not financially feasible in cases of contamination with less than 5-10,000 tonnes of contaminated soil. This is due to the fact that on-site technologies imply great start-up costs as the devices applied are large and thus entail significant costs of transport and installation.

An international study of the policy of selected industrial countries in connection with soil protection, cf. /39/, estimates that with minor sites (less than 2 ha) a standard solution in the form of excavation followed by external disposal or treatment will always be preferred. This attitude is supported by the interviews /21/ in which, as previously mentioned, excavation followed by off-site treatment/disposal is estimated to be an easy solution in terms of administration.

3.3.4 Financial and Market Barriers

In publicly financed cleanups as in all other cleanups, the preferred technology should as a general rule be price competitive. A comparison between traditional technology and innovative technology will usually demonstrate that innovative technology is the most expensive solution. This is probably due to several factors:

Firstly, application of innovative technology will entail stricter requirements for documentation as this is naturally not available beforehand to a satisfactory extent.

Secondly, innovative technology normally involves development costs, which is not the case for traditional remedial technology where the development costs have already been paid.

Finally, external treatment and disposal are estimated to be relatively inexpensive in Denmark as compared with the price level in e.g. Germany /21/.

3.3.5 Secondary Barriers

The secondary barriers are illustrated in outline in figure 3.3. A more detailed description is provided in annex 2. It should also be noted that some of the secondary barriers to application of innovative technology are primary barriers to development of new technology, see chapter 4.

Figure 3.3
Overview of secondary barriers to application of innovative technology.

LEGISLATIVE BARRIERS Recourse pursuant to Waste Deposits Act Approval pursuant to Environmental Protection Act
INSTITUTIONAL BARRIERS Diverging authority objectives Guarantee in connection with application of technology Neighbour relations and surroundings Landfill disposal of contaminated soil
TECHNICAL BARRIERS No secondary barriers have been identified
FINANCIAL AND MARKET BARRIERS No secondary barriers have been identified

It can, furthermore, be mentioned that *diverging authority objectives* constitute a significant barrier in the USA and *neighbour relations and surroundings* have also caused great difficulties in the implementation of cleanups within the Superfund framework, cf. /27/.

Finally, it can be mentioned that *approval of heavily polluting enterprises* in Germany is a slow process as compared with Denmark. Thus, approval procedures in Germany are estimated to be a significant barrier to application of on-site and in-situ technology.

Any changes in the rules in Denmark may result in secondary barriers becoming primary barriers and vice versa.

3.4 Summary of the Importance of Primary Barriers

3.4.1 Impact on the Choice of Remedial Technology

Choice of remedial technology in general

Generally, it can be established that the choice of remedial technology in Denmark is made on the basis of an assessment of technical as well as non-technical factors. Thus, in addition to the technical assessment of environmental and health aspects, non-technical factors also have an impact on the choice of remedial technology. This finding is fully supported by various investigations abroad, cf. e.g. /37/.

Criteria for the choice of remedial technology

The non-technical barriers are generally estimated to be just as decisive as the technical barriers for the criteria for the choice of a specific remedial technology. Moreover, ordinary financial criteria are important as the most inexpensive technology for the buyer is naturally chosen.

The non-technical barriers primarily stem from the existing legislation and from the administrative practices deriving from such legislation, e.g. the Act on Economic Blight for Family Housing etc. on Contaminated Land. The importance of the non-technical barriers to the choice of remedial technology forms the basis of making a division of cleanups into different cleanup reference situations characterized by the legislation determining the purpose of the cleanup.

Figure 3.4 lists the cleanup reference situations available within the legislation presently in force in Denmark.

Figure 3.4
Cleanup reference situations in Denmark.

Cleanup reference situations in Denmark

Situation A	A1	Waste Deposits Act - very sensitive land use at the time of cleanup
	A2	Act on Economic Blight to Family Housing etc. on Contaminated Land
	A3	Order pursuant to the Environmental Protection Act
Situation B	B1	Other cleanup pursuant to the Environmental Protection Act
	B2	Other cleanup pursuant to the Waste Deposits Act
Situation C	C1	Cleanup according to agreement on the Danish Oil Industry Association for Remediation of Retail Sites

Each of the listed cleanup reference situations is characterized by a number of criteria for the choice of remedial technology. The cleanups in situation A, for instance, are determined by the following criteria:

- cleanup for de-registration
- low time consumption (fast termination of cleanup)
- certain success

These three criteria naturally reduce the list of remedial technology to be chosen from. A more detailed analysis of the cleanup situations available in Denmark at present is provided in section 5.2 below.

3.4.2 Possibilities of Removing Barriers

Can barriers be removed?

Annex 2 contains an assessment of the possibilities of removing each of the barriers described above. Removal of barriers is as illustrated above of the utmost importance to the possibilities of changing the criteria on the basis of which the choice of technology is made.

Legislation can be changed

Removal of legislative barriers is in most cases possible if political consensus can be reached. A typical feature of the legislative barriers is that the rules constituting a barrier to innovative technology can be substituted by other rules. For instance, a cleanup for the purpose of redressing economic blight can be substituted by purchase of the property, which can subsequently, if desired, be cleaned up by means of in-situ technology.

Administration can be changed

As is the case with legislative barriers, it is also possible to remove the institutional barriers deriving from such legislation. This may either be done by changing the existing administration, an example of which could be to grade the existing soil quality criteria, or by elaborating guidelines for certain areas (e.g. documentation) where the presently prevailing uncertainty constitutes a barrier to application of innovative technology.

Market mechanisms

Financial and market barriers can be removed for instance by means of support schemes for development of new technology and a decision to the effect that the principle of the cheapest possible solution should not be taken into consideration in the choice of remedial technology, whereas requirements for cleaner technology should be decisive.

Poor possibilities of removing technical barriers

The technical barriers, on the other hand, cannot be removed. They can, however, be overcome by technological development:

> "Any technical problem can be solved; it is merely a matter of price."
> *(Quote: P. Harremoes, The Technical University of Denmark)*

The physical conditions of a case of soil contamination determined by geology, e.g. type of soil and permeability, are thus parameters which can be handled by means of considerable technical progress only, e.g. by means of fracturing.

Scenarios for application of technology

It is beyond the scope of this project to make proposals for the removal of barriers, including elaboration of strategies for appropriate application of remedial technologies in the future. However, two scenarios for application of technology have been created to illustrate the mechanisms determining the choice of technology, and the mechanisms behind the present application of technology are also described, cf. chapter 5 below.

4. Barriers to Development of Innovative Technology

4.1 Background

Similar to the assessment of barriers to application of innovative technology, an identification of barriers to *development* of innovative technologies has been made.

Interviews concerning barriers to development of innovative remedial technology

In the interviews, cf. /21/, the respondents were asked to assess the importance of each barrier listed in figure 4.1. Furthermore, the respondents were asked to evaluate the following three statements:

- *Development of advanced soil cleaning technology is not required; the present level of technology is satisfactory!*

- *Development of simple and inexpensive remedial technology is required!*

- *It is not possible in the foreseeable future (5-10 years) to develop technologies capable of handling the Danish problems of soil contamination!*

Below, the results of the interviews are compared and parallels to a round-table discussion at an international NATO/CCMS conference held in 1994, cf. /35/, are drawn.

4.2 Primary and Secondary Barriers

Primary and secondary barriers have been identified on the same basis as that of chapter 3, and an overview of the barriers identified is provided in figure 4.1.

Primary and secondary barriers

The respondents agreed that the primary barriers to development of new technology were included in the groups of institutional and financial and market barriers. Technical conditions and legislation on subsequent approval of prototype technology were only assessed to be of minor importance.

An exception is, however, the legislation on genetically modified microorganisms, which might be applied in connection with biotechnological methods. Danish companies working with gene technology are estimated to have very little interest in development of genetically modified microorganisms for soil cleaning as it is not possible to obtain the patent rights /21/.

Figure 4.1
Identified barriers to development of new remedial technology.

LEGISLATIVE BARRIERS

Approval (e.g pursuant to the Environmental Protection Act)

INSTITUTIONAL BARRIERS

Cleanup criteria for soil

TECHNICAL BARRIERS

Inhomogeneous geological conditions
Composite contamination

FINANCIAL AND MARKET BARRIERS

Market unpredictability
Cost-benefit with the alternative of cost-effectiveness
Insufficient market volume in Denmark

Off-site treatment/disposal is inexpensive

The low price level of off-site treatment and disposal is estimated to be a significant barrier to development of new technology. The price level is stated to be lower than that of treatment at similar facilities in Germany and the Netherlands. The low price level results in the situation that the established soil cleaning companies cannot find the financial means to develop new methods.

Small market volume

Furthermore, the market volume in Denmark is estimated to be very small. Consequently, it cannot be expected that all the foreign technologies, as mentioned in annex 1, will be transferred to Danish conditions.

Market unpredictability

Market unpredictability is estimated to be a factor of primary importance. Thus, it is estimated that an actual market analysis, which may contribute to a more positive investment climate, is most certainly required.

4.3 Development of More Technologies

Assessment of the three statements

The respondents did not agree on whether the present level of technology is satisfactory. Among other requests, development of methods for treatment of soil contaminated with heavy metals was of interest. Moreover, the majority of the respondents believed that documentation of the effect of the methods was a field requiring further description.

There was a consensus of opinion that development of simple and inexpensive remedial technology is required. Some of the respondents, however, believed that the "next generation" of methods will be more expensive than the simple ones available at present. For instance, second generation biological treatment with bioreactors will probably be more expensive than land farming.

Whether it will be possible within the coming years to develop technology capable of handling the Danish problems of soil contamination at all is estimated to be a matter of will. It was stated that several such methods are already available, but not sufficiently documented.

4.4 Future Development of Remedial Technology

Research and development

It was stated that no platform for research and development of methods for remediation of contaminated soil is available /21/. Moreover, a forum for collaboration with the participation of both the research institutes and environmental consultants is called for.

At the Technical University of Denmark as well as at other universities, research within processes in soil and ground water and to some extent also more application-orientated research within technology development are carried out. According to information received, PhD studies of soil contamination and soil cleaning technologies are being carried out at the Technical University of Denmark. One of the students is employed as an industrial researcher with A/S Bioteknisk Jordrens.

The DEPA has not set aside special resources via the strategic environmental research programme for an effort within soil cleaning.

Pilot demonstration tests

The grant set aside for cleanups pursuant to the Waste Deposits Act is primarily allocated for full-scale cleanups and not for development and demonstration tests.

As described in section 2.3.2 possibilities of obtaining support for projects have been established, e.g. via the Landfill Project and in connection with the gasworks package. Furthermore, financing from the EU for two demonstration projects, full-scale and pilot scale respectively, has as previously described been obtained.

In connection with the Priority Project Concerning Contaminated Sites and Ground Water of the DEPA, which the present project is part of, support for one demonstration test concerning in-situ biological treatment of oil contaminated soil has been granted /49/.

Market conditions

It is estimated that the way in which the market for soil cleaning will develop is subject to great uncertainty. Consequently, some hesitation regarding investments in advanced treatment facilities such as thermal treatment plants has been observed.

What with the frequent changes in and discussions of the existing legislation, it is, furthermore, estimated to be extremely difficult to determine the size of the present and the future market volume.

Total assessment

The total assessment is that there is a need to establish a forum in which a more systematic effort can be made to improve the research and development effort within soil cleaning technology.

5. Scenarios

5.1 Setting up of Scenarios

Three scenarios

This chapter presents a review of three scenarios for application of technology in connection with soil contamination in Denmark.

The scenarios should as previously mentioned not be construed as proposals for future strategies for application of technology in Denmark, but should solely illustrate the mechanisms and contexts having an impact on the choice of remedial technology in each specific case.

Scenario 0 describes the reference scenario with the present application of technology, whereas scenarios 1 and 2 include maximum application of in-situ/on-site technology and maximum application of off-site treatment, respectively.

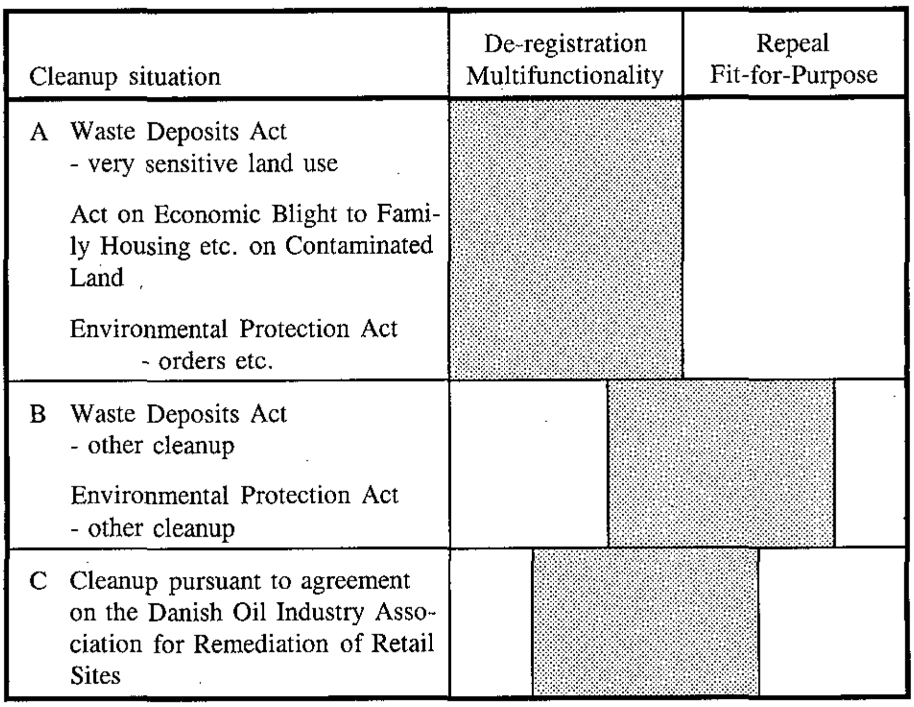
The three scenarios are described below on the basis of the cleanup reference situations presented in section 3.4.1 above.

5.2 Scenario 0 : Present Application of Technology

5.2.1 Cleanup Reference Situations

As stated in section 3.4, the present application of technology in Denmark is controlled by the situation in which the cleanup is carried out. In order to clarify this fact, figure 5.1 illustrates each cleanup situation and the requirements for the degree of cleanup.

Figure 5.1
Cleanup reference situations and degree of cleanup.



In the figure, the degree of cleanup is shown either as de-registration (multifunctionality) or as release (fit-for-purpose). For each situation the screened area illustrates the number of cleanups carried out for the purpose of de-registration and release, respectively. For instance 1/3 of the cleanups in reference situation B are estimated to be carried out for de-registration whereas 2/3 are carried out for release.

Cleanup situation A

As illustrated in the figure, cleanup situation A is characterized by cleanups being carried out for the purpose of cleaning up the area. For registered contaminated sites this means cleanups for de-registration, which in turn means that a cleaned up area subsequently has unrestricted application. Cleanup situation A includes cleanups pursuant to the Waste Deposits Act, where the present land use is deemed very sensitive, and cleanups pursuant to the Act on Economic Blight to Family Housing etc. on Contaminated Land. Moreover, cleanup situation A includes cleanups carried out on the basis of orders pursuant to the Environmental Protection Act.

For cleanup situation A the criteria for choice of remedial technology listed in table 5.1 apply.

Table 5.1
Criteria for cleanup situation A.

Criteria for cleanup	**Possibility of applying innovative in-situ/on-site technology**
De-registration	Very limited
Short time span	Very limited
Documentation of applicability of technology	Limited
Documentation of control of remediation	Limited

Cleanup situation B

Cleanup situation B includes other cleanups pursuant to the Environmental Protection Act, e.g. voluntary cleanups as part of a sale. Moreover, cleanup situation B includes voluntary cleanups pursuant to the Waste Deposits Act, i.e. cleanups typically carried out in connection with changes in the land use or sale.

Cleanup situation B is characterized by the degree of cleanup in most cases being limited to a level determined by the present (or desired) not very sensitive land use. The cleanups carried out for the purpose of multifunctionality (de-registration) thus include cleanups involving an intention to establish permanent housing on former industrial sites.

Table 5.2
Criteria for cleanup situation B.

Criteria for cleanup	Possibility of applying innovative in-situ/on-site technology
Release or similar level	Neutral
Short time span	Very limited
Long time span	Neutral
Documentation of applicability of technology	Limited
Documentation of control of remediation	Limited

An overview of the essential criteria for cleanups in cleanup situation B is provided in table 5.2.

Cleanup situation C

Finally, cleanups in connection with the Danish Oil Industry Association for Remediation of Retail Sites constitute a special cleanup situation where the purpose of the cleanup for a large number of the cleanups is determined by the same criteria as those of cleanup situation A. Thus, cleanup situation C can be considered something between situations A and B, however with most points in common with cleanup situation A.

5.2.2 Reasons for the Present Application of Technology

As stated in section 2.3.2, excavation followed by treatment/disposal is the prevailing technology relating to remedial action in connection with soil contamination in Denmark. This is estimated to be due to the following factors:

In the priority ranking of publicly financed cleanups, soil contamination constituting a threat to the ground water and soil contamination in conflict with the present land use of a property will be given cleanup priority /44/. However, it is estimated that there are only few cases in which soil contamination alone constitutes a threat to the ground water.

The majority of publicly financed cleanups thus include soil contamination involving sensitive land use at the time of cleanup, i.e. cleanups in cleanup situation A.

Cleanups in cleanup situation A are carried out for the purpose of deregistration with a choice of technology determined by the criteria listed in table 5.1. What with the identified barriers of a non-technical nature and the present level of development and documentation of innovative remedial technology, no real alternative to application of excavation and off-site treatment and/or disposal seems to be available for cleanups in this reference situation. Moreover, in connection with considerations of the extent of contamination, it often seems intuitively easier to remove the contamination from the property.

The fact that the criteria listed in table 5.1 have an inhibiting impact on the application of innovative technology is, furthermore, supported by the general picture of the application of technology in all cleanups in Denmark, see figure 2.3, which represents all three cleanup reference situations. For cleanups where no requirement for de-registration or a similar level of "purity" is made, it is possible to apply innovative technology.

In cleanup situation C, presently involving approximately 160 cleanups, about 25 cleanups are carried out by means of innovative technology /21/.

Consequently, as long as the public priority cleanups fall under cleanup situation A, i.e. until the cleanups under this category have been finalized, the present picture of the application of technology is estimated to remain unless changes in the barriers of a non-technical nature impeding the application of innovative in-situ and on-site technology are made. Section 5.5 below contains a more detailed discussion of this factor.

5.3 Scenario 1 : Maximum Application of in-situ/on-site Technology

5.3.1 Background for Scenario

As illustrated above, the criteria for the choice of remedial technology involve technical conditions to a limited extent only. Technical barriers to in-situ technology, e.g. the permeability of the soil and the type of contamination, have proved to be barriers of minor importance in comparison with barriers caused by legislation and administration.

In order to illustrate the technical barriers in a more detailed manner, a scenario involving maximum application of in-situ/on-site technology has been set up in this section. Moreover, annex 3 contains criteria typically applying to the choice of in-situ remedial technology in each specific case.

Cleaner technology in connection with remedial action

The scenario should be part of a strategy for implementation of cleaner technology through promotion of the application of e.g. biotechnological methods for remedial action in connection with soil contamination.

5.3.2 Removal of Non-technical Barriers

Table 5.3 provides an overview of non-technical barriers impeding the application of in-situ/on-site technology. For each of the barriers it is indicated how to remove the barrier. It should be emphasized that the list of possibilities of removal provided in the table is in no way exhaustive.

Table 5.3
Non-technical barriers to innovative in-situ/on-site technology

Primary barriers	Possibilities of removal
Requirement for de-registration	Abandonment of cleanups for the purpose of remediating economic blight. Purchase, for instance, of the site instead. Arrangements with mortgage credit institutions and other lenders for extensive lending to priority properties.
Soil quality criteria	Grading or modification of soil quality criteria.
Documentation of remedial technology	Establishment of support scheme for promotion of innovative remedial technology, e.g. a scheme similar to the US-EPA SITE programme.
Documentation of remediation of contamination	Elaboration of guidelines for documentation of cleanups.
Cost-Benefit	Elaboration of guidelines for the choice of remedial technology where the price is a secondary factor.

Removal of non-technical barriers is primarily determined by political factors, and the possibilities mentioned above should also be assessed in connection with other objectives for environmental protection. A modification of the valid soil quality criteria will, for instance, most probably lead to more widespread application of in-situ technology, although this will happen at the expense of a weakening of the present protection level for health in relation to the application of contaminated sites.

5.3.3 Technical Barriers

Below, an assessment of technical barriers to in-situ/on-site technology is made.

Table 5.4
Technical criteria for application of in-situ/on-site technology.

Barriers	Impact on application of innovative technology
Type of contamination	
Volative organic compounds	Small
Heavily volative organic compounds	Moderate
Heavy metals	Great
Composition of contamination	
Composite contamination	Great
Geology and hydrogeology	
Relatively inhomogeneous geology	Great
Relatively low permeability	Great
High ground water level	Moderate

Table 5.4 contains an overview of the most significant conditions of a technical nature for application of innovative technology. Table 5.4 also illustrates the present level of the development of innovative technology. Thus, it can be established that application of innovative technology will in connection with several types of contamination entail significant difficulties. This is, for instance, true for heavy metal contamination and for composite contamination. Contamination involving inhomogeneous geological conditions is also difficult to handle.

A high ground water level has an impact on the application of in-situ technology as it is typically necessary to lower the ground water level under such conditions in order to achieve an efficient in-situ cleanup. Lowering of the ground water and drainage of pumped up water are subject to comprehensive costs.

If maximum application of in-situ/on-site technology is desired, an effort for the purpose of further development and documentation of methods is consequently required.

Areas of effort

Table 5.5 contains an assessment of the technical barriers to the innovative in-situ technology which may have a potential in Denmark, cf. also annex 1.

Table 5.5
Assessment of technical barriers to application of in-situ technology.

In-situ technology	Technical barrier
Biological methods	
Bioremediation Bioventing	Difficulties in connection with inhomogeneous geology and low permeability. Moreover, it is doubtful whether the soil can be cleaned to the level of the present quality criteria. A number of controlled pilot scale tests should be carried out for the purpose of optimizing the application of methods.
Physicochemical methods	
Soil vapour extraction Steam stripping Forced soil flushing Soil flushing with detergents Chemical treatment	Difficulties in connection with inhomogeneous geology and low permeability. Moreover, it is doubtful whether the soil can be treated to the level of the present quality criteria. A number of controlled pilot scale tests should be carried out for the purpose of developing new concepts and optimizing the application of methods.
Sealing methods	
Liner sealing Vitrification	Difficulties in connection with long-term durability of liners and sealing systems. The technologies should be regarded more as methods for reduction of leakage than as the final solution to a problem of contamination.
Other methods	
Pneumatic fracturing Electrokinetics	Pneumatic fracturing is known from the oil research industry and is typically applied in combination with other methods (e.g. biological methods). Electrokinetics can primarily be applied in soil with a high content of clay. Research in the effect of the methods and controlled pilot scale tests for the purpose of developing new concepts are required.

As it appears from table 5.5., by and large all the technologies are estimated to require controlled tests at pilot scale for the purpose of developing new concepts and optimizing the methods. As far as the biological methods are concerned, it is estimated that concepts for application of such methods have been developed also in Denmark and that there is only a need for an optimization of the methods.

Areas of effort for on-site technology

Application of on-site technology is limited by the physical conditions of a specific cleanup. For instance, in connection with cleanups of single-family housing sites it will be difficult to apply on-site technology, solely because of a lack of space.

Table 5.6
Assessment of technical barriers to application of on-site technology.

On-site technology	Technical barrier
Biological methods	
Windrow composting Land farming Bioreactor	As far as windrow composting and land farming are concerned, it is difficult to provide documentation to the effect that biological treatment and not emission of the contaminants to the atmosphere is taking place. This can be countered by applying bioreactors, which include both composting reactors (possibly as pre-treatment prior to windrow composting) and slurry phase reactors. A number of controlled pilot scale tests with bioreactors for the purpose of developing new processes, including application of e.g. solvents, and optimizing the application of methods should be carried out.
Physicochemical methods	
Thermal treatment Thermal desorption	Development of treatments for air emissions (off gas) particularly in treatment of soil contaminated by chlorinated substances. Requirements for documentation in connection with reuse of treated soil. Thermal treatment and thermal desorption of contaminated soil require establishment and mobilization of relatively large plants.
Soil vapour extraction Forced soil flushing Soil washing Extraction (acid/solvents) Chemical dechlorination	Difficulties in connection with low-permeable and inhomogeneous soil as there may be a tendency towards agglomeration and formation of channels so that the total soil mass is not treated. For the technologies of extraction, separation and flotation, application of detergents and solvents should be developed for the purpose of raising the solubility of the contaminants. An effort should also be made to minimize the residual amounts generated by the treatment.
Sealing methods	
Stabilization/solidification	Difficulties in connection with determination of long-term durability of stabilized/solidified materials.

Consequently, it is estimated that several of the on-site technologies will hardly be attractive to develop for application on the Danish market. This is true for e.g. on-site thermal treatment, including thermal desorption and possibly also soil flushing, and other cleaning technologies which require relatively large plant investments and handling of relatively large plant units.

On the basis of annex 1, table 5.6 makes an assessment of the technical barriers to the innovative on-site technologies which might be relevant in Denmark.

With the present possibilities of off-site treatment/disposal, in-situ/on-site technology is estimated to be difficult to develop without public support and control, cf. also chapter 4.

5.4 Scenario 2 : Maximum Application of Off-site Treatment

5.4.1 Background for Scenario

The essential barriers stemming from economic blight have, as previously mentioned, an inhibitory impact on in-situ/on-site technology. Moreover, it will, all other things being equal, be an attractive solution to treat minor contamination off-site.

It is therefore deemed relevant to make a description of a scenario involving off-site treatment, i.e. a situation in which all types of soil contamination are removed from the properties in question for the purpose of treatment at e.g. central treatment facilities. The scenario is very similar to the recommendations made by the Brauer Committee in 1987 /45/.

It should be noted that excavation of contamination on existing housing sites is often difficult, partly because there may be geotechnical difficulties relating to excavation near foundations and partly because it is rarely possible to remove contamination below substructures. Excavation of contaminated soil will therefore not always result in a level which corresponds to de-registration of the contamination.

5.4.2 Existing Treatment Facilities in Denmark

Table 5.7 provides a list of central treatment facilities in Denmark, cf. /50/. In addition to the companies listed in the table, it should be mentioned that several of the coal-fired power plants also undertake incineration of soil contaminated with oil or tar.

5.4.3 Barriers to Off-site Treatment

Small market volume

As it appears from table 5.7, the commercial companies primarily engage in first generation biological methods and only to a lesser extent in extraction and thermal treatment. This is estimated to be due to the very extensive investment requirements connected with e.g. thermal treatment plants.

Moreover, it appears that off-site soil washing is presently not carried out at a commercial scale in Denmark, as is the case in Germany and the Netherlands. Soil washing is estimated to be an attractive solution, particularly where the treated soil is to be reused within the construction and demolition sector.

It can also be established that biological treatment in reactors has not been implemented in Denmark. Consequently, whether a 100% biodegradation is taking place in the established biological treatment or whether part of the treatment involves evaporation of the contaminants is not subject to control today.

Table 5.7
Soil cleaning facilities in Denmark.

Company	Method(s)
Bioteknisk Jordrens[1] Maglehøjvej 10 4400 Kalundborg	Windrow composting
K.K. Miljøteknik Sjælsø Allé 7 3450 Allerød	Windrow composting Thermal treatment[2]
Dansk Jordrens Egevej 9 4050 Skibby	Windrow composting Thermal treatment[3]
Hovedstadens Jordrens Kraftværksvej 31 2300 Copenhagen S	Windrow composting[4]
Ren Jord Fuglsangsallé 14 6600 Vejen	Extraction with dichloromethane[5]
Marius Pedersen Ørbækvej 49 5863 Ferritslev	Land farming
Municipality of Vejle Skolegade 1 7100 Vejle	Land farming
Soil Recovery Klintholmvej 49 5874 Hesselager	Thermal treatment

1) Has a facility in Esbjerg as well
2) Carried out as a pilot test at Kommunekemi A/S
3) Is being carried out in cooperation with Skærbækværket and Asnæsværket
4) Planned
5) Mobile facility, which is presently applied as a stationary facility

On this basis it is estimated that so far, Denmark has not had the sufficient market volume to justify private investments in technologically advanced soil treatment facilities.

Landfill disposal

Treated soil as well as non-treated soil is disposed of or applied as operating material on sanitary landfills. No total account of the amount of soil disposed of or applied on landfills without pre-treatment is available, and the standards for the amounts allowed at the disposal facilities vary from county to county. The amounts are, however, deemed significant.

A more detailed analysis of these soil flows is expected to be elaborated in connection with the work of the Soil Contamination Committee.

Disposal and application of contaminated soil at landfills are considered to be a significant barrier to primarily off-site soil treatment and secondarily in-situ/on-site technology.

Return of cleaned soil

The majority of the central treatment facilities have a possibility of regaining the soil after treatment. As the treatment in the biological methods may take months, soil is estimated to be returned to the client to a minor extent only.

Furthermore, information has been provided to the effect that reuse of treated soil is not always an attractive option as the treater of the soil does not make any guarantees of the geotechnical properties of the treated soil, e.g. the compressibility of the soil, cf. /21/. Hence, crushed construction waste is more attractive than treated soil.

Documentation of off-site cleaning of soil is provided and collected according to guidelines elaborated by the DEPA /26/ and /46/.

5.4.4 Actions for Promotion of Off-site Treatment

Control of soil flows

If promotion of off-site treatment of contaminated soil is desired, it is deemed important to establish control of the amounts of contaminated soil.

Tightening of the rules limiting the supply of non-treated contaminated soil to landfills is thus estimated to promote the supply of soil to the central treatment facilities.

The price level for disposal of contaminated soil (and partly cleaned soil) is expected to rise, cf. /21/. At present, Denmark has significantly lower prices than e.g. Germany and the Netherlands. An increasing price level of disposal, possibly also in combination with stricter requirements for waste incineration, must all other things being equal be expected to canalize contaminated soil from landfills to the central treatment facilities.

As an example of how to direct contaminated soil to cleaning, the conditions in the Netherlands where an independent organization for contaminated soil from publicly financed cleanups has been established are described below, see also section 2.3.4.

In 1989, an independent enterprise with the overall objective of promoting optimization of soil cleaning in the Netherlands was established. The enterprise consists of two parts, which are each independent limited companies, cf. /47/:

Service Centrum Grondreiniging (SCG)

Service Centrum Grondreiniging NV with the following tasks:

- assessment of possibilities of soil cleaning,
- acceptance of soil for cleaning,
- acceptance of part cleaning of soil for reuse in the construction and demolition sector,
- certification of cleaned soil for unrestricted application,
- incentive to development and further development of technology,
- supervision of soil cleaning facilities.

TOP's Grondbeheer (TGB)

TGB NV, which is also a limited company, with the objective of operating TOPs, Tijdelijke Opslagsplaatsen, which are contaminated soil deposits. TGB NV was established during the central take-over of deposits, which had to some extent previously been established by the individual provinces in the Netherlands.

Contaminated soil is temporarily stored until possibilities of treatment arise or until the depot is sufficiently large for it to bear the necessary investments in treatment facilities.

Seven deposits located all over the country, each with a capacity of between 20,000 and 380,000 tonnes, have been established. In total, there is a storage capacity of 685,000 tonnes.

Whether SCG and TGB should handle contaminated sediment and sludge, e.g. harbour sludge, is presently under consideration.

Function of SCG

In all publicly financed cleanup operations involving removal of contaminated soil from the property in question, the SCG should be consulted concerning the choice of cleaning of the soil. Hence, it is not possible in publicly financed cleanups to dispose of the contaminated soil at a landfill. SCG fixes a price for off-site treatment of the soil on the basis of an agreement on cooperation with the privately operated soil treatment facilities. Furthermore, SGC assumes the responsibility for the soil which is not returned.

Advantages and disadvantages

SCG is a monopoly as it has been laid down by law that all contaminated soil removed in connection with publicly financed cleanup operations should go through this enterprise. SCG can, for instance, in principle favour some kinds of treatment to others.

However, SCG operates on the basis of ordinary market conditions as contaminated soil from non-publicly financed cleanups is not subject to the same requirements for approval of off-site treatment.

SCG has no influence on whether in-situ or on-site technology is applied in a given cleanup, but the relatively good possibilities of disposing of contaminated soil for off-site treatment or temporary storage are estimated to contribute to a preference for this solution.

Off-site treatment

If contaminated soil in Denmark is to be taken to off-site treatment facilities more frequently than today, it has previously been estimated that the following treatment technologies are required, cf. e.g. /45/:

Thermal methods	Alone or in combination with coal firing at power plants
Physicochemical methods	Extraction and/or soil washing
Microbiological methods	Treatment in closed systems, e.g. reactors

As far as thermal and physicochemical methods are concerned, pilot and full-scale facilities for treatment of several types of contamination have already been established. Germany in particular has positive experience of both soil washing and various kinds of thermal treatment. Also in the Netherlands thermal high temperature plants and soil washing facilities have been in operation for several years.

If a special effort within off-site treatment methods is aimed at, it is on this basis deemed appropriate to concentrate the effort on microbiological treatment in closed systems, e.g. in bioreactors.

5.5 Choice of Remedial Technology in the Future

As it appears from the three scenarios, there is a connection between legislative, organizational and technical conditions, which contribute to the state of application of technology within cleaning of contaminated soil.

Consequently, the present application of technology in Denmark is to a large extent determined by non-technical criteria controlled by the present legislation on economic blight and the rules governing registration, release and de-registration pursuant to the Waste Deposits Act.

Moreover, the possibilities of disposing of contaminated soil at landfills are deemed to be an inhibitory factor to primarily off-site treatment and secondarily in-situ/on-site methods.

Finally, it is with several types of minor contamination intuitively deemed most appropriate to apply excavation followed by off-site treatment.

In-situ/on-site technology

If strategies entailing more widespread application of in-situ/on-site technology are aimed at, this is with the present legislation and administration and the present level of technology estimated only to be possible in connection with contamination where no economic blight is involved or possibly with contamination where the economic blight is compensated for by an attractive location or similar factors.

More widespread application of in-situ/on-site technology should, therefore, not be expected without public support and control.

Off-site treatment of contaminated soil

Strategies involving excavation and off-site treatment of contaminated soil may, as in the Netherlands, contribute to a redirection of contaminated soil from landfills to treatment facilities. At the same time, a safer market for the existing private soil cleaning companies will be established.

If the present legislation is maintained and if the same level of activity is operated with, the pattern for application of technology, as illustrated in table 5.8, is expected to remain.

Whether off-site treatment or direct disposal of contaminated soil will be preferred is estimated to be a matter of the price of disposal and of the possibilities of disposing of contaminated soil for application as operating material at landfills.

Table 5.8
Expected future application of technology without public support and control.

Cleanup situation		In-situ/on-site treatment	Off-site treatment and/or disposal
A	Waste Deposits Act - very sensitive land use Act on Economic Blight to Family Housing etc. on Contaminated Land Environmental Protection Act - orders etc.		░
B	Waste Deposits Act - other cleanup Environmental Protection Act - other cleanup	░	░
C	Cleanup pursuant to agreement on the Danish Oil Industry Association for Remediation of Retail Sites	░	░

The choice of in-situ, on-site or off-site remedial technology naturally depends on each case of contamination and on the background for the requirement or the desire for a cleanup.

Tools or methods for determination in each specific case of whether in-situ, on-site or off-site treatment should be chosen from an environmental point of view are not available neither in Denmark nor abroad. Consequently, no investigations of the total impact of a specific cleanup on e.g. energy consumption and emissions in the form of odour, dust and noise and no methods for assessment of "most environment for the money invested" are available.

A standard method for the choice of remedial technology, cf. e.g. /40/, in which all environmental and resource contributions are considered could be a tool for determination of whether in-situ/on-site technology or excavation followed by off-site treatment should be applied in a specific cleanup operation.

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The following companies did not wish to participate: Birch & Krogboe A/S, COWIconsult A/S, Dansk Geo-servEx A/S, I. Krüger A/S, Kampsax Geodan A/S and A/S Samfundsteknik.

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The interviews included the following persons: Erik Arvin (Department for Environmental Technology (Technical University of Denmark)), Susanne Hansen (Bioteknisk Jordrens), John Frederiksen (Danish Railways), Lotte Marianne Petersen and Jørgen Skaarup (Agency of Environmental Protection, Municipality of Copenhagen), Bjørn Jensen (Danish Environmental Group (DCR - c/o VKI)) and Carl Köhne (Danish Oil Industry Association for Remediation of Retail Sites).

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Remedial Technology

Background

This annex provides an overview of technologies applicable to remediating soil contamination. The list has been elaborated on the basis of a study of literature, particular from Denmark, the USA, the Netherlands and Germany /1-21/.

In the list, the remedial technologies are categorized as follows:

- off-site technologies
- on-site technologies,
- in-situ technologies.

Types of Soil Contamination

For each technology it is indicated to which types of soil contamination the technology in question is applicable. Soil contaminations are in the list divided into the following classes:

	I Volatile organic compounds	II Heavily volatile organic compounds	III Heavy Metals
Biodegradable	/	/	
Non-biodegradable	X	X	X

Note that technologies based on biodegradation of contaminants are indicated by a "/" instead of an "X" in the list.

Indication of Degree of Implementation

For each technology, the degree of implementation in Denmark as well as abroad, is evaluated. The implementation is in the list indicated as follows:

	No. of full-scale remediations with the technology application in question	Degree of implementation
Denmark	< 10	Tried out on a few sites
	10 - 20	Tried out on several sites
	> 20	Carried out on several sites
Abroad	< 20	Few full-scale remediations
	20 - 100	Several full-scale remediations
	> 100	Many full-scale remediations

Off-site		Soil Contamination			Degree of implementation	
Technology	Description	I	II	III	DK	Abroad
External treatment and/or disposal	Excavation and removal of contaminated soil. External treatment and/or disposal of contaminated soil. Possible return of treated soil. External treatment by for instance thermal, biological, physical methods.	X	X	X	Most widespread method for full-scale remediation	Most widespread method for full-scale remediation

On-site		Soil Contamination			Degree of *implementation*	
Technology	Description	I	II	III	DK	Abroad
Thermal treatment	Contaminated soil is treated in thermal treatment plants (incineration).	X	X			Many full-scale remediations. Can hardly be described as innovative.
Windrow composting	Contaminated soil is stacked in windrows on a liner and to a height of 1-2 metres. The soil may be mixed with wood chips or similar. Oxygen is added by means of turning the windrows or by air injection. Degradation can be enhanced by adding water and nutrients.	/	/		Tried out on a few sites	Several full-scale remediations have been carried out
Land farming	Contaminated soil treated in lined beds. The beds are frequently turned or air is added in other ways. The beds are watered with water supplied with nutrients and possibly adapted microorganisms. Degradation can be enhanced by growing plants in the beds.	/	/		Tried out on a few sites	Several full-scale remediations have been carried out
Bioreactors (slurry phase or solid phase reactors)	Contaminated soil is treated in a closed system (a bioreactor). The soil may be mixed with wood chips or similar. During treatment, oxygen, water, nutrients and possibly adapted microorganism are added to the soil.	/	/			A few full-scale remediations have been carried out.
Soil Vapour Extraction (SVE)	Contaminated soil is treated by blowing air through the soil, whereby contaminants are stripped from the soil. Treatment of off-gas may take place.	X			Tried out on a few sites	A few full-scale remediations have been carried out.

On-site		Soil Contamination			Degree of implementation	
Technology	Description	I	II	III	DK	Abroad
Thermal desorption	Contaminated soil is treated in a closed system. By means of heat, the contaminants are evaporated from the soil. Steam or an inert gas (e.g. N_2) may be applied to remove the contaminants from the soil. Incineration during the desorption process is avoided. The off-gas is treated by means of activated carbon filtration, catalytic oxidation etc.	X	X		Tests have been carried out	Many full-scale remediations have been carried out. Can hardly be described as innovative.
Soil flushing	Contaminated soil is placed in a lined bed. Water is percolated through the soil. The water is collected, cleaned and recirculated over the soil. Oxygen and nutrients may be added to the percolating water to enhance biodegradation.	X			Tried out on a few sites	Few full-scale remediations have been carried out.
Soil washing	Contaminated soil is put through a washer. During washing the fine fraction of the soil particles (with the major portion of the contaminants) can be separated. Coarser fractions can be included in an additional washing procedure. The soil washing can be enhanced by adding e.g. detergents. Additional treatment of washing water and fine particle fraction.	X	X	X	Tests have been carried out	Several full-scale remediations have been carried out. Can hardly be described as innovative.
Extraction with acid	Contaminated soil is washed with an acid solution (is extracted) to remove heavy metals. The washing water is subsequently treated.			X		Few full-scale remediations have been carried out.
Extraction with solvents	Contaminated soil is treated by extraction with a solvent, e.g. propane. butane, freon, dichloromethane, tri-ethylene-amine etc. The extracted liquid is separated from the soil, distilled, and the extracting agent is reused.	X	X		Commercial treatment plant exists, but is not used in on-site treatment.	Few full-scale remediations have been carried out.
Solidification/-stabilization	Contaminated soil is mixed with a stabilizing agent, e.g. different types of cement. The mixture hardens, whereby leakage of contaminants is minimised.	X	X	X	Tried out on a few sites	Many full-scale remediations have been carried out. Can hardly be described as innovative for contaminants of type III.

Annex 1

On-site		Soil Contamination			Degree of implementation	
Technology	Description	I	II	III	DK	Abroad
Chemical treatment - dechlorination	Soil contaminated with chlorinated compounds is chemically treated. Active agents substitute the chlorinated contaminants with the aim of forming less toxic compounds.	*	*			A few full-scale remediations have been carried out.
		* chlorinated compounds only.				

In-situ		Soil Contamination			Degree of implementation	
Technology	Description	I	II	III	DK	Abroad
Bioremediation	Biodegradation of contaminants in the soil. Degradation may be enhanced by percolation of oxidized water supplied with nutrient and agents such as e.g. detergents. Adapted nutrients may be applied.	/	/		Tried out on several sites	Several full-scale remediations have been carried out
Bioventing	Biodegradation of contaminants in the soil. Degradation may be enhanced by sucking or blowing air (and thereby O_2) through the soil. The air may be cleaned before release to the atmosphere. Percolation of water supplied with nutrients may further enhance the degradation process.	/	/		Tried out on a few sites	Several full-scale remediations have been carried out
Soil Vapour Extraction (SVE)	Contaminants are stripped from the soil by means of venting. Typically, the venting system is designed as a vacuum system. The air may be treated before release to the atmosphere.	X			Carried out on several sites	Many full-scale remediations have been carried out. Can hardly be described as innovative.
Steam stripping	Contaminants are stripped from the soil by means of venting with steam and hot air. The air may be treated before release to the atmosphere.	X				Few full-scale remediations have been carried out
Soil flushing	Flushing of contaminants from the soil is enhanced by percolation with water. The water is collected, treated and recycled. Oxygen and nutrients may be added to the water to support the biodegradation.	X			Carried out on several sites	Several full-scale remediations have been carried out
Soil flushing with detergents	Flushing of contaminants can be enhanced by the use of detergents. Contaminated soil is percolated with water and detergent in a mixture. The water is after percolation collected and disposed of off-site.		X		Tests are carried out	Test are carried out

In-situ		Soil Contamination			Degree of implementation	
Technology	Description	I	II	III	DK	Abroad
Sealing systems	Contaminated soil is sealed (sides, bottom, surface). The encapsulation may be with cement, plastic liners or by sealing the surface with tiles or other means of cover.	X	X	X	Carried out on several sites	Several full-scale remediations have been carried out
Vitrification	Electrodes are placed in the soil. By applying a current, the soil can be heated up to a temperature where soil and stone are melting to a glass-like mass.	X	X	X		Few full-scale remediations have been carried out
Electrokinetics	Electrodes are placed in the soil. An electric potential is applied, and the contaminants are led towards the electrodes where they can be collected.			X	Test are carried out	Test are carried out
Chemical Treatment	Percolation of active agents (e.g. H_2O_2) through the contaminated soil with the aim of enhancing degradation to less toxic compounds.	X	X			Few full-scale remediations have been carried out
Pneumatic fracturing	Contaminated soil is (by means of boreholes) exposed to high pressure to increase the permeability. Combines with other methods such as venting.	X				Few full-scale remediations have been carried out

Barriers to Application of Innovative Remedial Technology

LEGISLATIVE BARRIERS

Cleanup for De-registration due to Economic Blight

Background

The purpose of the Act on Economic Blight to Family Housing etc. on Contaminated Land is to give the owner of contaminated properties applied for permanent housing a cleanup at the request of the owner, e.g. in connection with a planned sale of the property. The objective of the cleanup is to remove the loss of value on the property as a consequence of the contamination on the property.

Effect

As mentioned above, the objective of the cleanup is to remove the loss of value on a property. A removal of the loss of value seems to be the same as a removal of the contamination, which will in practice primarily consist of excavation of the contaminated soil.

Assessment of the barriers

Time consuming technology or technology not deemed well tested or documented are not estimated to be applicable in connection with cleanups due to economic blight.

Importance of the barrier

The barrier is estimated to be of **primary importance**.

Possibilities of removal

The barrier can be removed by abandoning cleanups for the purpose of countering economic blight.

An agreement with mortgage credit institutions, banks or similar institutions may be made to the effect that when a cleanup has been given priority, the loss of value no longer applies.

Recourse Pursuant to Waste Deposits Act

Background

Subs. (3) of s. 3 of the Waste Deposits Act gives the authorities the possibility of recovering their expenses for remediation of cases of contamination through civil proceedings against the polluter.

Effect

In the recourse cases tried in court emphasis has in addition to the determination of culpa been put on the following factors during the consideration of the judgment:

- the necessity and extent of the operation,
- the success of the operation,
- the cost of the operation, including whether the person responsible for the contamination has been granted the possibility of suggesting alternatives.

For cleanup operations in which recourse is planned subsequently, it is thus important that the operations are carried out quickly (there is an immediate demand). Nothing more than absolutely necessary should be carried out to reduce the contamination. Moreover, success should be certain and it should be ensured that the cheapest technology possible is applied.

Assessment of the barrier

In consideration of the above criteria, emphasis will automatically be put on application of well-documented remedial actions. Cleanups involving subsequent recourse against the polluter are therefore not estimated to be a field in which experiments with innovative technology can be made.

Importance of the barrier

The barrier is estimated to be of **secondary importance**.

Possibilities of removal

The barrier can be removed by generally **abandoning recourse** against polluters.

Approval Pursuant to the Environmental Protection Act

Background

The Environmental Protection Act requires approval of heavily polluting enterprises. This requirement also applies to facilities treating contaminated soil, whether this is in-situ, on-site or off-site.

In cleanups within the framework of the Waste Deposits Act approval is not required, cf. subs. (1) of s. 23. The general practice, however, is that exemption from approval only applies to publicly financed cleanups so that voluntary cleanups still require approval according to the rules laid down in the Environmental Protection Act where a treatment facility falls under the stipulations of the rules.

Effect

Approval pursuant to the Environmental Protection Act constitutes a barrier to in-situ methods involving addition of xenobiotic substances to an unsaturated/saturated zone, e.g. forced soil flushing by means of detergents and similar substances.

As far as on-site methods are concerned, the application of environmentally dangerous substances, e.g. methylene chloride, in connection with extraction facilities is probably unacceptable considering the level of environmental protection usually applied in Denmark. Moreover, air emissions, noise etc. may entail the rejection of a technology.

Assessment of the barrier

As far as in-situ methods are concerned, the barrier is estimated to be of significant importance to the further application and popularization of in-situ methods with application of xenobiotic substances. In connection with on-site treatment the barrier will probably only be of importance to a minor part of on-site treatment plants.

Importance of the barrier

The barrier is estimated to be of primary importance to in-situ methods applying xenobiotic substances, and of secondary importance to on-site methods. All in all, the barrier is estimated to be of **secondary importance**.

Possibilities of removal

The possibilities of removing the barrier are slim as the general requirements for environmental protection will in that case have to be modified.

Another possibility of removing the barrier may be to elaborate guidelines for control and documentation of the execution of in-situ cleanups in order to ensure that the general level of environmental protection is preserved.

Making priorities in connection with the national ground water protection effort, cf. e.g. the present work in the Priority Project Concerning Contaminated Sites and Ground Water of the DEPA, may lead to the possibility of modifying the requirements for ground water protection in some areas for the benefit of application of in-situ soil treatment methods.

INSTITUTIONAL BARRIERS

Diverging Authority Objectives

Background

With the division of labour of the Waste Deposits Act between central (DEPA) and decentral (counties and the Municipalities of Copenhagen and Frederiksberg) authorities, disagreements as to the purpose of cleanups may arise.

Effect

Disagreement between authorities often requires several negotiations to reach a compromise between the parties involved, which in turn entails greater time consumption before consensus is reached.

An example is the cleanup in Mundelstrup Stationsby where negotiations of whether the remedial actions should involve purchase of the land or whether excavation of the contaminated soil should be carried out dragged out for years.

Assessment of the barrier

In cases of disagreement between authorities concerning cleanups, the disagreement initially often focuses on levels of cleanup.

Choice of technology rarely gives rise to disagreement.

Importance of the barrier

The barrier is estimated to be of **secondary importance**.

Possibilities of removal

The barrier can be removed by introducing a system involving one authority only.

Cleanup Criteria

Background

Cleanup criteria, in Denmark called soil quality criteria (for the most sensitive land use), are defined as the maximum permissible residual contamination after a cleanup operation.

Soil quality criteria should be regarded as a "once and for all" risk assessment of a given substance in relation to sensitive land use. At present, Denmark has soil quality criteria for approximately 10 substances elaborated on the basis of human and partly also ecotoxicological considerations.

In draft guidelines for the Danish Oil Industry Association for Remediation of Retail Sites the present soil quality criteria are dependent on depth (A, B and C soil) in such a way that larger concentrations can be accepted at greater depths (< 1 metre) /34/.

Effect

Soil quality criteria are applied in connection with determination of the extent of cleanups, e.g. that the concentration in the soil of any given substance at a given depth should not exceed the soil quality criteria.

Soil quality criteria thus determine the level of cleanup.

Assessment of the barrier

With in-situ methods it is assessed that it may be a problem to reach the required levels, which is closely connected with the accessibility of the substances involved.

In specific cases, in-situ cleaning to the level of the soil quality criteria has, however, been achieved, cf. /33/.

Relatively lenient cleanup criteria may, furthermore, have the effect that contaminated soil is temporarily disposed of in anticipation of more lenient cleanup requirements in time and thus lower costs for the cleanup operation. In voluntary cleanups, particularly in connection with industrial enterprises in operation, relatively lenient cleanup criteria may entail a postponement of cleanups, cf. /37/.

Importance of the barrier

The barrier is estimated to be of **primary importance**.

Possibilities of removal

Grading and possibly modification of the soil quality criteria.

A model for grading has already been suggested in the draft guidelines for the Danish Oil Industry Association for Remediation of Retail Sites.

Documentation of Remedial Technology

Background

Documentation is required in connection with the execution as well as the termination of cleanups.

Effect

In the choice of cleanup method, emphasis is put on documentation of the operational effect of the method and in some cases also on the method being documented under Danish soil conditions.

Innovative technology which due to lacking demonstration and documentation gives rise to doubts about the effect and success of the method is therefore rarely applied.

Assessment of the barrier

Documentation of the effect and probability of success of a remedial technology is of decisive importance to the application of the technology.

Importance of the barrier

The barrier is estimated to be of **primary importance**.

Possibilities of removal

The barrier can be removed if a scheme involving testing and documentation of new technology under Danish conditions is established, cf. e.g. the American SITE programme.

Background

Documentation also involves proof of the fact that the contamination has been removed at the end of the remedial action.

Effect

Guidelines for the extent of documentation required in connection with demonstration of the removal of contamination are not available. Usually excavation followed by off-site treatment or disposal of the contaminated soil is regarded to be more acceptable than in-situ treatment, which may stretch over several years.

Importance of the barrier

The barrier is estimated to be of **primary importance**.

Possibilities of removal

The barrier can be removed by elaborating guidelines for the extent of documentation required in connection with the execution as well as the termination of cleanup operations.

Guarantees in Connection with Application of Technology

Background

In connection with the application of remedial technology a certain guarantee that the method is working is required.

Effect

Any liability in connection with the application of innovative technology may be a barrier to the application of technology in the cases when a supplier of technology cannot live up to the guarantee requirements made.

Assessment of the barrier

Liability is estimated to be of a certain significance when applying in-situ methods such as electrokinetics and maybe also biological methods. Most often, however, the purchaser of technology will be willing to assume a certain degree of responsibility for the success of the method. The barrier is, furthermore, closely connected with the present requirements for documentation.

Importance of the barrier

The barrier is estimated to be of **secondary importance**.

Possibilities of removal

The barrier can be partly removed if standards for the documentation of cleanups are elaborated. This will contribute to greater transparency for the suppliers of technology as the requirements for the quality of the technology will be pre-determined.

Neighbours and Surroundings

Background

Neighbours and surroundings may be a decisive factor in the choice of remedial technology, particularly in densely populated areas.

Effect

Considerations of neighbours and surroundings primarily concentrate on odour and noise nuisances and secondarily on psychological factors. The latter have in the USA proved to be of importance where the neighbours in several cases have preferred a removal of the contamination to living with an in-situ facility as their neighbour. Similar psychological factors have not been reported in Denmark.

Assessment of the barrier

In cleanups in urban areas in Denmark, maximum consideration is paid to the neighbours and great emphasis is put on information and involvement of the parties affected.

An example is the cleanup of Østre Gasværk in the municipality of Copenhagen where the excavation of contaminated soil and construction materials was carried out in a tent designed for the purpose. The barrier is thus estimated to be of importance in connection with the planning of cleanups only and will result in additional costs for special protective measures.

Importance of the barrier

The barrier is estimated to be of **secondary importance**.

Possibilities of removal

The barrier can as mentioned above be removed by means of special measures for reduction of particularly noise and odour nuisances. Moreover, an effort can be made to inform the neighbours prior to the cleanup.

Disposal of Contaminated Soil

Background

In Denmark as in several other countries it is common practice to landfill contaminated soil according to specified guidelines, whether it be applied as operating material (covering etc.) or disposed of as waste.

Furthermore, in a number of cases special deposits have been established at landfills as disposal in special deposits is exempted from the waste tax.

Effect

In the cases where disposal of contaminated soil at approved landfills in terms of price is just as competitive as off-site, on-site or in-situ treatment of the contaminated soil, the landfill solution will typically be preferred.

Danish soil cleaning companies disagree on whether this is a significant reason for the fact that the market for soil cleaning is not as great as originally expected. Abroad, e.g. in the UK, landfill disposal of contaminated soil is regarded to be a significant barrier to application of actual soil cleaning methods.

In the Netherlands a special publicly controlled soil mediator company has been set up to see to it that soil from publicly financed excavations are cleaned to the extent technically possible and economically attractive.

Assessment of the barrier

Disposal of contaminated soil at landfills and at special deposits is estimated to constitute a barrier to a certain extent to primarily off-site treatment of contaminated soil and secondarily on-site and in-situ treatment.

Importance of the barrier

The barrier is estimated to be of **primary importance** to the application of innovative technology.

Possibilities of removal

The barrier can be removed by strengthening the rules for landfill disposal of contaminated soil, possibly in connection with new landfill guidelines or the ongoing work of the DEPA concerning soil flows.

TECHNICAL BARRIERS

Inhomogeneous Geological Conditions

Background

Denmark is a country with great geological variation and with large parts covered by clay till.

Effect

Heterogeneous soil gives rise to problems in connection with the execution of both in-situ and on-site/off-site treatment and the subsequent documentation of the effect of the cleanup operation. These factors are also true for soil with a large clay content.

Denmark's heterogeneous geology is often applied as an argument for foreign technology not being immediately applicable under Danish conditions. It is, however, doubtful whether this argumentation can be upheld in practice as, for instance, large parts of Canada and the USA have largely the same geological conditions as those of Denmark.

Assessment of the barrier

The geological conditions in Denmark are estimated to constitute a barrier to the application of in-situ technology as almost all of the technologies require reasonable homogenous and permeable soil conditions.

Importance of the barrier

The barrier is estimated to be of **primary importance** to the application of in-situ technology whereas it is of **secondary importance** to on-site/off-site treatment methods.

Possibilities of removal

None.

Time Consumption of the Cleanups

Background

The time consumption of the cleanups is a factor of importance as far as action against acute environmentally and/or health threatening contamination is concerned or when a relatively quick cleanup due to an existing loss of value on a property is expected.

Effect

Time consumption is often a parameter of significant importance when remedial technology has to be chosen. In most cases it is not possible to wait for a long-lasting test of the possibilities of applying innovative technology at the site in question.

Assessment of the barrier

The possible time consumption for a give cleanup depends on the purpose of the cleanup. As mentioned above, time is a significant factor in connection with cleanups for remediation of acute health and/or environmentally threatening contamination and removal of a loss of value, whereas in other cases, for instance with stable soil contamination and non-sensitive land use, the time factor is not very important.

Importance of the barrier

In total, the barrier is estimated to be of **primary importance**.

Possibilities of removal

Slim.

Composite Contamination

Background

In approximately 50% of the public priority cleanups in the period of 1992-94 in Denmark it can be established that the contamination is of a composite nature, i.e. a contamination where several contaminating substances or compounds are present at the same time.

Effect

Composite contamination or contamination with more than one substance is a restraint on the application of technology. An example is simultaneous contamination with petrol and heavy metals. Petrol contamination can under suitable soil conditions be countered fairly easily by means of biological in-situ or on-site methods, whereas this is not true for heavy metals.

Assessment of the barrier

Composite contamination will be a significant parameter in the choice of technology, both in-situ and on/off-site. In cleanups of such contamination, traditional technology (excavation and disposal etc.) must be expected to be applied. Cleanup of composite contamination may be carried out by means of various technologies in series, the so-called "treatment trains", which are a well-known concept from e.g. water treatment.

Importance of the barrier

The barrier is estimated to be of **primary importance**.

Possibilities of removal

None.

Extent of Contamination

Background

The extent of contamination may vary considerably measured in m^2 or m^3.

With industrial sites the extent of a given contamination naturally depends on the nature of the contaminating processes applied. Whereas e.g. traditional wood impregnation industry with large draining sites is an example of an industry typically with a great extent of contamination (in the range of hectares), contamination from dry-cleaning companies will typically result in soil contamination limited to a size of the property of a single-family house (500-1,000 m^2).

Effect

In cleanups of smaller cases of contamination, typically in the range of the property of a single-family house, the financial framework will usually not allow of cost demanding bench scale tests or pilot tests of innovative technology.

Thus, with smaller cases of contamination there will be a tendency to choose solutions in which the contamination is removed from the property for off-site treatment or disposal, also because it in most cases is considered to be the easiest solution.

Assessment of the barrier

The fact that excavation and off-site treatment or disposal are applied in smaller cases of contamination is first and foremost estimated to be due to the cleanups being carried out to remediate health hazards as a major part of these cleanups are typically carried out on sites with very sensitive land use.

Importance of the barrier

The barrier is estimated to be of **primary importance**.

Possibilities of removal

None.

FINANCIAL AND MARKET BARRIERS

Cost-Benefit with the Alternative of Cost-Effectiveness

Background

In publicly financed cleanups as well as in other cleanups the technology should be price competitive.

Effect

With publicly financed cleanups an economic comparison of alternative cleanup concepts is required in connection with the elaboration of the conceptual project.

If a traditional, thoroughly tested technology (e.g. excavation and off-site treatment or disposal) is compared with an in-situ technique, the traditional solution will usually be more economically advantageous. This is partly due to the greater requirements for documentation of in-situ technology than for off-site treatment and disposal facilities.

Assessment of the barrier

No comparative studies of the costs relating to e.g. documentation of in-situ innovative technology and traditional off-site treatment, respectively, for any given contamination are available.

The overall assessment in connection with innovative technology is that a supplier of technology will naturally attempt to have his development costs covered. With traditional technology the development costs are regarded as having already been paid.

Importance of the barrier

The barrier is estimated to be of **primary importance**.

Possibilities of removal

If innovative technology is to be competitive in comparison with traditional and thoroughly tested technology, a third party bearing or neutralizing the development costs is necessary.

In the USA, e.g. within the framework of SUPERFUND, a demonstration programme (SITE) in which the suppliers of technology are given the opportunity to have their technologies tested and approved has been established. The SITE programme has been established for the purpose of promoting the application of innovative technology.

Criteria for Choice of In-situ Remedial Technology

Annex 3

Background

Below, an overview of the criteria typically applied in connection with the choice of in-situ remedial technology is provided.

Cleanup reference situations

On the basis of section 5.2.1 the importance of the criteria is assessed in relation to cleanup situations A and B. No similar assessment of cleanups pursuant to the Danish Oil Industry Association for Remediation of Retail Sites has been made as this is estimated to be covered by the coming guidelines for the scope of work of the Association, cf. /34/.

It should be emphasized that it is deemed difficult to make sure that all criteria are included. As any contamination is subject to specific local conditions which cannot be considered here, it should be emphasized that the overview should not be regarded as complete.

Thus, the overview should be regarded as a paradigm for a list of possible criteria to which specific local criteria can be added as required.

Finally the overview of criteria can be applied as a check list in the assessment of the suitability of potential in-situ innovative remedial technology.

Possibilities of Applying In-situ Remedial Technology

Cleanup situation A

As previously mentioned, cleanup situation A includes cleanups pursuant to the Act on Economic Blight to Family Housing etc. on Contaminated Land and cleanups of contaminated sites presently with a very sensitive land use. Cleanup situation A is consequently characterized by the cleanups being carried out for de-registration or a similar level.

Cleanup situation B

Cleanup situation B includes all other cleanups pursuant to the Waste Deposits Act as well as voluntary and ordered cleanups pursuant to the Environmental Protection Act. In cleanups in situation B, cleanup for de-registration or a similar level is not required.

Table 1 makes a proposal for an overview of criteria and check list for cleanup situations A and B. As it appears from the table, the criteria have been elaborated in the form of questions to which yes or no can be answered.

For each criterion the importance of that criterion to the application of innovative in-situ technology has been stated for cleanup situations A and B, respectively.

When going over the check list for a specific location, the table is thus designed in such a way that the higher the number of times "yes" is the answer, the better the chances of in-situ technology being recommended as remedial action against the contamination in question.

In conclusion it should be emphasized that the check list can be applied at a preliminary stage of the selection procedure only. If it appears from the check list that the possibilities of applying in-situ technology are good, more detailed considerations of the choice of in-situ technology and the specific design of the technology should naturally be paid.

Table 1
Overview of criteria and check list for assessment of the suitability of potential in-situ innovative remedial technology.

Criteria	Yes	No	Importance (small/moderate/great) Situation A	Situation B
Non-technical criteria:				
Has potential innovative remedial technology previously been documented for the contamination in question at full scale?			Great	Great/ Moderate
Has the procedure for documentation of the cleanup been determined?			Great	Great
....				
Technical criteria:				
Is the time of treatment short (< 3 months)?			Great	Moderate/ Small
Does the contamination consist of one substance only?			Great	Great
Is the contamination biodegradable/ easily volatile?			Great	Great
Is the contamination extensive?			Moderate	Small
Are the permeability conditions good?			Great	Great
Is the geology relatively homogeneous?			Great	Great
Can lowering of the ground water level be avoided?			Moderate	Moderate
Can significant noise, dust or odour emissions be avoided?			Moderate	Moderate
....				
Specific local criteria:				
Can nuisances to the neighbours be avoided?			Small	Small
Can special working environmental measures be avoided?			Moderate	Moderate
....				

Data Sheet

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Abstract:
The report analyses the use of remedial technologies in Denmark, and gives an overview of the technical and non-technical barriers determining the criteria for application of primarily in-situ/on site technologies and secondarily for application of off-site treatment technologies. The report is strictly limited to technology for application in connection with soil contamination, and also includes an account of remedial technology presently applied in the USA and the Netherlands.

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Resumé:
I denne rapport er der foretaget en analyse af anvendelsen af afværge-teknikker i Danmark. Der er endvidere gennemgået de barrierer af teknisk og ikke-teknisk art, som er bestemmende for kriterier for anvendelse af primært in-situ/on-site teknik, og sekundært for anvendelse af off-site behandlingsteknik. Rapporten begrænser sig til alene at behandle teknikker til anvendelse over for jordforurening. Endvidere omfatter rapporten en status over afværgeteknikker anvendt i USA og Holland.

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12 : Toksikologiske kvalitetskriterier for jord og drikkevand
13 : Økotoksikologiske jordkvalitetskriterier
14 : Zoneopdelt grundvandsbeskyttelse
15 : Værdimåler for grundvandsressourcen
16 : Kildestyrkevurdering af gamle lossepladser
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18 : Feltmetoder til forurenet jord
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20 : Kemiske stoffers opførsel i jord og grundvand: 2 bd.
21 : Barriers to Development and Application of New Remedial Technology

Barriers to Development and Application of New Remedial Technology

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