

Selection of remedial treatments for contaminated land

A guide to good practice

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CIRIA *sharing knowledge ■ building best practice*

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Summary

The guide presents best-practice methodology for the selection of remedial treatments. It is aimed at a broad spectrum of practitioners, including project and development managers, consultants, contractors, operators, regulators, local authorities and clients. While most users of the guide are likely to have a reasonable understanding of contaminated land and its implications, the book has been written assuming only a basic knowledge.

The user is taken through the various stages by which remedial techniques for treating contaminated land are identified, screened and selected, highlighting the key stages and providing pointers towards best practice. Although it is self-contained, the reader is directed towards documents containing more detailed information on scientific and technical aspects and also those discussing procedural approaches. In particular, readers are recommended to consult the forthcoming Environment Agency publication *Model procedures for the management of land contamination* (DEFRA document CLR 11).

Selection of remedial treatments for contaminated land. A guide to good practice

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CIRIA

CIRIA C622

© CIRIA 2004

ISBN 0-86017-622-3

RP678

British Library Cataloguing in Publication Data

A catalogue record is available for this book from the British Library.

Keywords Contaminated land, environmental good practice, ground improvement, pollution prevention, project management, regulation, sustainable construction	
Reader interest Owners and developers of contaminated land; project managers, consultants and contractors concerned in site remediation; regulators and local authorities	Classification AVAILABILITY Unrestricted CONTENT Recommendations STATUS Committee-guided USER Engineers, regulators, developers

Published by CIRIA, Classic House, 174–180 Old Street, London EC1V 9BP, UK.

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Foreword

CIRIA Research Project 678 investigated the selection of remedial treatments for contaminated land. The resulting guide sets out the current state of good practice.

The management of contaminated land is changing, as is the legislative and regulatory approach. At the same time, the technology available for remediation is expanding. To some extent, these changes are driven by advances in understanding of the effects of contamination on humans and the environment. They are also being encouraged by the increasing scarcity of land, which creates a need for land to be reused, especially in countries such as the UK. More than ever before, the approach to managing contamination must be thorough, appropriate and technically justified.

Current best practice is summarised with the aim of raising awareness of existing guidance and competence in its use. The guide provides a framework for the selection of appropriate remedial strategies. It describes the stages of identifying, selecting and justifying appropriate remedial approaches, but stops short of describing later stages of the process, in which the remedial treatments are implemented and their effectiveness is verified.

The guide is in four main sections.

1. **Introduction**

An outline of the origins and significance of ground contamination, the importance of remediation and the purpose of the guide. The need for specialist advice on treatments is stressed.

2. **Viability of remediation**

Remedial works are usually constrained by a range of practicalities and may not be viable. Before remedial options can be reviewed and selected, the feasibility of the project should be assessed against selected financial and technical requirements and the results of consultation with stakeholders.

3. **Motives and goals**

The treatment of contaminated land is a response to regulatory, financial and other requirements, which must be identified and assessed. An important consideration is whether the selection of remedial measures is set within the context of an overall risk management approach to contaminated land, or whether, as with the delicensing of nuclear sites, the purpose is to achieve a predetermined land condition.

4. **Selection procedure**

The main steps to be taken in a systematic approach. A framework is presented for determining management and technical objectives and for identifying, shortlisting and deciding on remedial options.

In addition to references cited in the text, the guide provides signposts to further reading for those who need detailed knowledge. The principal characteristics of various treatment technologies and the regulations applicable to contaminated sites in the UK are summarised in appendices. A case study is also presented to illustrate some of the main themes.

Acknowledgements

Research contractor This guide is the result of CIRIA Research Project RP678, “Selection of remedial treatments for contaminated land”. The research was carried out by **Halcrow Group Ltd** under contract to CIRIA

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Steering group Following CIRIA’s usual practice, the research was guided by a steering group, which comprised the following individuals.

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CIRIA manager CIRIA’s research manager for the project was Ms J Kwan.

Funders The work was funded by:
Atomic Weapons Establishment
UKAEA
British Nuclear Fuels Ltd.

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Abbreviations

ASB	Accounting Standards Board
BATNEEC	best available technology not entailing excessive cost
BGS	British Geological Survey
BPEO	best practicable environmental option
BPT	best practical technique
BRE	Building Research Establishment
CDM	Construction (Design and Management) Regulations 1994
DEFRA	Department of Environment, Food and Rural Affairs
DETR	Department of the Environment, Transport and the Regions
DoE(NI)	Department of the Environment for Northern Ireland
DTLR	Department of Transport, Local Government and the Regions
EA	Environment Agency
EPA 90	Environmental Protection Act 1990
EQS	environmental quality standard
HSE	Health and Safety Executive
IPC	Integrated Pollution Control, inserted under Part 1 of the Environment Act 1990
MNA	monitored natural attenuation
MoD	Ministry of Defence
NIA	Nuclear Installations Act 1965 (as amended)
Part IIA	Part IIA of the Environmental Protection Act 1990 (inserted by the Environment Act 1995)
PCB	polychlorinated biphenyl
PPC	Pollution Prevention and Control Act 1999
RSA	Radioactive Substances Act 1993
RCEP	Royal Commission on Environmental Pollution
SEPA	Scottish Environment Protection Agency
SVE	soil vapour extraction
SVOC	semi-volatile organic compound
USEPA	United States Environmental Protection Agency
VOC	volatile organic compound
WHO	World Health Organisation
WRA	Water Resources Act 1991

1 Introduction

1.1 BACKGROUND

The traditional approach to the remediation of contaminated land has been “excavate and dispose”, meaning that in most instances the contaminated material has simply been removed and redeposited, usually as landfill. As demand for land increases some landfill sites in the UK are themselves being reused, and in some cases the material is being moved on again. Clearly, this approach is unsustainable and increasingly expensive. New techniques are available that help reduce the amount of waste going to landfill and eliminate the contamination at site. To encourage the adoption of these more sustainable techniques, information on their availability and good practice in choosing them needs to be made available to all who have an interest in contaminated sites.

1.2 LAND CONTAMINATION

Land is considered to be contaminated if it contains elevated concentrations of potentially harmful substances. The contaminants may cause biological, chemical or physical harm, eg by radioactivity. They can be present in solid, liquid or gaseous form – and they may often change between these states. A contaminant may be “any natural or artificial substance, whether in solid or liquid form or in the form of a gas or vapour” (DETR, 2000). The statutory definition of contaminated land in accordance with EPA 90 Part IIA is land “that is actually, or could be causing, an unacceptable risk to human health and the environment, including controlled waters”.

Contamination of ground has various causes. Much of the UK’s contaminated land is the result of historical industrial use, before environmental protection policies were implemented and before working practices were planned to minimise environmental impact. However, ground contamination still arises from leaks, spills, accidents, poor waste disposal practice and discharges.

The main implications when land becomes contaminated are:

- the contamination may render the site unsuitable for either its current use or planned new uses
- it may be causing, or have the potential to cause, unacceptable harm to the environment – in particular, watercourses and groundwater
- it may breach conditions specified for compliance with planning consents or other regulations.

A site that becomes unsuitable for its intended use may become derelict. Pollution of a water resource may affect an adjacent water body, resulting in harm to the local ecology or inferior quality at a drinking-water abstraction point. A breach of compliance criteria may result in regulatory or other legal action.

Abandoned contaminated sites in towns and cities may become unsightly wasteland and can contribute to large areas becoming disused and derelict, with detrimental effects on the whole neighbourhood in social as well as environmental terms. Remediation of such contaminated land provides the opportunity for that land to be brought back into use, benefiting both private and public investors and local communities. Remediation can

help to stimulate local regeneration, lead to significant environmental improvement and raise the quality of both groundwater and river water. Remediation also addresses the requirements of the regulatory authorities – for example, for delicensing or the surrender of permits issued under the Pollution Prevention and Control Act 1999 (PPC).

1.3 PURPOSE AND SCOPE OF GUIDANCE

The present guide is intended to assist a wide range of practitioners involved in the remediation of contaminated land. It directs attention to best-practice techniques under current policy and legislation and sets out a standardised, transparent, step-by-step methodology for the selection of appropriate remedial treatments with a view to promoting industry-wide consistency.

The aims of the guide are to:

- outline the general principles behind the selection of remedial treatments for sites that are contaminated by potentially harmful substances, taking into account UK Government policy and legislation
- outline the parameters that affect the selection of treatments for contamination in a variety of situations
- impart to all who have an interest in the selection of remedial treatments a basic appreciation of the processes and procedures by which such a selection is made
- be applicable to different types of contaminated sites, including those being proposed within the construction industry for redevelopment and those used by the nuclear industry
- describe the procedures for evaluating and selecting options for remediation within a risk-based approach and also in circumstances where an approach based on risk assessment may not apply.

The document should not be used as a comprehensive manual for carrying out the selection of remedial treatments. Rather, the reader should use this publication for direction to sources of further information and guidance, which will assist in the development of a situation-specific selection strategy.

1.4 THE NEED FOR SPECIALIST ADVICE

The selection of suitable remedial treatments for a contaminated site usually calls for a multidisciplinary approach, with input from biologists, chemists, engineers, environmental scientists, toxicologists and others. The guidance given here is not a substitute for expert professional advice, and this is likely to be required as specialist technical skills are essential in many cases.

2

Viability of remediation

The selection of remedial measures is central to the management of contaminated land. Recognition of the need for remedial works is usually the culmination of a period of investigation, measurement, consultation, regulatory discussion/negotiation and planning. In the UK the need for, and practicalities of, remediation projects are often constrained by the following factors:

- the motives and goals of the remedial work
- the technical appropriateness of available methodologies
- stakeholder perception and requirements
- costs and benefits
- sustainability issues.

2.1

MOTIVES AND GOALS

The drivers for remediation are discussed in detail in Chapter 3. They may include one or more of the following:

- regulatory requirements –a response to action by regulators to ensure compliance with licences, consents or other statutory requirements, or voluntary action by responsible persons to ensure that conflict with regulators is avoided
- protection of human health, the environment, water and structures
- regeneration and the need to produce land that is suitable for use
- commercial agreement, acquisition or divestment of land
- limitation of potential liabilities
- voluntary remediation to ensure good environmental practice and responsible management
- stakeholder demands and perception
- emergency response to spills, leaks or accidental contamination of land and water.

2.2

TECHNICAL APPROPRIATENESS

Techniques for the treatment of contamination are appropriate if they address all the technical and regulatory requirements for the situation successfully and are compatible with any other remedial treatments employed at the same site. An assessment of whether a technique is appropriate will take into consideration

- its performance in eliminating the contaminant(s) of concern and meeting the remedial objectives, and also its durability (its ability to remain effective for a long time)
- whether the process will work in the given site conditions, such as where access is restricted, where buried obstructions are present, with the groundwater levels encountered at the site, and so on
- whether remediation will be completed within the time available
- stakeholder agreement
- the availability of the process.

A rigorous selection procedure is needed such that constraints to the application of each technique are identified at an early stage.

2.3

STAKEHOLDER PERCEPTION AND REQUIREMENTS

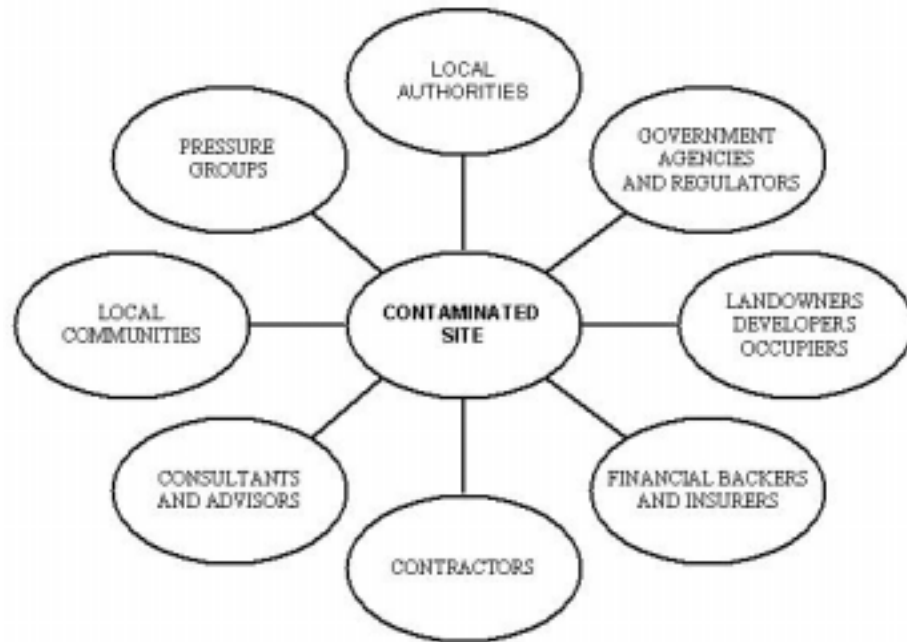


Figure 2.1 Stakeholders

Figure 2.1 identifies the main stakeholder groups. At most contaminated sites remediation will involve some, if not all, of these. All will have a particular interest in the remediation process, including the selection of the technology, and will make decisions about it that will become translated into decisions on cost, investment and acceptability. It is good practice to allow stakeholder involvement in the selection of remedial treatments (SNIFFER, 1999). Communication with stakeholders is essential during the assessment, selection and implementation of remedial options.

2.4

COSTS AND BENEFITS

The final selection of remedial techniques should be concerned not only with the physical means by which the remediation may be achieved but also with the effect on the wider environment, in accordance with the principles of best available technology not entailing excessive cost (BATNEEC), best practicable environmental option (BPEO), best practical technique (BPT) and sustainable development. BATNEEC, BPEO and BPT all encourage the selection of options that are technically feasible but do not have disproportionate financial implications.

The central principle of BPEO is to establish a framework that allows those remedial techniques to be selected that provide “the most benefit or least damage to the environment as a whole, at acceptable cost, in the long term as well as the short term” (RCEP, 1988). It therefore encourages the remediation designer to look beyond the immediate needs of the contaminated site to the effects on the wider environment within and beyond the site boundaries. BPEO makes environmental impact a major factor in the final choice of remedial technique. The choice of strategy should not entail excessive

cost, however, and in the case of risk-based approaches BATNEEC and BPT introduce a test of “reasonableness” in the selection procedure (Martin, 2001).

2.5 SUSTAINABILITY ISSUES

The selection of remedial techniques is not just about environmental issues. The principle of sustainability is well established in project planning and development at both local and regional levels and embraces social and economic effects as well as impacts on the environment.

In the context of remedial design, sustainability encourages the selection of options that address the wider concerns of the community, such as job creation or potential for the depletion of local resources. The following examples show how considerations of sustainability could influence a decision.

1. A sustainability assessment might favour the treatment and destruction of contamination within a site if the alternative were to transport the contaminated material through one or more communities to a landfill site in another community.
2. The assessment might favour remedial options that maximise the use of a site, perhaps for the development of affordable housing.
3. If handled inappropriately, remediation of one site may make it more difficult to reclaim adjoining land in the future. Remedial action is unsustainable if it does not address the needs of the wider community, such as loss of amenity space or the opportunity to create it.

3 Motives and goals

The reasons that may underlie the decision to carry out remediation at a particular site were summarised briefly in the previous section. The motivation for such a project will combine elements of meeting statutory requirements, exploiting commercial opportunities and addressing stakeholder concerns, in a greater or lesser proportion in each case. In practice, most remedial work in the UK is driven by potential or actual regulatory action.

3.1 REGULATORY REQUIREMENTS

Until recently, remedial treatment of land came into consideration mostly in response to a specific pollution incident or threat, a breach of waste or nuclear licence conditions or when the site became subject to development via the planning process. In this context, the main impetus tended to be the requirement to protect human health or the water environment or to prevent damage to building structures and services.

Now legislation and policy are becoming more comprehensive and proactive in protecting the environment and promoting sustainable development. Legislation governs the environmental aspects of the number of processes operated. Both UK Government and European policy is to minimise the likelihood of contamination occurring in the future. In the UK historical contamination is targeted by central government policy to promote the reuse of derelict sites in preference to the development of equivalent greenfield sites, with the aims of protecting rural areas and encouraging urban regeneration. It is inevitable that the regeneration process will often include land remediation.

The main regulatory requirements in the UK are discussed below and in Box 3.1. The application of the regulatory regimes to radioactive and non-radioactive contaminated land is also summarised in Appendix 3.

Remediation is dominated by civil engineering solutions, with process-based technologies being applied at 20–30 per cent of UK sites treated. The improving availability of process-based technologies, pressure to find sustainable solutions and the growing requirement for pretreatment of wastes are likely to lead to an increase in this percentage.

3.1.1 Reducing risk to human health and the environment

In most cases, the remediation of contaminated land is a natural progression from risk assessment. Where unacceptable risks are demonstrated, action is required to manage them. The assessment process should provide an objective, transparent and recordable justification for the management of these risks. It should be driven by the need to protect human health, the environment and controlled water.

The risk assessment should be designed to identify significant pollutant linkages (DETR, 2000):

Source of contamination \Rightarrow Pathway \Rightarrow Receptor

Risk-driven remediation concentrates on the need to break pollutant linkages, either by removing the source of the contamination or the pathway or (on rare occasions) by removing the receptor. If any of these is absent, the site poses no risk and remediation is not normally required. Conversely, if one or more significant pollutant linkages are proved, remedial action may be considered. Ensuring adequate risk assessment and, if necessary, remedial action on contaminated sites is a central component of planning and Part IIA legislation (see Box 3.1).

Box 3.1 *Summary of key legislative drivers (see also Appendix 3)*

1. Non-radioactive contaminated land

Part IIA of the Environmental Protection Act (EPA) 1990

Part IIA of the EPA provides a regulatory regime for the identification and remediation of land where contamination is causing unacceptable risks to human health or the wider environment. The risk of contamination should be assessed according to the current use and circumstances of the land such that it is “suitable for use”. The philosophy of Part IIA is that the “polluter pays”: any person (or persons) who caused or knowingly permitted the land to become contaminated is deemed the “appropriate person” and, where the person can be found, is liable for the cost of the remediation.

Remediation undertaken under Part IIA must be reasonable and cost-effective and must comply with requirements for practicality, durability and effectiveness as detailed in Circular 02/2000 (DETR, 2000). Remediation of land deemed to be contaminated land may be carried out voluntarily by the appropriate person(s) or initiated by the serving of a formal remediation notice requiring the work to be undertaken. The minimum requirement is to ensure that any “significant harm” or “pollution” is remedied.

Some sites licensed under the Nuclear Installations Act 1965 may also come under the Part IIA regime. The Part IIA definition of contaminated land currently does not cover harm caused by radioactivity or the radioactive pollution of controlled waters. However, if land on a nuclear-licensed site is considered as contaminated land because of the presence of a non-radioactive contaminant, it is dealt with as a “special site” and regulated by the Environment Agency (EA) or Scottish Environment Protection Agency (SEPA) as appropriate. Although at present none of the Part IIA regime applies to radioactively contaminated land, a new regime is being considered that will create a similar risk-based approach for land of this nature.

Town and Country Planning Act 1990 (Scotland Act 1997)

One of the underlying policies of the UK planning system is to encourage the reuse of land. Planning authorities need to be satisfied that land is in a suitable condition for a proposed new use. If it is found not to be so, remediation may be undertaken to satisfy a Section 106 agreement or other condition in respect of planning permission.

Pollution Prevention and Control (England and Wales) Regulations 2000 and Pollution Prevention and Control (Scotland) Regulations 2000 (PPC)

The principle of the PPC regulations is that when operations cease at a licensed installation the necessary measures should be taken to avoid any risk of pollution and return the site of the installation or mobile plant to a satisfactory state. The operator applies to surrender the permit, and the regulator must be satisfied that the site has been returned to a satisfactory state before accepting the application. Remediation may therefore be carried out to support the surrender of a PPC permit.

Integrated Pollution Control (IPC)

Part I of the 1990 EPA places a requirement on operators of prescribed industrial processes to operate within the terms of permits issued by the regulator to control harmful discharges.

Response to pollution incidents

Remediation may be required to make good damage caused by a pollution incident. Such action may be driven by a desire to follow good practice or by pressure from the regulating bodies exerted through such legislation as the European Community Directive on Integrated Pollution Prevention and Control.

Waste management licensing

Part II of the 1990 EPA and the PPC Regulations place controls on the handling, treatment and disposal of controlled wastes to manage the potential for contamination of land and its remediation.

Pollution of groundwater – Groundwater Regulations 1998

The Groundwater Regulations are aimed at preventing certain types of discharge of listed substances through land to groundwater. The Water Resources Act 1991 (or, in Scotland, the Control of Pollution Act 1974) requires the remediation of polluted “controlled water” (defined in Part IIA and Section 30A of these Acts, respectively).

2. Radioactive contaminated land

Nuclear licensed sites – Nuclear Installations Act 1965

On nuclear licensed sites the regulator of radioactive contamination is the Health and Safety Executive (HSE). The HSE requires the operators of such sites to maintain a strategy for managing radioactively contaminated ground, and remediation will be required if conditions of the licence are breached – for example, by the unauthorised discharge of radioactive substances into the environment. (At operational nuclear defence sites the Ministry of Defence is the nuclear safety regulator.) The EA and SEPA also have some powers relating to unauthorised discharges of radioactive substances to the environment (such as the entry of radioactive contamination into groundwater).

At nuclear licensed sites remediation of *non-radioactive* contaminated land may be needed to comply with site licence conditions related to general safety or where the contamination could compromise nuclear safety.

Delicensing

Remediation may be required when sites are considered for delicensing. Before delicensing part or all of a nuclear licensed site the HSE must be satisfied that there is “no danger” from ionising radiation from anything on, in or under the land that is to be delicensed (HSE, 2001(2)).

Radioactive substances and radioactive wastes control regime

The Radioactive Substances Act 1993 describes the management of radioactive waste. Where naturally occurring radioelements exceed defined levels or where defined circumstances give rise to non-natural radioactive contamination it is considered that there may be a risk to people and the environment. Action is then required to assess and treat the land.

Part IIA and planning in relation to radioactive contaminated land

As already mentioned, the coverage of EPA Part IIA is being extended to radioactive contaminated land. New planning guidance from the DTLR will cover the assessment

and remediation of “land affected by radioactive contamination” and will apply to all sites coming within the planning system, delicensed sites and defence sites proposed for redevelopment under the planning system.

3.1.2

Legal obligations not linked to risk assessment

In some cases remedial treatment of contamination is prompted by obligation rather than risk-based assessment. In these circumstances the requirement will be to attain a predetermined condition or state – most often defined within the conditions of a licence agreement – and the treatment will not necessarily have to conform to what would be considered “reasonableness” (compare EPA Part IIA). Examples may include remediation carried out:

- to enable the surrender of a permit to operate a PPC licensed activity
- to comply with waste management licence conditions
- to meet “no danger” criteria as a precondition for the decommissioning of a radioactive (nuclear) licensed site.

The remedial strategy in these circumstances is likely to be less flexible than in risk assessment-based approaches. Methodologies that concentrate on the removal of the receptor or pathway may not be sufficient and treatment of the source may be required (Box 3.2).

Box 3.2 *Example of remedial work not prompted by risk assessment*

A leak of leachate occurred from a landfill site’s leachate pumping system, in direct contravention of the terms of the site’s waste licence. The material that escaped entered a small surface watercourse beyond the boundary of the licensed site. Remedial works were conducted in accordance with the terms of the licence to recover as much material as possible from the watercourse, although studies soon after the spill had occurred indicated that the impact on ecosystems in the watercourse and on water quality at a monitoring point some 200 m downstream had been minimal.

It should be noted, however, that measures stipulated as conditions, such as planning conditions, may have been determined originally on the basis of risk assessment. The management of radioactive contamination is moving increasingly towards a risk-based approach.

3.2

COMMERCIAL OBLIGATIONS AND LIABILITIES

Businesses may be exposed to a variety of risks arising from environmental impact, and land contamination is one of the major sources. A corporate accounting standard, Financial Reporting Standard 12 (ASB, 1998), requires companies to report liability for land remediation in their financial statements. Some companies are becoming more proactive in dealing with land contamination responsibly, partly because of tax incentives. In many cases their actions are unilateral and voluntary.

Remedial treatment is often carried out to fulfil commercial requirements, such as on a transfer of assets or corporate acquisition. Part of the commercial agreement may include an obligation on one or more of the parties to transfer land in a suitable, defined state or to arrange its remediation either before or after transfer.

3.3

EMERGENCY RESPONSE

On occasion, remedial action is required urgently to deal with leaks, spills or accidental loss of material that contaminates the ground. In these circumstances there may not be an opportunity for thorough investigation and assessment, and the selection of a remedial treatment will be based on expediency. However, the treatment must still be chosen so as not to cause further or new damage to the environment. For example, where contaminants have been lost to a river, the remedial technique chosen to contain and remove the contamination should not damage the structure of the watercourse or cause additional adverse effects on habitats, as could occur when excavating the river bed to remove settled contaminant.

In the event of an incident requiring urgent action, the remedial measures are likely to fall into at least two parts:

- action taken to respond to the urgency of the incident, such as measures to control and contain an escaped contaminant and minimise environmental impact
- ongoing, non-urgent treatment to deal with the remaining contamination.

4 Selection procedure

4.1 A SYSTEMATIC APPROACH

A systematic approach to the selection of remedial treatments starts with the setting of the objectives of the remediation process and finishes with the development of the remedial strategy. The site must always be fully characterised to determine sources of contamination, the potential for migration and the medium in which the contamination resides. Then a remediation scheme must be developed to deal with the contamination in the long term, taking account of land use, development needs and (as appropriate) delicensing requirements. The scheme should also take into account such other issues as the potential exposure of workers to the contaminant and treatment materials, effects on the environment and sustainable development. Figure 4.1 illustrates the whole process of selection.

The selection procedure, whatever the motivation, comprises the following three main stages, each of which involves progressive refinement of the information.

1. Identify objectives
2. Appraise the options
 - a. Identify and evaluate the potential options, by reviewing available remedial measures to identify those which are potentially appropriate for treating parts or all of the site. This should be done for each contaminant or pollutant linkage, as appropriate. These options should be evaluated by assessing applicability, costs (Box 4.1), track record, treatment duration, working area required, health and safety, environmental consequences, flexibility, potential for integration with other methods and post-treatment issues.

Box 4.1 *Costs of remediation*

Numerous elements can contribute to the cost of a remedial action:

- project management
- public involvement/participation
- site characterisation
- evaluation of alternatives and selection
- reimbursement for regulatory support
- setting up, monitoring, operating and maintaining remediation system
- treatment and disposal of waste arising from remedial work
- permits and legal expenses
- post-treatment requirements and costs.

- b. Analyse the alternative options in detail – assess the advantages and disadvantages of each appropriate remedial option, taking into account site-specific characteristics and constraints and using a number of parameters including costs and benefits. This stage may include pilot testing, if it could assist in determining the technical appropriateness of options.

Figure 4.1 Summary of the selection procedure

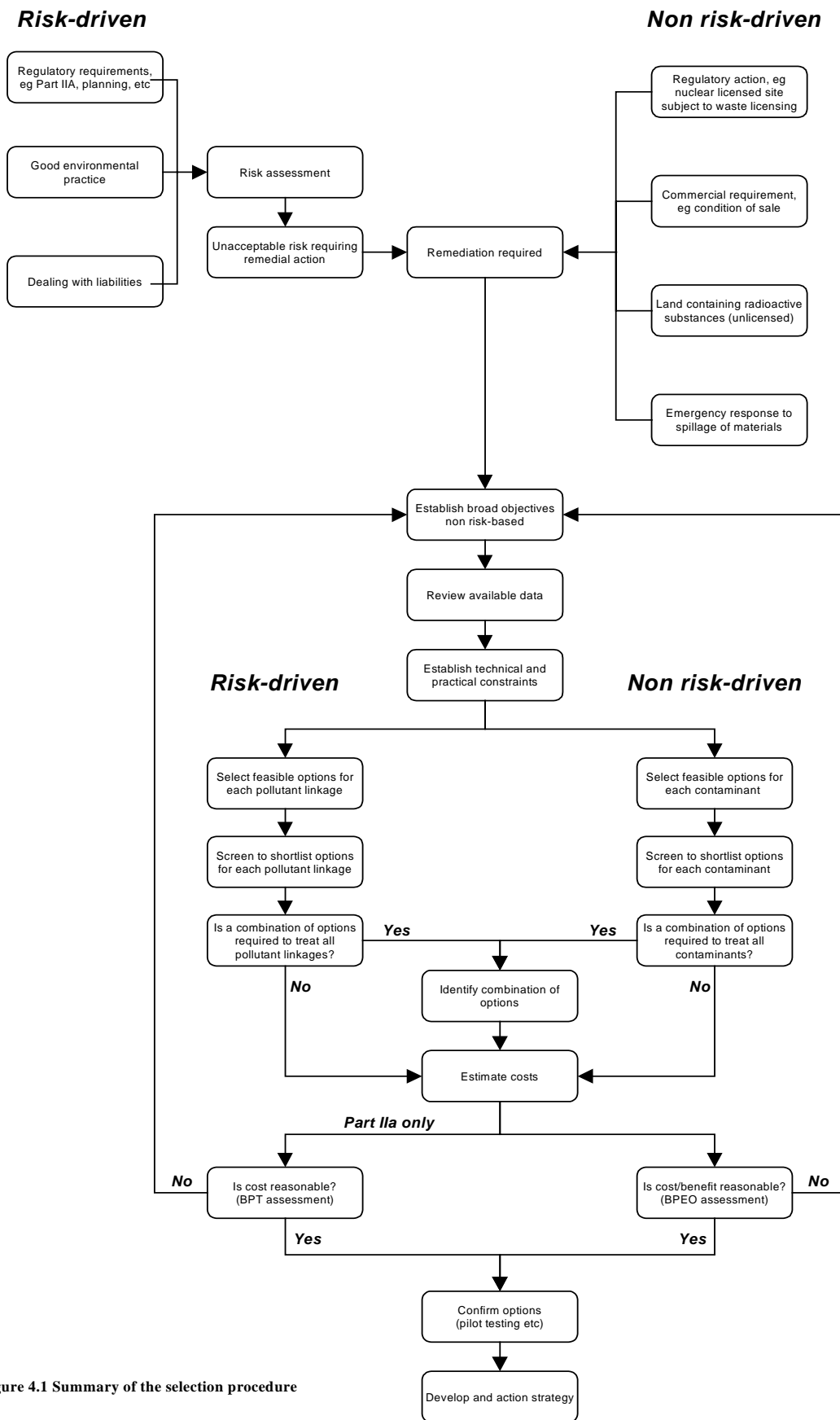


Figure 4.1 Summary of the selection procedure

3. Develop the strategy – select the preferred strategy by comparing the extent to which the shortlisted remedial options or combinations of options meet the risk management objectives.

Further information on the selection of risk management action will be found in *Model procedures* (EA, in preparation).

4.2 IDENTIFICATION OF OBJECTIVES

A wide range of commercial, legal and technical factors will shape the remedial process at each particular site, as will the opinions and objectives of stakeholders. Any remediation strategy will seek improvement of the site within a set of defined objectives. These will consist of *management objectives* – non-technical factors driving the process and constraints to the operation of selected options – and *technical objectives* – the site-specific remediation targets, which provide a measure against which compliance with the management objectives can be measured.

4.2.1 Management objectives

Management objectives reflect the main criteria for successful execution of the remedial works and ensuring that the contamination has been effectively managed. They will vary depending on the reason for remediation – for example, to avoid or respond to regulatory action and/or to facilitate land transfers (be they lease returns, new leases or transfer of ownership).

The overall objectives typically include one or more of:

- ensuring that the site is suitable for use or in an acceptable condition
- ensuring that any environmental liabilities associated with the site are limited to an acceptable level
- satisfying the requirements of the regulating authorities (eg as set out in nuclear site licence conditions) and obtaining approval.

Other management objectives relate to practical considerations. Factors that may affect the technical confidence achievable with the available resources need to be identified. Such constraints may include ownership boundaries, possible secondary environmental effects and consequences for the environment outside the site. The management objectives typically need to take into account

- the time limit within which the remedial works must be completed
- the durability of the strategy
- any limitations on cost, including capital, operating, maintenance and ongoing management costs
- site-specific practicalities, such as the space available for remedial operations, access requirements, issues of nuisance to the surroundings, working around existing buildings and any requirement not to interfere in the running of an operational site
- requirements for sustainable development.

4.2.2

Technical objectives

Technical targets must be set for the remediation. These are likely to include an acceptable concentration of contaminant as a desired end-point. This end-point (in effect defining how clean is “clean”) may be derived from:

- guideline values (such as soil guideline values, drinking-water standards or environmental quality standards)
- site-specific criteria developed from risk-based assessment models
- predetermined or agreed compliance levels
- engineering requirements, such as soil cover thickness.

Adequate site characterisation is essential for determination of the technical objectives. This might require highly detailed information about the contaminant, its extent, behaviour, mobility, activity etc. Sometimes one or more areas of a site may appear to have different characteristics from the remainder and the site may be divided into zones to be considered independently, so as to allow for differences in soil properties and previous or proposed land uses. This could result in specific technical (and management) remedial objectives for each zone.

4.3

APPRAISAL OF OPTIONS

The next stage is to identify the most appropriate remedial option – that is, the best in terms of technical appropriateness, practical application, timeframe, durability and cost. Risk management approaches seek to identify the appropriate option for each pollutant linkage; other approaches seek to identify options that offer the best performance in source removal or reduction.

In practice, remedial options are selected on the basis of site geology, hydrogeology, chemicals of concern, efficiency of selected removal rates and cost-effectiveness of the removal rates for the specific site. The appraisal starts with broad screening to identify a manageable number of potentially viable techniques. This is followed by evaluation and detailed analysis to arrive at the favoured technique for dealing with each pollutant linkage or contaminant source.

The identification of options presupposes sufficient site characterisation. In all cases, before identification can proceed, a thorough review of the available information must be made to ensure that the data indicated in Box 4.2 are to hand and to refine the technical understanding of the nature and scale of the contaminant (Rudland *et al*, 2001). In many situations, information on the location of the contaminant may already be available. However, additional site investigation may be necessary to gain further understanding of the environmental setting, such as hydrogeology, phase of containment etc. Where remediation is a consequence of risk assessment the site characterisation must seek to identify all the pollutant linkages.

Box 4.2 Example of information required for initial selection of potential remedial options

Site characteristics

Location, access, size, current ownership and boundaries
Past and present uses
Nature of adjacent land
Statutory and other available records pertaining to the site
Service equipment locations
Proximity to water abstraction points
Ground covering, site layout and existing structures
Topography of the site and its surroundings
Location of proximal surface water bodies and sensitivity

Properties of the ground

Soils

Solid geological deposits

Groundwater

Type, name and description
Stratigraphy and description
Depth
Thickness
Quality and chemistry
Permeability
Hydraulic gradient
Clay content
Structure
Direction of flow
Organic content
Aquifers/aquitards
pH
Thickness and types
Particle size distribution
Variations
Density

Contaminant information

Type(s)

Concentration(s)

Distribution

Phases (solid, liquid or gas, floating product etc)

Properties (solubility, viscosity, vapour pressure, diffusivity in air/water etc)

Armed with sufficient information on the site, the appraiser can begin to identify the options that would address the situation best and draw up a shortlist. Many techniques are available that remove or fix contamination or reduce it to required levels, but none copes with all contaminants in all situations. Frequently there is a requirement for remediation schemes to address more than one pollutant linkage or contaminant source, and the selection process should allow a parallel process of option selection for each.

In general, processes either treat contamination or leave it unchanged. The processes may also be divided into biological and non-biological, and further into *in-situ* and *ex-situ*. Appendix 2 summarises the available techniques and the references cited in Appendix 2 give more detailed information.

Where the contamination is radioactive remediation focuses on source containment, reduction or removal. Unlike organic contaminants (but similar to metals), radionuclides

cannot be destroyed or degraded and the applicable technologies involve separation, concentration/volume reduction and/or immobilisation.

4.3.1 Initial screening

As there are so many techniques available, an initial screening process is necessary to produce a shortlist. The screening is usually quite coarse, being based on the management and more general technical objectives rather than on detailed technical information. The assessor begins by determining screening criteria along the lines of those suggested in Box 4.5.

Box 4.5 *Initial screening criteria*

Will the technique address the contaminant of concern?
How effective is the technique and has it been sufficiently developed?
Is the cost/benefit relationship likely to be reasonable?
Will the technique integrate with others?
Is the technique available?
Will the process be complete within the programme time-scale?
What are the nuisance and safety impacts?
What are the likely verification and monitoring requirements?
What are the regulatory requirements for licences, permits and planning permission?
Would the technique address stakeholder concerns and demands?
Are there significant verification and monitoring requirements?

The assessor then collects information on the general characteristics of the available options and evaluates their applicability to the specific situation to help eliminate those that would not be suitable. If, for example, hydrocarbon reduction or removal were required, the initial screening would remove any options that did not treat hydrocarbons. Then costs, track record, duration of treatment, required working area, health and safety, environmental consequences, flexibility, potential for integration with other methods, post-treatment issues and stakeholder acceptability are examined. An example of an initial screening is given in Table 4.1. The screening process may involve qualitative assessment, in which one or more failures to address the site-specific screening criterion eliminates the option.

Table 4.1 *Example of initial screening for a particular pollutant linkage*

Screening criterion	Technique					
	A	B	C	D	E	F
Does the option treat the contaminant or linkage of concern?	✗	✓	✓	✓	✓	✗
Is the technique readily available?	✓	✓	✓	✗	✓	✓
Is there sufficient time available?	✗	✓	✓	✓	✓	✗
Is the available space sufficient?	✗	✓	✓	✗	✓	✓

Acceptability to stakeholders?	✓	✓	✓	✓	✓	✗
Take option to detailed evaluation?	✗	✓	✓	✗	✓	✗

A screening matrix such as that shown in Table 4.1 allows inappropriate methodologies to be discarded. Sometimes only one option is found to be applicable, but usually the screening process should result in the identification of a small number of potential options, which can then be taken forward for further review.

1.1.2

Detailed analysis

The assessor now has a short list of options that are feasible for the site in question and must carry out detailed evaluations on these few options to select the most appropriate for each pollutant linkage or contaminant.

First, the amount, quality and applicability of the data available on both the option and the site must be reviewed, and more obtained if necessary. If, for example, the shortlisted options rely significantly on the contaminated ground being highly permeable and there is insufficient information on the site geology and hydrogeology to confirm that it is, the necessary data must be obtained at this point.

The assessor needs then to develop site-specific evaluation criteria based on the management and technical objectives. A series of detailed criteria is needed – more detailed than the coarse criteria used at the initial screening stage. The costs of each option (an estimate of the relative cost, including set-up, operation and maintenance charges etc), its technical feasibility (such as the effectiveness of each option in achieving the objectives within the constraints) and the time-scale for the process (EA, 2000a) will be investigated in detail. Also, the effects of each option on the surrounding environment will be evaluated, taking into account environmental nuisance (noise and dust), waste arising from the process, the possible escape of treatment materials and the availability of the treatment within the planned programme. All this requires a detailed knowledge of the technique.

Often, a detailed qualitative scoring system is set up in which options are marked down if they produce excessive amounts of waste, require high energy inputs, and so on. For example, two techniques that can be applied to volatile hydrocarbons contained in soil are *ex-situ* bioremediation and thermal desorption. Whereas thermal desorption might allow the remedial programme to be completed sooner, the energy inputs are considerably greater and secondary treatment will be required to treat the off-gases generated from this process. *Ex-situ* bioremediation might therefore be preferable in terms of both BPEO and cost. The final selection of appropriate option should be justified by the evaluation criteria and by reference to the objectives of the remediation.

Comparisons of techniques for radioactively contaminated land must take account of radiation doses from residual contamination, radiological (and non-radiological) environmental impacts and doses to workers and the public during the remediation process. A technique is justified only if it results in an overall reduction in dose (the ALARP principle).

Laboratory or field trials are sometimes required either to demonstrate that a process will work in the given site conditions or as an aid to design of the remedial works. Such trials may consist in operation of a scaled-down version of the main process or studies to determine the site-specific response of the contamination to treatment. For example,

pilot testing may be carried out to guide equipment size selection or the placement of soil vapour extraction wells across the site, or laboratory-based biotreatability trials may be undertaken to determine whether treatment criteria are attainable. These studies help to build confidence in the likely effectiveness of an option in achieving the remediation objectives in the time allowed. Trials involve capital outlay without any assurance of a completely favourable outcome, but even though they are usually applied to remedial options that are very likely to be developed to the implementation stage, it is more risky to commit to a full-scale treatment programme without the information that they yield.

A case study that illustrates the whole process of remedial technology selection is presented in Appendix 4.

1.4

DEVELOPMENT OF STRATEGY

By now, the assessor has identified the most appropriate remediation, whether to be operated as an individual process or as several parallel processes. At this stage the assessor should look at the practical means of implementation, including preparatory steps to be taken before implementation, and review the original objectives to ensure that they are met.

The final stage of the selection process is development of a remediation strategy. A report of this is prepared as a briefing for stakeholders. The strategy report sets out all the decision-making that characterises the selection of appropriate techniques and gives some provisional information on how the works are to be implemented. It allows debate about the preferred options for the remedial works and how they will be implemented, but should win the support of stakeholders for the preferred option(s). The contents of such a report are set out in Box 4.6.

Box 4.6 *Typical content of remediation strategy report*

Background information on the site:

- history and environmental setting
- origins of contamination and regulatory/licence position.

Key site investigation findings summarised to provide an overview of current ground condition and the need for the remediation:

- site investigation findings
- assessment and interpretation of these findings
- obligations as to remediation
- constraints
- technical and management requirements.

Summary of the objectives and constraints for the proposed remediation:

- constraints – size, space, noise restrictions etc
- technical requirements – remedial targets
- amount of material to be treated.

Outline of how remediation will be achieved:

- legal and regulatory requirements
- likely site-specific design requirements
- site preparation and demolition, rerouting of services

- verification requirements
- communication with stakeholders and community.

Selection of options:

- how specific techniques were shortlisted
- ranking and shortlisting criteria
- final selection.

Estimates of costs/budget for:

- detailed design
- further site investigation, monitoring and verification
- permits and licences
- advance works (eg utilities diversions)
- health and safety, CDM requirements
- any disposal costs for wastes, residues.

Estimates of programme and time-scale:

- regulatory approval
- permits and licences
- trials
- detailed design
- implementation and completion.

Potential suppliers:

- identification and likely availability.

Verification that objectives have been achieved:

- design, programme, technical requirements.

The document provides detailed information on how the remedial works will be achieved and includes technical requirements, time-scales and budgets. It requires the authors to have some idea of how the remedial works might progress, beyond an understanding of the generic application of the identified options and in the context of the site. For this reason the remedial strategy contains an element of preliminary design, a first consideration of how the whole strategy might be implemented in practice and the order in which specific tasks might be completed. The preparation of a strategy may need input from specialist contractors and consultants – for example, to determine the availability of equipment and outline costs. A field trial might be considered to refine the data on likely treatment times.

The strategy should cover how it will be demonstrated that the remediation criteria have been achieved. For example, the remedial works may be required to bring all soil contaminant concentrations within a defined area below a defined threshold. The verification plan will establish the requirements for sampling, testing and analysis, including testing methods, accuracy and lower limits of detection, and statistical treatment.

A1 Publications on contaminated land for further reading

The following are publications not otherwise referenced in the guide that provide useful background reading on particular topics.

A1.1 UK GOVERNMENT PUBLICATIONS

DTI (2002)
Managing the nuclear legacy, a strategy for action
Cmnd 5552, DTI, London

DTLR (2002)
Development on land affected by contamination. Consultation paper on draft planning technical advice
DTLR, London

DETR (1998)
Control and remediation of radioactively contaminated land – a consultation paper
DETR, London

A1.2 ENVIRONMENT AGENCY AND SEPA PUBLICATIONS

ENVIRONMENT AGENCY (1999)
Technical support materials for the regulation of radioactively contaminated land
R&D technical report P307, Environment Agency, Bristol

ENVIRONMENT AGENCY (2000)
Guidance for the safe development of housing on land affected by contamination
R&D technical report P66, HMSO, London

ENVIRONMENT AGENCY (2000)
Costs and benefits associated with the remediation of contaminated groundwater: a framework for assessment
R&D technical report P279, Environment Agency, Bristol

ENVIRONMENT AGENCY (2002)
Costs and benefits associated with the remediation of contaminated groundwater: application and example
R&D technical report P2-078/TR, Environment Agency, Bristol

ENVIRONMENT AGENCY (2002)
Guidance on the use of permeable reactive barriers for remediating contaminated groundwater
Environment Agency, Bristol

ENVIRONMENT AGENCY (in preparation)
Guidance on the use of stabilisation/solidification for the treatment of contaminated soil
R&D technical report P5-064/TR, Environment Agency, Bristol

ENVIRONMENT AGENCY (in preparation)
Guidance on treatability studies for permeable reactive barriers (PRBs)
Environment Agency, Bristol

A1.3 BUILDING RESEARCH ESTABLISHMENT (BRE) PUBLICATIONS

CARD, G B (1996)
Protecting development from methane, 2nd edn
Report 149, CIRIA, London

PAUL, V (1995)
Bibliography of case studies on contaminated land: investigation, remediation and redevelopment
Report BR291; Domestic buildings guide BR293, Building Research Establishment, Watford

SCIVYER, C R, CRIPPS, A and JAGGS, M P R (1998)
Radon sumps: a BRE guide to radon remedial measures in existing buildings
Report BR227, Building Research Establishment, Watford

SCIVYER, C R and GREGORY, T J (1995)
Radon in the workplace: a guide to radon measurement and remedies for non-domestic buildings
Report BR293, Building Research Establishment, Watford

WELSH, P, PYE, P W and SCIVYER, C R (1994)
Protecting dwellings with suspended timber floors: a BRE guide to radon remedial measures in existing dwellings
Report BR270, Building Research Establishment, Watford

A1.4 CIRIA PUBLICATIONS

HARRIS, M R, HERBERT, S M and SMITH, M A (1995)
Remedial treatment for contaminated land, volume II: decommissioning, decontamination and demolition
Special Publication 102, CIRIA, London

HARRIS, M R, HERBERT, S M and SMITH, M A (1995)
Remedial treatment for contaminated land, volume III: site investigation and assessment
Special Publication 103, CIRIA, London

HARRIS, M R, HERBERT, S M and SMITH, M A (1995)
Remedial treatment for contaminated land, volume IV: classification and selection of remedial methods
Special Publication 104, CIRIA, London

HARRIS, M R, HERBERT, S M and SMITH, M A (1995)
Remedial treatment for contaminated land, volume V: excavation and disposal
Special Publication 105, CIRIA, London

HARRIS, M R, HERBERT, S M and SMITH, M A (1995)
Remedial treatment for contaminated land, volume VI: containment and hydraulic measures
Special Publication 106, CIRIA, London

HARRIS, M R, HERBERT, S M and SMITH, M A (1996)
Remedial treatment for contaminated land, volume VII: ex-situ remedial methods for soils, sludges and sediments
Special Publication 107, CIRIA, London

HARRIS, M R, HERBERT, S M and SMITH, M A (1995)
Remedial treatment for contaminated land, volume VIII: ex-situ remedial measures for contaminated groundwater and other liquids
Special Publication 108, CIRIA, London

HARRIS, M R, HERBERT, S M and SMITH, M A (1995)
Remedial treatment for contaminated land, volume IX: in-situ methods of remediation
Special Publication 109, CIRIA, London

HARRIS, M R, HERBERT, S M and SMITH, M A (1995)
Remedial treatment for contaminated land, volume X: special situations
Special Publication 110, CIRIA, London

HARRIS, M R, HERBERT, S M and SMITH, M A (1995)
Remedial treatment for contaminated land, volume XI: planning and management
Special Publication 111, CIRIA, London

HARRIS, M R, HERBERT, S M and SMITH, M A (1998)
Remedial treatment for contaminated land, volume XII: policy and legislation
Special Publication 112, CIRIA, London

A1.5 HEALTH AND SAFETY EXECUTIVE PUBLICATIONS

HEALTH AND SAFETY EXECUTIVE (2001)
Guidance for inspectors on decommissioning on nuclear licensed sites
HSE, Sheffield

HEALTH AND SAFETY EXECUTIVE (1999)
Reducing risks, protecting people, discussion document
HSE Books, Sudbury, Suffolk

A1.6 OTHER GUIDANCE – RADIOACTIVE CONTAMINATED LAND

<www.safegrounds.com>

BARDOS, P, MARTIN, I and KEARNEY, T (1999)
“Framework for evaluating remediation technologies”
Paper presented at IBC 10th Conference on Contaminated Land

INSTITUTE OF PETROLEUM (1998)
Guidelines for investigation and remediation of petroleum retail sites
Institute of Petroleum, London

The Ionising Radiations Regulations 1999
SI 1999/3232, Stationery Office, London

MARTIN, I and BARDOS, P (1996)
A review of full scale treatment technologies for the remediation of contaminated soils
Prepared for the Royal Commission of Environmental Pollution, EPP Publications,
London

MOBBS, S F, BARRACLOUGH, I M, MCDONNELL, C E, MORREY, M, COOPER, J
R and FRY, F A (1998)
Radiological protection objectives for land contaminated with radionuclides
National Radiological Protection Board, Didcot, UK

A2

Available remedial techniques

Table A2.1 sets out basic information on the availability of remedial technologies, gives guidance on which are applicable to the various types of contaminant and indicates the key issues for determining their suitability in various situations. The feasibility of any technology will be dependent on site constraints. References are included for further reading.

A3 UK legislative regimes for contaminated land

Table A3.1 Summary of key regulatory regimes

Type of site	Radioactive contamination	Non-radioactive contamination	Mixed contamination
1. Nuclear-licensed sites			
Operational sites	NIA (RSA)	Part IIA (special sites), WRA	NIA (RSA), Part IIA (special sites)
Sites to be delicensed	NIA, RSA	Part IIA, <i>DTLR planning guidance</i> , WRA	<i>NIA, RSA, Part IIA, DTLR planning guidance</i>
2. Defence (MoD) sites (non-licensed)			
Nuclear sites	<i>MoD</i>	Part IIA (special sites), WRA	MoD, Part IIA (special sites)
Non-nuclear sites, no change of land use planned	DEFRA regulations under EPA, RSA	Part IIA (special sites), WRA	<i>DEFRA regulations under EPA, RSA, Part IIA (special sites)</i>
Non-nuclear sites, change of land use planned	DTLR planning guidance, RSA	<i>DTLR planning guidance</i> , WRA	<i>DTLR planning guidance, RSA</i>
3. Other sites			
No change of land use planned	DEFRA regulations under EPA, RSA	Part IIA, WRA, PPC	<i>DEFRA regulations under EPA, RSA, Part IIA (special sites)</i>
Change of land use planned	DTLR planning guidance, RSA	<i>DTLR planning guidance</i> , WRA, PPC	<i>DTLR planning guidance, RSA</i>

Regimes shown in italics are under development, in whole or in part. Where NIA, RSA or Part IIA are shown in italics it means that, although the legislation exists, regulatory guidance is being or may be developed to clarify the application of the legislation in the particular context.

Table A3.2 Principal regulators for each type of contamination

	Radioactive contamination	Non-radioactive contamination	Mixed contamination
Nuclear licensed sites	HSE	Environment Agency or SEPA	HSE, Environment Agency or SEPA
Defence sites (non-licensed)	MoD, HSE, Environment Agency, SEPA, DoE(NI)	Environment Agency, SEPA, DoE(NI)	MoD, HSE, Environment Agency, SEPA, DoE(NI)
Other sites	Environment Agency, SEPA, DoE(NI), local authorities	Local authorities (Environment Agency or SEPA on “special sites”)	Environment Agency, SEPA, DoE(NI), local authorities

A4

Case study: hydrocarbon contamination at a small site

A4.1

BACKGROUND

The site, located in the south-east of the UK, had been occupied by a small residential property with a large garden. The total area was less than 0.5 ha. The property had become disused and was scheduled for incorporation into an adjoining public parkland. The parkland comprised semi-managed woodland and open areas, with a large lake for water sports.

The bungalow on the site had been used as a residence for more than 40 years, but the owner had operated a haulage and, later, a scrap metal recycling business from the large garden. Over the years, abandoned scrap, refuse and unwanted vehicles had completely filled the site. As part of an executor's sale, the property was completely cleared of surface scrap, allowing access for site investigation.

A4.1.1

Geology

Reference to the BGS geological map shows that the site is underlain by alluvium and river gravels above about 10 m of London Clay. The geological sequence is:

- river alluvium
- river terrace gravels
- London Clay
- Upper Chalk.

Site investigation confirmed the superficial geology to be as shown in Table A4.1

Table A4.1 Summary of geology

Description	Thickness (m)
Made ground	0.40–1.30
Alluvium	0.50–1.90
Sands and gravels	2.90–3.20
London Clay	Not determined

A4.1.2

Hydrogeology

There are two main aquifers beneath the site. The terrace gravels form the upper aquifer and the Upper Chalk forms the lower aquifer. The aquifers are separated by a low-permeability zone, or aquitard, consisting of the London Clay (possibly around 10 m thick). The minor aquifer is partially confined beneath the alluvium. Because a river is nearby, the groundwater table is quite close to the ground surface.

Environment Agency data indicate that the site is located just outside a groundwater source protection zone.

A4.1.3 Potential for contamination

It was apparent that there could be considerable contamination of the near-surface soil by metals as well as hydrocarbons and PCBs arising from machinery that had been dismantled there. Some of the contamination might have entered the shallow groundwater beneath the site.

A4.1.4 Pollutant linkages and conceptual model

At present, the site is fenced and human access is minimised. In the future, however, it is intended to incorporate the site into the adjoining parkland after landscaping. Some of the site may be planted to create woodland and full public access will be allowed. Possibly the surface will be covered with clean topsoil to provide a growing medium, but planting may take place in soil without imported cover.

As part of the preliminary assessment of risk, all pollutant linkages were identified and a conceptual model was created to represent identified complete linkages. The potential receptors will include humans, water and ecosystems (especially trees and landscaping plants).

In terms of human risk, the model takes into account the possible means by which park users may be exposed to contamination (chronic exposure) and allows for a “worst case” of users who visit this part of the park daily and thus come into regular contact with the contaminated ground.

The conceptual model is summarised in Table A4.2.

Table A4.2 *Summary conceptual model*

Source of contamination	Receptors	Pathways	Justification
Soil-bound toxic metals (eg copper, nickel and zinc) and PCB	Humans	Direct contact, ingestion, inhalation of contaminated dust	Probable linkage, likely uptake of contaminants during regular recreational use.
			Short-term risk to landscaping staff
Mobile toxic metals (eg copper, nickel and zinc) and hydrocarbons	Groundwater	Percolation of contaminated runoff through ground	Probable linkage, especially if contaminants are mobile
	Watercourses	Migration of contaminated groundwater from site to lake down gradient of site	
	Landscaping plants	Direct uptake from soil	

The preliminary risk assessment indicated potentially unacceptable risks to human health because of the high metal content of the surface deposits and possible adverse effects on plant growth as well as impacts on groundwater and surface water quality. In such circumstances the actual presence of contamination must be confirmed by site investigation.

A4.1.5 Site investigations

An initial investigation was carried out and it confirmed high concentrations of metals within the made ground. Hydrocarbons, identified as diesel, were found both within the

near-surface ground towards the front of the site and in the shallow groundwater within the terrace gravels.

A4.2 PROCEDURE FOLLOWED IN SELECTION OF REMEDIAL OPTIONS

A4.2.1 Definition of management objectives

The management objectives were identified as:

- to ensure that the site was suitable for reuse as woodland, which would entail replanting
- to maximise the area for use
- to remove buried tanks to address the residual safety risk
- to minimise the risk to the river from hydrocarbon contamination arising from site.

The main constraints on remedial action were:

- budget
- other residential property adjoining the site
- means of access being limited to a residential road alongside the river bank
- a designated “site of borough importance” along the eastern boundary
- time – the site was to be available in time for the planting season.

The principal regulatory concern (established through consultation) was to protect the surface water quality of the river some 30 m to the west of the site.

A4.2.2 Review of data

A comprehensive environmental audit of the site revealed that the property had been agricultural land that had been converted to residential use in the 1950s. The data obtained from the initial site investigation had indicated near-surface metals contamination and hydrocarbon (diesel) contamination of the shallow groundwater.

The review of the data showed up significant gaps in understanding and knowledge of the site and the behaviour of the contamination. There was no indication as to the source of the diesel oil, which was seen floating on groundwater in some trial pits.

An additional site investigation was launched and the source of the diesel oil was identified as a steel tank of 2 m³ capacity buried about 1 m below ground level near the entrance to the site. The tank was nearly full of what appeared to be “red” diesel, and the investigation found a plume of contamination leading from the tank towards the river. There was no evidence from boreholes placed between the site and the river that hydrocarbons on groundwater had migrated beyond the confines of the site, although with a shallow groundwater gradient towards the river it was possible that this would occur.

The site conceptual model prepared in Table A4.2 was modified to that shown as Table A4.3.

Table A4.3 *Plausible pollutant linkages*

	Source of contamination	Receptor	Location	Pathway
Pollutant linkage 1	Diesel hydrocarbons	Surface water (river)	Tank and in soil around tank and floating on groundwater	Migration through soil and groundwater
Pollutant linkage 2a	Soil-bound toxic metals	Humans	Near-surface made ground	Direct contact
Pollutant linkage 2b				Inhalation of airborne dust
Pollutant linkage 3	Metals	Landscaping plants	Near-surface made ground	Direct uptake

A4.2.3

Identification of potential remedial options

The management objectives for the remedial work had been identified. The concentrations of metals in near-surface ground were considered unacceptable in terms of the risk to site users and the potential detriment to the normal growth of the trees and shrubs that were to be planted. The presence of a small hydrocarbon plume at site was considered to pose unacceptable risks to the river, although so far there has been no evidence on any impairment of the quality of water in the river.

The following were established as parameters for the initial screening of remedial options:

- ability to tackle the specific contaminants in the given circumstances
- ability to remove physical objects spoiling the ground (the tank) and material released from them
- completion of the work within the allotted time
- minimal disturbance to adjoining property.

These overall objectives and performance criteria were translated into specific targets against which the effectiveness of remediation could be assessed. The remediation options would have to achieve concentrations of the contaminants at or below criteria for human health derived from contaminated land exposure assessment, an appropriate EQS for the lake drafted in discussion with the regulator and criteria applicable to plant growth.

A4.2.4

Detailed analysis of shortlisted options

The remedial approach was required to treat more than one pollutant linkage, involving more than one contaminant type and more than one medium. The space limitations meant that any contaminant that could be recovered could not be treated on site and that any significant emissions of chemicals or dust would be unacceptable because of the closeness of residential property. *In-situ* techniques, such as *in-situ* bioremediation, were inapplicable because the available time was too short.

Screening was used to help in the selection of the most appropriate technique and to provide evidence that would facilitate decision-making (Table A4.4). The screening was

qualitative and the favoured shortlisted techniques were able to fulfil *all* the requirements.

Table A4.4 Initial (qualitative) screening of remedial techniques

Remedial option	Site-specific relevance to contaminants	Likelihood of unacceptable air/noise arisings	Timing	Ability to facilitate removal of groundwater contamination	Boundary effects likely (dust, noise, encouraging migration)	Major space requirements
Passive techniques						
MNA	Y ‡	Y	Y*	Y	Y	Y
Engineering methods						
Cover system	Y	X	Y	X	X	Y
Excavation and tipping – “dig and dump”	Y	Y	Y	Y	Y	Y
Biological processes						
<i>In-situ</i> remediation	Y ‡	Y	X	Y	Y	Y
<i>Ex-situ</i> remediation	Y ‡	Y	Y	Y	Y	X
Chemical processes						
Chemical oxidation/reduction	Y	X	X	Y	X	X
Precipitation						X
Physical processes						
Soil washing	Y	X	Y	Y	Y	X
Pump and treat	Y ‡	Y	Y	Y	Y	Y
Solidification						
Vitrification	Y	X	Y	Y	Y	X
Cement/other encapsulation	Y	X	Y	Y	Y	X
Thermal treatment						
Incineration	Y	X	Y	Y	Y	X
Thermal desorption	Y ‡	X	Y	Y	Y	X

* With monitored natural attenuation (MNA) the construction of parkland can begin during the process.

‡ Hydrocarbons

A4.2.5

Strategy selection

The removal of near-surface ground was identified as necessary to reduce the risks to humans and plants from the contaminating metals. Excavation and disposal to landfill off site were selected as the most acceptable means by which these pollutant linkages would be removed. Importing soil to replace this ground had the advantage of bringing in a nutrient-rich growing layer to replace the poor-quality existing soil. Excavation and disposal would have the additional advantage of removing hot-spots of near-surface hydrocarbon contamination.

Since there was, as yet, no demonstrable effect on groundwater quality, MNA was identified as a potential approach to the small plume of hydrocarbon found floating on groundwater. It would be monitored to determine whether it remained static or decreased in size. If neither turned out to be the case and the river water quality became affected by the hydrocarbons, further remedial works would become necessary.

It was concluded, however, that the risk of adopting MNA as the only remedial strategy for hydrocarbon control would not be acceptable. The requirements for reuse of the site include removal of the buried tank. The tank would have to be emptied before it could be removed from the ground. Thus, an element of product removal would be required in any event. The technology required to collect and remove the oil could be usefully engaged in general removal of free diesel oil in the vicinity of the tank to help reduce the hydrocarbon loading in the ground.

Table A4.5 summarises the main features of each proposed technique as a contribution to the record of the decision-making process.

Table A4.5 *Factors for and against chosen technique*

	In favour	Against
Excavation and off-site disposal		
Applicability	Removes contaminant from site Excavation will be required to remove tanks in any event	Will require import of soil to restore formation level Access to site via residential roads with traffic generated by regular disposal trucks Does not allow ready removal of floating product on groundwater.
Specific technical limitation	Complete removal of contamination and all buried obstructions	Does not treat contamination
Regulatory acceptance	Proven technology accepted	
Local community approval	Complete removal draws line under matter	Large number of truck movements with nuisance factor
Local environmental effects	Minimal risk	Risk to watercourse if material lost during loading or transit, runoff from major excavations
Operational requirements	Proven technology Local landfill sites will accept contaminated soil	
Duration	Acceptable time-scale	
Cost	Within budget – landfill tax exempt	

Pump and treat

Applicability	Removes source of contamination from site Emptying of tanks would be required anyway before removal.	
Specific technical limitation		Will not remove soil contamination
Regulatory acceptance	Yes	
Local community approval	Complete removal draws line under matter	
Local environmental effects	Minimal risk	
Operational requirements	Minimal volumes of contaminant for off-site treatment	
Duration	Acceptable time-scale	
Cost	Within budget	

MNA

Applicability	Parkland construction can proceed during monitoring	
Specific technical limitation		Additional well installation required at additional cost If not effective, further treatment may be required
Regulatory acceptance	Yes, subject to agreement of testing protocol	
Local community approval	Yes, provided regular assessments reported to residents committee	
Local environmental effects	Minimal risk if effective	If not effective, risk of hydrocarbons entering surface water

Operational requirements

Duration		If further remedial treatment is required at a later date, access to site may be restricted
Cost		Ongoing monitoring costs for some years until plume stabilises

The selection process led to the conclusion that all three methods would be suitable for use at the site, and because no one method would address all the contamination, a combination of all three would be adopted.

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