CIRIA W30

London, 2009

SAFEGROUNDS

Good practice guidance for site characterisation

Version 2

P Towler

A Rankine

P Kruse

A Eslava-Gomez

SAFEGROUNDS Learning network

Classic House, 174–180 Old Street, London EC1V 9BP
TEL: +44 (0)20 7549 3300 **FAX:** +44 (0)20 7253 0523
EMAIL: enquiries@ciria.org **WEBSITE:** www.ciria.org

SAFEGROUNDS Good practice guidance for site characterisation. Version 2

Towler, P, Rankine, A, Kruse, P, Eslava-Gomez, A

CIRIA

CIRIA W29 © CIRIA 2009 RP767

Keywords	
Contaminated land, environmental good practice, ground improvement, ground investigation and characterisation, health and safety, *in situ* testing and instrumentation, nuclear, site management, sustainable construction	
Reader interest	**Classification**
This guidance has been developed primarily for site owners, site operators and their contractors. It is also addressed to governmental and non-governmental organisations and other groups within the public	AVAILABILITY: Unrestricted CONTENT: Guidance STATUS: Committee-guided/ Stakeholder dialogue USER: Site owners, site operators, contractors, governmental departments, local authorities, regulators, NGOs, and other groups within the public

Version control	
Document title:	SAFEGROUNDS *Good practice guidance for site characterisation*
Version and date:	Version 1, May 2009
Primary author:	Enviros with support from other authors
Prepared for:	SAFEGROUNDS Learning Network
History:	Second issue. Output of stakeholder dialogue The front pages were reformatted in February 2007 for consistency across the SAFEGROUNDS documents
Status:	SAFEGROUNDS good practice guidance document, prepared with the SAFEGROUNDS Project Steering Group This is a live document, subject to revision. Freely available web publication

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

Summary

This document presents current good practice guidance for the characterisation of legacy contaminated or potentially contaminated land on nuclear-licensed sites and defence sites. Defence sites are here defined as sites currently owned by the Ministry of Defence where activities involving radioactivity have been undertaken. The Defence sites include two groups of sites: the first group are those few sites where the Nuclear Installations Act 1965 (NIA65) does not apply but are managed according to the Act. The second group includes the majority of defence sites where contaminated land is regulated under either Part 2A of the Environmental Protection Act 1990 (as amended) or under the planning regime.

Contamination may be present on nuclear-licensed sites and defence sites as radioactive, non-radioactive contamination and mixed contamination. These sites are covered by this good practice guidance principally because of the issue of contamination of land by radioactivity, but also to acknowledge and manage other issues including increased client involvement, heightened public awareness and security requirements.

The guide has been produced for the SAFEGROUNDS Learning Network, a project managed by CIRIA, on behalf of stakeholders concerned with the health, safety, security and environmental management of contaminated land on nuclear-licensed sites and defence sites. It provides technical support to the main SAFEGROUNDS *Land management guidance* document (Hill *et al*, 2009a).

This guidance combines the technologies and approaches that are available for the characterisation of all types of contaminated land with those widely used for radiological protection. In particular, this guidance focuses on those areas where site investigations on nuclear-licensed sites and defence sites differ from those on other contaminated land sites because:

- nuclear-licensed sites and defence sites managed according to (NIA65) have a complex regulatory regime. There is a need for site characterisation on such sites to satisfy several regulators, who regulate under different legislation and who may have different perspectives on the management of contaminated land
- there are different regulatory scenarios, the aims of site characterisation on nuclear-licensed sites and defence sites may differ from other contaminated land situations
- on nuclear-licensed sites staff are required to be suitably qualified and experienced to undertake their responsibilities. On defence sites staff and contractors must have appropriate skills and expertise
- there will be greater client involvement on nuclear-licensed sites or defence sites managed under NIA65, primarily driven by nuclear site licence requirements such as site health physics requirements
- site characterisation on nuclear-licensed sites and some defence sites may have a higher public profile, because of the potential presence of radioactive contamination. Effective communication with stakeholders (typically a wider group than would be the case for characterisation of other contaminated sites) is essential
- radioactive contamination is potentially present at all nuclear-licensed sites and defence sites managed according to NIA65. It is also potentially present at defence sites where luminised or thoriated components is stored, used, maintained or disposed of. Good practice for characterisation of such sites is that radiation

protection advisers (RPAs) and radiation protection supervisors (RPSs) are appointed to provide advice to the employer in compliance with the Ionising Radiations Regulations 1999 (IRR99) and with the Radioactive Substances Act 1993 (RSA93) It is a statutory requirement under IRR99 to appoint RPAs and RPSs if working with ionising radiations (ie if radioactive contamination is encountered)

- characterisation of background radioactivity, including improvement due to anthropogenic activities, is required to provide a baseline for future phases of risk assessment involving radioactivity
- waste minimisation is an important issue on nuclear-licensed sites. There may be requirements for waste segregation, to ensure arisings of radioactive wastes are minimised
- waste arisings may be radioactive or may contain mixed radioactive and non-radioactive contamination and such wastes require appropriate disposal routes to be planned
- special requirements apply to transporting radioactive materials, such as samples, and these need to be planned and organised to prevent deterioration of sample quality
- on nuclear-licensed sites, there is a requirement for long-term storage of records. This may influence the selection of data collection and storage methods.

Structure of this guidance

The figure on page 6 maps the contents of this guidance document. Core site characterisation processes are shown continuously interacting with project planning and project review activities. A multiple readership is anticipated for this document, and early sections include background information and guidance on setting up a site characterisation project. Later sections describe the characterisation process, the technologies and techniques involved, and the requirements to effectively manage the wastes produced. Delivery of a report and the need for comprehensive record-keeping completes each site characterisation project. Practitioners of site characterisation are expected to be suitably qualified and experienced staff. The guide is in eleven chapters:

Chapter 1: Introduction

Chapter 2: Natural and anthropogenic radioactivity.

Chapter 3: Health, safety, security and environmental protection.

Chapter 4: Objective setting.

Chapter 5: Planning the site characterisation.

Chapter 6: Site characterisation: non-intrusive methods.

Chapter 7: Site characterisation: intrusive methods.

Chapter 8: Site characterisation methods: sampling and analysis.

Chapter 9: Waste management and transport of radioactive materials.

Chapter 10: Record-keeping.

Chapter 11: Uncertainty.

Chapter 1 describes the types of site addressed by this guidance and its relationship with the main SAFEGROUNDS *Land management guidance* (Hill *et al*, 2009a).

Chapter 2 provides a summary for readers on issues concerned with radioactivity, and radioactive contamination. It also discusses the concept of background levels of radioactivity and improvement of background, which are unrelated to activities at the site being characterised. **Chapter 3** covers the health, safety, security and environmental protection issues, with emphasis on those concerned with radioactivity and of particular importance on nuclear-licensed sites and defence sites.

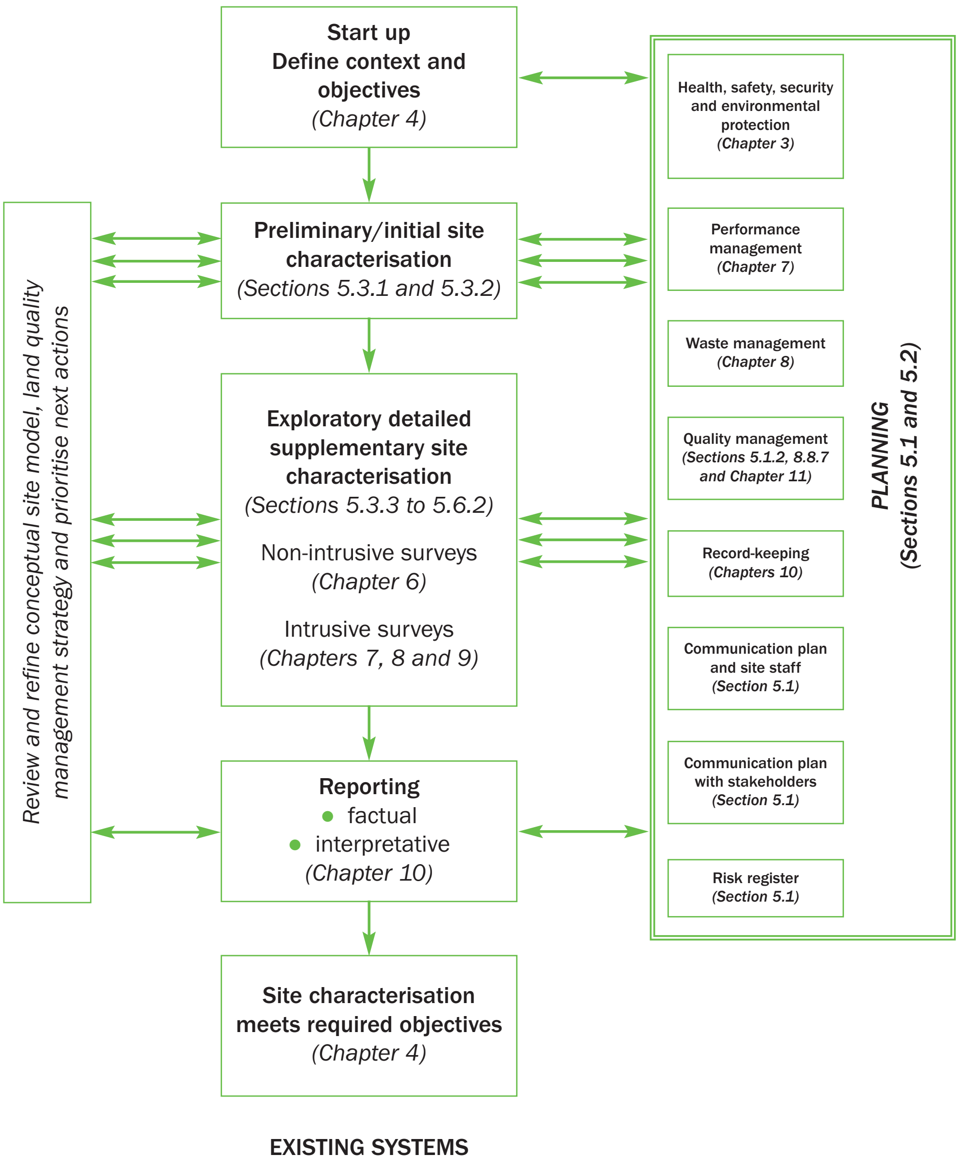
Chapters 4 and 5 present issues concerned with defining objectives for, and with the planning of, site characterisation programmes. **Chapter 4** emphasises the reasons why site characterisation may be required on nuclear-licensed sites and defence sites. It is recognised that the aims for a site characterisation programme depend on the regulatory scenario as well as the phase of characterisation in the overall sequence of a land quality management strategy.

Chapter 5 highlights the importance of project planning and interfacing with existing site systems. Early interaction with regulators is essential, to clarify matters such as statutory ambiguities and methods of approach to characterisation. Involvement of other stakeholders at an early stage is also important. This section presents some of the main technical considerations when planning a site characterisation programme, such as the role of the site conceptual model, the design of sampling strategies and the approach to establishing background environmental quality at a site, including background levels of radioactivity.

Chapters 6 to 8 describe the principal techniques for characterising contaminated land on nuclear-licensed sites and defence sites with a focus on the investigation of radioactively contaminated land. Specific issues in the application of widely used characterisation techniques to nuclear-licensed sites and defence sites are highlighted. Non-intrusive radiation surveys, geophysical surveys, intrusive investigations and chemical/ radiochemical analysis of samples are all discussed.

Chapter 9 describes waste management and transport of radioactive materials. It presents the legislation relevant to categorisation of radioactive wastes, and stresses the importance of waste minimisation and waste segregation as part of the site characterisation process. Issues concerned with the management of chemically contaminated wastes are also presented.

Chapter 10 sets out the management of data from site characterisation programmes, and the need for long-term storage of such records on nuclear-licensed sites. **Chapter 11** identifies the main areas of uncertainty arising during site characterisation and possible actions for minimisation.



A map of the SAFEGROUNDS site characterisation document with references in parenthesis to sections of the guide where the topic is covered

Acknowledgements

Authors

This guide was prepared by Enviros under contract to CIRIA on behalf of the SAFEGROUNDS Learning network by P Towler and A Rankine with assistance from P Kruse and A Eslava-Gomez. It is a revised edition of the guidance first published in 2000, which was then prepared by AEA Technology by A C Baker, C J Darwin, N L Jefferies, P Towler and D Wade.

Project steering group

The SAFEGROUNDS project was guided by a steering group. CIRIA and the research contractors wish to express their appreciation for the technical guidance and support given by the group during the project and in their additional review of drafts of the guidance. The members of the group during the process of production of this report were:

Sean Amos	Atomic Weapons Establishment
Peter Booth*	Nexia Solutions (now National Nuclear Laboratory)
David Brack	Defence Estates
Richard Bramhall*	Low Level Radiation Campaign
Anna Clark	Nuclear Decommissioning Authority
Julian Cruickshank	British Nuclear Group (now Sellafield Ltd)
Ray Dickinson	Defence Estates
Paul Dorfman*	University of Warwick
Joanne Fisher	Nuclear Decommissioning Authority
Bob Gardner	Ministry of Defence
Colette Grundy	Environment Agency
Ian Hall	Scottish Executive
Dick Haworth	Health & Safety Executive
Mark Hill	Defence Estates
John Kelly	Oxfordshire County Council
Shelly Mobbs	Health Protection Agency
Stephen Moreby	Gloucester City Council
Mike Pearl*	United Kingdom Atomic Energy Authority
George Reeves	North Highland College
Hugh Richards	Magnox Electric North
Colin Rogers	Parents Concerned About Hinkley
Adam Stackhouse	Scottish Environment Protection Agency
Andy Thomas (chairman)	Future Solutions
Gemma Urquhart	British Energy
Stephen Wilmott	Magnox Electric South
Mike Wyatt	United Kingdom Atomic Energy Authority
Jamie Woolley	UK Nuclear Free Local Authorities

* Also member of the Project Team, which provides detailed support for the management of the process of the network

CIRIA's research managers for this project were Mr Jeff Kersey, Mr Mark Bentley, and Miss Rajnika Patel, assisted by Miss Gemma Samlal under the direction of Dr Owen Jenkins.

CIRIA, on behalf of all those involved in preparing this guidance, would like to thank everyone who participated in the SAFEGROUNDS project.

Notes on revision of second draft

The second edition of this document has been prompted by the updating of the *Land management guidance document* (Hill et al, 2009a) the developments in regulation of radioactively contaminated land, and its assessment. With this there is a need for nuclear-licensed sites and defence sites to understand any land quality liabilities as the status of such sites is assessed for continued use, decommissioning or redevelopment.

The document has retained comprehensive "one-stop" coverage of site characterisation. Legislation and good practice guidance has been updated, and more emphasis has been placed on signposting to relevant guidance. Other major changes are listed in the following table:

Section	Title	Major changes
1	Introduction	These relate to the new document structure
2	Natural and anthropogenic radioactivity	More information has been provided on background radioactivity
3	Health, security, safety and environmental protection	The focus has been to highlight what is needed in practice. A section on security has been added
4	Objective setting	This section now provides links on contaminated land legislation that will direct the setting of key objectives. Performance management has been introduced to focus objective setting and monitor how objectives should be met
5	Planning the site characterisation	More emphasis has been given to this section as a planning stage. Good project management is fundamental to achieving successful outcomes for site characterisation
6	Site characterisation – non-intrusive methods	Characterisation methods have been split into the following three sections, and updated methods and techniques are presented
7	Site characterisation – intrusive methods	Updated methods and techniques are presented
8	Site characterisation – sampling and analysis	Updated methods and techniques are presented
9	Waste management and transport of radioactive materials	This section has been updated
10	Record-keeping	The previous *data management* section has been split into two. Record-keeping information has largely been replaced by the SAFEGROUNDS guidance on land quality records management (Cruickshank and George, 2007)
11	Uncertainty	The management of uncertainty now warrants a new section to reflect the importance of understanding uncertainty and its association with site characterisation, and how it can be reduced
	References	Updated
	Acronyms	Updated

The previous last Chapter 9 on *Current capabilities and lessons for practice* has been removed. Appendices have been changed with the case studies placed on the SAFEGROUNDS website: <www.safegrounds.com>.

Contents

List of boxes

List of figures

List of tables

1 Introduction

1.1 Background

The SAFEGROUNDS Learning Network <www.safegrounds.com> uses participatory approaches to develop and disseminate good practice guidance for the management of legacy *contaminated land* on *nuclear-licensed* and *defence sites*[1] in the UK. It is a large and well-established network strongly supported by a wide range of participating groups.

The main SAFEGROUNDS guidance document provides good practice guidance for the *management of contaminated land* with radioactive, non-radioactive or mixed radioactive and non-radioactive *contamination* on nuclear-licensed sites and those defence sites where there is radioactive contamination of the land. It is known as the *Land management guidance* or LMG. It provides a framework for land management and is underpinned by five key principles that were debated and agreed through independently assisted workshops. The LMG is kept under review so that experience and developments can be reflected in the guidance. The second version of the LMG was issued in 2009.

The LMG is supported by other documents, such as this one on *site characterisation*, that provide information on related issues. Other documents cover topics including the regulations that apply to the management of contaminated land, methods for comparing land management options and community *stakeholder involvement* (see Section 1.8).

1.2 Scope of SAFEGROUNDS

In SAFEGROUNDS guidance the term "management of contaminated land" means the taking of any actions to control, assess, characterise, monitor, remediate or remove (wholly or partially) legacy contamination once it has been discovered, and the associated *decision making* processes (full definitions are given in the *Glossary*). Prevention of contamination is outside the scope of SAFEGROUNDS.

This guidance focuses on the management of land with the potential for radioactive, non-radioactive and mixed contamination on nuclear-licensed sites and those defence sites on which there is radioactive contamination of the land.

Nuclear-licensed sites include civil nuclear sites that are being used for electricity generation or other purposes, and nuclear sites that are being decommissioned and are the responsibility of the Nuclear Decommissioning Authority (NDA).

Defence sites include those owned by the Ministry of Defence (MoD) where activities involving *radioactive material* have been undertaken. For instance, the maintenance of nuclear propelled vessels and the production and maintenance of luminised instruments for vehicles, aircraft and on board ships[2]. While the Nuclear Installations Act (NIA) does not apply to the MoD certain defence sites are regulated under the Act.

1 *Italics* indicate definition on first appearance given in the Glossary.

2 Low level radioactive contamination may be present because of the historical production, maintenance, storage and disposal of luminised instruments. The peak period for luminising was from the 1930s to the 1970s. In the late 1950s 14 luminising works were registered under the Luminising Regulations 1947 and owned by the MoD. The luminising paint originally contained radium, though more recently promethium and tritium were used. Thoriated metals may also be present because of use, maintenance, storage or disposal on some defence site.

MoD has a continuing programme of *land quality assessment*, which is co-ordinated by Defence Estates, the organisation predominantly responsible for the management of the MoD Estate.

For more information applicable to non-nuclear defence sites, that is beyond the scope of this document, a good practice guide on such sites has recently been prepared (EA, 2008).

1.3 SAFEGROUNDS approach

SAFEGROUNDS has identified five key principles for the management of contaminated land on nuclear and defence sites. The detail and background to these key principles are given in the *Land management guidance*, version 2 (Hill *et al*, 2009a). The principles are complementary and apply at various stages in land management. The key principles are presented in an order of priority of stakeholder importance that were agreed by consultation rather than an order of service:

Principle 1: Protection of people and the environment

The fundamental objective of managing contaminated land on nuclear-licensed sites and defence sites should be to achieve a high level of protection of people and the environment, now and in the future.

Principle 2: Stakeholder involvement

Site owners/operators should involve stakeholders in the management of contaminated land, particularly to inform decision making.

Principle 3: Identifying the preferred land management option

Site owners/operators should identify their preferred management option (or options) for contaminated land by carrying out a comprehensive, systematic and consultative assessment of all possible options. The assessment should be based on a range of factors that are of concern to stakeholders, including health, safety and environmental impacts and various technical, social and financial factors.

Principle 4: Immediate action

Site owners/operators should assess both potential and known areas of land contamination and where appropriate implement a prioritised programme of investigation and any appropriate monitoring. On confirmation of areas of land contamination being present, control measures should be instigated until an acceptable management option has been identified and implemented.

Principle 5: Record-keeping

Site owners/operators should make comprehensive records of the nature and extent of contamination, the process of deciding on the management option for the contaminated land and the findings during the implementation and validation of the option. All records should be kept and updated as necessary.

A systematic approach to the management of contaminated land on nuclear-licensed sites and defence sites has been developed (Hill *et al*, 2009a). The process is illustrated in a generic flow diagram (Figure 1.1) based on the process of managing land contamination outlined in Contaminated Land Report 11 (CLR 11) prepared by the EA (2004a) with some modifications. As such CLR11 should be consulted when interpreting the decision flow diagram. The modifications incorporate the

SAFEGROUNDS key principles and highlight the extra factors to be considered on both nuclear-licensed sites and defence sites. A full description and flow diagram is presented in Appendix A1 showing the various feedback loops, the decision points and application of the key principles throughout. After deciding on the applicability of SAFEGROUNDS, site characterisation then supports every stage by informing the development of a *conceptual model* that allows improved understanding of the process and enables risks to be assessed and evaluated, leading to identification of the *preferred options*.

Careful planning is required from the start, followed by phases of investigation to provide increasing levels of detail and confidence about the nature and extent of the radioactive and mixed contamination. In practice, the individual parts of the whole land management process are iterative. For simplicity, these have been omitted from the generic diagram in Figure 1.1, but are described in full in Appendix A1. Key principles apply throughout the land management process and are represented by a continuous horizontal box at the top of Figure 1.1.

This guidance on site characterisation is designed to support this overall scheme, without being entirely prescriptive.

1.4 Audience

This guidance is principally for a technical audience with a wide range of knowledge, skills and competence. An overview of characterising *radioactively contaminated land* is provided highlighting the needs for comprehensive capabilities and compliance with good practice, site-specific procedures and regulation on nuclear-licensed sites and defence sites. Site characterisation requires many disciplines including managers, engineers, geologists, chemists, health physicists and risk assessors. Several organisations will also be involved in site characterisation with different roles and responsibilities such as site owners, site operators, regulators, consultants, contractors and other stakeholders. All will find this a comprehensive guide to implementation of the SAFEGROUNDS approach.

On nuclear-licensed sites all staff in vital roles should be suitably qualified and experienced personnel (SQEP) for their work. In respect of other MoD sites, Defence Estates also require all staff and contractors involved in the management of contaminated land to be suitably qualified and experienced including a professionally qualified specialist to review and sign-off land quality reports before issue to the client.

1.5 Purpose

The purpose of the document is to explain the main differences and problems that assessing radioactive contamination on nuclear-licensed sites and defence sites poses, compared to conventional contaminated land. This document identifies and describes:

- types and characteristics of contaminated land commonly encountered on nuclear-licensed sites and defence sites where radioactivity may be present
- key health, safety, security and environment issues in site investigations on nuclear-licensed sites and defence sites where radioactivity may be present
- reasons for carrying out investigation of potentially contaminated land on nuclear-licensed sites and defence sites where radioactivity may be present, and the required aims of those investigations
- good practice planning of site investigations for a systematic approach

- available site characterisation methods
- issues associated with radioactive waste arising from characterisation, and the transport of radioactive samples
- how stakeholders should be involved at the various stages of characterisation work
- how site characterisation works should be recorded
- signposts and references to other relevant documentation.

The guidance supplements government and regulatory guidance on the management of contaminated land. It is not intended to be prescriptive, but a systematic approach is advocated.

Where statutory requirements are referred to in this document, the detail should always be checked with the original act or regulation.

1.6 Status

This is the second version of the guidance, and like the first, it is a "living document". It is intended to be revised at intervals in the future following experience in using it and in response to policy, regulatory and other changes.

The guidance is not binding on site owners/operators and has no legal standing. It represents good practice, but adherence to it does not necessarily guarantee regulatory compliance. However, site-specific requirements should always be discussed and negotiated with the appropriate regulators.

1.7 Structure

This guidance essentially covers site characterisation in support of preliminary, *generic* and detailed *quantitative* risk assessments, as well as supplementary investigations to clarify land management options and validate remediation strategies (Figure 1.1).

The decision flow diagram and associated description in Appendix A1 of this guidance provides more detail. It shows the characterisation process with the underlying processes of record-keeping and stakeholder involvement.

Information in this guidance is structured under topic headings arranged in eleven chapters. Chapters 1 to 5 demonstrate the complexities of site characterisation work, and provide a background understanding of how project resources and timescales are defined. Practitioners of site characterisation will be expected to be SQEP. As such they should have full knowledge of Chapters 1 to 5, but will find Chapters 6 to 11 useful for updating.

A list of references and a glossary, including a list of acronyms are presented at the end of this document.

1.8 Other SAFEGROUNDS documents

The SAFEGROUNDS documents listed in Box 1.1 are available in PDF format to download from: <www.safegrounds.com>.

Box 1.1 ***Relevant SAFEGROUNDS documents***

Main SAFEGROUNDS guidance document:

COLLIER, D (2005a) *Community stakeholder involvement*, W16, CIRIA, London

COLLIER, D (2009c) *Approach to managing contaminated land on nuclear-licensed and defence sites – an introduction*, W27, CIRIA, London

HILL, M, PENFOLD, J, HARRIS, M, BROMHEAD, J, COLLIER, D, MALLET, H and G SMITH (2002) *Good practice guidance for the management of contaminated land on nuclear and defence sites*, W13, CIRIA, London

HILL, M, PENFOLD, J, WALKER, R, EGAN, M, COLLIER, D, ESLAVA-GOMEZ, A, KRUSE, P, RANKINE, A and TOWLER, P (2009a) *Good practice guidance for the management of contaminated land on nuclear-licensed and defence sites*, version 2, W29, CIRIA, London

PENFOLD, J (2009) *Guide to the comparison of contaminated land management options*, W28, CIRIA, London

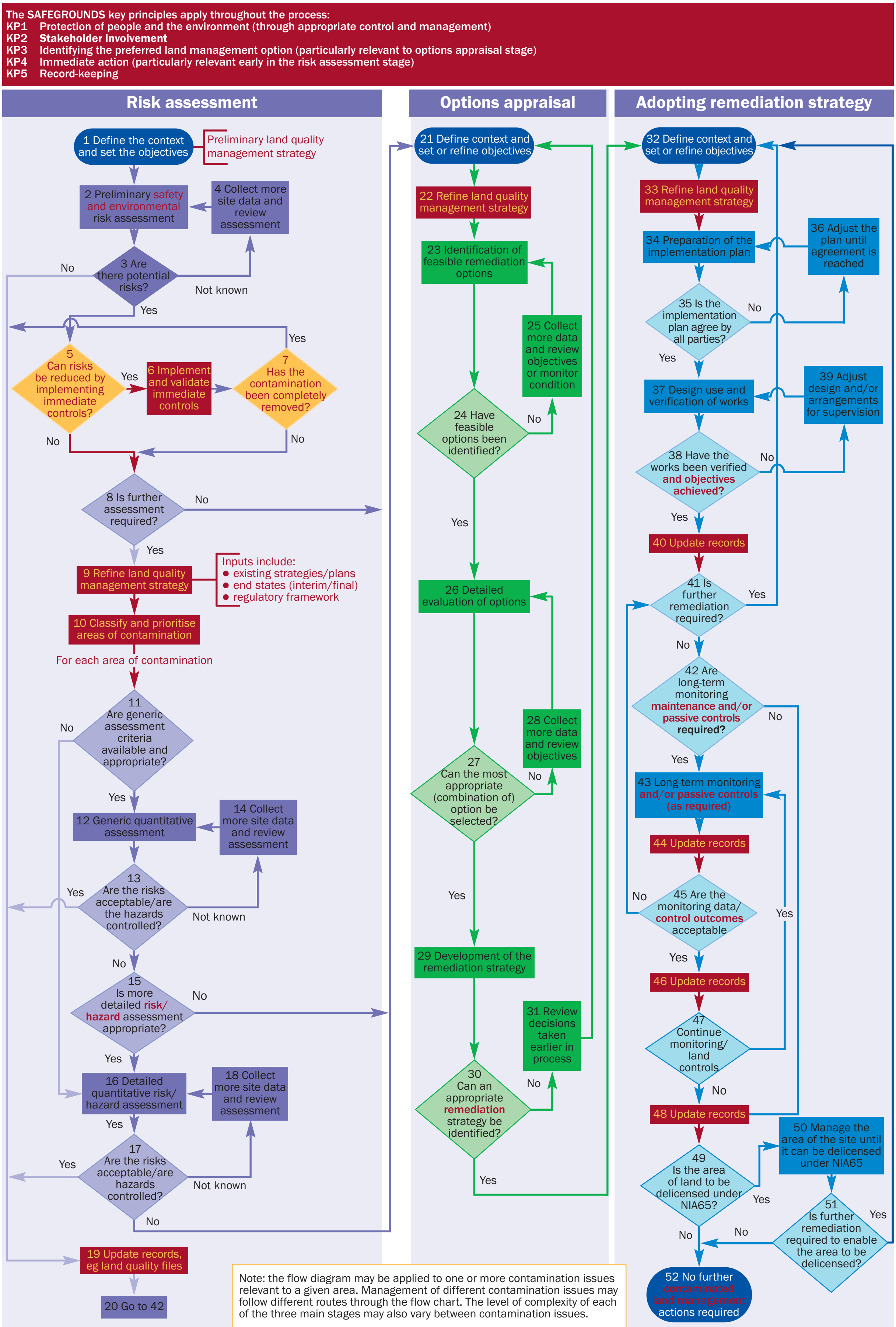
SMITH, G (2005) *Assessments of health and environmental risks of management options for contaminated land*, W15, CIRIA, London

SAFEGROUNDS information papers

HILL, M D (2005a) *Briefing note on the Energy Bill*, W19, CIRIA, London

HILL, M D (2005b) *The regulatory framework for contaminated land on nuclear-licensed sites and defence sites*, version 4, W17, CIRIA, London

SMITH, G M (2005) *Review and commentary on site end-points and radioactively contaminated land management*, W20, CIRIA, London



Note: the modifications to the CLR 11 decision flow diagram for SAFEGROUNDS are highlighted in **dark red** boxes with tan lettering

Figure 1.1 ***Decision flow diagram for management of contaminated land according to SAFEGROUNDS***

2 Natural and anthropogenic radioactivity

Box 2.1 ***Aims of Chapter 2***

- to send the reader to sources of information on the principles of *radiation* and radioactivity
- to identify the principal radionuclides, which are relevant to contaminated land
- to introduce the concept of natural radioactivity, and to explain the importance of establishing natural background levels of radioactivity at the site of interest for later stages of risk assessment.

2.1 Introduction

Although some fundamental knowledge of radioactivity is assumed, the basic concepts of radioactivity are summarised here with further sources of information given in Collier (2009c), IAEA (2004), and NRPB (1998).

To summarise:

- each nuclide is characterised by the name (or symbol) of the element and the nuclide's atomic mass. For example, nitrogen-14 (N-14) or strontium-90 (Sr-90)[3]. Nuclides of the same element with different atomic masses, for example, uranium-235 and uranium-238 are known as isotopes of the element. Most elements have more than one known isotope, so the total number of nuclides is several times greater than the number of elements
- most nuclides found in nature are stable, but some nuclides produced by humans – as well as some that occur naturally – exhibit the property known as radioactivity. These are referred to as radionuclides
- a nuclide that is radioactive is unstable. The atomic nucleus spontaneously decays, ie it changes into the nucleus of a different nuclide, emitting radiation in the process. This is a random process – it is not possible to predict exactly when a particular nucleus will decay – but the average rate at which nuclei decay and the type of radiation they emit are both characteristic of the radionuclide
- the rate at which a radionuclide decays is called its *activity* – the average number of decays per second. The unit of activity is decays per second, which is given the name *Becquerel* (Bq). 1 Bq is 1 decay per second and is a very small level of activity. For example 5000 Bq is usually found in the human body
- activity is often quoted in multiples such as kBq, MBq and GBq
- a related measure of the rate at which a radionuclide decays is the *half-life*, also a constant characteristic of the radionuclide. This is the average time it takes for one-half of the atoms in a sample of the radionuclide to decay. After two half-lives, one-quarter of the atoms will remain, after three half-lives there will be one-eighth left, and so on. After 10 half-lives, the activity will reduce to about one-thousandth of the initial value. Half-lives of known radionuclides range from tiny fractions of a second to many millions of years
- a radionuclide will eventually decay into a stable nuclide, this may take one step or many steps. For some natural radionuclides this decay chain can extend through many intermediate radionuclides, known as daughters, before a stable state is achieved. When the half-life of the *daughter radionuclide* is much shorter than the

3 Depending on the scientific discipline radionuclides may be written in the form ^{1}137Cs, Cs137, with the numbers in either normal font, subscript or superscript (eg ^{137}Cs, Cs_{137}), with or without hyphens. For consistency all radionuclides are reported in the form Cs-137.

half-life of the parent radionuclide, the quantity of the daughter radionuclide builds up until the decay rate becomes equal to the number being produced per unit time, so the quantity of the daughter reaches a constant, *equilibrium* value. This is known as secular equilibrium, and is particularly important for some radionuclides such as Cs-137. Cs-137 is a beta emitter, however its daughter Ba-137m is a *gamma* emitter. Cs-137 and Ba-137m are often treated together because they occur in secular equilibrium. This is important to recognise in *fingerprinting*.

2.2 Radiation dose units

2.2.1 Absorbed doses of radiation

Absorbed dose is a measure of the energy deposition in any medium by any type of *ionising radiation*. The unit of absorbed dose is the **gray (Gy)** and is defined as the energy deposition of 1 J/kg. When quoting an absorbed dose it is important to specify the absorbing medium. It is also worth noting that because of this the dose from 1 Bq of activity is different for different radionuclides.

2.2.2 Equivalent dose

In biological systems, humans for example, different types of radiation (alpha, beta, gamma) produce different degrees of damage for the same absorbed dose so a *radiation weighting factor* is applied for each type of radiation. The sum of the corrected doses for each type of radiation is called the equivalent dose and is measured in *sieverts* (Sv). Dose limits to specific organs, for example the eye lens, are set in equivalent dose.

2.2.3 Effective dose

In radiation protection it is useful to think of radiation dose in terms of the overall impact it may have on the whole body. Because different organs have different susceptibilities to damage from radiation, further corrections (tissue weighting factor) must be applied. The resulting calculated dose measured in sieverts in µSv is called the "effective dose" and is often referred to as "whole body dose".

2.2.4 Dose rate

Both the gray and the sievert are units expressing the amount of radiation that may have been received over any period of time. When considering radiation exposure it is usually necessary to know the rate at which it is being received. So:

$$\text{dose} = \text{dose rate X time}$$

Given that the gray and the sievert are very large units it is usual to express dose rates in terms of microsieverts per hour (μSv h^{-1}) or millisieverts per hour:

(µSv h^{-1}).

2.2.5 Problematic nature of dose assessment

Recently various bodies (CERRIE, IRSN, ECRR, and ICRP) have acknowledged that when considering interactions at the cellular and molecular levels, where ionisation density may be very high, the concept of absorbed dose becomes virtually meaningless. Some stakeholders believe that such considerations may explain anomalous health observations associated with nuclear installations.

2.3 Human health impact

Humans are exposed to radiation by several different routes, called *pathways*. Pathways include *inhalation, ingestion, injections* and external exposure. The radiation dose to which individuals or groups of people are exposed depends upon the types of radiation they are exposed to and the exposure pathways (Watson *et al*, 2005).

In the *context* of contaminated land investigations, consider:

- the *external radiation* dose, measured directly at the workplace using personal monitors (eg film badges) and portable radiation monitors
- the *internal radiation* dose, measured by means of bioassay *sampling* (urine and faecal sampling) and estimated by means of *monitoring* air contamination levels.

Problematic nature of dose assessment

Recently various bodies (CERRIE, IRSN, ECRR, and ICRP) have acknowledged that when considering interactions at the cellular and molecular levels, where ionisation density may be very high, the concept of absorbed dose becomes virtually meaningless. Some stakeholders believe that such considerations may explain anomalous health observations associated with nuclear installations

In general, there are two opposing views represented within the SAFEGROUNDS Learning Network concerning the health risks from *radiation* exposure. One view is that a high level of protection of people and the environment is afforded by a combination of self-regulation and compliance with the relevant radiological regulatory regimes that apply in the UK. These regulatory regimes require the application of the principle of reducing risks "as low as reasonably achievable/practicable" (ALARA/P) and specifically rely on recommendations of the International Commission on Radiological Protection (ICRP) (ICRP, 1991). The other view is that a high level of protection of people and the environment is not afforded by current UK regulatory regimes, and suggests that risks from exposure to both low level radiation and other contaminants are significantly underestimated by the ICRP. SAFEGROUNDS guidance on this issue is under review at the time of writing (January 2009) and may be updated or replaced during 2009/10.

Differences of opinion among stakeholders may impact whether health protection criteria expressed in terms of exposure to radioactive contamination (eg as radiation dose or intakes of *radionuclides*) are accepted as demonstrating a given level of protection expressed in terms of risk. SAFEGROUNDS recommends that different views among stakeholders about such issues should be recognised, given explicit consideration, and show a demonstrable impact on decision making processes. Recognising the concerns raised is an important element of stakeholder involvement.

A fuller description of risk assessment and the effects on human health associated with radioactively contaminated land, including the radiological impact and alternative view points are described in Hill *et al* (2009a) and Smith (2007).

2.4 Radioactivity in the environment

Many materials contain some radioactivity, although typically at such a low level that sensitive instruments are required to detect them. The radioactivity occurs in the form of radionuclides derived from two sources:

1 Natural *ionising radiation* pervades our *environment*, in the form of *naturally occurring radionuclides*, which can further be classified as either primordial radionuclides (with half-lives comparable to the age of the earth) or *cosmogenic radionuclides* (produced by the interactions of cosmic radiation with matter).

2 *Anthropogenic radionuclides*, ie those produced by humans can be as a result of site-specific activities resulting in radioactive contamination. Anthropogenic radionuclides are widely distributed in the environment as a result of atmospheric nuclear weapons testing, nuclear accidents (of which Chernobyl in 1986 is now the most significant in the UK context) and authorised discharges of radioactivity from sites where radioactive materials are handled.

2.4.1 Primordial radionuclides

The most radiologically significant naturally occurring terrestrial radionuclides are in the decay series originating with U-235, U-238 and Th-232. The dominant naturally occurring isotope of uranium is U-238 (99.28 per cent natural abundance by mass). U-235 constitutes essentially all of the remaining 0.72 per cent by mass of natural uranium. In terms of activity the radioactivity from U-238 is about 22 times that from U-235 in natural uranium.

All materials in the earth's crust contain radionuclides, igneous and metamorphic rocks, on average, contain about 25 mBq g^{-1} U-238 (equivalent to 2 ppm U) and 30 mBq g^{-1} Th-232 (equivalent to 7 ppm Th). Some rocks in the UK, such as the granites of south west England, contain significantly higher levels of U: typically of order 16 ppm (0.2 Bq g^{-1} U-238). The activity of uranium in soils is also variable, and is influenced by the nature of the parent material, the mineralogy of the soil and the geochemical conditions in the soil column.

In the context of this guidance, an important long-lived member of the U-238 decay chain is Ra-226, which was used extensively to produce luminising paint. Ra-226 decays to Rn-222, a short-lived radioactive gas, which then decays to stable lead via a series of short-lived, predominantly alpha-emitting, radionuclides.

K-40 is a lighter radionuclide and has a half-life of 1.28×10^9 years, with an isotopic abundance of 0.0118 per cent. This leads to natural potassium being radioactive, and having an activity of about 30 Bq g^{-1}. Data for concentrations of significant primordial radionuclides in soil is presented in Table 2.1.

Table 2.1 ***Concentration in soil of significant primordial radionuclides in Bq kg^{-1} (UNSCEAR, 2000)***

Radionuclide	UK values		World values	
	Mean	Range	Median	Range
K-40		0–3200	400	140–850
U-238		2–330	35	16–110
Ra-226	37		35	17–60
Th-232		1–180	30	11–64

The dose rates associated with external *irradiation* from natural terrestrial radionuclides in the UK are in the region of eight to 89 nGy h^{-1} with a mean of 34 nGy h^{-1}. The annual dose received from external radiation from natural terrestrial radionuclides is about 300 microsieverts. This accounts for about 11 per cent of the annual average exposure to ionising radiation in the UK.

The HPA has published results of an environmental surveillance programme in the UK (NRPB, 2003) and more detailed information is available in *Radioactivity in food and the environment* (RIFE, 2007).

2.4.2 Cosmogenic radionuclides

The interactions between *neutrons* and protons associated with cosmic radiation and atoms of nitrogen, oxygen and argon produces a series of radionuclides, the most abundant of which are Ar-39, C-14, Be-7 and H-3. The equilibrium activity of these cosmogenic radionuclides is controlled by their production rate in the atmosphere and their residence times in the atmosphere, in the oceans and in the subsurface.

All living matter contains carbon of which a proportion is C-14. The relative concentration of C-14 is about 0.23 Bq g^{-1} of carbon. On the death of the organism, continued accumulation of C-14 stops, and the remaining unsupported C-14 decays (with a half-life of 5730 years).

Tritium (H-3) is produced naturally in the atmosphere by interactions of fast neutrons with nitrogen. Large amounts of tritium were also produced in the atmosphere by atmospheric nuclear weapons testing during the 1950s and 1960s. It has a half-life of 12.3 years. At its peak, in 1963, H-3 activity in precipitation reached about 200 Bq L^{-1}. At present, tritium activity in precipitation is about 2-5 Bq L^{-1}.

The concentration of cosmogenic radionuclides in the troposphere is presented in Table 2.2. Be-7 is found in recently deposited sediments but is otherwise generally absent from soils and rocks. Ar-39 is not of concern in contaminated land due to its gaseous state.

Table 2.2 ***Concentration of cosmogenic radionuclides in the troposphere (UNSCEAR, 2000)***

Radionuclide	Concentration in troposphere (mBq m^{-3})
H-3 (12.33 y)	1.4
Be-7 (53.29 d)	12.5
C-14 (5730 y)	56.3
Ar-39 (269 y)	6.5

Note: half-lives are presented in parentheses after the radionuclide.

2.4.3 Anthropogenic radionuclides

Anthropogenic radionuclides are produced as a result of:

- *nuclear fission:* the splitting of a heavy nucleus, such as uranium or plutonium, by spontaneous reaction, bombardment with neutrons or bombardment with charged particles. This is the process that occurs in a nuclear reactor to generate energy
- *activation:* the result of irradiation by neutrons. In a nuclear reactor, these reactions occur with the fuel, leading to the production of isotopes of plutonium, and with the structural components (eg steels and graphite), leading to the production of unstable isotopes such as Co-60 and C-14. Many radionuclides for medical and industrial use are also produced by this process.

The impacts associated with discharges on nuclear sites are presented in Watson *et al* (2005).

2.5 Sources

Anthropogenic radionuclides are often most associated with the nuclear fuel cycle, however other sources of manmade radionuclides exist such as nuclear weapons production and radioisotope production as well as other operations (Defra, 2006a).

The principal operations on nuclear-licensed sites that produce manmade radionuclides and/or concentrate naturally occurring radionuclides are summarised in Table 2.3.

A radionuclide "fingerprint" may be defined based on the relative proportions of concentrations of radionuclides found in a particular media at a particular time and location. Once identified and confirmed the fingerprint can be used to deduce the radiological composition of a medium following the characterisation of a few vital radionuclides. The radionuclide fingerprint that is produced from operations can be calculated given knowledge of the (neutron, or other) flux to which the material has been exposed, the duration of exposure and the composition of the material. Since a wide range of activation or *fission products* with widely varying half-lives are produced, the fingerprint will change as a function of the time that has elapsed since the end of irradiation. On sites where various materials are handled and various processes are carried out, it may be appropriate to define different fingerprints for different facilities on, or in areas of, the site.

Table 2.3 **Major nuclear operations on nuclear-licensed sites and illustrative radionuclides**

Operation	Radionuclides
Reactor operations (electricity generation for civil and military uses, research reactors)	*Fission products* (such as Cs-137, Sr-90 and isotopes of plutonium and americium) and activation products (such as Co-60)*
Fuel reprocessing	Fission products and activation products
Fuel fabrication	Uranium, plutonium, mixed oxide fuel (MOX) and thorium
Weapons production	Uranium, plutonium, polonium, americium, tritium (beryllium**)
Research and development	Various, dependent on nature of research
Manufacture of radioactive sources, chemical and pharmaceuticals	Various, including H-3, C-14, P-32 and iodine isotopes

Note:

* Fission products may end up in different areas of the facility due to fuel handling operations.

** Beryllium may also be present. It is toxic in its non-radioactive form.

The fingerprint defines the relative activities of radionuclides at the source of contamination. However, as radionuclides migrate away from the source area via transport mechanisms such as advection and diffusion via *groundwater*, the plume becomes spread out, with some radionuclides (such as tritium) moving faster than others (such as plutonium). The relative activities of radionuclides in the plume are a function of the distance travelled, and the concept of the fingerprint has to be used with care:

- for decommissioned reactor sites, where most of the shorter lived radionuclides will have decayed, the radionuclides of common concern are H-3, Cs-137 and Sr-90. However, specific operations and incidents may result in localised areas of contamination with a different profile

- for reprocessing facilities where a complex set of operations has been undertaken then it is likely that individual facilities and buildings could have their own specific set of radionuclides of concern
- for some sites, eg nuclear fuel fabrication, it is worth noting that chemical contamination could be the most limiting factor in undertaking any *remediation* operations on site
- for defence sites, the radionuclides present will depend on the activities at the site. On the non-nuclear sites low level radioactive contamination may be present because of the historical production, maintenance, storage and disposal of luminised instruments. The peak period for luminising was between the 1930s and the 1970s. In the late 1950s 14 luminising works were registered under the Luminising Regulations 1947 and owned by the MoD. The luminising paint originally contained radium, though more recently promethium and tritium were used. The contamination, if present, will be associated with paint spillages, the storage of exposed and flaking painted instruments, and the disposal of redundant instruments. Disposal, in keeping with practices of the time, may have been burnt and/or buried or else as ash and clinker locally dispersed on paths for example. Thoriated metals and tritium luminised apparatus have also been used by military establishments.

Importantly, the specific details can vary tremendously between sites because of historical activities and events. The history of nuclear-licensed sites can extend back to previous uses, which may or may not involve radioactivity.

Some of the principal longer-lived fission products and activation products, which may be encountered in contaminated land *site investigations*, are given in Table 2.4.

Table 2.4 ***Principal longer-lived radionuclides relevant to contaminated land as a result of human activities (NPL, 2008)***

Radionuclide	Half-life (days)	Major decay
H-3	4497	beta (low energy)
C-14	2.082×10^6	beta (low energy)
Fe-55	1003	Electron capture, x-ray
Co-60	1925.2	beta, gamma
Ni-63	36000	beta (low energy)
Sr-90, Y-90*	10520, 2.66684	strong beta
Tc-99	7.8×10^7	beta (low energy), gamma
Cs-134	753.5	beta, gamma
Cs-137, Ba-137m*	10976, 1.7722×10^{-3}	beta, gamma
Ra-226	5.844×10^5	alpha, gamma
Pu-238	32046	alpha
Pu-239	8.806×10^6	alpha
Pu-240	2.396×10^6	alpha
Am-241	158000	alpha, gamma
Pu-241	5234	beta
Pu-242	1.362×10^8	alpha
U-234	8.967×10^7	alpha
U-235	2.5706×10^{11}	alpha, gamma
U-238	1.6319×10^9	alpha

Note:

* The second radionuclide listed is the progeny of the first and is assumed to be in secular equilibrium.

The nature of the operations in some industries can result in the accumulation and concentration of naturally occurring radionuclides. These are often referred to as naturally occurring radioactive material (NORM) and technologically enhanced naturally occurring radioactive material (TENORM). The most obvious example where an accumulation of material would occur is uranium mining operations. However other activities would also result in the accumulation of NORM, such as:

- oil and gas extraction
- fertiliser production
- tin smelting
- chemical industry
- phosphoric acid production
- iron and steel production
- cement industry
- ceramics industry.

Another source of anthropogenic derived radioactivity may arise from sites authorised to dispose of wastes containing low levels of radioactivity to approved landfill sites. Also, wastes with very low levels of radioactivity can be disposed of in general waste, including consumer products like smoke detectors, leading to the generation of landfill emissions containing radioactivity, such as tritium in leachate. Some landfill sites may have in the past accepted wastes from NORM and TENORM industries resulting in elevated levels of natural radionuclides in the emissions. The IAEA have published guidance on the measurement and impact of operations involving NORM (IAEA, 2003).

2.6 Background radioactivity

It is important to distinguish between radioactive contamination resulting from human activities on the site and the background level of radioactivity, which arises from natural radioactivity in the soils and rocks and from levels of manmade radionuclides originating from sources unrelated to the site (for example, *atmospheric fallout* from the Chernobyl accident).

There are several important considerations in the determination of background levels on contaminated sites. The level for action must be distinguishable from background otherwise it may be difficult to suitably differentiate areas for clean-up. This may be hindered if there are areas of natural radionuclides that may improve gamma survey results. This improvement may also cause issues with transport and waste disposal. Distinguishing the contribution of background radiation from that of past activities can be particularly difficult where operations have included naturally occurring radioactive materials such as Ra-226. Careful assessment of the background together with any improvement as a direct result of the practices carried out on the site, is required to provide a baseline.

Background levels of radioactivity will vary spatially both from one site to another and within the same site. Background levels of radiation can vary over time as well. The principal factor that controls the background level of natural radionuclides at a site is the level of radioactivity in the rock from which the soil was derived. Natural series radionuclides can also be concentrated in different parts of the soil column and weathering profile, typically associated with iron oxides, clay minerals and organic material. So it is to be expected that background levels of naturally occurring radionuclides in the rocks and soils will vary with depth.

Many sites contain areas of *made ground*, ie material that has been imported onto the site, or moved from another area of the site, to fill depressions and raise ground level. Some types of made ground, such as ash and metallurgical slag materials, contain elevated levels of naturally occurring radionuclides. Others, such as imported sand and clay, may have levels of radioactivity that differ from that of the natural soil at the site. This may make determination of background levels difficult, where the usual practice would be to go to a known, uncontaminated area nearby to determine the local background rate. This might not take account of the content of any made ground on the site. Variations in natural background level may be detected by some walkover radiation surveys (see Figure 2.1) and should be noted when deriving background levels for the site.

Levels of atmospheric fallout-derived radionuclides (for example, H-3 and Cs-137) are influenced largely by altitude and rainfall patterns. In the UK, atmospheric fallout has arisen from the testing of nuclear weapons and from more recent events, principally the Chernobyl accident. The RIFE report published annually by FSA, EA, SEPA and NI EHS contains data on regional monitoring remote from nuclear sites and includes concentrations of natural and anthropogenic radionuclides in air and drinking water.

Radium-226 and Lead-210 are commonly found in the UK in drinking water at very low levels, typically in the range 0–180 and 40–200 mBq l^{-1} respectively (UNSCEAR, 2000). Levels of H-3 found in rainwater in the UK range between <1.2 and 3.8 Bq l^{-1}, while levels of Cs-137 range between 0.01 and 0.06 Bq l^{-1} (RIFE, 2007).

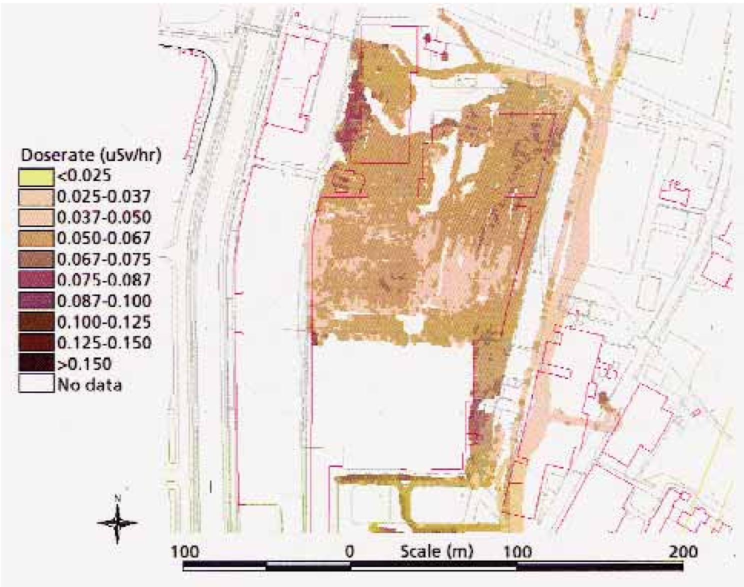


Figure 2.1 ***Survey showing variation in background radioactivity at a site***

Levels of radioactivity in the environment can be influenced by past or present authorised radioactive discharges into the atmosphere and aquatic systems. The impact of marine discharges can extend some distance away from the site. This is because of the processes of the advection and diffusion of material away from the site resulting in the accumulation of material in sediments over an extended period of operations.

External radiation dose rates from the background levels of radioactivity in rocks and soils depend on the levels and nature of the radioactivity. Typical background dose rates are 0.05-0.1 μSvh^{-1}.

The location of sampling points for soils, sediments, rocks and water to determine *background radioactivity* should be discussed with the regulators.

2.6.1 Sources of information

Nuclear-licensed sites are legally required to undertake off-site monitoring. This data can help in determining background levels, although care needs to be taken in interpreting this data to account for the impact of authorised discharges.

The UK Meteorological Office is responsible for the operation of the Radioactive Incident Monitoring Network, replacing Defra. The remit of this network was originally to act as a resource, part of the National Response Plan (NRP), to a nuclear accident overseas. It includes over 90 gamma monitoring stations distributed across the UK. These automated monitoring stations record gamma dose rates routinely. As a consequence a large data set of background gamma dose rate monitoring data has been established[4]. Defra has a store of data on environmental radioactivity on their website[5]. The RIFE reports are published on the FSA website[6]. A selection of background radioactivity levels is given in Box 2.2.

SERMG is a local authority consortium of southern England local authorities in partnership with the University of Southampton that measures and reports on environmental background radiation levels[7].

The Local Authorities Radiation Network (LARNet) arose from the Local Authority Radiation and Radioactivity Monitoring and Coalition Centre (LARRMACC) whose primary role was to deliver consistency across individual local authorities and consortia when it came to radiological monitoring as a direct result of the Chernobyl accident in 1986. Over time the support for local authority monitoring has declined but some areas still maintain records that might be useful.

Guidance on determining appropriate background levels is provided in Section 5.6. Guidance on transport and waste disposal are given in Chapter 9.

4 <www.defra.gov.uk/environment/statistics/radioact/radrimnet.htm#ratb18a>.

5 <www.defra.gov.uk/environment/statistics/radioact/alltables.htm>.

6 <www.food.gov.uk/science/surveillance/radiosurv/rife11>.

7 <www.sermg.org>.

Box 2.2 ***Indicative levels of radionuclides from human activity (RIFE, 2007)***

Concentrations of Cs-137 in 2006 in the UK		
Aberporth	rain	<0.052 Bq L^{-1}
Eskdalemuir	grass	<0.51 Bq kg^{-1}
Eskdalemuir	soil	25 Bq kg^{-1}
Chilton, Oxfordshire	rain	<0.045 Bq L^{-1}
Chilton, Oxfordshire	air	$<6.1 \times 10^{-7}$ Bq m^{-3}
Orfordness	air	$<7.8 \times 10^{-7}$ Bq m^{-3}

Activity in surface water leachate from landfill sites in Scotland in 2006	
H-3	<5.0–1000 Bq L^{-1}
C-14	<15 Bq L^{-1}
Cs-137	<0.05 Bq L^{-1}
Am-241	<0.05 Bq L^{-1}

Concentrations in the marine environment in Northern Ireland in 2006		
Co-60	mud	<0.52–<0.91 Bq $kg^{-1'}$
Cs-137	mud	6.8–48 Bq $kg^{-1'}$
Co-60	sand	<0.39–<0.40 Bq $kg^{-1'}$
Cs-137	sand	<0.6–1.8 Bq $kg^{-1'}$

Impacts of marine discharge in 2006	
In sediments and mud affected by marine discharge from reprocessing operations at Sellafield affecting the Cumbrian coastline	
Co-60	<0.5–25 Bq kg^{-1}
Sr-90	<1.8–330 Bq kg^{-1}
Cs-137	27–1300 Bq kg^{-1}
Pu-239/240	47–2500 Bq kg^{-1}
Am-241	<15–3500 Bq kg^{-1}

In sediments and mud affected by marine discharge from nuclear power operations (Severn Estuary coastline)	
Cs-137	32 Bq kg^{-1}
Am-241	**<1.7 Bq kg^{-1}**

3 Health, safety, security and environmental protection

Box 3.1 ***Aims of Chapter 3***

> Ensuring compliance to SAFEGROUNDS Key Principle 1 (protection of people and the environment) is fundamental to site characterisation.
>
> This chapter describes the key aspects of health, safety, security and environmental management on nuclear-licensed sites and defence sites that are different from those on conventional contaminated sites. This chapter focuses on health and safety from working with radioactivity. To ensure compliance with the principal legislation concerned with radioactivity (IRR99 and RSA93, as amended) it is important to appoint and consult a suitably qualified *radiation protection adviser* (RPA). The requirements for security and for environmental protection are also presented.

3.1 Introduction

This guidance focuses on aspects of health, safety, security and environmental management on nuclear-licensed sites and defence sites that differ from those on conventional contaminated sites. Detailed guidance of safe working on conventional contaminated sites is already available Steeds *et al* (1996), HSE (1991) BS ISO 10381-3:2001, BDA (2002) and during site investigation BS 10175:2001 (Annex B). The reader is referred to these reports for information.

One important aspect of health, safety, security and environmental management on operational nuclear-licensed sites is the nuclear site licence issued under the Nuclear Installations Act 1966 (as amended). Sites licensed under the Act are required to have procedures in place to ensure compliance with 36 standard licence conditions. A summary of these conditions can be found together with guidance notes for nuclear installations inspectors in a document produced by HSE *Nuclear Site License Conditions* summary (2009). Of particular relevance to work associated with land and groundwater characterisation are Licence Conditions 9, 10, 12, 14, 25, 32, 33 and 34. HSE also publish *Safety assessment principles for nuclear facilities* (HSE, 2006), which must be applied during the risk assessment of work on a nuclear-licensed site. This latest edition, while remaining applicable to new nuclear facilities, makes greater provision for *decommissioning* and radioactive waste management, and is also clearer in its application to safety cases related to existing facilities. Further interpretation is given in supporting Technical Assessment Guides (TAGs), which are being prepared over the next few years and updates will be found at: <www.hse.gov.uk>.

Under the nuclear site licence, the site operator has clearly specified site procedures that must be followed by all contractors as well as by employees of the *licensee*. These procedures cover many issues of relevance to contaminated land investigations, such as excavation and waste management. It should be noted that site procedures will differ from licensee to licensee, and may differ between sites operated by an individual licensee. It is essential that all parties understand the requirements of the site procedures before any work is undertaken.

For all nuclear-licensed sites, the operator retains ultimate responsibility for all health, safety, security and environment issues. So, it is to be expected that the licensee will manage contractors more closely than would be expected on a conventional contaminated site.

Each MoD site has established comprehensive safety rules and procedures that contractors must follow without exception. Also, through Defence Estates' co-ordinating role for their land quality programme, MoD has established comprehensive land quality assessment guidance, procedures and standards (MoD, 2004 and Defence Estates, 2007). The latter refers to BS 10175:2001 and thereby its guidance of health and safety for site characterisation.

3.2 Summary of key safety legislation relevant to site investigation on contaminated land

The prime legislation for health and safety management is the Health and Safety at Work etc Act 1974 (HSAWA). Under this act are a series of regulations, with some being relevant to contaminated land investigations on nuclear-licensed sites and defence sites. The most relevant regulations are summarised in Box 3.2 under generic headings: management, working environment, construction, hazards. Persons responsible for health and safety planning should know the regulations that are appropriate for their site-specific conditions.

IRR99 are discussed in more detail in Section 3.4 and Appendix A2. The potential presence of radioactive contamination is one of the issues that distinguish safety for site characterisation on nuclear-licensed sites and defence sites from sites that are not at risk of radioactive contamination.

Before starting the site characterisation, it may not be clear whether the nature, quantities and concentrations of radioactivity that will be encountered are such that IRR99 is applicable. Good practice is that a radiation protection adviser (see Box 3.3) is appointed to give advice on this, and other radiological issues.

Box 3.2 ***Key regulations relevant to site investigations on contaminated land***

Management

Management of Health and Safety at Work Regulations 1999

Working Time Regulations 1998

Health and Safety (First-Aid) Regulations 1981

Reporting of Injuries, Diseases and Dangerous Occurrences Regulations 1995

Working environment

Personal Protective Equipment (PPE) at Work Regulations 1992

Workplace (Health, Safety and Welfare) Regulations 1992

Provision and Use of Work Equipment Regulations 1998

Regulatory Reform Fire Safety Order 2005

Fire Certificates (Special Premises) Regulations 1976

Lifting Operations and Lifting Equipment Regulations 1998

Confined Space Regulations 1997

Provision and Use of Personal Protective Equipment 1992

Health and Safety (Safety Signs and Signals) Regulations 1996

Carriage of Dangerous Goods Regulations and Use of Transportation Pressure Equipment Regulations 2007

Construction

Construction (Design and Management) Regulations 2007

Construction (Head Protection) Regulations 1989

Hazards

Control of Substances Hazardous to Health Regulations 1999

Control of Substances Hazardous to Health (Amendment) Regulations 2004

Ionising Radiations Regulations 1999

Electricity at Work Regulations 1989

Manual Handling Operations Regulations 1992

Control of Noise at Work Regulations 2005

Control of Asbestos Regulations 2006

Control of Lead at Work Regulations 2002

3.3 Safety management arrangements

The overall safety principle should be to provide competent and trained employees working under a safe system carried out in a safe place of work with safe plant and materials. These principles are featured in the common law "duty of care" and in occupational health and safety law, such as the HSAWA 1974. The safety management arrangements provide the basis for the working procedures used for the work activities.

Operators of nuclear-licensed sites will have procedures in place to ensure safe systems of working. The detail of the procedures will vary according to the operator and site. However, the following are important elements common to most nuclear-licensed sites.

- safety categorisation of the proposed work by the site operator. A hazard and operability study (HAZOP) will be required to identify and evaluate the hazards and to propose appropriate controls
- preparation of a health and safety plan and method statements by the contractor
- acceptance of a health and safety plan and method statements by the site operator and issue of permit to work and excavation permits (if required)
- completion of point of works safety assessments (POWSA)
- completion and closure of permit to work and excavation permits at the end of the project.

On operational MoD sites, the overall responsibility for co-ordinating health and safety rests with head of establishment or a delegated representative and they should be consulted on the planning of any site characterisation works to ensure that the contractors' procedures are fit for purpose. Sites that are closed and deemed surplus are passed to Defence Estates for sale or lease. For contaminated land investigations, subject to the control of the site passing to the contractor, MoD transfers responsibility for safety to the contractor under Section 4 of the HSAWA 1974. In cases where the land may be radioactively contaminated, Defence Estates ensures that an appropriate RPA is appointed.

It is good practice that the health and safety plan (see Box 3.3) should conform to the requirements of the Construction (Design and Management) Regulations 2007 (CDM2007), which came into force on 6 April 2007. Guidance on the application of the Regulations is given by HSE in an approved code of practice (HSE, 2007a). The roles and responsibilities under CDM Regulations are set out in HSE/CITB (2007b to 2007f). In accordance with the CDM Regulations, a CDM co-ordinator should be appointed, and a health and safety file should also be produced and maintained for the duration of the project (see Box 3.4).

Guidance on all aspects of health and safety, including personal protective equipment (PPE), respiratory protective equipment (RPE), protected environments, monitoring and safety procedures for both radioactive and non-radioactive working environments can be obtained from the HSE website: <www.hse.gov.uk>.

Box 3.3 ***Key contents of a health and safety plan***

- notification to HSE of the initial intention to work with ionising radiations (if appropriate, this is also required under the IRR99)
- arrangements to ensure the health and safety of all workers (hazard identification and risk assessment, COSHH assessment, manual handling assessments, PPE and RPE assessment)
- management arrangements, including letters of appointment of staff in safety-related posts (such as the RPA and *radiation protection supervisor* (RPS) and of the *approved dosimetry service* (if appropriate)
- local rules for all radiologically designated areas
- method statements
- arrangements for monitoring of compliance
- COSHH assessments
- welfare requirements
- communications, co-operation and training arrangements
- emergency procedures
- provision of first aid facilities
- accident and possible exposures reporting procedures.

Box 3.4 ***Key contents of a CDM health and safety file***

- workplace authorisations (eg acknowledgement that workers have read and understood relevant safety documents and method statements)
- training records (to demonstrate that all staff are suitably competent and have attended all required site-specific training/induction courses)
- all permits (eg permits to operate, excavation permits)
- all PPE/RPE service records
- all radiation and contamination survey records and clearance certificates
- site diaries
- all documentation relating to disposal of wastes (eg duty of care notices)
- records of any permanent changes to land or buildings as a result of the work.

3.4 Radiological safety

Work on the characterisation of potentially radioactively contaminated land brings with it special requirements beyond those for chemically contaminated land. The main piece of legislation that relates to the health and safety of workers involved with radioactively contaminated land is IRR99. This provides the general requirements for control of work with ionising radiations and is based on the principle that the exposure to ionising radiation should be kept as low as reasonably practicable (ALARP). The concept of ALARP is discussed in detail in the HSE guide *Reducing risks, protecting people* (HSE, 2001a). Further guidance on compliance with IRR99 is provided in the approved code of practice and guidance (HSE, 1999)

To ensure statutory compliance with IRR99 appoint competent staff to carry out the work, and appoint and consult with a radiation protection adviser, (RPA) from the beginning of the project.

The following sections give an indication of some of the special requirements when working with radioactivity but the advice of the RPA should always be sought when planning any such work.

3.4.1 Risk assessment

Central to IRR99, as to other UK safety legislation, is the requirement to carry out a risk assessment before any work with ionising radiation is carried out (before risk assessment). All hazards associated with work on radiologically contaminated land should be considered in consultation with an RPA. Guidance on carrying out risk assessment and on the outputs sought from the assessment is to be found in the approved code of practice and guidance (HSE, 1999)

In identifying the radiological hazards associated with contaminated land on a nuclear-licensed site it will be necessary to also consider hazards associated with other work on the site. For example radiation from a nearby facility that may cause extra dosage to workers taking part in site characterisation.

3.4.2 Restriction of exposure

IRR99 reflects the principles of restriction of exposure outlined by the International Commission for Radiological Protection (ICRP) (ICRP, 2007) and meets the requirements of the European Union Directive (EC, 1996). While the Regulations set dose limits the focus is on optimisation of radiation exposure, ie steps to ensure that all exposures are kept as low as reasonably practicable (ALARP). Techniques can be used to reduce exposure to external and internal dose.

External dose

External dose is exposure to radiation affecting the body that originates from a source outside the body. The exposure can be to a large field of radiation that affects the whole body, or to more localised areas such as the hands. On a radioactively contaminated site, external dose can arise from the contamination in the soil or from nearby processes or activities. Reducing exposure to external radiation can be achieved by:

- reducing the time of exposure to ionising radiation. If the time of exposure to ionising radiation can be reduced, the total exposure can be reduced by the same factor
- increasing the distance between a source of radiation and the person exposed. Remote handling techniques may be required if sufficient distance cannot be achieved to reduce dose to an acceptable level
- introducing a shielding material between the source of radiation and the person exposed. The amount of reduction will depend on the type of radiation, the properties of the shielding material and the amount of shielding material present.

Internal dose

Internal dose comes from radioactivity that gets into the body through the following pathways: inhalation, ingestion, injection and absorption. Depending on the chemistry of the radionuclide, it can be taken up by the body's metabolism and moved to specific organs where it can irradiate the body from within. Once inside the body even alpha particles, which cannot penetrate the skin in external exposure, can cause damage when deposited inside the body. The best way to reduce internal dose is to prevent the radioactivity getting into the body in the first place. A range of controls is available to reduce the hazard to acceptable levels. The principal should be that preference is given to controlling the hazard at source.

The principal controls relevant to characterisation of contaminated sites are:

- ventilation (engineering control) – provision of ventilation systems can control internal exposure by extracting airborne contamination away from workers. Examples are extracted "tents" and other enclosures
- dust suppression (work method) – work methods should be designed to reduce the possibility of contamination becoming airborne. This could include techniques such as misting or wet cutting/drilling
- respiratory protective equipment (personal protective equipment) – for internal exposure, respiratory protective equipment is the most important type of PPE. Depending on the level of hazard encountered or expected, RPE can range from dust masks through full face respirators, powered respirators to full body air suits
- washing and changing facilities (welfare facilities) – wherever contamination is a hazard, suitable washing and changing facilities should be available to enable workers leaving a designated area to wash and change out of contact clothing or PPE. Monitoring equipment should be provided to enable workers to confirm that they have not been contaminated.

3.4.3 Designation of areas

The site to be investigated may be radiologically designated before the start of the project. This would have been identified in the risk assessment but might be the case if, for example, the site contained facilities that use radioactive materials or if the presence of radioactive contamination was already known.

There are two classes of radiologically designated area defined under IRR99: the controlled area and the supervised area. (Note that there is a requirement under IRR99 to consult an RPA before designating a controlled or supervised area).

In a controlled area special controls are required to ensure that exposure to ionising radiation is controlled and all staff entering must either be classified workers or covered by a "written arrangement". The written arrangements should be drafted before the project starts (with advice from an RPA).

A supervised area is one where the radiation employer (the employer who has designated the area) has identified that the radiological conditions need to be kept under review to ensure that it does not need to be a controlled area.

Work in any designated area will require coverage by a risk assessment and may require special working practices, including the wearing of appropriate dosimeters and the use of personal protective equipment (PPE).

For any designated area a set of local rules must be in place to identify the main working instructions intended to restrict any exposure. The local rules will include the name of the radiation protection supervisor, contingency arrangements and any special monitoring arrangements.

The requirement to designate an area may be because of the proposed works and again the designation will come from a risk assessment.

3.4.4 Dosimetry

Dosimetry enables recording and review of dose uptakes by individuals. This allows working practices to be reviewed, and amended if appropriate, in accordance with the principles of ALARP. At the start of the project, the RPA, Approved Dosimetry Service (ADS) and project manager should devise a dosimetry strategy suitable for the nature of the contamination, work and classification of staff. The dosimetry requirements will be given in the local rules.

External dosimetry: external dosimetry will generally involve the wearing of a suitable whole-body dosimeter, either a passive dosimeter such as a thermo-luminescent dosimeter (TLD) badge or an electronic dosimeter, which also provides an immediate indication of dose uptake.

Internal dosimetry: where the risk assessment identifies the potential for internal dose, usually through the generation of airborne activity, consideration should be given to internal dosimetry. Several methods of assessing internal exposure are available. The choice will be determined by the level of risk associated with the particular work being undertaken and the radionuclides involved, for examples:

- wearing personal air samplers (PAS) by individuals working in the area
- biological sampling, including urine and faecal sampling
- direct measurements for radioisotopes in the chest or whole body.

The regime should be reviewed if radiological conditions, particularly airborne activity, or the type of work changes significantly.

In some establishments excreta sampling or whole body monitoring (WBM) is required to be carried out on contractor's staff before the start and on completion of any work where there is a high probability of encountering loose radioactive contamination.

3.4.5 Staff competency and training

To ensure compliance with the requirements of IRR is the appointment of a suitably qualified and experienced radiation protection advisers (RPA) and radiation protection supervisors (RPS), as required by Regulations 13 and 17 of the IRR99.

Radiation protection advisers (RPA): all companies that are engaged on the project must appoint an RPA if they are involved with working with radioactive substances. An RPA must be appointed in writing and must hold a certificate of competence and be deemed suitably qualified and experienced (SQEP) for the particular type of project.

Radiation protection supervisors (RPS): all companies involved with the project (and working with ionising radiation) must appoint at least one RPS. The role of the RPS is to supervise all work carried out complies with the local rules, and to ensure that all exposures to ionising radiation are kept as low as reasonably practicable.

All persons involved in work with ionising radiation should be suitably qualified and experienced (SQEP) in working with ionising radiation. On nuclear-licensed sites and MoD sites, the site operators will generally require evidence that staff are of SQEP status for the tasks that they are required to perform.

3.5 Security

HSE's Nuclear Directorate has the Office for Civil Nuclear Security (OCNS), which is the security regulator for the UK's civil nuclear industry. It is responsible for approving security arrangements within the industry and enforcing compliance. OCNS conducts its regulatory activities on behalf of the Secretary of State for Business, Enterprise and

Regulatory Reform under the authority of the Nuclear Industries Security Regulations 2003. Other important legislation relevant to security on nuclear-licensed sites is the provisions of the Official Secrets Acts 1911 to 1989, the provisions of Section 11 of the Atomic Energy Act 1946, and the Terrorism Act 2006. The Nuclear Industries Security Regulations 2003 require temporary security plans to be adopted during building works.

Compliance with security clearance of all staff, including main subcontractors, is expected on nuclear-licensed sites and defence sites. The level of clearance required will be commensurate with activities, and should be confirmed with the site security manager. Maintaining a cadre of security cleared staff is particularly challenging in an industry with a mobile workforce such as site investigation drilling. Escorting requirements for un-cleared staff can be onerous and contractors should consider having cleared replacement staff available to cover unexpected eventualities.

Each site will also have its own security access arrangements that should be established at the earliest opportunity before the planning stage. Special arrangements, for example, may need to be made for courier deliveries and collections. Obtaining clearance is not necessarily a routine process for all individuals, and may take many months. Inevitably the need to comply with security has budget and time implications for the project.

3.6 Environmental protection

3.6.1 Environmental protection compliance

Participants in site characterisation work will be expected to comply, as a minimum, with the environmental legislation and regulations at all places of work and other guidelines specified in any scope of work. Owners and operators of nuclear-licensed sites and defence sites are large organisations, and can be expected to hold, or have management systems designed to meet the requirements of BS EN ISO 14001:1996. Such organisations will also be committed to continuous improvement programmes, and it may be expected that their consultants and subcontractors should meet specified requirements of environmental management competency. The adherence of suppliers to these requirements should also ensure:

- compliance with corporate environmental policies
- minimisation of liabilities (ie not to exacerbate risk from any existing contamination or create new contamination or impacts)
- maintenance of integrated compliance with health, safety, security and environmental aspects
- stakeholder involvement (potentially including regulators, local wildlife trusts, national wildlife advisory bodies, local communities and their representatives).

3.6.2 Operation and control of environmental protection

When producing specifications or evaluating tenders for site characterisation works, site owners and occupiers (who are typically also the client) should ensure that the works comply with the requirements of the site's environmental policy and environmental management system. In demonstrating that this is the case, consultants and subcontractors should ensure that their own assessments are site-specific and activity-specific. Effective communication and flow of information between the client/liability holder and consultant/contractor is necessary to demonstrate that the environmental protection systems of the two parties are compatible.

Guidance on compliance with an environmental management system is given in the BS EN ISO 14000 series.

Identification and evaluation of potentially significant environmental effects will be undertaken in a risk assessment specific to a site characterisation activity. Such an assessment is likely to include consideration of the environmental aspects, and may extend to the commissioning of ecological surveys. Guidance on site characterisation specific environmental considerations is given in BS 10175:2001, and good practice techniques for environmental monitoring has been prepared by the EA (2007). An environmental checklist is presented in Box 3.5:

Box 3.5 ***Environmental protection checklist***

- check contractual environmental requirements
- check own organisational environmental requirements
- check and agree allocation of responsibilities
- check need for ecological surveys
- estimate and review environmental impacts for the project
- produce list of environmental impacts for the project
- check staff competence, equipment suitability and maintenance
- check procedures for monitoring and recording, audits and reviews, for communications of emergency incidents.

3.7 Health, safety, security and environment plan

In summary, the preparation of a combined health, safety, security and environmental protection (HSSE) plan and its approval will be required before any on-site works can start. The plan will cover but not be limited to:

- arrangements to ensure the health and safety of all workers (including hazard assessment, hazard evaluation and proposed control measures if required)
- management and standards
- selection of subcontractors
- emergency procedures
- accident reporting
- arrangements for monitoring of compliance
- welfare requirements
- communications, co-operation and training arrangements
- security procedures
- environmental issues
- environmental impacts register, which identifies the potential environmental impacts that activities will have. The register should cross-reference to project-specific method statements, in which consideration will have been given to environmental aspects, and to the relevant environmental policies of the client and contractor
- environmental mitigation, monitoring and control measures.

There are close links between the site waste management plan (SWMP, see Chapter 9) and the HSSE plan. Originally developed as a DTI voluntary code of practice, SWMPs provide a structure for systematic waste management at all stages of a project's delivery. The SWMPs became a legal requirement for all construction projects over £300 000 (excluding VAT) in April 2008. There are advantages in ensuring that both the SWMP and the HSSE plans are filed together, or even prepared in a single document, demonstrating an integrated approach, avoiding multiple repetition of documents and reducing paper use.

4 Objective setting

Box 4.1 ***Aims of Chapter 4***

Objective setting for site characterisation on both radioactive and non-radioactive contaminated land will follow a common process using existing good practice guidance. This chapter aims to describe the various circumstances on nuclear-licensed sites defence sites, which will form the basis for setting site-specific *objectives*. Development and refinement of the conceptual site model is highlighted as being vital to identifying further specific project objectives, together with any boundary or controlling factors. Measuring performance against the set objectives allows for continuous improvement.

4.1 Introduction

Compared to conventional contaminated land sites the SAFEGROUNDS process may need to be adopted over a long time, particularly on nuclear-licensed sites where restoration and *decommissioning* are taking place. Also, where operational sites have no plans for closure contaminated land needs to be managed. The sites will be constantly changing and management systems will continuously evolve. To control projects, like site characterisation, in such a dynamic situation there is a need to regularly review the project objectives and continuously improve performance, according to the requirements of quality management.

In long-term projects, there is also a tendency, undertaken over years by a series of contractors, to "re-invent the wheel" at contractor handover. So owners and operators, together with the contractors should set robust objectives and monitor adherence, continuity and improvement according to the good practice of performance management (OGC, 2002). As part of this management process stakeholder involvement should be defined and actively encouraged to obtain feedback with different perspectives as site characterisation progresses.

4.2 Project and task objectives

The integrated SAFEGROUNDS and CLR11 approach requires the setting of objectives at the start of each major stage where site characterisation is required (Figure 1.1). Also these objectives should be reviewed with phase-specific objectives set. One of the most likely overall project objectives of site characterisation will be to gather information to form a site conceptual model that can be used to assess the risks posed by the nature and extent of any existing or potential contamination. However, the detailed objectives for each aspect of the process require careful consideration. Consultation with stakeholders for example the regulators, the Nuclear Decommissioning Authority (NDA) or other on-site projects or employee unions at the objective setting and planning stage can make site characterisation and assessment decisions more effective and durable.

The process of setting the project objectives is summarised in Figure 4.1. Four main aspects require consideration:

1 Stating the problem or problems (why it is being done?).

2 Defining the process (how is to be investigated?).

3 Identify the goals of the study (what is to be achieved?).

4 Identify the boundaries and controlling factors (when, where, who/how much?).

Each of these main areas is discussed in Figure 4.1. Further information on objective setting can be found in DETR (2000a), BSI (2001) and USEPA (2006). All project objectives and the process of setting them, together with associated measures, targets and responsibilities, should be documented. Task objectives and associated performance measures will be developed with the project plans and reflect the detail of data gathering.

Stating the problem

- defining the questions to be asked (if not clearly defined by the project brief)
- context and aims
- regulatory framework
- stage of characterisation process:
  - development of site conceptual model (preliminary site characterisation)
  - detailed development of site conceptual model and risk assessment (exploratory and main site characterisation)
  - remedial options comparison (supplementary site characterisation)
  - implementation of preferred option (supplementary site characterisation)
  - validation (supplementary site characterisation).

Defining the process

- conceptual model and characterisation of source(s), pathway(s) and receptor(s)/critical groups
- the process (*preliminary*, generic qualitative, quantitative risk assessment)
- baseline/background
- data and information needs
- data performance and acceptance criteria.

Identify goals of study

- project-specific required outcomes:
  - healthy, safe and secure working
  - protection of the environment
  - waste minimisation
  - maintenance of quality and record-keeping
  - stakeholder involvement.

Identify the boundaries and controlling factors

- temporal
- spatial
- resource.

Figure 4.1 ***Main issues for project objective setting***

4.3 Stating the problem

To set project objectives it is important to be clear as to the context in which the site characterisation work is being undertaken ("the context") and the desired aims of the investigation. It is also essential to define the regulatory regime that applies, remembering that compliance levels may only supply minimum requirements, and a precautionary approach may be needed.

With devolved government it is also imperative to understand the nuances of the different national legislation. The third element of the problem definition is to understand the needs of the project by its position on the land management process timeline (Figure 4.2).

No guidance exists on the most appropriate number of objectives to set, but overall objectives should be succinct and frame the aims and scope of the work. Project objectives should cover each major area of the project with subordinated task objectives to form the basis for performance management.

4.3.1 Context and aims

There are a variety of reasons for site characterisation at nuclear-licensed sites and defence sites, and each situation may require specific objectives to be set and met. The regulatory framework, which sets the compliance requirements, is discussed in Hill (2007) and summarised in Appendix A3. Objective setting may also need to take account of other legislation such as the Groundwater Directive (80/68/EEC), Habitats Directive and Environmental Liabilities Directive. Different scenarios with their aims are expanded in Boxes 4.2 to 4.10:

Box 4.2 ***Regulatory compliance with requirements of a nuclear site licence***

Scenario 1 Regulatory compliance with the requirements of a nuclear site licence

The Nuclear Installations Act 1965 requires HSE to attach conditions to site licences that define areas of nuclear safety that the licensee should pay attention to ensuring safe operation of the site. This requires the licensee to prepare and review nuclear *safety cases* for commissioning, operations and decommissioning (Licence Condition 14). Also, unless it is an authorised disposal, the radioactively contaminated land represents an accumulation of nuclear matter and should be managed by the site licensee as required under site Licence Condition (LC) 32. Other conditions that are particularly relevant are LC4, LC23, LC25 and LC34 (HSE, 2002).

Site licence conditions have been supplemented by the fundamental Safety Assessment Principles (SAPs) (HSE, 2006), which provide the regulator with a framework for making consistent regulatory judgements with respect to the assessment of nuclear safety cases. SAPs are statements of HSE expectations of licensees' arrangements and safety cases. Along with the fundamental principles, the SAPs expect the control and remediation of radioactively contaminated land (including groundwater) on these sites, and their requirements include that:

- the duty holder must demonstrate effective understanding of the hazard and their control for a nuclear site or facility through a comprehensive and systematic process of safety assessment
- radiation risks are controlled and no individual bears an unacceptable risk of *harm*
- people, both present and in the future must be protected against radiation risks.

These fundamental SAPs are augmented by specific contaminated land SAPs, includng:

- where radioactively contaminated land exists, a strategy should be produced for its control and remediation
- steps should be undertaken to detect any areas of radioactively contaminated land on or adjacent to the site
- where radioactively contaminated land is discovered, appropriate arrangements should be in place to ensure the source is identified and controlled
- radioactively contaminated land should be characterised to help its safe and effective control and remediation
- radiological survey, investigation, monitoring and surveillance of radioactively contaminated land should be carried out at suitable intervals so that its characterisation is kept up-to-date
- a plan should be prepared and implemented to ensure that radioactively contaminated land is being safely controlled or remediated
- arrangements should be made for recording and preserving the information that may be required both now and in the future for the safe control and remediation of radioactively contaminated land.

The HSE refer to nuclear safety cases as meaning "the totality of a licensee's documentation to demonstrate high standards of nuclear safety and radioactive waste management" (HSE, 2006). NII requires safety cases for all operations that might affect conventional as well as nuclear safety. To fulfil these requirements may involve site characterisation or routine environmental monitoring (compliance monitoring) to determine levels of radioactivity in soil and controlled waters.

The defence sites operated by AWE plc are regulated by HSE under NIA65 since their site licenses came into effect on 1 April 2000.

Scenario aim 1: determination of radioactive contamination and radiation dose to humans.

Box 4.3 *Regulatory compliance with regulatory requirements under Part 2A of EPA 1990*

Scenario 2 Regulatory compliance with regulatory requirements under Part 2A of EPA 1990

Part 2A of EPA 1990 places a requirement on local authorities to identify chemically contaminated land on nuclear-licensed sites and associated land. It also requires chemically and more recently radioactively (Radioactive Contaminated Land (modification of Enactments) (England) Regulations 2006) or (the Radioactive Contaminated Land (Scotland) Regulations 2007) contaminated land on other sites to be identified and remediated. Where a nuclear-licensed site is to be, or has the potential to be, classified as chemically contaminated, or is a defence site, then it will be treated as a special site. The local authority then transfers the status of enforcing authority to the local environment agency (Environment Agency/SEPA), and on nuclear-licensed sites to NII. Liability-holders may consider it appropriate to take a pro-active approach and undertake site characterisations themselves on a voluntary basis to evaluate their contaminated land liabilities under Part 2A.

For defence sites local authorities are likely to ask commanding officers/heads of establishment for information on past activities and details of any known contamination to make an initial assessment. If further site characterisation is required, the local authorities can seek the assistance of the Environment Agency (England and Wales), SEPA (Scotland) or EHS (NI) to help them with investigations and making assessments. Only when part or all of a defence site is formally designated as contaminated land by the local authority does it become a “special site” and the regulatory responsibility transfers to the EA, SEPA or EHS(NI) (Defence Estates, 2007b).

Scenario aim 2: assessment of whether land constitutes contaminated land under Part IIA EPA 1990.

Box 4.4 *Regulatory compliance with the Radioactive Substances Act 1993*

Scenario 3 Regulatory compliance with the Radioactive Substances Act 1993 (RSA93)

Nuclear site licensees must also consider whether site characterisation is required to comply with the Radioactive Substances Act 1993 (as amended), which treats uncontrolled off-site migration of radioactivity as an unauthorised discharge. For non-licensed sites on which there are “premises used for the purpose of an undertaking”, site characterisation is required to determine whether any parts of the site are radioactively contaminated so that action can be taken to comply with RSA93. To underpin such decisions made relating to radioactive substance regulation the Environment Agency has developed a set of environmental principles (EA, 2005b).

Defence sites are exempt from RSA93, but arrangements to parallel RSA93 regulation are available to the environment agencies.

Scenario aim 3: determine presence of radioactive substances on the site, its associated radiological risks along with the control, management and ultimately the elimination of unauthorised discharges.

Box 4.5 ***Decommissioning, care and maintenance***

Scenario 4 Decommissioning, care and maintenance.

Under Site Licence Condition 35 (decommissioning) the licensee is required to ensure the safe decommissioning of facilities. These arrangements would be supported by appropriate documentation. The decommissioning plan may include a period of "care and maintenance". This may be a necessary step before final activities to allow delicensing. During the decommissioning and care and maintenance phases there may be a requirement under SAPs RL5 to ensure that characterisation is kept up-to-date, particularly given that the survey, investigation, monitoring and surveillance arrangements should be reviewed and modified to reflect changing circumstances (HSE, 2006).

Scenario aim 4: determination of presence of radioactive substances on the site (and usually evaluation of radiological risks to humans) and elimination of unauthorised discharges.

Box 4.6 ***Delicensing of all or part of a nuclear-licensed site***

Scenario 5 Delicensing of all or part of a nuclear-licensed site (HSE, 2001 and 2005)

The Nuclear Installations Act 1965 places a series of requirements on the nuclear site licensee over issues such as site security, emergency arrangements, radiological protection and safety management. If the licensable activities are no longer being undertaken, and if the facilities have been decommissioned, it may be appropriate for the licensee to seek to delicense all or part of the site. This may be as part of the overall site restoration strategy or to enable redevelopment or divestment of the site.

NII will allow the site to be delicensed only if it is satisfied that there is "no danger" from radioactivity on the site. Site characterisation is required to demonstrate, to the satisfaction of the regulator, that this is the case. It should be noted that the NII mainly requires evaluation of hazards from radioactivity, while assessment of the risk from chemical contamination is controlled by the regulators designated under the Contaminated Land Regime in Part 2A of EPA 1990.

Scenario aim 5: demonstration of "no danger" from ionising radiations to humans.

Box 4.7 ***Evaluation of liabilities***

Scenario 6 Evaluation of liabilities

Site owners or operators of nuclear-licensed sites defence sites are in the league of organisations that work to quality management systems (BSI, 1994). As such, these systems require the need to assess the safety and environmental impact of activities and to manage continuous improvement. So it is essential to understand, by site characterisation, the size of such impacts and to estimate actual or potential remediation costs and associated liabilities, thereby budgeting for improvement works, taking account of such liabilities in land valuation, financial reporting[8] or costing for decommissioning[9].

Scenario aim 6: evaluate whether site is suitable for current use.

8 Financial Reporting Standard (FRS) 12 *Provision and contingent liabilities*

9 NDA *Waste and nuclear materials strategy lifetime plan guidance notes* EGG01 (2006).

Box 4.8 *Divestment and/or redevelopment of land*

Scenario 7 Divestment and/or redevelopment of land

Once site activities have ended, divestment and/or redevelopment may be considered an option for either nuclear-licensed sites or defence sites. Site characterisation may be required to evaluate the size of any risks posed by radioactive or non-radioactive contamination to human health and the environment, and to determine what management strategy is appropriate. Any unacceptable risks to human health, buildings and other property and the natural and historical environment from the contaminated condition of land may require, under planning legislation (including environmental impact assessment), that the risks are identified and appropriate action taken to address them. Site characterisation may be required to discharge a planning condition. Also planning permission may be required for some remediation schemes involving significant engineering works, for example, or where re-profiling of a landscape feature is part of the overall scheme. RSA93 requirements are not risk-based (ie they do not require a *contaminant-pathway-receptor* approach). Regulators may encourage such an approach to land remediation.

Scenario aim 7: evaluate whether site is suitable for proposed or planned use.

Box 4.9 *Remediation design or validation*

Scenario 8 Remediation design or validation

Further *supplementary investigations* may be needed following the risk assessment stage to provide a detailed design for a remedial option, and to fully quantify the volumes of soil and or groundwater that need to be remediated. Following remediation the remaining soils or groundwaters will require validation of quality immediately after remediation at post remediation to determine efficacy of the actions.

Scenario aim 8:

- *averaging volume* for calculating activity levels in soil must be defined at the start (see Chapter 9)
- validation of remedial package implementation
- verification of continued efficacy of remedial strategy and remedial package.

Box 4.10 *Regulatory compliance with other non-radioactive regulatory regimes, eg Groundwater Regulations*

Scenario 9 Regulatory compliance with Groundwater Regulations

It is a requirement under the Groundwater Regulations 1998 to monitor the impact of discharges and disposals of certain prohibited (List I) and restricted (List II) substances as defined by the Groundwater Directive (80/68/EEC). The degree and location of this "requisite surveillance" monitoring will be selected on the basis of the type of facility involved and the vulnerability of, and risk to, local groundwater. Requisite surveillance may require the construction of groundwater monitoring boreholes on nuclear-licensed sites defence sites where List I and II substances are being handled. The Environment Agency is to publish guidance on "prior investigation" and "requisite surveillance".

Scenario aim 9: evaluate compliance with Groundwater Regulations.

4.3.2 Stage of characterisation process

The objectives of a site investigation will vary, depending on the stage in the land management process timeline (Figure 4.2). Development of a site conceptual model is important when setting site characterisation objectives. In the early stages the objectives will inevitably be broad, and in the later stages they will be focused on refinement of knowledge. As the site characterisation develops it is essential to review the conceptual site model and objectives to establish whether the last phase of investigation has been completed satisfactorily, and to refocus objectives for the next phase.

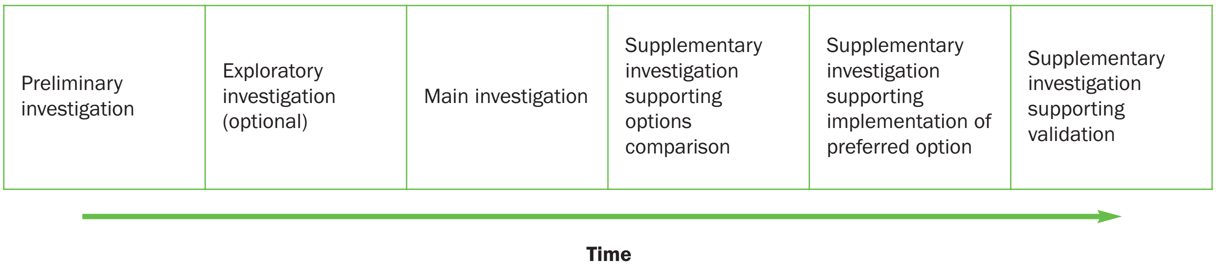


Figure 4.2 ***Site characterisation and the land management process timeline***

BS 10175:2001 for the investigation of potentially contaminated sites recommends three stages of the characterisation process, with supplementary investigations to fill deficiencies in information. This Standard offers guidance on detailed generic objectives for each stage, but the setting of project-specific objectives is recommended wherever possible. These should be clearly documented. The three stages of the characterisation process are:

1. A preliminary investigation comprising a desk study and site walkover to establish historical activities, current status, and the environmental setting. From this information, an initial conceptual model of the site can be formed and potential hazards identified (see Section 5.3.1.1).
2. An exploratory investigation may be necessary, particularly where the preliminary investigation has found little or ambiguous information and there is a high degree of *uncertainty*. Non-intrusive investigation techniques, including surface radiation surveys, are very useful at this stage. This phase is seen as an opportunity to gather a limited amount of extra information to plan the detailed phase of investigation (see Sections 5.3.3 and 5.3.4).
3. A detailed investigation, mainly using intrusive ground investigation, provides information on the horizontal and vertical distribution of both radioactive and non-radioactive contamination, together with geological, geotechnical and hydro-geological information. Surface surveys may also be required to provide, for example, ecological and hydrological data. Supplementary investigations may be necessary to produce specific information on areas of uncertainty not resolved by the main phase, information required to clarify technical matters related to remedial options, or for validation studies (see Sections 5.3.3 and 5.3.4).

4.4 Defining the characterisation process

Project objectives and task objectives for site characterisation should consider the following aspects:

- the characterisation process
- components of risk assessment
- baseline or background conditions
- data and information needs
- data performance and acceptance criteria.

4.4.1 The process

Although the first objective of site characterisation seems to simply establish whether the land is contaminated, the site characterisation may then feed into assessment and prevention of risks. So it is expedient to plan for site characterisation as an integral part of risk assessment from the start.

The CLR11 (EA, 2004a)[10] approach with (Figure 1.1 and Appendix A1) or without the SAFEGROUNDS modifications provides a technical framework for applying a risk management process to land affected by contamination, including radioactively contaminated land, whether as part of the risk assessment at an early or later stage in the land management process. How the model procedures are incorporated into specific site characterisation studies can be established for specific projects at the objective setting and planning stages.

The CLR11 phased process of risk assessment followed by options appraisal and then implementation of the chosen *remediation strategy* has scope for iteration within individual elements (Appendix A1). It also provides flexibility in terms of the possible response options for a particular set of conditions or findings, so that time and financial resources are used to best effect. The procedures encourage the formalisation of outputs from the process. These include written records and reports that cover both what decisions were made (the decision record), and how those decisions were reached. Further outputs may include specifications, design drawings and reports on the work actually carried out.

4.4.2 Components

For land contamination, there are three essential components to any risk assessment. To set project and task objectives for characterisation of each component it is important to understand which components are being investigated and how they fit together as part of the site conceptual model. The three components are:

- a contaminant source – a radioactive or non-radioactive substance that is in, on or under the ground (including the groundwater) and has the potential to cause harm or pollution of controlled waters
- a receptor (or critical group) – in general something that could be adversely affected by a contaminant, such as humans, an ecological system, property, or a water body
- a pathway – a route or means by which a receptor can be exposed to, or affected by, a contaminant.

4.4.3 Baseline/background

Establishing baseline or background data for the environment both in the immediate investigation locality and over the area where harm may be expected should be an objective of any characterisation investigation. This may be achieved through a desk study, or use of existing survey database (district surveys at nuclear-licensed sites), or require a bespoke survey. The method of choice should be achieved by review of existing data and its appropriateness for use.

4.4.4 Data and information needs

Objectives should be set to acquire the sources and types of information needed to resolve or produce the desired outcomes, using appropriate sampling and analysis methodology to reduce uncertainty (see Chapter 11). The Data Quality Objectives (DQO) process (EPA, 2006) provides a systematic procedure for defining the criteria that a data collection design should satisfy, including when and where to collect

10 CLR 11 is due to be updated.

samples, the tolerable level of decision error for the study, and how many samples to collect, balancing risk and cost in an acceptable manner. It is a good example of objective setting for data collection.

4.4.5 Data performance and acceptance criteria

Performance or acceptance criteria objectives will need to be set so that the collected data will minimise the possibility of either making erroneous conclusions or failing to keep uncertainty in estimates to within acceptable levels (see Chapter 11). Performance criteria, together with the appropriate level of quality assurance practices will guide data collection, while acceptance criteria will guide the procedures to acquire and evaluate existing data relative to the intended use.

4.5 Identify goals of study

Some investigations are straightforward with clear goals. However, in complex situations the ultimate goals of the study need to be clear, and the questions that the information from the investigation will be used to resolve. This is particularly so where there are multiple project needs. For example, characterisation of a radiation controlled area (RCA) on a nuclear-licensed site may require data gathering that can be used for both risk assessment and options comparison studies. In the RCA the project may be subject to individual or a combination of constraints such as dose, space or time frames related to other operational projects. So efficient data collection is imperative otherwise there may be little future opportunity to revisit locations, even without considering the onerous project cost implications.

It is not possible to be prescriptive about project goals, but other aspects that should be considered are highlighted in the following sections.

4.5.1 Health, safety, security and environmental protection

It is important to ensure that the objectives of individual or combined plans for the maintenance of healthy, safe and secure working environments, as well as that of wider environmental protection are reflected in the overall project objectives (Chapters 3 and 4).

4.5.2 Waste minimisation

The minimisation of all site characterisation wastes generated on the project should be an individual objective, because there are significant project cost implications for management and disposal if adequate provision has not been made. This is particularly so for any material classed as radioactive waste (Chapter 9).

4.5.3 Quality management

The management of quality throughout the project should be established with a high level objective, which is then implemented through a project quality management system. Record-keeping of all project activities and deliverables should be dovetailed with the quality management system (Chapter 5).

4.5.4 Stakeholder involvement

Another overall project requirement may cover the involvement of stakeholders, and a stakeholder involvement plan should be developed, to enable robust levels of engagement.

4.6 Identification of the boundaries and controlling factors

An important requirement for any site characterisation is ensuring that its boundaries are clearly defined. The boundaries can relate to factors such as:

- the spatial extent of the characterisation works, and any constraints
- target populations (including those remote from site affected by waste disposal)
- the temporal extent and any consequences (eg length of monitoring periods and timelines of other site projects)
- the timescales for deliverables (ie when information is needed)
- the resources that can be assigned to the characterisation works
- the weight of decision to which the risk assessment will contribute
- any other legal, commercial and financial factors affecting the characterisation and follow-on processes.

The grounds for selecting these boundaries should be documented.

4.7 Site characterisation performance management plans

In summary, setting sound objectives that performance can be measured against provides a framework for the formulation of site characterisation performance management plans. Performance can be measured against a series of objectives representing agreed core areas. In the examples provided in Table 4.1 the core areas selected are familiar corporate/operational and resource requirements. Establishing means of learning from the project is less familiar, while considering stakeholder involvement is fundamental to the SAFEGROUNDS process.

Table 4.1 ***Examples of performance management plans at project and task levels***

Core areas	Objectives	Measures	Targets	Ownership
Project level: characterisation of groundwater pathway (generalised)				
Corporate/ operational	To ensure characterisation of the groundwater pathway for site conceptual mode	To review reported geological findings, water levels, hydraulic testing, quarterly return on monitoring for numbers of boreholes monitored, samples analysed, LODs and representations of findings	To undertake strata identification, water level monitoring, hydraulic testing and quarterly groundwater level and quality monitoring	Site management team and contractor project manager
Resource	To provide a site characterisation team to install groundwater monitoring network	To check viability of installed boreholes with CCTV	To install groundwater monitoring network of 10 boreholes by a specified date	Contractor project manager
Learning	To establish which are the most representative/ sensitive borehole locations	To monitor costs	To reduce monitoring with regulator approval to the most representative/sensitiv e borehole locations and analyses	Contractor project manager
Stakeholders	To involve environment agency regulators in determining borehole location, design, sampling and analysis	To hold regular meetings with regulators to build a successful working relationship	To achieve regulator approval for design by a specified date. Sign-off findings and monitoring by specified dates	Contractor project manager
Task level: tritium monitoring in groundwater				
Operational	To produce a quarterly GIS map of tritium concentrations in groundwater	To produce a GIS map at 50 TU spacing, based on analyses with an LOD of 5 TU (TU = tritium units)	By the fourth week of each quarter to the regulator	Task manager
Resource	To provide two-man groundwater monitoring team	Turn around monitoring and analysis in 15 working days. Turnaround GIS map in five working days	By first week of each quarter and analyses completed by third week of each quarter	Task manager
Learning	To review GIS tritium map and establish boreholes to be monitored next quarter	To complete review record for land quality file, and complete authorisation for next monitoring round	By eighth week of each quarter after negotiation with regulator	Task manager/project manger
Stakeholders	To post GIS map on stakeholder website as PDF	To record number of hits on PDF file and review if this is effective communication	At end of each quarter	Task manager

5 Planning the site characterisation

Box 5.1 ***Aims of Chapter 5***

This chapter describes the framework of activities that comprise site characterisation. It emphasises the importance of developing a conceptual model (or models) of the site at an early stage of the programme, and of using this model(s) to design an appropriate site characterisation programme. Regular refinement of the conceptual model(s) during the investigation programme is advised. Important issues relevant to designing surveys of radioactively contaminated land are discussed. These include the need for contingency planning (ie what to do if radioactivity is encountered during the survey), sampling patterns and frequencies, groundwater investigations, and the establishment of background levels of radioactivity.

5.1 Formulation of plans

To assist in the planning process reference to Chapters 3 and 4 of this guidance is recommended.

For site characterisation this comprises the project plan itself with project-specific subordinate plans covering:

- HSSE (see Chapter 3)
- performance management (see Chapter 4)
- waste management – radioactive and non-radioactive waste (see Chapter 9)
- record-keeping (see Chapter 10)
- quality management
- communication plan – on-site
- communication plan – to define stakeholders and their means of involvement. Refer to Collier (2005), Hill *et al* (2009a) and Collier (2009c)
- project risk register.

All these plans refer to activities that take place on the owner's or operator's site. Each site will have its own management and control systems. The project plans need to interact with the site systems and the integrated SAFEGROUNDS and CLR11 approach (Figure 5.1), and some flexibility on both sides may by be required so that they mesh together.

Site characterisation issues related to quality management and communications will be highlighted in this chapter – the first four subsidiary plans are covered in detail elsewhere in this guidance. Aspects of the project plan in relation to the framework of activities for site investigation established by BS 10175:2001 are discussed in Sections 5.2 to 5.6.

Typically, projects will also require a project risk assessment, which identifies potential technical and non-technical risks to the project. This enables contingency plans to be developed (see Section 5.5.1).

5.1.1 Approval of plans

The approvals required for documents will depend on the client and on the safety categorisation of the project. As a minimum, the documents would require approval by the client's project manager. Typically, approval by the client's radiation protection adviser (commonly designated the facility RPA), and the responsible manager for the area is also required.

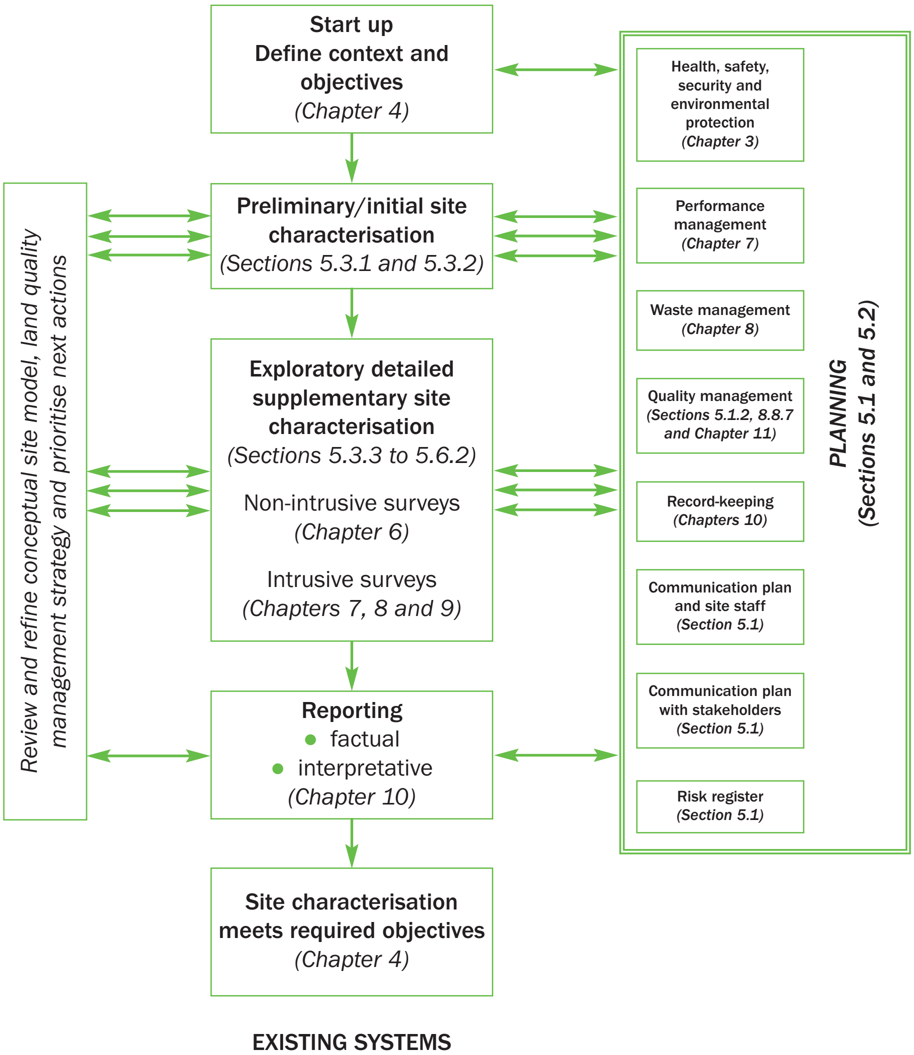


Figure 5.1 ***Interrelationship between project, subsidiary and existing site plans***

5.1.2 Quality management

Throughout the site investigation process, it is necessary that the procedures used to collect samples and to determine contaminant levels are fit for purpose and the level of uncertainty is minimised. This is achieved by adherence to method statements that form part of the quality management system set out in the quality management plan.

Method statements describe the procedures for carrying out the principal activities (such as drilling boreholes, collecting samples, managing wastes and decommissioning boreholes). Procedures described in method statements should be in line with project contractual requirements and technical objectives, and should take account of health and safety issues including the need to minimise environmental impacts. The method statements aim to maintain quality through appropriate and consistent approaches and ensure that any quality criteria specified are met. These documents will need to be supplied for approval by management of both the procuring and providing organisations before starting work.

Both organisations procuring and providing site characterisation work are likely to hold company accreditation to BS EN ISO 9001:2000 for quality management systems. So both the client and organisations providing services have responsibilities in ensuring the quality of site investigation work. Some issues to be considered in this are:

- qualifications and experience of staff carrying out work
- qualifications, accreditation and experience of subcontractors
- chain of custody procedures
- establishing quality criteria
- setting quality control procedures for sampling and analyses
- accurate record-keeping and data storage
- review and audit of all works carried out at all stages of the investigation, including reporting and interpretation.

It is essential that quality procedures are applied at all stages of the investigation. The procedures used should be capable of ensuring the reliability and robustness of the investigation carried out and the data produced. Ultimately, the data produced should meet the criteria set for its intended use later, such as risk assessment, remediation options appraisal, verification or monitoring. Uncertainty in the data should also be limited, and this is discussed further in Chapter 11. General guidance on quality management can be found in the BSI publications, with information specific to contaminated land in Harris *et al* (1995), DETR (1997) and BSI (2001).

In the United States a systematic planning process that generates performance and acceptance criteria for collecting environmental data has been developed and is known as the Data Quality Objective (DQO) process (USEPA, 2006). The DQO process is a series of eight logical iterative steps that serves as a basis for designing a plan for cost-effective data acquisition of sufficient quality and quantity to support the goals of the study. It is aligned to the US highly prescriptive regulatory context, and the application of such an onerous approach should be considered with caution. However, where statistical methods for developing data collection are envisaged this may help towards meeting project objectives.

5.1.3 Communications plan – on site

Nuclear-licensed sites and defence sites are often large with areas of controlled access, so close interaction between project and site staff is necessary. Plans identifying clear lines and means of communication should be established. This is particularly important where the use of mobile telephones on site is prohibited. On-site communications are also fundamental to the HSSE plan.

5.1.4 Stakeholder involvement plan

It is important to make and implement at an early stage a communications plan for robust stakeholder involvement for site characterisation works on nuclear-licensed sites and defence sites. Guidance is given in Collier (2005 and 2009c) and through SNIFFER (1999).

Early interaction with regulators is essential, to clarify matters such as statutory ambiguities and the suitability of methods of approach to characterisation. For radioactive contamination on nuclear-licensed sites, this liaison with the HSE/NII will occur naturally in the process of fulfilment of the site licence conditions. Such communication is likely to be the responsibility of the site *owner/operator*. On defence sites, a proactive approach with the relevant environment agency is required where regulatory intervention is needed. On any non-licensed site there is a requirement to inform the HSE 28 days in advance of any work involving quantities and concentrations of radionuclides greater than specified in the IRR99.

At nuclear-licensed sites, although there are existing site stakeholder groups, it is unlikely that only their involvement would be sufficient, and other stakeholders should be encouraged to participate. This is because there are concerns with the representative nature of the current site stakeholder group structure. The extent of stakeholder involvement is not predictable. In general, the more significant the issues there are, the greater the levels of stakeholder involvement. Although stakeholder involvement takes time and resources, the benefits of early stakeholder involvement cannot be overestimated.

Because work on nuclear-licensed sites and defence sites is of public interest, it is important that the site characterisation process is well documented. All meetings, records and information should be available to stakeholders at the appropriate time, in an appropriate format without compromise to security needs. Information provided should be authentic, appropriately documented and the decision making procedure should be technically defensible. Adherence to good practice and a quality management system at all times should be the aim.

5.2 Identification of project key roles

Contaminated Land Report 12 (CLR12) (DETR, 1997) describes the client-consultant relationship, and identifies the vital skills required by the contaminated land consultant. CLR12 also recognises that consultants may need to procure the services of contractors to complete some activities, such as borehole construction or chemical analysis. Criteria for selecting contractors are given, and particularly for nuclear-licensed sites it will be a requirement that all practitioners can demonstrate suitably qualified and experienced personnel (SQEP) status.

For some site characterisation projects, the Construction (Design and Management) (CDM) Regulations 2007 are applicable and the CDM co-ordinator and or a principal contractor will need to be appointed (see Section 3.3).

5.3 Framework of activities in a site characterisation project

A framework for site characterisation is given in Figure 5.2. This framework is developed from that provided in BS 10175:2001 with greater emphasis placed on the review of health, safety, security and environmental (HSSE) aspects of the characterisation.

The main elements of the framework are:

- determination of characterisation-specific objectives (see Section 4.2)
- preliminary investigation
- formulation of the conceptual model
- design and planning of field investigations and HSSE management
- undertaking of field investigations (exploratory, main or supplementary)
- review activities including achievability of objectives, the conceptual model, HSSE management and the need for further investigation.

The second, third and fourth steps of the framework together with the review activities, which are an essential undertaking at the end of each major stage of the process, are expanded on in the following sections.

5.3.1 Preliminary investigation

The aim of the preliminary investigation is to compile and evaluate the available information on the potentially contaminated site. From these data an initial site conceptual model (or models) may be constructed, which will be later used to design the site investigation phases of work. The model(s) will also be the basis for a hazard assessment and aid development of HSSE management plans, SWMPs, quality management plans and communications plans. Guidance on preliminary investigations of contaminated land is given in BSI (2001), Harris *et al* (1995), DoE (1994a, b and c) EA (2004a), Scottish Enterprise (1994) and WLGA (2006). In general, the preliminary investigation will consist of two parts:

1 Desk study.

2 Site reconnaissance.

5.3.1.1 *The desk study*

Standard data sources (for example, records held by the Environment Agency and the British Geological Survey) may be searched. These data sources are described in some detail in the documents referenced in Section 5.3.1. Many nuclear-licensed sites and defence sites have had multiple uses and contamination may be presently related to historical activities. Information may be held by the Public Records Office and various museums and archives for current and former defence sites (eg wartime airfields). Publicly available sources should be approached first before contacting Defence Estates to request a search of information on the historical use of current and former defence sites. Details of the policy and process for application are given at: <www.defence-estates.mod.uk>. Site-specific information of relevance to the desk study may be located at the site itself, although this tends to be widely dispersed across different departments (see Box 5.2). Further checklists are provided in BSI (2001). To understand the industrial processes and practices that use materials containing radioactivity, Defra have published an industry profile (Defra, 2006a).

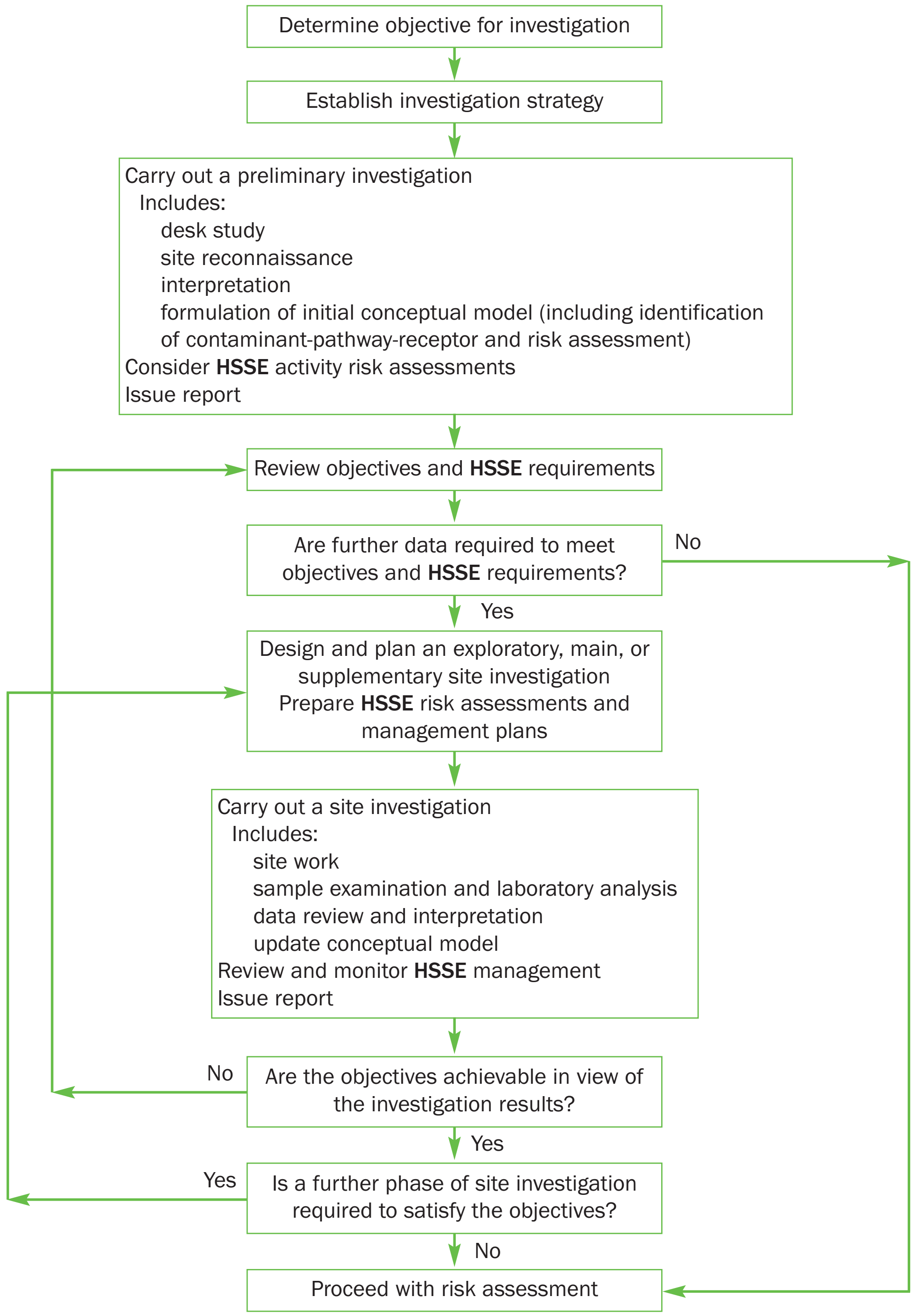


Figure 5.2 ***Framework for site characterisation planning (derived from BSI, 2001)***

Interviews with past and present employees are often revealing about working practices, and particularly waste disposal. Such interviews should be carried out with an understanding that no blame is to be attributed. It is often helpful to prepare a basic list of questions to be asked of all interviewees to establish the level of certainty about a particular activity or process.

The use of the other industry profiles produced by Defra is strongly recommended as a guide to understanding non-radioactive activities, processes and contaminants on sites (DoE, 1995). They are not definitive studies but they introduce some of the technical considerations that should be noted at the start of an investigation for possible contamination. Several are helpful when considering the many possible activities on defence sites that may have resulted in contamination, for example, airports, chemical works (eg explosives, propellants and pyrotechnic manufacturing works), dockyards and docklands. As with all desk studies of sites that have had a long period of development, care should be taken not to equate lack of information with evidence that activities have not occurred in the past.

Box 5.2 ***Data sources on nuclear-licensed sites and defence sites***

Several site-specific data sources on nuclear-licensed sites defence sites may provide useful historical data, these are:

- photographic archives, which include aerial photographs for some nuclear-licensed sites defence sites and may include photographs taken during construction of facilities
- general site archives
- occupational health archives (individual's records will not be accessible)
- reports on previous site investigations (geological, hydro-geological, contamination)
- health physics survey reports, which provide information on the radiological status of land and buildings
- stores records, which can provide information on the volumes and types of chemicals being handled and used on the site
- environmental officer's records (generally recent data). The most recent data may already be entered into geographical information systems
- site drawing office records, which will include details of the development of the site, demolition of buildings and the location and types of underground services
- unusual occurrence/accident reports. These are mandatory on nuclear-licensed sites, and are a valuable source of information
- waste categorisation records, which may provide information on radioactive contamination encountered during previous investigation and remediation projects
- plant modification proposal/records are a useful source to establish possible leaking pipework
- current and former employees.

5.3.1.2 *The site reconnaissance*

It is essential to inspect the site and adjacent lands to validate the desk study information and understand the relationship between features. The site reconnaissance should also be used to:

- collect extra information and visually inspect the site and contaminant sources, the environmental setting and potential receptors
- assess constraints to investigation, such as the extent of hard cover, overhead cabling, difficulty of access, service runs, and present-day site use
- establish site operating procedures, which are often complex at nuclear-licensed sites and defence sites
- where existing groundwater monitoring wells exist, selected sampling may also take place to improve or verify existing data.

An extensive list of site reconnaissance activities is provided in Harris *et al* (1995) and DoE (1994b). A photographic record is recommended in both these documents, but at some sites this may not be possible because of security restrictions.

A guided tour by someone familiar with the site is desirable. Any unaccompanied staff visiting a site will probably require site induction training, and should be thoroughly briefed on any hazards that could be encountered, as highlighted by the desk study and local rules. It is unlikely that such unaccompanied visits would be allowed on a nuclear-licensed site.

5.3.2 Formulation of the site conceptual model

Development of a conceptual model (or extra models for different scenarios or for sub-areas) of a site from the preliminary investigation is the essential first step in the risk assessment process (ASTM, 2000). In the SAFEGROUNDS process, this is part of Stage 3 and Box 10 in the associated flow diagram (Appendix A1). Uncertainty associated with the conceptual model is discussed in Chapter 11.

Guidance on carrying out a risk assessment is given by DETR (2000a), BSI (2001), EA (2001a and 2004a), UKCIP (2003) and for sites containing radioactivity Oatway and Mobbs (2003), Defra (2006b and 2007) Williams (2007) and Smith (2005b).

A conceptual model is a hypothesis of the source(s) and nature of contamination on a site, the pathway(s) and migration mechanism(s) by which it may be transported, and the receptor(s) that may be affected. At the start of a site characterisation programme, limited information may only be available to develop the initial site conceptual model. So there may be a wide range of possible hypotheses that are consistent with the data. If this is the case, it may be appropriate to develop a range of initial site conceptual models that reflect different interpretations of the data, and which may highlight different potential pollutant linkages. As site characterisation proceeds, it will be possible to obtain information that can be used to discriminate between the different models and to build confidence in a particular model of the site.

The conceptual model is a written or schematic description of the site and the potential source-pathway-receptor linkages (see Figure 5.3). The level of detail and type of information required in a conceptual model will depend on its intended use. For example, a conceptual model to enable a preliminary risk assessment may require only limited site-specific pathway characteristics such as type and estimated thickness of strata. A conceptual model to enable quantitative assessment will also require information on the mobility of contaminants in soil and groundwater, as well as site-specific characterisation of the pathway and receptor(s). A checklist for the conceptual model construction is given in Box 5.3, with further information in BSI (2001).

Guidance on the preliminary risk assessment phase is provided elsewhere (Rudland *et al*, 2001, DoE, 1996, DETR, 2000a and EA, 2004a). It is considered good practice to set out, and adhere to, a consistent set of definitions of risk. These should be based on size of hazard, sensitivity of receptor and probability of impact occurring.

Careful consideration should be given to the nature and location of radioactivity when preparing even a qualitative risk assessment. For example, a radium painted surface that is loose and flaking is more of a hazard than radium sealed beneath a coated surface. Another feature of recent guidance for Part 2A including radioactivity (Defra, 2006c) is that now controlled waters and ecological systems are not included as receptors.

Continuous refinement of the conceptual model and feedback throughout the investigation process is essential, and this should take place during the review activities after each phase of the characterisation programme. It is also required to continuously develop the site-specific HSSE management plan.

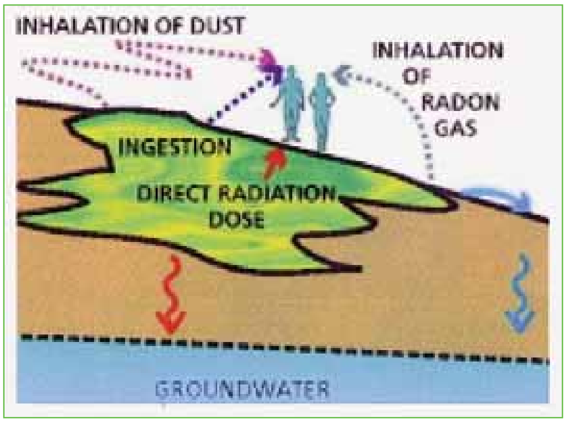


Figure 5.3 *Simple conceptual model (diagram) of contaminant migration pathways in the immediate vicinity of an area of radioactively contaminated land*

Box 5.3 *Examples of information requirements for a conceptual model*

Source characteristics

- timing and duration of contamination
- mechanism of contamination, eg fallout from stack discharge, leaking drain, spillage during transport
- physical, chemical and radiological properties of contaminants
- vertical and lateral extent of source, including discussion of any barriers or preferential pathways.

Pathway characteristics (air, soil, and water)

- pathway length (distance between sources and receptor)
- shielding potential (eg thickness of "clean" soil layer)
- pathway characteristics and processes (physical, chemical and biological) that will affect rate of migration and contamination concentrations
- temporal changes in the pathway
- potential for transfer between environmental compartments, eg aqueous to sediment phases or surface soils to airborne dust
- prevailing wind direction, velocity and dust loading
- presence of burrowing animals
- surface water flow patterns and distribution of subsurface drainage systems
- expected groundwater flow patterns and travel times to receptors (including rising groundwater)
- influence of artificial structures assisting contamination migration, eg service trenches, drains
- influence of artificial structures constraining contaminant migration, eg foundations as barriers.

Receptor characteristics

- humans, eg construction workers, site workers, on- and off-site public
- specific ecological systems, both on-site and off-site
- property in the form of crops, timber, domestic produce, livestock, other owned or domesticated animals, and wild animals that are subject to shooting or fishing rights both on-site and off-site
- property in the form of buildings both on-site and off-site
- controlled waters, eg surface waters, surface water abstractions, wetlands, groundwater abstractions, springs, groundwater within aquifers, estuaries and near-shore environments.

5.3.3 Design of field-based site characterisation

Having prepared the initial conceptual site model, it is important that it is used to design the site characterisation. In BS 10175:2001 a decision sequence is suggested to determine the appropriate investigation strategy (Figure 5.4). This is annotated with sections from this guidance where detailed information can be found.

Each decision should be documented so that other parties can understand why the design was selected.

Decision 1: Is there enough information to meet project objectives (for risk assessment, options comparison, preferred option implementation or verification and validation)? If not, the objectives of the next phase of the investigation should be defined (see Chapter 5).

Decision 2: What form (non-intrusive or intrusive) of investigation is necessary? (see Chapters 6 and 7)

Decision 3: What locations should be sampled and how many samples should be taken? (see Section 5.5.2)

Decision 4: From what depths should the samples (soil, water, gas) be collected, and what are the monitoring requirements? (see Sections 5.5.3 to 5.5.5 and 8.2 to 8.7)

Decision 5: What are the samples for and what is the specification for the analyses? (see Section 8.8)

Decision 6: What techniques and monitoring installations should be employed to obtain samples (soil, water, gas)? (see Sections 8.2 to 8.7)

Decision 7: What quality measures will be employed to ensure accurate data from the point of sample collection or monitoring to the laboratory and then data interpretation? (see Section 8.8.7)

Figure 5.4 ***Decision sequence for site investigation (after BSI, 2001)***

Examples of the links between the conceptual model and the site characterisation design are given in Table 5.1. Potential contamination linkage pathways for a site are identified, and site characterisation activities to investigate these potential mechanisms are listed.

Where more than one initial site conceptual model has been developed, site characterisation data should be obtained to test the various models and discriminate between them. This may start with limited investigations to prepare for the main characterisation plan. Some models may be rejected because they are inconsistent with the new data, and uncertainty in the remaining model(s) will be reduced.

In many site characterisations, it is appropriate to phase the investigations. More detailed characterisations are deferred until the results of earlier phases of work have been evaluated. This approach ensures that the later investigations are focused on relevant areas with the appropriate degrees of accuracy and confidence employed.

Table 5.1 ***Examples of the linkage between conceptual model and site investigation design***

Pathway identified in the conceptual model	Survey design to address potential contamination through identified pathway
Diffuse airborne contamination	• air quality sampling • surface sampling for radioactive and non-radioactive contaminants on an appropriate sampling pattern • migration of historically deposited contamination addressed by intrusive investigations on an appropriate sampling pattern.
Spillage from vehicles during transport operations	• walkover radiation surveys • soil vapour survey • surface and shallow sampling adjacent to roads.
Disposals/spillages/losses associated with former buildings and historic spillages in current buildings	• walkover radiation surveys • soil/building vapour survey • surface and shallow sampling adjacent to roads/within buildings • trial pits/boreholes located at the position of known buildings, adjacent to existing buildings or within buildings, is appropriate.
Leakage from drains	• a drain survey, including sampling of drain sediments • trial pits/boreholes located along the line of the drain • *geophysics* to identify drain runs.
Burial of waste materials	• walkover geophysics survey prior to intrusive sampling, in order to detect disturbed ground, buried objects and services • soil vapour survey • walkover radiation surveys • intrusive investigations.

5.3.4 Planning of field-based site characterisation

At this stage in the process, plans are made for achieving the project objectives within the constraints of working on nuclear-licensed sites and defence sites. The constraints should not be underestimated, particularly in respect of how the project timescale is affected. For example, on non-licensed sites, an authorisation issued under RSA93 may be required for accumulation and disposal of radioactive wastes that will be generated during site investigation (and later remediation). Such authorisations can take several months to obtain and are frequently the rate-determining step in a project.

On nuclear-licensed sites, working in controlled areas and contaminated areas of C2 status (higher significant risk), with the associated health physics control, monitoring and decontamination is time consuming. Site investigation rigs and equipment in controlled areas also may have to be moved off the sampling location when not in use to maintain emergency access. High standards of tidiness and cleanliness need to be imposed within controlled areas, which also consume extra time.

Guidance on planning the investigations is given in BS 10175:2001. However, on nuclear-licensed sites and defence sites there will be further requirements, with time implications, for all or some of the following:

- security clearance
- radiological protection
- site-specific health and safety training
- conformance with site procedures (eg excavation procedures and management of

subcontractors, time taken for staff and equipment to get in and out of controlled areas)

- development of contingency plans in the event that ordnance is discovered (see Section 7.2.2 for safe digging practices on sites where buried unexploded ordnance (UXO) may be present)
- obtaining approvals and permits to work
- locating subsurface services
- identifying constraints imposed by operational activities
- integration with other site projects.

On nuclear-licensed sites, there are strict and detailed procedures that must be followed before any ground excavation activities can proceed. These procedures are designed to ensure that excavations are not undertaken into any infrastructure and services that:

- could cause harm to the staff undertaking the excavations
- could cause disruption, or potential disruption, to any operations on the nuclear-licensed site (note that any incidents that have a potential impact on the safe working of nuclear plant would be reported to the NII and might be regarded as a serious breach of law).

As a result, extensive documentation is typically required before characterisation of nuclear-licensed sites and defence sites. Obtaining permits to work can be difficult and time consuming, typically at least a month. Sites may have a rolling work programme with built-in lead times. If the location of excavations is changed then the permitting process may need to re-start, so flexibility should be incorporated at the planning stage.

5.4 Project review

Sufficient time should always be allowed between investigation phases for:

- a review of the project objectives
- a review of HSSE management
- updating the conceptual model of the site following available information
- a review of the information required from the next stage of the investigation.

Where information from a phase of site investigation significantly changes understanding of the nature or extent of contamination, or of the environmental or health impacts, time should also be allowed for consultation with all relevant stakeholders.

5.5 Main issues for survey design

5.5.1 Contingency planning

Contingency planning should be undertaken during the design of any contaminated land investigation. Contingency planning in this context is used in the broadest sense rather than in relation to specific requirements detailed in IRR99. The project risk assessment identifies the important actual and potential risks to be identified, and contingency plans developed. In the context of site characterisations on nuclear-licensed sites and defence sites, extra technical issues to those that would be considered for chemically contaminated sites are principally concerned with radioactivity.

For all site characterisations on potentially radioactively contaminated sites, the radiological protection adviser will specify dose constraints for the workforce (see Appendix A2). So on potentially radioactively contaminated sites, it is typical to use the concept of "hold-points" during the site investigation. A hold-point defines the maximum radiation dose rate at which operations can be undertaken using the specified operating instructions and health, safety and environment controls. If the hold-point is exceeded, work should stop, the workplace should be left in a safe condition and staff should withdraw. The method of working should then be re-evaluated, and, if necessary, revisions made to operating procedures and health, safety and environment control measures.

Main contingency planning issues in the event of discovering unexpected levels of radioactivity are:

- can staff safely withdraw from the workplace, leaving it in a safe condition?
- is the radiation protection adviser available on an appropriate timescale to advise on workplace safety and environmental monitoring?
- if radioactive substances and wastes (as defined by RSA93) are unexpectedly produced, their management should have been previously considered and documented in the site waste management plan (SWMP), including the waste disposal routes for any samples taken (see Chapter 9).
- in the event that the work area requires designation under IRR99, do subcontractors have the relevant authorisations and qualifications to enable them to continue work?
- what precautions are necessary to minimise spread of contamination?
- are suitable storage and transport arrangements available for radioactive samples?
- are suitable analytical facilities available to analyse radioactive and mixed radioactive and non-radioactive contamination?

Main contingency planning issues in the event of discovering unexploded ordnance (UXO) are:

- can staff safely withdraw from the workplace, leaving it in a safe condition?
- is a specialist munitions adviser available to advise on risk from the munitions and on workplace safety?
- are staff aware of the procedures for notifying the appropriate authorities of the discovery of buried munitions (see also Section 7.2.2).

5.5.2 Soil sampling patterns and frequencies

As previously described, the design of the site investigation must be clearly linked to the preliminary conceptual model of the site, and procedures must be in place to allow regular and systematic review of the strategy. An important aspect of the site investigation plan is the amount of non-intrusive versus intrusive work, and the design of an appropriate sampling strategy to meet the objectives of the site investigation.

Where remediation is the probable outcome of the site characterisation, it is essential that the survey design is suitable to allow waste volumes to be predicted. In particular, in the case of radioactively contaminated land, disposal costs (per unit volume) for exempt wastes are considerably lower than for low-level radioactive wastes (LLW). Over-estimation of LLW based on poor data results in high and unrealistic project budgets. Conversely, under-estimation of LLW has the opposite effect.

Extensive guidance is already available on sampling strategies for contaminated land investigations (Harris, 1995, DoE, 1994c, USEPA, 2000 and 2002, EA 2000a, 2001b and 2007, and BSI, 2001, 2002 and 2005). Where appropriate the application of the DQO approach (USEPA, 2006) for probability-based sampling design may be considered, using professional judgement and experience. DQO sample planning is supported by a publicly available software tool called Visual Sample Plan (VSP), which helps the user determine the optimal number and location of samples using defensible statistical methods and displays locations on maps or aerial photographs. VSP can be downloaded at no cost from: <http://dqo.pnl.gov/vsp>.

Experience of using the DQO approach for nuclear sites can be found for the Hanford site in Washington Stats on: <www.hanford.gov/dqo>.

A summary of the main issues discussed in the guidance documents referenced here follows.

There are two approaches to soil sampling:

- targeted or judgmental sampling, which focuses on known or suspected sources of contamination, such as storage tanks, disposal pits and pipelines. The results from non-intrusive surveys (such as geophysical surveys, radiological surveys and drains surveys: (see Chapter 6) are used to support the design of the targeted sampling
- non-targeted sampling, which aims to characterise the contamination status of an area or a volume of ground.

In each case, it is necessary to select the frequency and distribution of sampling points. This can only be achieved by considering the conceptual model and asking questions such as:

1. What are the principal pathways for contamination (see Box 5.3)?
2. For the principal mechanisms of contamination at the site, what are the typical sizes and spacings of the source areas?
3. How mobile are the contaminants? For example, is it possible that a contaminant in the soil will also contaminate groundwater?
4. How deep are the contaminants likely to penetrate into the subsurface environment, and what is the depth to groundwater?
5. Is there a possibility that discrete "hot particles" might be present?
6. What are the minimum detectable amounts (MDAs) and maximum missable amounts (MMAs) associated with the different monitoring approaches?
7. What are the objectives of the site investigation, and what is the required level of confidence in the results?
8. If remediation is required, what "averaging volume" would be used for waste characterisation? (see Box 9.2) This issue is of greatest importance on sites where contamination is heterogeneously distributed (ie an area of elevated contaminant concentration is present). What extra data are required to determine particular remediation approaches?
9. How many phases of intrusive investigation are likely to be required and what are the aims of each phase?
10. How much of the ground is uncontaminated?

In the case of targeted sampling of a known area of significant contamination, for example, where significant levels of radioactivity have been detected by a non-intrusive radiological survey, it may not be necessary to characterise the area in detail during the early stages of the investigation. Instead, it may be more valuable to characterise the surrounding area to define the "envelope" of contamination and to provide information on the extent of land that may require remediation. More detailed characterisation of the most contaminated areas will be required to define a remediation and waste management strategy, and it may be appropriate to undertake this as a supplementary investigation.

Two approaches to designing non-targeted sampling grids are presented in the existing guidance.

BS 10175:2001 states that:

> "Typical densities of sampling grids can vary from 50 m to 100 m centres for exploratory investigations and 20 m to 25 m centres for main investigations. A greater density of sampling grid may be considered appropriate where heterogeneous contamination is indicated, for example on a former gasworks site where in localised areas 10 m centres may be necessary. A high density sampling grid may also be necessary where a high level of confidence is required for the outcome of a risk assessment (for example, for a housing development)."

In contrast, DoE (1994d) presents a statistical approach in which the number of sampling points required to detect an area of elevated contaminant concentrations with a certain level of confidence can be calculated. Given this frequency of sampling, it is possible to state that, at the level of confidence specified:

- an area of elevated contaminant concentration of specific size (if one exists) will not be missed
- if contamination is not found, an area of elevated contaminant concentration of at least the specified size does not exist.

The size of the area of elevated contaminant concentration can be considered in several ways. It may be the expected size of the contaminated area or the maximum size of contamination that could be economically and safely remediated. Further, it could be the size of an area of contamination in an otherwise uncontaminated site or an area of greater contamination (for example, above some guideline "trigger" concentration) within a site that is generally contaminated.

The two approaches to designing the sampling grid take into account the same broad issues: the need for more frequent sampling to provide higher levels of confidence and to characterise areas with physically smaller contaminant sources. The statistical approach designed by DoE (1994d) is the more rigorous approach. However, the information needed to define parameters for the model can only be obtained from a conceptual model of the site. The statistical approach proposed by DoE (1994d) also addresses the identification of an appropriate sampling pattern (eg square grid, random, herringbone), stating that the "efficient sampling pattern should satisfy four conditions":

1. It should be stratified (ie the area to be sampled should be partitioned into regular sub-areas).
2. Each sub-area should carry only one sampling point.
3. It should be systematic.
4. Sampling points should not be aligned.

A square grid pattern satisfies points 1 to 3 but, because sampling points are aligned, reduces the ability to detect elongated hot spots aligned parallel with the grid. A herringbone pattern is considered by DoE (1994d) to be the optimum type of non-targeted grid pattern. In practice, on operational sites there will be restrictions on the possible positions of sampling points due to the presence of underground services, buildings etc. This aspect is discussed further in Chapter 7. The consequence will be that the actual non-targeted sampling grid will probably not conform to the ideal pattern. A judgement then has to be made as to whether deviations from the ideal grid geometry are so great as to render the statistical measures of confidence invalid. Importantly, if there is reason to suspect that highly active particles may be present on the site then an intensive sampling regime may need to be undertaken. This may include a global positioning system (GPS) linked system to accurately record any material monitored. It is important to understand the concepts of minimum detectable amounts and maximum missable amounts associated with any sampling methodology to have confidence in the results presented.

Composite sampling (BS 7755-2.6:1994) from spoil heaps or imported materials may need to be considered for verification purposes. Other deterministic, classical statistical and geoestimation techniques may be required on a site-specific basis (Petts *et al*, 1997). Optimisation of sampling costs with potential liabilities may also need to be taken into account (Ramsey *et al*, 2002).

CL:AIRE (2008) has produced industry sponsored guidance introducing a structured process with signposts to existing guidance, to explain the scientific basis for testing, to encourage appropriate scrutiny and treatment of data and, most importantly, to ensure appropriate (statistical) questions are posed for particular legal contexts so that correct inferences are drawn.

5.5.3 Depth-dependent sampling of soils

The sampling approaches described in the previous section consider only a 2D (area) distribution of contaminants. It is essential to understand the 3D structure of the site and the distribution of contaminants within that volume if valid conclusions are to be drawn from the survey. To achieve this, the soil sampling strategy needs to address the required depth of boreholes and trial pits and the approach to collecting samples from them (BSI, 2001).

The required depth of boreholes/trial pits and the strategy for collecting soil samples from them depend on the reason for characterising the site (see Section 4.3), and take into account issues such as:

- the expected depth distribution of contaminants in the source areas. This is dependent on:
    - the mechanism(s) of contamination (eg surface deposition, depth of made ground, subsurface leakage from storage tanks)
    - the geological and hydrogeological properties of the soils and rocks (eg the presence of major fracture zones, which may act as pathways for deeper penetration, or of low-permeability horizons, which may act as barriers to contaminant migration)
    - the variation of the water table at the site (eg the effective infiltration rate or the presence of rising groundwater)
    - the physical properties of the contaminant (eg dissolved in groundwater, light or heavy non-aqueous-phase liquids that float or sink in groundwater, colloids/particulates)

    - the chemical properties of the contaminants (eg its solubility and sorption characteristics in the subsurface environment at the site)
- the potential contaminant migration pathways identified in the conceptual model:
    - analysis of the immediate surface layer of soil would invariably be required because of human health issues such as ingestion and inhalation of soil. This surface layer should be defined on a site specific basis related to the conceptual model. Sampling depths may vary between the surface and 0.5 m, and may require sampling at more than one level
    - samples from each distinctive horizon of made ground, fill and natural strata should be collected
    - samples in both the unsaturated and saturated zones to establish whether there is a secondary source of contamination above, at or below the water table
    - the focus placed on sampling deeper soils would depend upon the expected significance of subsurface pathways in transporting contaminants from the source area to potential receptors, particularly off-site
    - any extra testing requirements (eg geotechnical characterisation of the site).

5.5.4 Ground gas surveying

Where spills or leaks of volatile organic compounds have occurred, ground gas surveying is recommended. Areas of waste disposal may be identified by ground gas surveying for landfill gas if the waste was *putrescible*, or for volatile compounds if it contained organic chemicals. Variations in carbon dioxide may also pick up areas of disturbed ground. Extensive guidance on ground gas monitoring is available (Wilson *et al*, 2007b).

Radium decays to radon, a short-lived radioactive gas. So detection of radon in ground gas may provide information on the presence of buried radium-contaminated materials. Ground gas surveying for radon is already widely used in the mineral exploration industry to detect uranium ore bodies. Detection of radon in air may also be required to evaluate radiological dose arising from the inhalation of radon. Sufficient radon to require action can occur naturally and is frequent and widespread in some geological settings.

Action levels of 200 Bq/m^3 for dwellings built post-1990 and 400 Bq/m^3 for dwellings built pre-1990 were set by the former National Radiological Protection Board (NRPB), now part of the Health Protection Agency (HPA). Further information on radon can be found in guidance published by BRE (1999) and on the HPA website: <www.hpa.org.uk>.

5.5.5 Surface water and groundwater characterisation

It is also possible that contamination of surface water and groundwater may have arisen as a result of operations and activities on the site. Once in the groundwater contaminants may laterally migrate from the source area, and potentially affect extensive volumes of the subsurface, including beyond the site fence. Groundwater may also contribute to local surface waters through the process of base flow, creating a pathway for further contaminant migration. Consideration should also be given to the impact of flooding and the spread of contamination during unusual events. So an understanding of the hydrological and hydrogeological environments is an important element in the conceptual model.

Sampling surface water and groundwater may be necessary to any comprehensive site characterisation survey. Guidance on the design of such programmes is given by the EA

(2000a, 2001b and 2003a and b), DoE (1994a), and BS 10175:2001). Guidance on all forms of water sampling is given in BS 6068 and the ISO 5667 series. Sampling of groundwater and non-aqueous-phase liquids is discussed further in Sections 8.5.2 and 8.5.3.

The locations of the surface water and groundwater sampling points should take account of factors affecting the temporal and spatial variation in water quality and flows, including:

- the locations and extents of known or suspected sources of contamination
- surface water and groundwater catchments
- tidal patterns
- seasonal or ephemeral variation in surface water flow
- the local and regional groundwater flow pattern at the site (including the identification of both horizontal and vertical hydraulic gradients)
- the hydrogeological properties of the rocks and soils (which, together with information on hydraulic gradients, enables groundwater flow directions and velocities to be estimated)
- background water quality.

Main considerations for the design of a groundwater characterisation programme are given in Box 5.4.

Box 5.4 ***Key considerations for a groundwater characterisation programme***

Boreholes should be located to provide information on water level and water quality:

- up-gradient of any potential sources
- in or close to potential source areas
- on the down-gradient boundary of the site
- as sentinel boreholes (between the source and the receptor/compliance point to monitor progress of contaminant migration)
- at the compliance point.

If significant groundwater contamination is detected, further boreholes may be required to define the plume of contaminated water.

Hydrogeological testing should be performed to determine the permeability of the rocks/soil and to establish the hydraulic gradients within and across the site. Water samples taken over the duration of such pumping tests can also provide information on groundwater quality over a significant radius of formation.

Boreholes should not be completed as long-term monitoring points until the geological and hydrogeological environment is fully understood. In particular:

- the main horizons for contaminant transport should be identified and targeted
- monitoring boreholes should be designed to minimise or prevent vertical flows (“cross-flows”) through the screen and open section
- the requirements for monitoring and sampling non-aqueous-phase liquids (NAPLs) should be considered
- well construction materials should be compatible with the types and concentrations of contaminants present.

Targeted sampling of groundwater is appropriate where the groundwater pathway can be identified with reasonable confidence, ie where contaminant sources and groundwater flow directions are known. In this manner, the contaminant plume(s) can be delineated and groundwater quality leaving the site can be monitored. Non-targeted sampling may be appropriate to the earliest stage of an investigation, if there is no information on potential sources of contamination or on the hydrogeological environment.

Following completion of the hydrogeological characterisation, long-term monitoring of groundwaters and/or surface waters may be required to:

- evaluate environmental liabilities and their development with time
- ensure compliance with regulatory limits (eg requisite monitoring, see Section 4.3)
- to provide temporal and spatial evidence of geochemical changes
- to provide input data for predictive modelling
- validate *in situ* remediation measures (including "natural attenuation").

In some instances, the requirement for long-term monitoring will be established at the start of the site characterisation programme. In other instances, the requirement will only become evident after completion of the site works and evaluation of site data. Where the requirement for long-term monitoring is established at the start of the investigation, the survey design should take account of this. The frequency of sampling will depend on any seasonality or tidal effect in the groundwater system, and the rate of contaminant migration.

If long-term monitoring is to be undertaken, it is good practice to define and document clearly the objectives of the monitoring before the programme starts. Further, the data from the programme should be subject to regular quality checks and technical assessment, and there should be regular review of the need for continued monitoring (see Chapters 8 and 11). These procedures will ensure that inappropriate data are not collected and that the monitoring programme does not continue beyond the period when it was required.

Good practice procedures for the collection of representative groundwater samples are available (eg EA, 2003b), and are discussed further in Section 8.5.2. Water abstracted from the boreholes during development and sampling must be managed in accordance with the operating procedures of the site and with UK water and environmental protection legislation. It may be necessary to treat water before disposal onto the ground surface (for example, using activated carbon to remove organic contaminants) or to transport the wastewater to a liquid effluent treatment plant (for example, to remove radioactive contamination). Finally, a borehole maintenance programme should be established to ensure that the groundwater sampling points remain fit for purpose.

5.5.6 Geographical location of survey points

The sites covered by this guidance commonly have a long history of industrial development. In some cases, redevelopment or decommissioning of the site will be in progress. Significant amounts of environmental data may have already been obtained from routine environmental monitoring programmes and previous site investigations.

Given these factors, it is important that *topographical* survey points are accurately located using a consistent convention. Survey points should be referenced to National Grid co-ordinates. If a local site grid is used instead, as is found on many nuclear-licensed sites, then the conversion to National Grid co-ordinates should be provided. Surveys should not be located relative to local landmarks, which, particularly on sites being decommissioned or redeveloped, have a tendency to disappear.

Record-keeping issues are discussed in Chapter 10. On nuclear-licensed sites, there is a requirement to retain all records relevant to compliance with the site licence for an initial period of 30 years. Once this period has elapsed the records will be reviewed to ascertain whether they should be kept, how they should be stored, and what can be destroyed. One consideration may be to store data in electronic format using geographical information systems (GIS), assuming the need for longevity of software is managed. Guidance on the use of GIS is given by the EA (2000b).

5.6 Establishing background environmental quality

5.6.1 Background radioactivity

For the reasons discussed earlier in Chapter 2, it is important to establish the background level of radioactivity in soils and waters at the site. It should be noted that the determination of whether a substance is exempt from consideration as a radioactive material under the Substances of Low Activity Exemption Order made under RSA93 is related to the natural background activity for the area. Once the background concentrations have been measured, then the definition of "background" has to be agreed with regulators (HSE and the relevant environment agency) before decisions can be taken on land management.

It would be possible to define background as the average activity of a selection of the samples analysed (omitting those shown to be contaminated). However, the disadvantage of this approach on a heterogeneous site (ie where natural radioactivity and fallout-derived radioactivity vary spatially) is that it could be unnecessarily cautious. For example, it could lead to a recommendation to remediate an area that had not been contaminated by site activities. A more pragmatic approach may be to define "background" in terms of the activity below which a certain percentage of the distribution lies. Clearly, the percentile chosen would need to be justified.

As discussed in Section 2.5, background levels of radioactivity will vary (i) from site to site and (ii) spatially in 3D within a site. Concentrations of naturally occurring radionuclides will be strongly influenced by the composition of the rocks and soils, by the extent of near-surface weathering effects, the import of different fill materials and a re-working of ground in earlier construction phases in a site's history. Anthropogenic radionuclides derived from global fallout are (with the exception of tritium) unlikely to penetrate significantly below surface soils, so it would be inappropriate to use the background levels of such radionuclides in surface soils to derive a background for deeper soils and rocks. To determine background levels of radioactivity at a site, it is necessary to characterise an area that has similar rock and soil compositions to the site under investigation, and to evaluate any depth-dependent changes in the background activity of naturally occurring and fallout-derived radionuclides. Also, it will be necessary to consider the "fingerprint" of the background, and it may be required to carry out more detailed analysis rather than always relying on a simple measurement, say gross alpha or beta activity.

Typically, this would involve collecting samples from an area sufficiently close to the site that its natural radioactivity characteristics are similar to those of the site, but also sufficiently far away that site-derived radioactivity will not have significantly improved the background levels. In site investigations where data are collected across large areas, some of which may never have been used for radioactive operations, it may be possible to obtain on-site information on background levels of radioactivity. However, it is desirable to supplement this information with data from off-site areas. For heterogeneous sites, it may be possible to define different background levels for different soil types and at different depths, for example, to distinguish between made ground and different natural strata. Note that ground may consist of material imported from elsewhere and this needs to be considered when determining a sampling plan.

5.6.2 Background chemical quality

For chemical contamination it is important to understand the background quality for soils and ground gases (Wilson *et al*, 2007b) because, in some locations the natural background may contain elevated concentrations of a compound or element. Background may also be elevated due to contamination from a neighbouring site and it is necessary to establish the concentrations to apportion liability. However, in both these media the risks from naturally elevated concentrations need to be assessed, and if necessary managed and controlled.

With groundwater (EA, 2000d, 2003a and b, and 2006a and b) establishing the background quality (field parameters and dissolved constituents, and pH, redox, salinity etc) is necessary, particularly where no quality objectives exist.

Deriving background concentrations to benchmark the quality of local environmental media is integral to the decision making process for both risk assessment and risk management purposes.

6 Site characterisation: non-intrusive methods

Box 6.1 ***Aims of Chapter 6***

This chapter describes the principal techniques for characterising contaminated land on nuclear-licensed sites defence sites using non-intrusive methods. Many of the techniques, such as the use of geophysics, are already described in existing contaminated land guidance. It is not the intention of this chapter to reproduce this existing guidance in detail but to give the reader further information. Instead, the focus is on describing those characterisation techniques that are specific to the investigation of radioactively contaminated land, and to highlight specific issues in the application of widely-used characterisation techniques to nuclear-licensed sites defence sites.

6.1 Introduction

This section introduces the non-intrusive methods of site characterisation that may be employed drawing on SAFEGROUNDS site experience. Non-intrusive survey techniques are used to rapidly obtain information about the site to focus intrusive methods of investigation and sampling (Figure 6.1). Methods commonly employed are:

- radiological surveys
- geophysics
- drain surveys.

6.2 Non-intrusive radiological surveys

Ionising radiations (in particular, gamma radiation) can be detected in the field in real time using hand-held instruments. In contrast, most chemical contaminants can only be detected some time later through laboratory measurement. As a consequence, non-intrusive radiation surveys (or "radiological surveys") are important in any investigation on a potentially radioactively contaminated site. At present there are no routinely used counterparts for detecting chemical contamination (with the possible exception of the use of gas monitoring equipment).

Radiological surveys, as with the other characterisation methods described in this section, should only be carried out by organisations experienced in undertaking such work. The guidance given in this section is not a method statement for carrying out a radiological survey, but highlights important issues and good practice and to identify some common problems and mistakes.

The discussion is summarised primarily from two references, which provide extensive information on the subject:

1 *Multi-agency radiation survey and site investigation manual* (MARSSIM) (USEPA, 2000 and <www.marssim.com>).

2 R&D Technical Report *Technical support material for the regulation of radioactively contaminated land* (EA, 1999a).

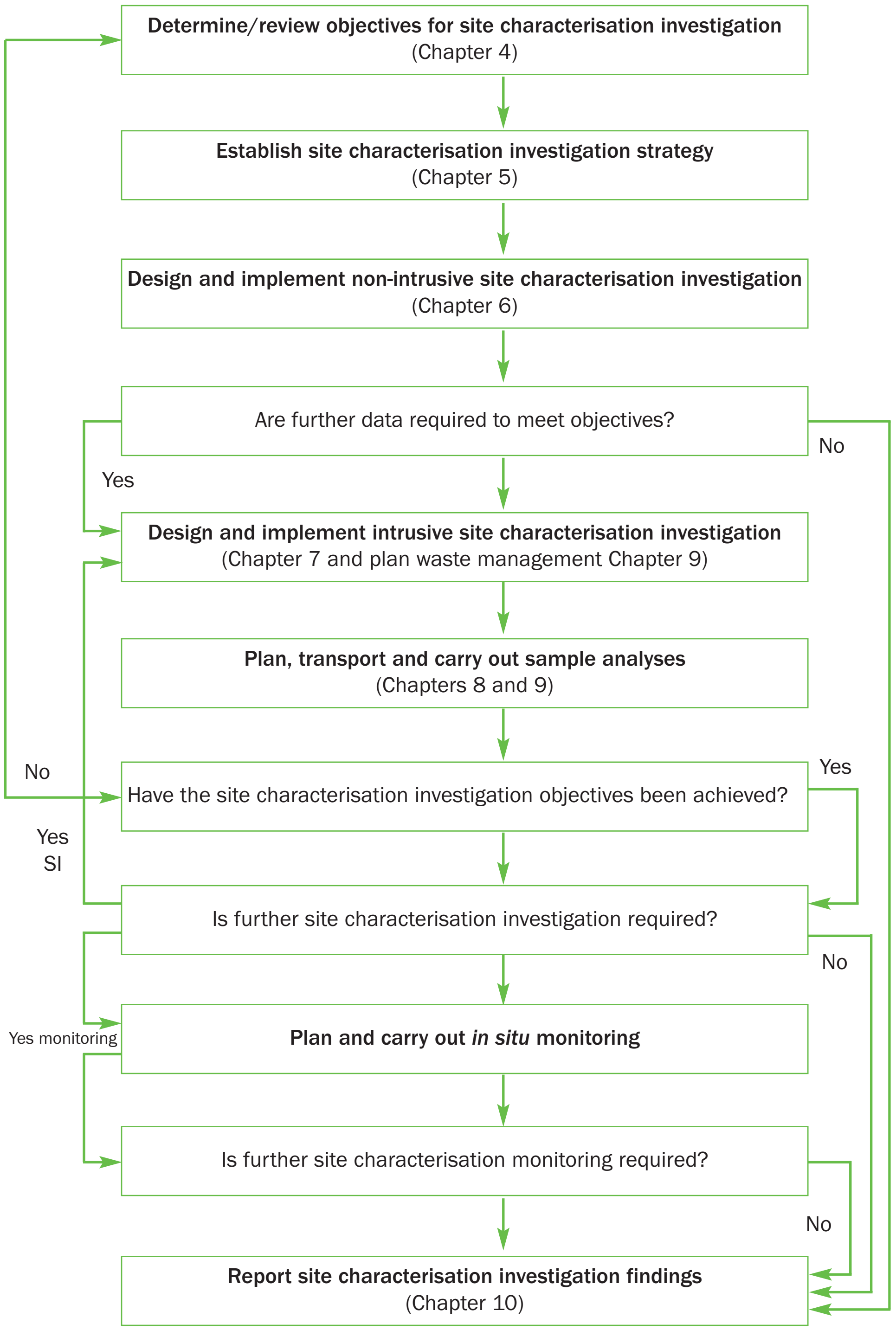


Figure 6.1 ***Flow diagram showing phases on a field-based site characterisation investigation (after Nexia, 2008) with reference to sections from this guidance***

Radiological surveys in the field can be broadly divided into two types (USEPA, 2000):

1 **The scanning survey:** scanning radiation surveys (sometimes called walkover radiation surveys, because they are typically undertaken on foot) are carried out using portable radiation detection equipment that responds rapidly to the presence of primarily gamma-emitting radionuclide contamination on or close to the ground surface. The aim of these surveys is to rapidly identify the areal distribution of contamination at a site to focus further investigations. The results of the survey are generally presented in terms of counts per second and give an indication of the relative levels of radioactivity across the site.
2 **Direct (point) measurements:** direct measurements are carried out on the site to determine absolute values for certain parameters or to provide a better understanding of which radionuclides are present. Direct measurements tend to use instrumentation that is slower to respond or bulkier than that used for scanning surveys.

In general, a scanning radiological survey is carried out first, followed by point measurements (if necessary) in areas of interest highlighted during the scanning survey.

It should be noted that surveys in which data are recorded as equivalent dose (for example, in $\mu Svhr^{-1}$) may be directly compared with other surveys. In contrast, surveys in which data are recorded as counts per second are not directly comparable with each other unless the same instrument has been used.

6.2.1 Design of the radiological survey

The first stage of designing the radiological survey is to identify the objectives of the work. In most cases, this will consist of one or more of the following:

- to determine if radionuclides on the site present a hazard to site staff
- to determine the spatial distribution of radionuclides on the site
- to determine the degree of heterogeneity in the distribution of any contamination
- to determine whether and what proportion of the contamination is present only in the surface
- to determine the radioactive "fingerprint" of the radionuclides on the site.

Having identified the objectives, the questions in Table 6.1 should be used to design the survey. The detailed survey design and equipment selection will depend on the site conditions and the radionuclides expected to be present. For instance it will be important to understand whether continuing operations and activities on the site may improve radiation, which will affect the ability to identify radioactivity in the area of the survey. It is also important to understand through the development of site conceptual models whether the contamination will have a surface, or close to surface, presence that will be detectable with non-intrusive methods.

In general, three aspects will be considered, and the type of radiation detector, its method of use and the scale of the survey grid.

Table 6.1 ***Design issues for radiation surveys***

Which radionuclides are likely to be present on the site and at what activity levels?	• based on the desk study (previous usage of radionuclide used, environmental monitoring etc) • important because it is the primary driver in the selection of radiological monitoring equipment (see Section 6.2.2).
What are the background levels of radioactivity, both natural and artificial at the site?	• from previous monitoring from the area. If inadequate background information exists, it will be necessary to make measurements and assessments of the natural variations • on some sites there may be an artificial background that will affect the ability to carry out measurements of low levels of contamination.
What are the detection limits required for the radionuclides of interest?	• based on the derived concentration guideline levels for the radionuclides of interest, SoLA EO (1986) or background (see Section 6.2.2). It is also important to consider the relative position of contamination in the soil column and how this may affect limits of detection • if the radionuclide fingerprint is known, it may be possible to infer the presence of a radionuclide by measuring the most easily detectible radionuclide in the fingerprint.
What is the size of the area to be surveyed, and what are the sizes of the anomalies?	• the entire area of ground that has the potential to be contaminated (or a sub-set of it), with focused surveying on known or suspected problems (see Section 6.2.4) • important because this will drive selection of the transportation used during surveying and may impact on the grid size selected (see Section 6.2.5).
What are the time/cost limitations on the job?	• financial and time constraints will often have a significant impact on the type of survey selected.

A conventional design for a radiological survey is presented in Box 6.2. However, recent developments in global positioning system (GPS) technology and electronic data capture have led to surveys being conducted in which the site is not gridded. Instead, data on both location (from the GPS) and radiological measurement are directly stored in a data-logger and the data are later displayed using GIS. An example of a radiological survey conducted using such a technique is presented in Figure 6.2.

Box 6.2 ***A conventional design of radiological survey***

A conventional design of a scanning radiological walkover survey may consist of:

- the gridding of a site at a 5 m spacing
- a surveyor slowly walking over the whole of each grid square swinging a gamma or beta/gamma monitor a few centimetres above ground
- recording the locations and size of elevated radioactivity readings by hand in a notebook
- spray-marking the ground at locations of elevated radioactivity measurements
- further investigation of suspect areas by swabbing for alpha or beta activity.

Note: the specific details on any single site may vary and so this approach should not be adopted without carefully considering the objectives and design of the survey previously highlighted.

6.2.2 Instrumentation

A wide range of instruments is available for the detection of radioactivity. It is outside of the scope of this guidance to give a detailed description of each instrument available, however, reviews of many types of instrument are presented in other literature, for example NPL (2002), Burgess (1998), EA (1999a), IAEA (1999) and Burgess (2001).

Recent developments include improvements in the speed of equipment reading, linking radiological surveying instrumentation to GPS equipment, providing rapid data visualisation, and interfacing with GIS systems. A competent person, such as a radiological protection adviser, should select appropriate radiation detectors. Instruments should be used by suitably qualified and experienced staff (such as a health physics surveyor, or a radiation protection supervisor) capable of carrying out the survey while adhering to the appropriate quality control and health and safety rules.

Figure 6.2 ***The output produced from a radiological survey that uses GPS to locate measurement positions***

The selected instrumentation should be appropriate to obtain the data required. Different radiation detectors will be required to detect different types of radioactivity (alpha, beta and gamma). However, in most cases field radiological surveys focus on detection of gamma-emitting radionuclides and, to some extent, of high-energy beta emitters. This is primarily because these are the most penetrating radiations and are easily detectable at distances of tens of centimetres to metres from the ground surface. Identification of alpha emitters or low-energy beta and gamma-emitters is generally not possible during an on-site radiological survey of a contaminated site (see Box 6.3).

Box 6.3 ***Difficulties in detecting alpha radiation and low-energy beta and gamma radiation***

There are certain radionuclides which, because of the types, energies and abundances of their radiations, cannot be detected to appropriate detection limits using field monitoring equipment. Examples include low-energy gamma emitters such as Fe-55 and I-125 and low energy beta emitters such as H-3 or Tc-99. Also, it is generally not possible to detect alpha-emitters on rough or wet surfaces because of their extremely low penetration. This being the case, the use of alpha detectors for walkover surveys of contaminated land sites (where inevitably the soil surface is rough and damp) is not recommended.

In many cases, a suite of radionuclides may be present associated with the processes carried out at the site or the products of a decay chain. In these cases, it is possible to look for more easily detectable radionuclides.

If radionuclides are suspected that are not detectable in the field or associated with other detectable radionuclides, then sampling and analysis will be required.

The main types of radiation detector used for most field radiological surveys are:

- *gas-filled detectors*
- *scintillation detectors*.

Other radiation detection methods are now also used (solid state detectors and passive integrating detectors) in more complex situations.

Gas-filled detectors: radiation ionises the gas within the tube or chamber in the detector. The ions travel to the electrodes, producing a signal, which is amplified by electronics. Common gas-filled detectors include the Geiger-Muller tube and ion chambers, the main characteristics of which are as follows:

Geiger-Muller tubes (for example, mini EP15 alpha and beta contamination meter):

- cannot tell the difference between alpha, beta or gamma radiation
- may sometimes under-read in high activity areas (due to the dead time between counts)
- ion chambers (for example, Eberline RO-2, x-ray and gamma dose rate meter)
- a good response to gamma radiation over a large energy range
- do not easily detect narrow beams of radiation (chamber must be filled with radiation)
- long response time.

Scintillation detectors: radiation interacts with certain materials, causing them to emit light. A photomultiplier tube captures the photons emitted by these materials. The electrical signal is proportional to the light output, which is, under the right conditions, proportional to the energy of the radiation hitting the scintillant. Common scintillants are:

- NaI(Tl) used in sodium iodide gamma detectors
- ZnS(Ag) used in alpha detectors.

Solid state detectors are those using advanced materials such as semiconductors. These detectors are generally used in the same manner as scintillator-based detectors. Advanced materials such as germanium or the recently popular cadmium zinc telluride (CdZnTe) offer better energy resolution, less noise, and better spatial resolution than the standard scintillators. This will allow scientists to carefully measure gamma-ray line emission. Some materials, such as germanium, require more care than scintillators, ie cooling them to low operating temperatures. They also tend to be more expensive.

6.2.2.1 *Choice of instrumentation*

Many different instruments are available for radioactivity surveys. Most of these are based upon the detection techniques given in Section 6.2.2. However, each instrument will be designed to monitor for particular radioactivity types or energies. Also, each instrument will have limitations to its use or may be interfered with by other radiations.

Some of the criteria on which selection of appropriate monitoring equipment should be made are:

- the type of radioactivity present (alpha, beta, gamma)
- the limits of detection required

- the potential for interference
- size/weight of equipment.

Detailed descriptions of some of the advantages and disadvantages of different radioactivity monitors are provided in USEPA (2000) and EA (1999a). The selection of the most appropriate and cost-effective instrument to use for a scanning survey should be made by an appropriately experienced person.

6.2.2.2 *Point measurements*

The most common point measurements made during the characterisation of potentially radioactively contaminated sites are:

- dose measurements
- gamma spectrometry measurements
- alpha measurements.

These measurements are generally not carried out during scanning surveys because the response time of the equipment is often too slow.

Dose measurements are usually made at 1 m elevation (the elevation of the approximate centre of mass for a standing person) and provide a direct measurement of the dose being received at the location. Dose measurements are made to:

- ensure that site staff are not exposed to unacceptable levels of radioactivity
- comply with the IRR99.

Gamma spectrometry measurements are used to provide on-site identification of the type and radioactivity of gamma-emitting radionuclides. This technique is useful because it can:

- limit the number of samples that need to be sent for laboratory analysis
- be used to infer the presence of radionuclides that are difficult to monitor for in the field (eg the presence of the gamma-emitter Am-241 may indicate that Pu-241, the beta-emitting parent, is present)
- provide valuable extra information on sites where the radionuclide fingerprint varies spatially
- provide some discrimination between surface and buried contamination (through analysis of spectra)
- be used to determine how samples need to be packaged in order to comply with the Radioactive Materials Road Transport Regulations 2002 (see Chapter 9).

Gamma spectrometry measures the gamma flux at the position of the detector. To convert this flux into activity per unit volume of contaminated medium (eg Bq/g of soil), it is necessary to define:

- the detector-source geometry (eg a point source or a laterally extensive plane detector in contact with the contaminated medium or some distance from it)
- the distribution of radioactivity in the contaminated medium (eg uniformly distributed or as a thin layer on the surface)
- the radiation attenuation characteristics of the medium.

These factors are then used to define the calculation that is applied to convert from gamma flux to activity per unit volume. There may be uncertainty in the calculated activity per unit volume, because of uncertainty in the input parameters listed on the previous page. If this is the case, some limited sampling and laboratory analysis should be undertaken to confirm the quantitative results from the *in situ* measurements.

The main types of portable gamma spectrometers available are sodium iodide based spectrometers and semiconductor spectrometers. Sodium iodide detectors are generally handheld units that are fairly robust, but with limited spectrometric ability. Semiconductor detectors have a greater ability to distinguish between close gamma energies, but are less robust and significantly heavier (due to the cooling unit required) than sodium iodide detectors.

Alpha monitoring should be carried out by collecting a swab of sample on a piece of filter paper or other appropriate material and (if damp) allowing this to dry. The swab samples are then held against an alpha monitor to determine if alpha activity is present (the thin smear of material minimises shielding of the alpha particles). This technique is for screening purposes only. If detailed information on alpha activities is required, samples should be collected for laboratory analysis. Direct overlay of the alpha monitor on the ground surface is not usually applicable to contaminated land investigations because dampness in the soil shields out the alpha particles. If direct overlay of an alpha monitor does detect contamination, it is likely that much higher activities are present than is indicated by the monitor reading.

Where there may be a beta-only emitting radionuclide present it is difficult to carry out a point measurement unless the activity is close to the surface. This can be done using a scintillation or thin window gas type detector. As with alpha activity it is necessary to take samples for laboratory analysis, but note that this can be a lengthy process for some common beta emitters such as Strontium -90.

6.2.3 Measurement of background radioactivity

The protocols for establishing the background level for a site should be agreed with the regulator. Establishing the background will often involve measurements off-site.

6.2.3.1 *Background for a screening (walkover) survey*

The most appropriate method of determining background during a screening survey is to expand the scope of the screening survey beyond the boundaries of the potentially contaminated area and into an area that is known (or at least assumed) not to be contaminated. The background survey should be carried out at the same frequency of measurement as the survey of the potentially contaminated area or at least enough of it repeated to confirm that it has not changed significantly. The data from outside the area of contamination can be analysed to determine the distribution of background radioactivity (range, mode, mean etc). Background would be recorded in terms of the units used during the screening survey (often counts per second).

6.2.3.2 *Background for a point measurement survey*

For a survey in which point measurements are made, either using radioactivity monitors, or by collection of samples and analysis, a representative number of samples should be collected to evaluate background. Ideally a non-intrusive screening survey would have already been undertaken over both the potentially contaminated area and the background measurement area, increasing confidence that the background point measurements are appropriate. The results of the measurements should be compared to assess the variability in background. If a large variability occurs, further measurements should be made to increase the confidence in the range of background activity.

The total number of background point measurements made will depend to a large extent on the purpose of the site investigation. If the aim of the survey is to identify an area in which contamination occurs at activities significantly above background, few background samples would be required. However, if the aim is to characterise a site more fully, a high degree of confidence would be required in the value of background and so more measurements would be necessary.

6.2.4 The survey grid

While with portable and vehicle mounted GPS linked monitoring it is easier to carry out full areas surveys, many radiological surveys are carried out using a grid, especially if undertaking surface or sub-soil sampling. The scale of the grid should be selected to ensure that it is unlikely that features of interest will be missed, but should be compatible with the proposed survey instrumentation and with the scale of the overall survey area. The scale may vary over the site, to allow for focused surveying in the areas of most interest. The statistical design of surveys is discussed in Section 5.5.2.

The survey grid should be designed to take into account:

- the proposed measurement technique
- the size of the area to be surveyed
- the anticipated size of anomalies that may be present
- the likely depth of any radioactive contamination
- desk study information on potential sources of contamination in the area
- possible obstructions such as buried structures.

6.2.4.1 Locating the survey positions

Radiological surveys are usually located using a grid marked out over the area of interest by conventional *topographical surveying* methods. More recently an alternative approach has been to use GPS measurements to locate survey positions, removing the necessity of marking out a grid on the site. Differential GPS can be used to locate measurement points to an accuracy of better than 1 m. GPS is suitable for locating measurements in open areas with a good view of the sky, but becomes less reliable under trees or close to buildings because of satellites being obscured. Accurate location of measurements made during a survey is important for many reasons:

- to ensure that no parts of the survey area have been missed
- to allow areas of contamination to be relocated at a later date
- to allow the data to be accurately plotted and presented.

Further to these locational techniques, it is also common practice to mark areas of contamination detected on site using spray paint.

6.2.5 Scale of surveying

There are three main methods by which radiological monitoring equipment may be transported:

1 By hand
2 In a ground-based vehicle
3 By air.

The relative advantages and disadvantages of each approach are given in the following sub-sections but it is noted that the choice will depend on the specific requirements on speed, accuracy, and specific local features such as radiation shine from adjacent facilities:

6.2.5.1 *Walkover survey*

This consists of a single person carrying up to about 15 kg of equipment. The walkover survey is suitable for areas up to a few *hectares* (both inside and outside buildings), and may be undertaken over relatively rough ground. As the equipment is carried by a single person, lightweight probes with little *collimation* must be used, limiting the type and precision of radiological measurements that may be made.

6.2.5.2 *Vehicle survey*

This consists of a ground-based vehicle, motorised or hand-pushed, carrying up to about 500 kg of equipment. The vehicle survey is suitable for large (tens of hectares), flat open areas, for example, airfields or roadways. The vehicle survey has several advantages over the walkover survey, which are predominantly due to the increased mass that can be carried and the fact that the vehicle is weather-proof. Sophisticated electronics may be carried that allow real time spectrometry, multiple detectors may be employed and large-area scintillation detectors can be used to achieve low detection limits. With the added ability to include collimation it is possible to reduce the effect of radiation from adjoining facilities. The main disadvantage of the vehicle survey compared to the walkover survey is that the site must be flat and open.

6.2.5.3 *Airborne survey (aeroplane or helicopter)*

This consists of an aeroplane or helicopter carrying up to about 500 kg of equipment. The airborne survey is a rapid method, suitable for very large (thousands of hectares), rough or inaccessible areas. However, it has the disadvantage that individual measurements will be averaged over tens to hundreds of square metres. Also, over-flying restrictions may apply on nuclear-licensed sites and defence sites, limiting the applicability of this technique. An example of Aerial Gamma Spectroscopy (AGS) being carried out on contaminated land is presented in Bechtel (2005).

6.2.6 Quality control

6.2.6.1 *Instrument calibration*

All radiation monitoring equipment should be routinely calibrated in accordance with the manufacturer's instructions. Before use, the following checks should be carried out:

- battery check
- check of the calibration date
- function test, using a source of known activity.

6.2.6.2 *Traceability (data recording and management)*

There are two main methods of recording the data collected during a radiological survey. The first is the manual recording of data in a notebook. The second is direct data capture into a data-logging device. Both methods are capable of recording good quality, traceable data, provided that appropriate quality assurance procedures are adhered to. Both methods have advantages and disadvantages in terms of the quality of data.

Manual recording data – advantages:

- simple to record other features noted during surveying
- simple to make sketches of features.

Manual recording data – disadvantages:

- human error possible (for example, some radiation detectors have manual switches to change between scales. If the switch is incorrectly set, a reading that is too high or too low could be recorded)
- data should be manually transferred from operator notebooks before interpretation and presentation, which can lead to transcription errors
- difficult and/or time-consuming to process large quantities of data
- difficult to record data in poor weather conditions
- needs close supervision to prove that the area has been thoroughly monitored
- during site decommissioning visible features will change, which could lead to confusion. Using survey co-ordinates overcomes this issue.

Automated data recording – advantages:

- once correctly set up, all data collection is automated and there is limited scope for human error
- large quantities of data can be collected and manipulated rapidly
- there is a full quality-assured record of all location and radiological measurements
- data recording in poor weather conditions is possible
- data can be directly transferred to a computer for processing and presentation reducing the likelihood of transcription errors.

Automated data recording – disadvantages:

- possible to set up data-logger incorrectly and record wrong or incomplete data
- more equipment to maintain and check
- data loss could occur if equipment is incorrectly used or maintained
- operator requires more training to use the equipment.

6.2.7 Limitations

Non-intrusive radiological surveys are limited in their applicability by three main issues:

1. The type of radionuclides present: in general a non-intrusive survey can only detect high-energy beta and gamma emissions.
2. The depth of burial/shielding of the radioactivity: a relatively thin layer of soil (can be from 20–200 mm depending on radiation) may shield radioactivity from a detector.

3 “Shine” from nearby buildings/facilities: non-intrusive radioactivity surveys will not be applicable if nearby buildings or facilities are allowing increased levels of radiation in an area that is being surveyed for radioactive contamination. In this case, either increased shielding on the detector would be required (with consequent weight increase) or samples would have to be removed to a low radiation area for monitoring or analysis.

6.2.8 Common mistakes

6.2.8.1 Soil shielding

The most common mistake made during the interpretation of radiological survey data is to assume that if the survey does not highlight any areas of elevated radioactivity, the site is clean. However, the shielding afforded by the soil can significantly attenuate all types of radioactivity, including gamma activity. The ability to detect buried radioactivity will depend on the type of detector used, the type and specific activity of the buried material, the depth of burial and the quantity of the buried material. In many circumstances, gamma-emitting radionuclides buried at greater than a few tens of centimetres below ground surface cannot be detected at surface.

6.2.8.2 Lack of background

Another common mistake is to carry out a survey of radioactively contaminated land, but not to have made any background measurements in uncontaminated areas. Background activities must be known if a sensible determination of the extent of contamination is to be made, see Section 5.6.1.

6.2.8.3 Unsuitable equipment

Many surveys undertaken in the past may have been with equipment that was not sensitive enough to detect very low levels of radioactivity (for example, close to the Radioactive Substances (Substances of Low Activity) Exemption Order (1986) limits). This may have lead to the incorrect conclusion that the sites were not contaminated.

6.3 Surface geophysics

6.3.1 The application of geophysical techniques

Geophysical techniques provide an indirect means of characterising a site before any intrusive works although some geophysical techniques can include intrusive components. For contaminated land sites, geophysical methods that identify variations in the near-surface structure or chemistry of the ground are required (Kearey *et al*, 2002 and McDowell *et al*, 2002).

Many nuclear-licensed sites and defence sites have a long history of development, and it is possible that records on the exact locations of disused disposal sites, underground storage tanks and demolished buildings have been mislaid. Operational sites have many subsurface services (including electrical supplies, water supplies, gas mains, trade waste drains, radioactive waste drains, telephone lines and fibre-optic cables), some of which may not be accurately located on site plans. Buried munitions may be present on defence sites and those nuclear-licensed sites that have been previously used for military purposes.

On nuclear-licensed sites and defence sites, geophysical methods have two principal uses:

1. Identification of subsurface services and munitions, which may be a hazard for intrusive investigations.
2. Characterisation of the geological structure of the site and identification of potential waste disposal pits or subsurface structures (such as buried tanks or foundations) or conduits that may act as preferential pathways (eg old drains).

A geophysical survey will not necessarily identify all features associated with the contaminated land, or all services or munitions in an area. Safe excavation practices should be employed during the intrusive phases of the work (refer to Section 7.2 for information on procedures for undertaking excavations and avoiding services).

6.3.2 Commonly used geophysical techniques

The four methods that are of most use for the investigation of potentially contaminated land on nuclear-licensed sites and defence sites are:

- electrical methods
- magnetic methods
- microgravity
- ground penetrating radar (GPR).

These techniques for the purposes of site characterisation provide surveys of the near-surface environment, typically within 3 m of ground surface, but can for other investigations achieve much greater depths. Other techniques, such as seismic reflection/refraction and other gravitational surveys, provide information on the deeper structure at the site. These techniques are less likely to be used in contaminated land investigations and are not discussed further here.

Features that can be identified by the geophysical techniques include:

- buried objects (in particular concrete and metallic wastes)
- areas of disturbed ground (such as waste disposal pits)
- services (in particular metallic pipes or electrical supplies)
- buried foundations and subsurface voids.

Also, but less reliably, variations in geology, plumes of contamination and groundwater saturation may be detected.

Recent innovations linking geophysical data acquisition with GPS data through sophisticated data processing software have significantly improved the visualisation and presentation of information. Transfer of the information to GIS formats with other layered data allows interpretation against mapped and digital layouts, particularly existing and historical building footprints and services.

Electrical methods are divided into two types:

1. Electromagnetic surveying uses electromagnetic induction to measure the subsurface electrical properties. Electromagnetic surveys generally produce an aerial plot of apparent resistivity over the area surveyed and can be configured to look, with limited resolution, at different depths. These surveys can often identify

buried objects (such as concrete foundations), disturbed ground, metallic services and reinforcing in concrete. They are significantly affected by surface metallic structures and care is needed to avoid anomalous readings adjacent to features such as fences. Electromagnetic surveying is a non-contact technique and has the advantage that it can be used over hard standing without the need for making surface penetrations.

2 Resistivity profiling is carried out by inserting an array of electrodes into the ground surface, passing electrical current through pairs of these electrodes and measuring electrical potential between other pairs. Interpretation of the results gives a depth profile or, using imaging methods, a cross-section of ground resistivity. Resistivity profiling is employed where resistivity data of good vertical and horizontal definition are required or where above ground metallic objects reduce the effectiveness of electromagnetic methods. Resistivity profiling may detect buried metallic objects and changes in ground conductivity.

Magnetic methods are used to map variations in the earth's local magnetic field caused by ferrous objects. Magnetic methods are primarily used to detect buried metallic objects such as cables, drums, pipes or waste materials. They can sometimes also be used to locate areas of fill material. Magnetic surveys can be used to estimate both the depth and mass of an object. The resolution of the method decreases with depth. Surface metallic objects may affect the results of magnetic surveys.

Microgravity techniques are based on measuring extremely small variations in the Earth's gravitational field caused by the presence of materials of different densities, or voids, in the subsurface. The presence of an anomalously high (or low) density buried object causes a localised high (or low) anomaly in the gravitational field. This technique is useful for establishing buried foundations, basements or tanks.

Ground penetrating radar (GPR) systems transmit pulses of electromagnetic energy at microwave frequencies into the ground and measure the amplitude and travel time of the returned signals. The systems are used to detect buried ferrous and non-ferrous objects including plastic pipes, void spaces, drums and concrete. The penetration depth of the electromagnetic radiation, and the maximum detection depth for buried objects, depends on the electrical properties of the soil. GPR works best in low conductivity soils (eg dry sand) and performs poorly on wet clay.

6.3.3 Selection of geophysical methods

The geophysical survey design will depend both on the survey objectives and the site and ground conditions. In most cases, a specialist geophysical consultant should be employed to carry out the geophysical survey and to provide input into its design. As a guideline, a list of typical survey objectives and some appropriate geophysical techniques are listed in Table 6.2.

Table 6.2 ***Typical objectives of geophysical surveys and illustrative techniques to provide the required data***

Objective	Proposed technique
To locate services (note: no technique will guarantee to detect all services. Safe digging practices must be used if services may be present)	• electromagnetic profiling (both in-phase and out-of-phase components) on a 2 × 1 m grid across all accessible areas of the site to detect metallic services and cables • targeted GPR on a 2 × 1 m grid to detect the most significant plastic and ceramic services (such as gas services) • cable avoidance tool (CAT) and signal generator, to be used at all proposed excavation positions to confirm absence of services.
To detect buried pits	• electromagnetic profiling on a 2 × 1 m grid across all accessible areas of the site.
To locate underground structures (eg building foundations)	• electromagnetic profiling on a 2 × 1 m grid across all accessible areas of the site • ground penetrating radar (GPR) targeted into the areas of interest • microgravity surveys targeted at the areas of interest.
To locate non-ferrous and ferrous metal items that could relate to buried munitions	• electromagnetic profiling on a 2 × 1 m grid across all accessible areas of the site • metal detector survey at sampling locations.

Guidance on use of geophysical techniques for groundwater pollution studies is given in EA (2000c).

6.3.4 Downhole geophysics

Geophysical logging of boreholes provides a range of measurement to various physical characteristics of the formations penetrated, physico-chemical indicators of the groundwater flows and quality. Where boreholes already exist on a site and the logging is used for verification purposes the method is essentially non-intrusive, but more often the logging is performed alongside an intrusive drilling programme.

A detailed description of all the techniques available can be obtained from standard geophysical texts and an industry summary is provided in Digby (2001). It is recommended that logs are run in boreholes to maximise the data gathered, and particularly those that have been cored, as recommended in BS 7022:1988. Borehole depth is not necessarily a consideration as to whether logging should take place, but will depend on an evaluation of the costs versus improvement in uncertainty.

Logging should be undertaken before borehole installations are fitted, and so sufficient time in the field characterisation programme should be allowed. The data supplied by the logging is essential to good monitoring well design, to allow well screens to be accurately placed in flow horizons. For low flow sampling equipment to work effectively, placement of pumps and well screens should be dictated by accurate geological and geophysical information.

Logging of existing boreholes with CCTV, particularly with sideways view, is a useful tool to ascertain borehole construction and condition where installations are old and records poor. It is also a technique that can be used to verify installations on newly installed boreholes.

Downhole radiological monitoring is described later in Section 8.4.

6.4 Drains surveys

Drain runs can be the means of access to subsurface contaminated areas, but are often the source or migration pathway for contamination. Drains and sediments within them may be radioactively and/or chemically and/or microbiologically contaminated. Leaks from broken or poorly maintained drains are a potential source of contamination to the surrounding ground. The past and present uses of drains on a site should be determined to identify those drains that may have been used to carry chemically or radioactively contaminated liquids. Also, historical incidents or past practice on a site may have resulted in contamination of drains that were not designated to carry contaminated effluents. The desk study (see Section 5.3.1.1) should be designed to obtain such information. Drain surveys may include:

- radiological surveying of selected manhole chambers and the collection and analysis of drain sediments
- surveying of drain runs using in-drain devices
- closed-circuit television (CCTV) can be used to identify breaks in the drains
- radiological surveying (typically total gamma probes) can be used to identify areas of increased levels of radioactivity. Consideration here should be given as to whether a simple dose-rate measurement or a spectral tool will provide the level of information required for assessment purposes and whether contamination in the drain or the surrounding ground can be differentiated.

Various in-drain devices can be used for drains surveys. Remotely operated vehicles (ROVs) are suitable for larger diameter drains: probes manually pushed along the drain using rods are used for smaller-diameter drains.

Some issues that should be considered when designing drain surveys are:

- sediment build-up in drain runs may prevent deployment of in-drain devices. Washing down the drains before the survey may be required. Facilities should be available to handle, and if necessary treat, the sediments washed out during this process
- the impact of continued use of the drains after the survey should be considered (in particular, the impact of connections to drains outside the survey area should be established)
- calibration of in-drain gamma devices is not straightforward, and depends on the size of the drain and the distribution of any radioactive contamination. The confidence in the quantification of radioactive contamination should be established. If necessary, *in situ* sampling may be undertaken using in-drain devices.

The results from the drains survey should be used to determine (i) whether the drains and sediments within them are radioactive substances, as defined under RSA93 and (ii) whether drains may be sources of contamination of the surrounding ground. In the latter case, targeted sampling of the ground along the drain run should be undertaken using trial pits or boreholes.

7 Site characterisation: intrusive methods

Box 7.1 ***Aims of Chapter 7***

This chapter describes techniques for characterising contaminated land on nuclear-licensed sites defence sites using intrusive methods, but it is not intended to be exhaustive. Only a summary is presented and the reader should refer to existing guidance for further information. Methods are described based on practical experience, highlighting factors that will aid the practitioner in selecting the most appropriate investigation techniques for specific site needs.

7.1 Introduction

Intrusive investigations are carried out to characterise subsurface materials to obtain information on contaminant distribution and on the geological and hydrogeological environment. This information is used to populate and better define the site conceptual model, so that the extent of sources and the nature of pathways in the subsurface can be established, as well as identifying whether the groundwater as a receptor has been affected. Ultimately, detailed investigations and testing will form the basis of any generic or detailed quantitative risk assessment. Also, subsurface investigations may be used to collect samples for delicensing or verification of land condition after remediation where intrusive surveys are used to demonstrate the absence of contamination.

In combination with land quality investigation *geotechnical testing* may also be expediently undertaken. Geotechnical sampling and testing is beyond the scope of this guidance document, although limited mention is made later in Section 8.7.3.

Sample material retrieved from intrusive investigations should be regarded as a resource for other projects. Later stages of the SAFEGROUNDS process such as options comparison may need samples for small scale pilot testing of remediation methods. Geotechnical studies for new builds may also require samples. The cost and benefit of storing and preserving retrieved samples should be considered against the resources to obtain intrusive investigation samples in the future.

Intrusive investigations divide into three main aspects:

1 Health and safety.

2 Techniques.

3 Sample collection.

Many of the health and safety issues have been covered in previous chapters. However, the issue of safe digging practices is important, and discussed here. Both intrusive investigation techniques and sample collection methods have been fully described in many other guidance documents (BS 5930:1999, BS 10175:2001, Harris *et al*, 1995, Scottish Enterprise, 1994 and EA, 2004b) and in the electronic site investigation handbook produced by Nexia Solutions and the University of Southampton (2008). An overview of these issues, with particular reference to features of nuclear-licensed sites and defence sites, is given in the next sections.

7.2 Safe digging practices

Safe digging on a nuclear-licensed site or defence site has three main aspects associated with it:

1. Avoidance of underground services.
2. Avoidance of buried munitions.
3. Radiological monitoring to protect workers and minimise the spread of contamination.

The avoidance of underground services and munitions are discussed in Section 7.2.1. Radiological monitoring issues during intrusive investigations are discussed in Appendix A2. Also, hazards appropriate to working on a conventionally contaminated site must be considered (for example, civil engineering risks and protection against chemical contamination).

7.2.1 Underground services

Safe digging practices should be used during the intrusive investigation, as described in HSE (2000b). Underground services typically present the greatest hazard during the intrusive phase of a site investigation. However, the hazards from overhead services should also be considered (HSE, 1997).

The general process for determining if it is safe to excavate is:

- collect and review service plans of the area in which the works are to be undertaken (either from the site owners/occupiers or from appropriate utility companies)
- identify the positions of all services using non-intrusive techniques (geophysical surveys, a cable avoidance tool (CAT) and signal generator and tracing of services between visible features such as manhole covers)
- if a planned excavation is close to the location of services, consider relocating it (provided the location is not critical to the site investigation)
- if excavating close to the position of a suspected service dig carefully by hand
- excavate carefully and stop should anything unusual be discovered.

It should be noted that:

- service plans may be inaccurate
- not all services may be shown on the service plans.

Nuclear-licensed sites and defence sites will generally have site procedures for excavations, which must be followed. A typical procedure for undertaking excavations at a nuclear-licensed site is given in Box 7.2. Experience suggests that the quality of site service plans provided by site owners/operators for land inside the main security fence of a nuclear-licensed site or defence site are no better than those for services outside the site. If excavating in public access areas owned by a nuclear-licensed site or defence site, it is recommended that the main utilities providers for the region are contacted, and where necessary the Highways Agency. This is to ensure that their service location plans can be checked for agreement with the site plans.

7.2.2 Buried munitions

Buried munitions may be present on both nuclear-licensed sites and defence sites. If the desk study has indicated that munitions could be a potential hazard at a site, a procedure must be established to ensure that drilling into such objects does not occur. It is recommended that site-specific advice be sought from a specialist munitions adviser, and that SQEP professionals are engaged on the investigation. CIRIA will produce the first UK good practice guidance to help developers and clients deal with UXO in 2009 (Stone *et al*).

Box 7.2 ***A typical procedure for undertaking excavations at a nuclear-licensed site***

1. Production of a plan showing the areas of proposed excavations.
2. Production of service plans of the areas by the licensee.
3. Selection of proposed excavation positions by the contractor, taking into account the service plans. Agree this plan with the licensee.
4. Cable avoidance tool survey of the proposed excavation positions by the contractor. If the proposed excavation positions are free of services, positions are marked out using spray paint (ie avoid penetrating the ground at this stage). If services are found to be present, alternative positions are agreed with the licensee.
5. Confirmation by the licensee that the excavation positions marked on the ground correspond with the proposed positions, and that the cable avoidance tool survey has been completed.
6. Production of an excavation permit by the licensee. The excavation permit would typically include a second set of service drawings and approvals from all interested parties (health physicists, appropriate building managers etc) for the excavations to proceed.
7. Issue and signing off of excavation permit by the licensee.
8. Issue and signing off of permit to work by the licensee's project manager.

Notes: also a cable avoidance tool should be provided on site, and used regularly during the excavations by suitable qualified and experienced personnel (SQEP).

Some establishments will require hand digging to about 1.2 m to start all excavations if services are in the vicinity.

Should any excavation need to be relocated, this entire procedure would need to be repeated for the new location. However, the permits would only require modification rather than re-issue.

Approvals are required from interested parties such as health physicists so that, if necessary, special instructions can be given on issues such as radiological hazards and monitoring requirements.

The following are some of the objects that could potentially be discovered:

- small arms ammunition rounds are typically non-ferrous and have a major dimension of around 50 mm. Although these may be present, they are a low hazard if found
- anti-aircraft shells, hand grenades, mortar bombs and thunder-flashes containing high explosive and/or phosphorus. These have a typical major dimension of at least 100 mm and contain ferrous parts. These would present a hazard if found or disturbed
- bombs are typically upwards of 500 mm in dimension and most contain ferrous components (aluminium casings are a potential problem). Shells can also have dimensions greater than 500 mm. Bombs and shells could be extremely hazardous if found or disturbed
- other buried containers that can be breached such as ammunition boxes.

During site characterisation, the greatest hazard could arise from drilling into the soil and encountering a shell or bomb. In this circumstance, the obstruction to drilling may not be identified and drilling may continue on the *assumption* that a piece of concrete has been encountered. The hazard is decreased by trial pitting on such sites, because munitions can be rapidly identified and works stopped. The procedure for investigating a site containing munitions is:

1 Undertake a desk study of the area to evaluate the potential for munitions to be present. If the desk study indicates a high potential present, it is advisable to consult a specialist munitions adviser. The results of the desk study would be unlikely to change the overall characterisation approach. However, if there is a high risk that munitions may be present, greater care should be taken during the excavation process.
2 Undertake a geophysical survey across the site to identify the positions of buried metallic (ferrous) objects. Appropriate geophysical techniques for detecting buried metallic objects are described in Section 6.3. However, advice from a specialist geophysical contractor should be sought so that the most appropriate geophysical technique for the site is employed. The geophysical survey should produce a map showing the locations of suspected buried metallic objects.
3 The results of the geophysical survey can be used either to plan the site characterisation so as to avoid all areas with suspected buried metallic objects, or to ensure that, if excavation should be undertaken near to buried metallic objects, the appropriate level of caution is exercised. In the majority of cases, buried metallic objects will not be munitions.
4 Excavation to identify buried metallic objects should be undertaken with care. Borehole drilling methods are not appropriate. An appropriate method would be to use an excavator to carefully remove about 20 cm thick layers of soil to expose the metallic object(s). An experienced banksman or dig warden should be present to observe the excavation and determine if the object has been located. This method of approach should allow munitions to be identified at an early stage, before they are significantly disturbed or punctured. If munitions or objects that may be munitions are discovered on nuclear-licensed sites, the site police must be informed. The site police will then involve the appropriate civilian and military authorities. Note that the civilian authorities will make the occurrence public and media interest may result. The licensee should inform the NII if buried munitions are later found. Where potential munitions are located on MoD sites, the contractor must report the find to the MoD on-site contact, who will call in the appropriate assistance.

7.3 Radiological monitoring during intrusive investigations

Radiological monitoring is undertaken during intrusive investigations for four main purposes to:

1 Protect the health and safety of workers.
2 Minimise the spread of contamination.
3 Provide environmental data.
4 Characterise for waste management purposes.

Radiological monitoring should be undertaken during all intrusive investigations where radioactive contamination may be present. In the context of this guidance, this means that radiological monitoring should be undertaken during all site investigations.

An appropriate monitoring regime for an intrusive investigation follows.. Selection of appropriate monitoring equipment:

- this should be determined by an appropriately trained person, such as a RPA
- monitors should be selected to detect the radionuclides expected to be present on the site
- monitors should be sensitive enough to ensure the safety of site workers, to enable on-site screening and selection of samples and to enable waste segregation (if required).

Monitoring of the ground surface before excavation at that location:

- this should be carried out extra to any previous radiological surveying works over the area, to ensure that the extent of the surface radioactive contamination is known.

Regular monitoring of the excavation:

- in trial pits and window sample holes, a probe can be lowered into the excavation to detect if radioactivity is present. Where it is not safe to approach an open excavation, the trial pit arisings can be monitored. This provides a sensitive measure of the first occurrence of radioactive contamination, which is detected before the contaminated material is excavated. (Note that the background level of radioactivity detected during excavation will alter as the excavation becomes deeper, because of geometrical effects and because different soil horizons are encountered).

Regular monitoring of the spoil generated during the excavation process:

- will ensure that any buried radioactive contamination will be detected in the spoil produced by the excavation process
- allows the spoil to be monitored at regular intervals, and any changes in radiological contamination should be noted.

Regular monitoring of soils to aid in the sample selection process:

- see Section 8.2.

Monitoring on completion of each excavation:

- staff should be monitored to ensure that they have not been contaminated with radioactivity
- the ground surface should be monitored to ensure that it has not been contaminated with radioactivity
- the excavation equipment should be monitored to determine if it has become contaminated with radioactivity (in which case decontamination will be required, and also any routine cleaning procedures taken to minimise cross-contamination)
- the outside of the sample containers should be monitored to ensure that (i) there is no loose surface radioactive contamination and (ii) any external radiation levels do not present a hazard to staff.

Monitoring on completion of the intrusive phase of the site investigation:

- all equipment used in the investigation should be monitored and a radiological clearance certificate issued by the relevant health physicist
- all samples should be monitored and issued with the appropriate documentation (eg a radiological clearance certificate for uncontaminated samples) before being transported to the laboratory.

7.4 Types of intrusive investigation

Samples collected during the site characterisation will be of the following types: soils and rocks, surface water and groundwater, and soil gases. Soil samples are collected either manually, by hand-digging or by using an auger, or mechanically, using an excavator (for trial pits), window sampler, or drilling rig (for boreholes). Various penetrometer techniques may also be used to obtain samples by pushing a sampling device into the ground, with the advantage that no spoil is produced. The general advantages and disadvantages of these techniques are presented in Table 7.1, but they are by no means exhaustive or systematic.

Each method should be appraised for its appropriateness in a given situation. Groundwater samples are generally collected from boreholes that are either temporarily or permanently cased or on occasions from trial pits. Gas samples are generally collected from temporary shallow probes or from boreholes completed as ground gas monitoring points.

7.5 Methods of intrusive investigation

There are several methods of excavating into the subsurface. Many of these methods have been described in detail in other guidance (BS EN 1997-2[11], BS 5930:1999, BS 10175:2001, Harris *et al*, 1995 and Scottish Enterprise, 1994). An outline of the methods that are applicable to nuclear-licensed sites and defence sites is given in Table 7.1. Particular reference is made to the specific details that make techniques more or less suitable for use on potentially radioactively contaminated sites. Of particular relevance are excavation techniques that minimise the amount of spoil generated, and minimise the potential for contamination to be spread around the excavation area. All of the methods described are technically valid, but their applicability will vary depending on site conditions and on the requirements of the survey. All requirements should be discussed with potential specialist contractors.

Because trial pits generate large quantities of spoil, their use should be minimised in areas known to be radioactively contaminated. Important aspects to be considered are:

- field logging
- minimising *cross-contamination*
- backfilling with, and disposal of, soil
- development pumping
- radiological clearance of equipment.

These are discussed in the next sub-sections.

7.5.1 Field logging

It is important to log all relevant information when carrying out an intrusive investigation following BS 5930:1999 and BS EN ISO 14688-2. As a minimum, such information should consist of:

- location of excavation and location number
- depth of excavation

11 Eurocode 7: *Geotechnical* is part published. Once fully published a period of co-existence with the existing BS 3950 will occur. The Eurocode will not be ready for use until its national annex is published on 31 August 2009.

- type of excavation
- date and time of excavation
- descriptions of the soil/rock/made ground with depths
- the depths, numbers and types of samples collected
- depth to groundwater
- presence of visible contamination or odours
- manmade structures
- field monitoring information (gamma monitoring, dose monitoring)
- backfilling details
- photographs taken.

The Association of Geotechnical and Geoenvironmental Specialists[12] has prepared the AGS-M format that caters for geotechnical, structural and geochemical data and is widely used. It provides a standard format for the transfer of data between a data provider and a data receiver.

7.5.2 Minimising cross-contamination

Cross-contamination of samples should be minimised by:

- selecting appropriate investigation and sampling techniques
- decontaminating equipment between sampling locations.

The main methods of minimising cross-contamination between different layers in the ground during excavation are:

- when trial pitting the spoil should be carefully segregated and replaced in order of excavation. The pit should be dug taking small scoops and it should not be enlarged beyond the horizons that are required to be characterised.

However, drilling techniques may be preferable to trial pitting, and:

- when drilling, use a method that installs a temporary or permanent casing to isolate different soil layers, with the installation of aquifer seals (EA, 2006b)
- if using a percussive method such as window sampling, remove the smeared layer from the outside of the core before samples are collected.

Between sampling locations, all equipment that has come directly into contact with the contaminated soil or groundwater should be cleaned. Cleaning will normally be carried out using a pressure washer or steam cleaner. The wash water from the cleaning process should be contained, tested and disposed via an appropriate route. It is good practice to sample first those areas that are expected to be least contaminated, and to work towards the most contaminated areas.

To minimise the potential for contamination to be spread, all excavation sites should be kept clean and tidy. One method of minimising the spread of contamination is to use polythene ground sheets or boards to prevent potentially contaminated spoil from mixing with uncontaminated surface soil. Use and disposal of these protective materials should be considered as part of the SWMP (see Chapter 9).

12 <www.ags.org.uk>.

7.5.3 Backfilling with, and disposal of, spoil

Spoil will be generated during intrusive investigations. Small quantities will be generated by drilling boreholes, and larger quantities will be generated during the excavation of trial pits. There is a potential for backfilled excavations to lead to future cross-contamination of the site (for example, by backfilling contaminated spoil at a depth beneath its current position on the site). So the approach to backfilling excavations with spoil should be addressed as part of a site waste management plan (SWMP) (Chapter 9), and agreed with the relevant environment agency before proceeding with the work.

Where contamination is detected in the field or is visible, the environment agencies will probably require that the excavated material is disposed as waste because it can strictly be considered an illegal disposal under RSA93, and that the excavation is backfilled with clean imported material. If contamination is not detected or seen in the field, a pragmatic approach could be to backfill excavations with spoil pending the results of laboratory analysis. This avoids the need either to create large volumes of (potentially unnecessary) waste or to leave excavations open until analysis has been completed (with the associated risks to safety). In any case it is important to discuss the situation with the relevant regulator.

When characterising known contaminated ground, the relative volumes of waste produced is one of the issues to be considered when deciding between the use of trial pits and boreholes (see Table 7.1).

In areas of known contamination characterisation methods and techniques should be discussed with the regulators to minimise waste arisings and to decide upon interim storage or disposal of any waste generated. Circumstances may arise where regulator approval is required before to replace contaminated spoil into an excavation where it was obtained. For example, when the external doses being received from the material are excessive, the material may be returned to the borehole (as storage rather than disposal) to reduce the immediate radiation hazard.

Backfilling with spoil is not acceptable for boreholes that penetrate an aquitard separating two aquifers: a low-permeability seal is required to prevent continued cross-flow through the borehole after it has been abandoned. Good practice on backfilling investigation holes is provided by the EA (1999b and 2006).

Surplus drilling spoil and samples not required for analysis are waste materials and should be disposed of appropriately.

A discussion of solid and liquid waste management procedures is given in Chapter 9.

7.5.4 Development pumping

Where boreholes are to be installed with well completions, it is good practice to pump the boreholes before and/or after installation to clear out the drilling debris and reduce the likelihood of any flow horizons being blocked or smeared. This process can generate large quantities of water. Methods of managing contaminated pumped water are discussed in Sections 8.5.2 and 9.2.2.2. Geophysics, through good characterisation of formations, can assist in the decision making as to the need and benefit of borehole development.

7.5.5 Radiological clearance of equipment

On completion of the site works in a potentially radioactively contaminated area, it is good practice to have all site investigation equipment radiologically monitored and a radiological clearance certificate issued. In radiologically designated areas, it will be necessary for equipment to be monitored and a clearance certificate issued before permission will be granted for the equipment to be removed from the site.

Table 7.1 ***Techniques for intrusive sampling***

Technique	Outline of method	General advantages	General disadvantages
Hand-digging	Dig with spade hand-dug pits to about 1 m, and sub-sample with trowel	• samples can be collected from any surface location • base of hole can be monitored during excavation • little equipment is required • low potential for contamination to be spread • low risk of damaging services • cheap.	• maximum depth of surface samples ~0.5 m • maximum depth of hand dug pits ~1.0 m • disturbed samples are collected.
Hand-augering	Use of hand auger to drill holes in soft materials to a depth of about 1 m	• little equipment required • cheap • samples can be collected in areas with poor access.	• maximum depth of sampling 1–2 m • samples are significantly disturbed and there is a high potential for cross-contamination of layers • only appropriate for fine grained soft sediments
Trial pitting	Use of tracked or wheeled excavator to dig trial pit to <6 m depth	• large volume of soil exposed – sampling and logging more representative • observations of base of trial pit can be used to identify potential hazards • base of excavation may be monitored for services and contamination as trial pit progresses if safe to approach/enter excavation.	• large quantities of potentially contaminated waste materials brought to ground service (see Chapter 9) • medium risk of damaging services (unless banksman identifies marker tape etc) • maximum depth 6 m. Note that the trial hole will often collapse when groundwater is encountered • excavation sides unstable – unsupported excavation may require shoring • monitoring undertaken on disturbed samples brought to surface.
Borehole drilling	Window sampling	• small quantities of waste produced • core can be produced in clear plastic sleeves • simple to monitor cores • to select samples and for health and safety purposes • relatively quick • cheap • rig moves affordable where ground penetration difficult • possible to use in special restricted areas.	• maximum depth usually < 5 m • samples are usually compacted • small quantities of samples are recovered • samples are not suitable for many geotechnical tests • difficult to identify water strikes • not very reliable in granular soils and easily stopped by stones.

	Cone penetrometer	• small quantities of waste produced
		• relatively quick
		• cost-effective
		• CPT equipment can be used to drive monitoring installations into the ground
		• provides CPT geotechnical information *in situ* from shear strength and relative density to stiffness and dynamic properties of the soil
		• reliable – UKAS accreditation and calibration available
		• immediate results on screen, site plots, and via email
		• continuous soil data at <2 cm depth intervals
		• repeatable results – operator independent
		• geo-environmental cones can be used alongside to detect presence of:
		  ○ landfill leachate
		  ○ methane
		  ○ ionic chemicals
		  ○ hydrocarbons
		  ○ chlorinated solvents
		  ○ radioactive contamination.
			• no sample recovery
			• penetration largely depends on geology. Unable to penetrate dense materials or deposits containing cobbles or boulders
			• maximum depth usually < 30 m
			• difficult to identify water strikes
			• risk of smearing clays and blocking drive-in monitoring wells
			• unable to seal off discrete layers
			• cannot be used in relatively confined spaces as the vehicle used to drive down the cone is large.

Table 7.1 (contd) ***Techniques for intrusive sampling***

Borehole drilling	Solid stem rotary augering in soils/weak rocks	• relatively fast • little or no drilling fluids required • suitable for the installation of permanent groundwater or gas monitoring installations • can undertake inclined drilling for sampling under buildings etc.	• high potential for cross-contamination of samples • depth resolution poor • not appropriate for coarse gravely materials.
	Microdrilling (small volume drilling) – various approaches	• rapid • cheap • less accessible places • all material collected by drilling is sample • ideal for immediate analysis • no secondary wastes.	• shallow samples <1 m.
	Sonic drilling	• sample recovery excellent • no need for drilling fluids, blasting air, spillings and cuttings. • very little smearing and limited cross-contamination • rapid installation of prefabricated wells • low noise production compared to hammering • forces much better controlled than hammering • extremely limited or no use of water, no water injection • rapid progress in "suitable deposits" • less waste spoil generated.	• vibration of drill bit causes heating of the bit and volatilisation of volatile organics, so it is unsuitable for obtaining volatile and semi-volatile samples for analysis • guaranteed progress to depth is expensive • typically it shatters competent rock rather than recovers core intact.
	Cable percussive in soils/weak rocks	• suitable for a wide range of materials • suitable for *in situ* geotechnical testing and geotechnical sampling • good definition of depth of materials • little or no use of drilling fluid • suitable for the installation of permanent groundwater or gas monitoring installations possible to use low-head room rigs for sampling in difficult areas.	• drilling process produces relatively large quantities of spoil (although less than trial pitting) (see Chapter 9) • driller's mate closely involved with drilling process and has relatively high potential to become contaminated • relatively slow • can be regarded as noisy • maximum depth tens of metres depending on material • difficult to keep drill site clean and tidy • difficult to use in subsurface where boulders and cobbles are present, and considerable chiselling time can be spent.
	Hollow stem rotary augering in soils/weak rocks	• relatively fast • good quality samples • good depth definition • suitable for the installation of permanent groundwater or gas monitoring installations • can undertake inclined drilling for sampling under buildings.	• not appropriate for coarse gravely materials.

	Rotary drilling in rock (truck or mini-rig mounted)	• rapid drilling possible
		• can be used to drill through overburden using rotary-percussive drilling
		• maximum depth hundreds of metres
		• good quality core and samples
		• suitable for the installation of permanent groundwater or gas monitoring installations.
			• expensive drilling fluids may contaminate samples and surrounding rock, if required
			• management of drilling fluids encountering radioactive contamination is a major issue, including:
			  ○ extra space needed for management of drilling fluids
			  ○ difficult to dispose of drilling fluids and cuttings (see Chapter 9)
			• difficult to monitor drilling cuttings if open hole drilling, and better to core drill to ease waste management issues
			• truck-mounted rigs not suitable for spatially restricted areas.

8 Site characterisation methods: sampling and analysis

Box 8.1 ***Aims of Chapter 8***

> **Guidance is given on obtaining solid, liquid and gas samples for analysis in the field (real time data collection) and for laboratory analysis. Procurement of accurate chemical and radiological analyses is discussed.**

8.1 Introduction

This section introduces the sampling and analysis methods of site characterisation. This is not exhaustive, but guides the reader to further information. Sample location selection has been described earlier in Section 5.5.2, and guidance in this section is given on the collection process of each soil, liquid or gas sample, and the growing area of real time data collection using sensing techniques and on-site analyses. Downhole radiological analyses are a specific area of real time measurement, which is particularly useful on nuclear-licensed sites and defence sites. Describing the samples obtained (physically, chemically and radiologically) and recording their location is fundamental to site characterisation. Accurate mapping of this data enables visualisation of the nature and extent of contamination using GIS techniques, calculation of the volumes of soil or water that require management, and enables return to locations for verification or remediation control.

8.2 Soil and rock sample selection

Sampling patterns are discussed in Section 5.5.2, and here the types of samples collected at those locations are described. Soil and rock samples are of two main types: mechanically disturbed or undisturbed. Mechanically disturbed samples are generally adequate for contamination surveys, whereas mechanically undisturbed samples are typically required for geotechnical surveys. There are three main methods of selecting soil and rock samples in the field:

1. Sampling from predefined depth intervals
2. Sampling based on visual features (ie from different geological units or different layers of made ground)
3. Sampling based on the results of radiological or chemical monitoring.

When excavating on a potentially contaminated site, radiation monitors may be used to identify the excavated material with the highest levels of radioactive contamination. This information can then be used to focus sampling, ensuring that at least some of the samples containing the highest levels of radioactive contamination are selected. Care should be taken to avoid over-estimating the volume of contaminated material present if only the most radioactive samples are selected for analysis.

In any survey, it is important (i) that samples are representative of ground conditions and (ii) that sufficient material is collected to enable all required analyses to be undertaken (including sufficient material for repeat analysis, should this be necessary). The sample size can be significant when undertaking radiological measurements. For example, the time taken to analyse for gamma-emitting radionuclides to a specified detection limit by gamma spectrometry is about inversely proportional to the weight of sample analysed. In general, it is sufficient to collect about 500–1000 g of sample in an appropriate container for gamma spectrometry analysis.

Certain other analyses require extra field sample preparation. For example, analysis for tritium or volatile organic compounds typically require the soil or rock sample to be stored in a sealed septum vial immediately after collection, the aim being to prevent the loss of volatile compounds during transportation to the laboratory. The chemical or radiochemical analyst will provide advice on the volumes of samples required and on any field preparation required (for example, the addition of ultra-pure water).

In some cases, for example when remediation of the site is a probable outcome of the site characterisation and where a large *averaging volume* has been agreed with the appropriate regulator, it may be appropriate to homogenise samples from a large volume of material.

8.2.1 Disturbed sample collection

Disturbed soil may be brought to ground surface using any of the intrusive investigation techniques listed in Section 7.4 and Table 7.1. Disturbed samples are generally collected from the spoil produced by the excavation process, using a tool such as a stainless steel trowel, and placed into the appropriate sample containers (as supplied or advised by the analytical testing laboratory).

It will often be necessary to characterise areas of made ground or coarse-grained soil (such as glacial till or rock fill). Consideration should be given to the conceptual model to decide how the contamination got into the soil and whether the coarse fraction (ie surface contamination on coarse gravels, cobbles and boulders) is important to characterise. Both geotechnical and the chemical laboratories should be consulted for the most appropriate techniques of analysing such contaminated materials.

If it is not appropriate (given that contamination is more likely to be concentrated within the finer-grained fraction) to analyse these coarse-grained components of the soil then this fraction should be discarded (> 2mm), and only the finer-grained fraction sent for chemical and radiochemical analysis. The proportion of unsampled material should be recorded to enable the measured contaminant concentration in the finer-grained component to be corrected (ie diluted), if required, to account for the presence of the coarser fraction.

It is good practice to consider the extent of any bias introduced by analysing only the finer fractions of the soil samples. This can be achieved by grinding and homogenising soil samples (at least the sub-pebble-sized fraction), and analysing the resulting sample. If tritium and analyses for volatiles is required, then a sub-sample should be taken before grinding the sample for any other radiochemical analysis.

8.2.2 Undisturbed samples

Relatively mechanically undisturbed soil samples are generally collected by using one of the standard drilling techniques (such as cable percussive drilling or coring through the centre of a hollow stem auger). The samples are usually collected using an open tube sampler, such as a U100 tube or a plastic core liner. Rotary coring is typically used to obtain mechanically undisturbed rock samples.

8.3 Real time collection of data

The collection of real time data is a developing area with improvements in instrumentation and miniaturisation of technologies. Some of the most difficult contaminated land problems are found on nuclear-licensed sites and defence sites, and it is here that there is potential for real time data collection methods to flourish. The fast gathering, interpreting and sharing of data helps real time decision making. The range of technologies with real time measurements includes field analytical instrumentation, *in situ* sensing systems, geophysics and computer systems that assist project planning, and store, display, map, manipulate and share data. Real time measurement is one of the three elements of the Triad approach (Crumbling, 2004).

Real time radioactive data collection has already been highlighted in Section 6.2. Geophysical acquisition of subsurface real time data is discussed in Section 6.3, and CPT geo-environmental probes are cited in Table 7.1.

Real time monitoring is suitable for other forms of physico-chemical parameters. The use of data-loggers to record groundwater fluctuations is an established technology, but other parameters could be monitored, particularly for water quality, as the technologies develop offering:

- high frequency data collection
- smart technology enabling conditional water sampling
- *in situ* calibration
- data retrieval via telemetry/mobile phone links.

Tests for chemical or radioactive contaminants can be carried out on site, as opposed to sending samples to a laboratory for analysis. In general, field tests provide indicators of contaminant concentrations, rather than actual concentrations. The Environment Agency advocates the use of *in situ* testing to complement MCERTS laboratory analysis (EA, 2006c). Examples (Nathanial, 2002) of commonly used field tests for non-radioactive contaminants in soils are:

- immunoassay techniques (measures relative concentrations of selected organics, eg VOCs, PAH)
- headspace analysis (FID or PID measurement of volatiles)
- field chromatography
- biosensors (eg enzyme systems, antibodies, deoxyribonucleic acid or microorganism)
- colorimetric test strip (wet chemistry, but not immunoassay)
- mobile XRF for metal analysis
- membrane interface probe.

Samples taken in the field may also be analysed in a mobile laboratory to obtain better detection limits, but care should be taken to protect against high background, particularly for radioactivity analyses.

The real advantage with collection of real time data is that it is quick and often relatively cheap, particularly on complex nuclear-licensed sites and defence sites. It also provides an instant result and can be used to direct investigation immediately. However, the quality of real time data should always be assessed against the quality criteria set for the project. Back-up off-site laboratory verification will be required for radioactive and non-radioactive contaminants, particularly where the data gathered is sent to the regulators.

8.4 Downhole radiological measurements

Downhole radiological measurements complement non-intrusive radiological surveys (see Chapter 6, and particularly Section 6.3.4) and radiological monitoring during intrusive investigations (see Section 7.3). The technique, which gives information on the distribution of radioactivity along the borehole axis, can be used in three situations:

1. In conjunction with permanent monitoring points (eg downhole logging of groundwater monitoring boreholes).
2. During construction of conventional temporary sampling boreholes from which soil and/or water samples are being collected (see Section 7.4).
3. In conjunction with temporary percussive holes from which no waste or sample are produced at surface (eg cone penetrometer testing, see Section 7.4).

Downhole radiological measurements can be used to improve targeting of samples taken for later laboratory analysis or to provide interpolation between sparse data from borehole samples (eg where contamination of bedrock is focused in fractures that may be difficult to sample, or where drilling conditions lead to depth intervals where no solid material is returned to surface for sampling). Also, the third situation is useful for characterising areas where there is relatively high contamination by gamma-emitting radionuclides, because measurements can be made without the need to produce waste.

In all applications of downhole measurements, it is necessary to consider the following:

- the penetrating power of the ionising radiation in the soil or rock around the borehole, in any borehole construction materials (such as casing) and in the air or water filling the borehole. Downhole logging is most appropriate to determining the distribution of gamma-emitting radionuclides
- calibration of results. The technique provides information on the distribution of areas of elevated radioactivity. Accurate calibration to derive specific activities (eg Bq g^{-1} of soil) requires information on source-detector geometry, on the spatial distribution of the radionuclide and on the attenuation characteristics of the radiation. If quantitative information on specific activities is required, laboratory analysis of samples will be needed to build confidence in the calibration
- the susceptibility of the approach to any external contamination of the detector assembly. It is important to monitor for surface contamination on the detector at frequent intervals and to evaluate results with caution if surface contamination is detected.

It is also necessary to consider the consequence of repeated purging of groundwater monitoring boreholes on downhole radiological measurements. Purging leads to some of the fine-grained material from the formation being drawn into the filter materials placed around the well screen (if these are present) or into the borehole itself. In the latter case, the material settles to the bottom of the borehole (silting up the well). Because radioactive and other contamination is often concentrated on the fine-grained fraction of the soil or rock, this redistribution of material can have a significant effect on downhole radiological measurements. In the extreme case, downhole measurements may be dominated by radioactivity from contaminated silt at the bottom of the borehole. For this reason, it is good practice to undertake downhole radiological measurements before groundwater sampling. Where this is not possible, data from downhole radiological measurements should be interpreted with caution.

8.5 Liquid and gas sampling

8.5.1 Installation of permanent monitoring points

All of the borehole drilling methods described may be used for the installation of groundwater or gas monitoring points. The main issues to consider when selecting the drilling technique are:

- achieving the project monitoring objectives
- confidence that the drilling technique can achieve the required depth of penetration at the required borehole diameter
- health and safety issues, such as the potential generation of airborne contamination during drilling (eg if air-flush rotary drilling is the selected technique)
- any limitations on the use of a flushing medium (eg air, foam, water), which may compromise sample quality
- environmental issues, such as spreading of contamination in the ground and control of drilling returns
- speed and cost.

Trial pits may also be used for the installation of shallow monitoring points by carefully backfilling around the monitoring equipment. However, it should be noted that a large volume of soil would be disturbed and this may affect the results obtained during monitoring.

Details of the design, construction, installation and commissioning of permanent groundwater and gas monitoring points are beyond the scope of this guidance document. Readers should refer to the extensive guidance already available on the subject (EA, 2006b and Wilson *et al*, 2007b).

8.5.2 Groundwater sample collection

Groundwater sampling methodologies are described in detail in other guidance documents (BS 6068-2, ISO 5667-18). An outline of the methodology follows. Groundwater samples are generally collected by one of two methods:

1. Pump sampling.
2. Bail sampling.

The method used will depend on the feature from which the groundwater sample is being obtained (completed borehole, temporary cased borehole or trial pit) and on issues such as the amount of suspended sediment present and the permeability of the surrounding material. Usual practice is for trial pits to be bail-sampled and for boreholes to be pump-sampled.

Pump sampling is the preferred method of sampling from a borehole because a large volume of water can be withdrawn before collecting the sample, ensuring that the sample is representative of the groundwater in the rock mass rather than that in the borehole. It is good practice to withdraw three borehole volumes of groundwater before collecting samples, or to carry out in line monitoring (for electrical conductivity, pH etc) and to sample after measurements have stabilised. Where it is difficult to remove three volumes because of slow recharge, an alternative approach is to empty the borehole and then sample once refilled.

When pump sampling a borehole on a nuclear-licensed site or defence site, adequate provision should be made for disposal of the wastewater generated (see Chapter 9). Direct disposal of radioactively contaminated water to ground, or by a surface water body, will not be possible. Similarly, disposal of chemically contaminated water to ground or by a surface water body would require authorisation from the Environment Agency. So pumping to bowser or to storage containers (drums or intermediate bulk carriers IBCs) for disposal via an approved route is recommended.

Use of low-flow pumps that are carefully located in well characterised and designed boreholes can limit the amount of liquid waste generated. Use of geophysical logging to optimise borehole installation and vertical sampling locations is recommended (see Section 6.3.4). These systems are designed not to pump out three borehole volumes, but to directly draw into the borehole, the aquifer water from a flowing horizon. The discharges of the pumps should be monitored for physico-chemical parameters (temperature, conductivity, pH and Eh), and samples should only be taken once these parameters have stabilised and indicate aquifer representative water is being taken. Even these pumps will generate some liquid waste.

Radiological monitoring using standard field instruments will typically not detect contamination in water samples because the radionuclides are often present at much lower *activity concentrations* than in soil and may only emit “soft” beta or alpha radiation. Laboratory analysis of groundwater samples for radioactivity is generally required. For example, this is the case for tritium, a “soft” beta emitter, which is a common radioactive contaminant found, as tritiated water, in groundwater in the vicinity of some nuclear-licensed sites and defence sites, see Section 8.8.6. Tritiated water is highly mobile in soils and groundwater. Naturally occurring dissolved radon/radon daughters are also likely to be present.

The selection of suitable sample containers and preservation techniques (typically involving refrigeration or the addition of acid or alkali to prevent precipitation or degradation of the sample) is discussed in existing guidance, for example EA (2003b and 2003c) and is not considered in detail here. Exact requirements should be discussed with the analysts, and these may change depending on the method of analysis used and the limit of detection required.

Discussions with the laboratory should take place as to which groundwater samples should be filtered (typically to 0.45 µm) in the field before adding the preservative. Samples for inorganic analyses are more likely to require filtration to remove particulates, but samples for organic analyses are not usually filtered because this would remove the compounds (eg on the membrane surface or on colloids) that are being investigated. It is good practice (i) to refrigerate groundwater samples to about 4°C after collection and before analysis, (ii) to store samples in the dark and (iii) to minimise sample storage time. This is particularly important for analysis of organic compounds, which may otherwise degrade during storage. In practice, refrigeration of large samples (around five litres) for radionuclide analysis is impractical and is not necessary. An illustrative groundwater sample storage and preservation scheme is shown in Table 8.1. The exact nature of the preservation chemicals should be identified to ensure that the chosen method of preservation does not interfere with any later laboratory testing, and for completion of COSSH assessments as part of the HSSE planning (Chapter 3).

Table 8.1 ***Illustrative scheme for storage and preservation of water samples***

Determinand	Container	Preservation
All radionuclides except tritium	5 litre HDPE	Acidified
Tritium	0.5 litre darkened glass	None, with minimum air space
Metals	1 litre HDPE	Acidified
Cyanide	0.1 litre HDPE	Alkaline addition
Major ions and anions	250 ml HDPE	Acidified
Non-volatile and semi-volatile organics	1 litre amber glass bottle	None
Volatile organics	Glass serum vials (sealed with PTFE-faced rubber septum)	None

8.5.3 Sampling of non-aqueous-phase liquids

Non-aqueous-phase liquids (NAPL) divide into two types: light NAPL (LNAPL) or dense NAPL (DNAPL). These types are less dense and denser than water respectively and so will either float on or sink through the groundwater.

Sampling DNAPLs is extremely difficult, primarily because the probability of intersecting a pool of DNAPL in the base of an aquifer, and having the DNAPL flow into the borehole, is low. DNAPL is usually inferred to be present in an aquifer by, for example, high or increasing dissolved concentrations with depth, or from records of known disposals. The sampling of DNAPL is not discussed here, but further information on DNAPLs is provided in Fetter, 1998.

The sampling of LNAPL may be carried out in many ways, provided that the borehole is of suitable design (the screen section of the monitoring point should extend from just above to below the zone of water table fluctuation). The most common and simplest method of sampling is to bail a sample from the surface of the groundwater. The LNAPL sample should be collected before any groundwater purging, and should be carried out in such a way as not to emulsify the free product. The thickness of LNAPL in the borehole can be determined using an interface probe, although it should be noted that this will probably not reflect the thickness in the aquifer, because of capillary pressure effects (Erskine *et al*, 1998).

Obtaining a representative water sample from beneath a LNAPL layer is extremely difficult. Examination of the results of the analysis may reveal whether or not the attempt was successful, or whether small amounts of free product were included.

8.5.4 Hydraulic testing

Hydraulic testing of boreholes to determine aquifer properties may be undertaken at the time of water sampling to reduce the volumes of effluent being treated. These tests include rising and/or falling head tests and slug tests. However, where the volume of water removed during sampling is not sufficient to supply such data, specific test pumping will be required. The determination of hydraulic conductivity by such testing is an essential parameter in characterising the groundwater pathway, but careful consideration should be given to optimising the benefits of the data gathering compared to the health and safety and waste disposal issues entailed in obtaining it. Practical guidance on test pumping is provided in Clark (1988) and Misstear *et al* (2006).

8.5.5 Ground gas surveying and sampling from permanent monitoring points

Sole reliance on ground gas spike surveys, where shallow temporary small diameter holes without a permanent closure are monitored, is not recommended (Wilson *et al*, 2007b). Good practice ground gas surveying is considered to be from shallow permanent monitoring points, with confirmatory laboratory analyses, providing information on volatile or gaseous contaminants within the near-surface soils (Wilson *et al*, 2007b). Such monitoring techniques are used to identify the source of volatile or gaseous contaminants (or their parents, in the case of Rn-222), such as those that may be associated with areas of contaminated land.

Although ground gas surveying appears to be straightforward, there may be significant uncertainties in interpreting the data, principally due to variations in the permeability and moisture content of the ground, which affect the ability of ground gas to migrate. Also, results are commonly influenced by meteorological factors, such as the extent of recent rainfall, barometric pressure and wind speed.

Ground gas surveys may be used as an indicator of the presence of several contaminants, including:

- volatile organic compounds (VOCs) such as petroleum hydrocarbons or organic solvents
- organic compounds that are not VOCs, but that produce CO_2 gas during biological or chemical breakdown
- mercury
- radon (an indicator of the presence of radionuclides in the uranium and thorium decay chains).

The largest potential use of ground gas surveying on nuclear-licensed sites and defence sites will be the identification of sources of VOC contamination. Radon gas surveying may also have some potential use on these sites as the presence of radon indicates that radionuclides in the uranium or thorium decay chains are present.

Limitations of ground gas surveying are that migration of ground gas may be significantly affected by the near-surface geological and manmade structures. Because of this the gas concentration may not be proportional to the concentration of contaminant in the source area. Interpretation of results may be difficult and a negative result does not necessarily indicate that there are no contaminants present.

The long-term monitoring and sampling regime for ground gases will be determined by the conceptual model on nuclear-licensed sites or defence sites. Extensive guidance on the identification of landfill gas already exists (Wilson *et al*, 2007, NHBC, 2007 and BS 8485:2007) and is not repeated here.

8.6 Sample labelling and transport

Samples should be clearly labelled and conform to the AGS standard so that they cannot be removed during handling. The labels should include the following minimum information:

- location number
- depth interval

- date of sampling
- hazard information.

Transport of samples to the laboratory should take place as soon as possible after sample collection to minimise the potential for degradation to occur. Site rules may require that all samples from a nuclear-licensed site are subject to basic radiological analysis before shipment off-site. This can compromise sample storage times and requires careful planning. Advice on storage conditions should be sought from the analyst.

Radioactively contaminated samples, containing greater than a defined level of total radioactivity or activity concentration, become subject to the Carriage of Dangerous Goods and Use of Transportable Pressure Equipment Regulations 2007. If this is the case, samples are required to be labelled, packaged and transported in accordance with the Regulations. However, the total radioactivity of a sample is not known until is analysed. All samples should be screened in the field to establish if they contain greater than the defined levels and so determine the appropriate method of transport. If this is not possible, then samples should be transported in accordance with the requirements of the Regulations. Waste management and transport of radioactive materials is discussed further in Chapter 9.

8.7 Geological logging/geotechnical testing

8.7.1 Geological logging

All boreholes and trial pits should be logged following BS 5930:1999/ISO EN 14688-2/BS EN 1997-2 (see Section 7.5.1).

8.7.2 Photography and drawings

Photographs and drawings provide a valuable record of a contaminated land survey. However, there are often significant restrictions to the use of cameras on nuclear-licensed sites and defence sites. Before using a camera on these sites, permission should be sought from the site operator. Ideally photographs and drawings should be made of:

- contaminant source areas
- all sampling locations before, during and after sampling and at reinstatement
- trial pit walls
- any exposed *in situ* geological materials
- cores samples before they are divided up for analysis.

All photographs and drawings should have appropriate labels and include a scale, and also for photographs a colour reference. It is recommended that each photograph is checked on-site for clarity before moving on.

8.7.3 Geotechnical testing

In some circumstances it may be possible to combine a contaminated land survey with a geotechnical survey. Samples retrieved from all types of subsurface investigations should be regarded as a potential resource for other projects. However, several points should be noted:

- the quality of the contaminated land survey may be degraded if sampling locations are moved to provide the best location for geotechnical sampling (or vice versa)
- the appropriate intrusive method for the contaminated land survey may not be appropriate for the geotechnical survey (or vice versa)
- samples should be tested for contamination before the geotechnical testing is carried out. This is required to establish any special health and safety measures that need to be undertaken. Note that any laboratory testing of radioactive substances, as defined under RSA93, will require an open source registration (see Section 8.8.1) from the relevant environment agency, and notification under IRR99 if activities involved are above exemption levels
- consideration should be given to the appropriate storage of materials retrieved for other project tests, such as remediation pilot trials.

Table 8.2 ***Common in situ and ex situ geotechnical tests***

In situ tests	*Ex situ* geotechnical tests
Standard penetration tests	Liquid and plastic limit tests
In situ California bearing ratio test	Particle size distribution
Hand shear vane test	Moisture content
Perth penetrometer test	Undrained triaxial compression tests
Cone Penetrometer (CPT)	Dry density
	Consolidation
	California bearing ratio tests
	pH and sulphate testing

Note: although pH and sulphate testing are chemical tests they are included in the geotechnical suite as they are used to determine the potential for degradation of foundations to occur.

Geotechnical testing methods are described in detail in BS 1377-9. Some examples of common tests are given in Table 8.2, but it is good practice for the tests to be specified by a geotechnical specialist in consultation with the geotechnical laboratory.

8.8 Chemical and radiochemical analysis

8.8.1 Selection of an appropriate laboratory

The laboratory chosen should be competent to undertake the required analysis. Competence is demonstrated, in a general way, by accreditation under United Kingdom Accreditation Service (UKAS). It is also obligatory that if chemical analyses of soils are going to be viewed by the environment agencies for regulatory purposes that MCERTS (the Environment Agency's Monitoring Certification Scheme) accreditation is held for the specific analyses required (EA, 2003d). Laboratories that undertake soil analyses are working towards MCERTS accreditation and the status of analyses under this scheme should be checked with the laboratory and the appropriate regulator.

The testing laboratory should be committed to the implementation of effective and efficient quality management systems consistent with the requirements of BS EN IS0 9001, and should be able to demonstrate that adequate quality control procedures are applied.

It is desirable that the laboratory participates in external inter-laboratory comparison schemes, such as the WASP (Workplace Analysis Scheme for Proficiency) inter-laboratory scheme run by the HSE covering hazardous substances. The AquaCheck scheme organised by WRc Ltd is a quality check of water analyses but includes gross alpha, gross beta, Sr-90 and aqueous H-3. CONTEST (CONtaminated land TESTing) organised by the Laboratory of the Government Chemist covers comparison testing of substances contaminating soils including metals, other inorganics, organics and leaching tests. The National Physics Laboratory run the environmental radioactivity comparison exercise every 18 months covering a large range of radionuclides (alpha, beta and gamma emitters).

The sites that are being considered by this good practice guidance are potentially radioactively contaminated. Chemical contamination may also be present. When selecting an analytical testing laboratory, it is necessary to ensure that it has the required authorisations to handle the types of sample that will be sent to it, and the capacity.

The laboratory requires an open registration (that is, a licence to handle open radioactive sources, such as radioactively contaminated soil and water) if it is to analyse radioactive material (as defined under RSA93) produced from a site characterisation. The regulatory authority for the registration process is the relevant environment agency. An authorisation to accumulate and dispose of waste may also be required. Notification of HSE under IRR99 will be required if the quantities of radioactive materials involved exceed specified levels.

8.8.2 Liaison with laboratory

The selected laboratory should be involved with the development of the sampling and analytical planning from the start. Close liaison with nominated staff should be established, with invitations to project meetings. Their advice on analytical methods, sample size and preparation, appropriate limits of detection, QA/QC and waste disposal should be sought.

8.8.3 Chain of custody

A chain of custody document should be prepared for each sample or batch of samples and should record collection in the field, off-site consignment to the testing laboratory and receipt by the testing laboratory. After testing, the surplus portions of the samples may be returned to the site operator (for long-term archiving, storage or disposal) or may be disposed by the principal contractor or analytical testing laboratory in accordance with UK legislation. The chain of custody document should record these transfers. A copy of the chain of custody document should be kept in the project file.

The disposal of radioactively contaminated samples should be considered as part of the site characterisation works waste management plan in Chapter 9.

8.8.4 Analytical testing strategy

It is not possible to analyse all samples for all possible contaminants, and a strategy is needed to prioritise and sequence the chemical and radiochemical analyses undertaken. It is always wise to seek expert advice in determining the most appropriate analytical techniques and strategies. The analytical strategy should be prepared as part of the overall quality management plan (Section 5.1.2), and should take into account:

- the objectives of the site investigation (eg is it to determine if a site is chemically or radioactively contaminated or to design or verify a remediation strategy)
- the conceptual model of the site, which would identify the potential contaminants of concern (PCOCs), potential sources and mechanisms of contamination, and the potential pathways and receptors
- the available budget and timescale for the site investigation.

Other parameters and their variables that should be considered when developing the strategy are listed in Table 8.3.

Table 8.3 ***Design parameters for an analytical strategy (after Petts et al 1997)***

Parameter	Variable
Scope of analytical programme	Ranges of tests Numbers of samples Types of samples
Use of screening techniques	Field-based Laboratory-based
Sample preparation	As received, air dried, other Size reduction Size fraction Extraction
Detection method	Sensitivity Reproducibility Turnaround time Reliability Cost
Quality control procedures	Sample logging Blank samples Spiked samples Recovery accuracy performance Storage of samples Disposal of samples

8.8.5 Phased approach

A phased approach is generally taken to the chemical and radiochemical testing, taking into consideration site-specific contaminants. This is likely to involve:

- on-site screening of samples (where appropriate), for example:
  - radioactivity, using hand-held alpha and beta/gamma monitors
  - volatile organic compounds (VOCs), using a photo-ionisation detector (PID) or gas chromatograph (GC).

- laboratory screening techniques (for targeting detailed analyses) for example:
  - gross alpha/beta
  - gamma spectrometry (which also provides detailed analysis for specific radionuclides)
  - tritium
  - hydrocarbon analyses (eg diesel range organics (DRO: C11 – ~C35) and petrol

range organics (PRO: C4–C10)) (DRO analytical results should be accompanied by a chromatogram and interpreted by a SQEP professional)
  - metals by inductively coupled plasma optical emission spectrometry (ICP-OES)
  - polyaromatic hydrocarbon (PAH) and polychlorinated biphenyl (PCB) screens
  - asbestos.

- detailed laboratory analysis (for generic and detailed quantitative risk assessment) for example:
  - analyses with lower detection limits (eg Hg)
  - alpha spectrometry to determine activities of uranium and plutonium isotopes
  - chemical separation followed by specific radionuclide analysis (for example, Sr-90)
  - trace metal analyses
  - analyses to determine the potential for *in situ* degradation of organic contaminants (eg presence of electron acceptors (sulphate, ammonium, nitrate and iron) and indicators of microbial degradation (CO2, methane, sulphide)
  - TPHCWG[13] banded hydrocarbon analysis , EPA 16 (or 19)[14] for PAH, ICES PCB -7[15] analysis
  - analysis to determine presence of potential degradation products, particularly if these are more toxic than the parent material
  - analysis of colloids.

In general, for all types of analyses, uncertainty in the results increases with decreasing concentration or activity of contaminant.

Note that some laboratory screening can be undertaken on site. This may be required to confirm that samples are correctly packaged and labelled for off-site transport in accordance with the Radioactive Materials Road Transport Regulations 2002 (see Chapter 9).

8.8.6 Analysis of radioactivity in soils and waters

This section provides an introduction to a very specialist analytical subject, and expert advice should always be sought. More detailed descriptions are provided in texts such as Warwick (2007) and in the electronic site investigation handbook produced by Nexia Solutions and the University of Southampton (2008).

Two principal analytical techniques used to detect radioactivity in soils and waters are gross alpha/beta analysis and gamma spectrometry. The application of these techniques is discussed.

a Gross alpha and gross beta measurements

In principle, a gross alpha and gross beta measurement (typically referred to as "gross alpha/beta") will be sufficient to characterise the total radioactivity of the sample. This is the case for analysis of **water samples**, where accurate and precise detection to less than 0.1 Bg L^{-1} can be achieved if water does not have high levels of dissolved solids. For assessment purposes the water analyses are compared to the guideline values produced

13 Total Petroleum Hydrocarbon Compounds Working Group.

14 US Environmental Protection Agency Priority 16 or 19 Poly Aromatic Hydrocarbons.

15 Institution of Civil Engineering Surveyors priority seven Polychlorinated Biphenyl congeners.

by the World Health Organisation for radioactivity in drinking water and the Water Supply (Water Quality) Regulations 2000.

In practice, gross alpha/beta analysis of **soil samples** is a screening technique, which enables distinction to be made between uncontaminated samples and those samples contaminated to levels of a few Bq g^{-1} or more. The intervening region is more difficult to characterise because:

- the soil sample required for analysis is very small (<1 g) and sub-sampling errors (arising from sample heterogeneity may be significant)
- the typical sample preparation technique involves using the fine-grained (<200 µm) portion of the soil. This can introduce a systematic bias in the result, because any radiation contamination tends to be associated with the fine fraction.

A more accurate measurement of gross alpha/beta activity in soil can be obtained if a 100 g-sized sample of soil is homogenised and crushed so that there is no size separation before analysis. However, due to the limiting factor of self-adsorption the sub-sample size for analysis will still be less than 2 g.

Gross beta analysis does not detect weak beta-emitters such as H-3, C-14, S-35, I-129 and so on. If these isotopes are potential contaminants in the soil or water samples, then further isotope-specific analysis will be required.

If the gross alpha or beta analyses show levels above the appropriate legislative or guidance level then it may be necessary to carry out a more detailed nuclide specific analysis. It is important to obtain expert advice on the detailed analysis that might be required.

b Gamma spectrometry

Gamma spectrometry detects gamma radiation that is produced during the decay of radionuclides. However, as shown in Table 2.4, there are some potential radioactive contaminants, such as Sr-90, which do not produce gamma radiation on decay and whose presence cannot be inferred from short-lived gamma-emitting daughter radionuclides.

In soil and water samples, gamma spectrometry is ideal as a complementary screening measurement to gross alpha/beta. The required sample size is in the range of 100 g to several kilograms. This is significantly larger than that required for gross alpha/beta analysis, so sub-sampling errors will be smaller and results will probably be more representative of *in situ* conditions. In particular, activities of common manmade radionuclides, such as Cs-137 and Co-60, and of natural series decay chains (headed by U-235, U-238 and Th-232) can be measured or inferred.

Not all radionuclides will be detected using gamma spectrometry. The technique should not be used in isolation unless the radionuclide fingerprint of the contaminated site is well understood, and there is confidence that total levels of radioactive contamination can be derived from the gamma spectrometry data.

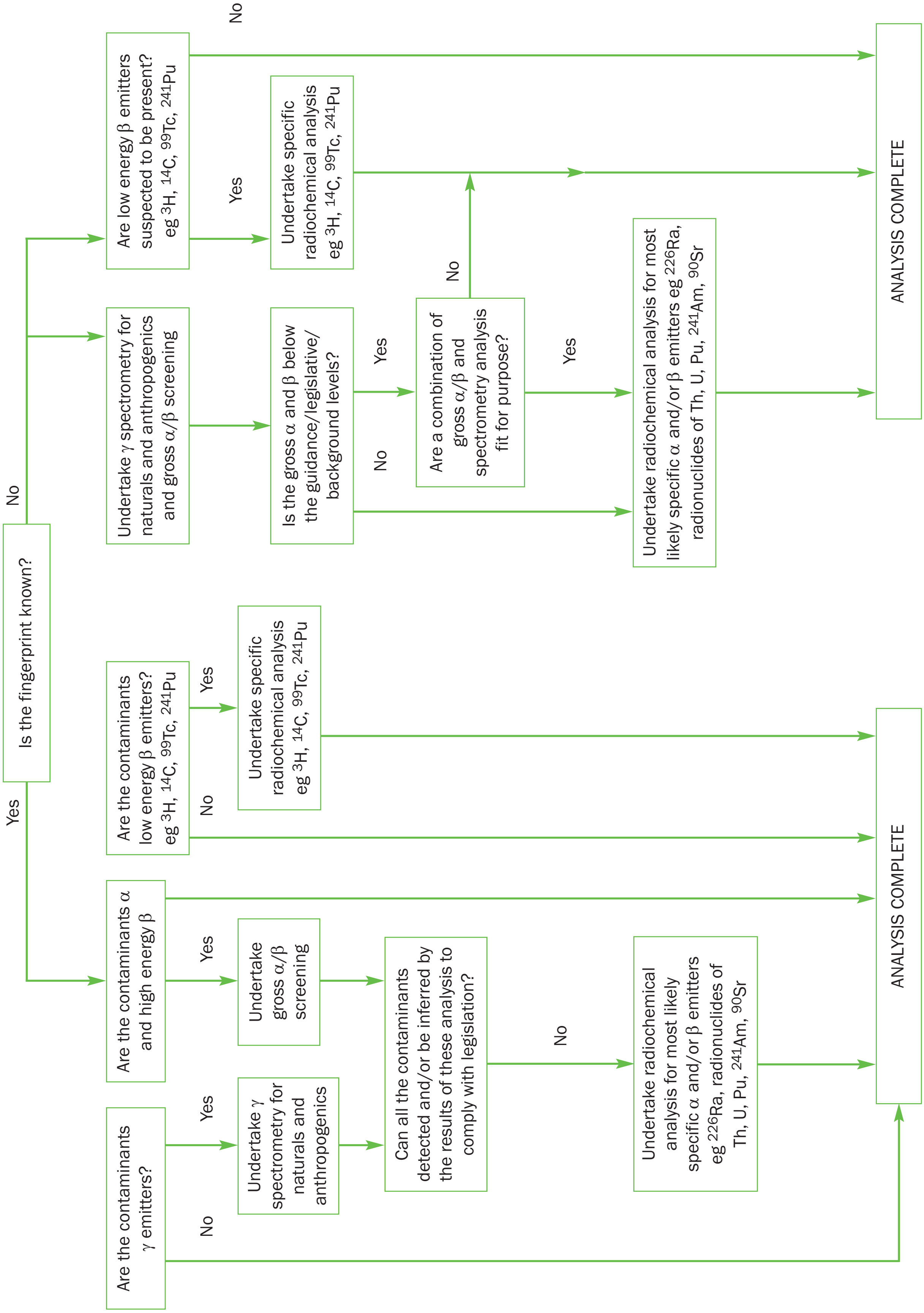
Tritium

Tritium is a common contaminant on nuclear-licensed sites. It is usually present as tritiated water (HTO), which behaves in a chemically identical way to naturally occurring water. As a consequence, it is highly mobile and commonly migrates from the near-surface environment into groundwater. The extent of migration is limited by the short half-life of tritium (12.3 years). Special precautions are needed when sampling and analysing for tritium, to prevent evaporation of the sample and/or isotopic exchange with naturally occurring water. It is possible to analyse for tritium both in soil samples and in waters: in both cases, tritium is present in the aqueous phase. Tritium may also be present in the form of Organically Bound Tritium (OBT), where its behaviour will have more in common with carbon than HTO. While the physical half-life remains unaffected compared to HTO its migration through the environment and incorporation in to plants and animals will be different. This can result in longer residence times and a corresponding increase in potential dose impact. The speciation of tritium and the resultant risk assessment would need to be captured within the conceptual model.

Quantification of tritium contamination in the unsaturated zone generally involves analysis of soil samples. The tritium activity can be expressed either as Bq/g of soil or as Bq L^{-1} of soil porewater. The latter is more informative, because it can be directly compared with the activity concentration of tritium in the underlying groundwater. However, the moisture content of the soil sample must be measured to derive the porewater activity. In the saturated zone (ie below the water table), either soil samples or water samples can be collected and analysed. In practice, determination of tritium activities in soil or rock from beneath the groundwater table would only be undertaken if the samples were cohesive and fine-grained (ie porewater did not freely drain from the samples on collection). It can be difficult to differentiate between HTO and OBT in soil samples. Radiochemical analyses using a sequential leach test may prove to be a suitable approach with any tritium retained after the aqueous extraction would commonly, and conservatively, assumed to be organically bound.

It is preferable to determine tritium activity concentration directly in the groundwater although, in principle, the tritium activity concentration in the soil porewater and in the groundwater should be identical if the porewater and the mobile groundwater that is sampled by pump testing are in close contact. Analysis of tritium in soils may be appropriate at an early stage of a characterisation programme to evaluate whether a potential problem exists. If tritium contamination below the groundwater table is detected, it is good practice to install groundwater monitoring boreholes and to obtain groundwater samples for further analysis.

Flow sheets suggesting possible strategies for gross radioactivity and radiochemical analysis of soils and waters are given in Figures 8.1 and 8.2.



Note: gross alpha and beta analysis is only a screening technique and gives an indication of the level of activity of the sample due to these emitters. It provides a guideline to carry out the radiochemical analysis. For a full analysis of uranium radioisotopes radiochemical and ICPMS analysis is required.

Figure 8.1 ***Soil analysis (for radionuclide determination)***

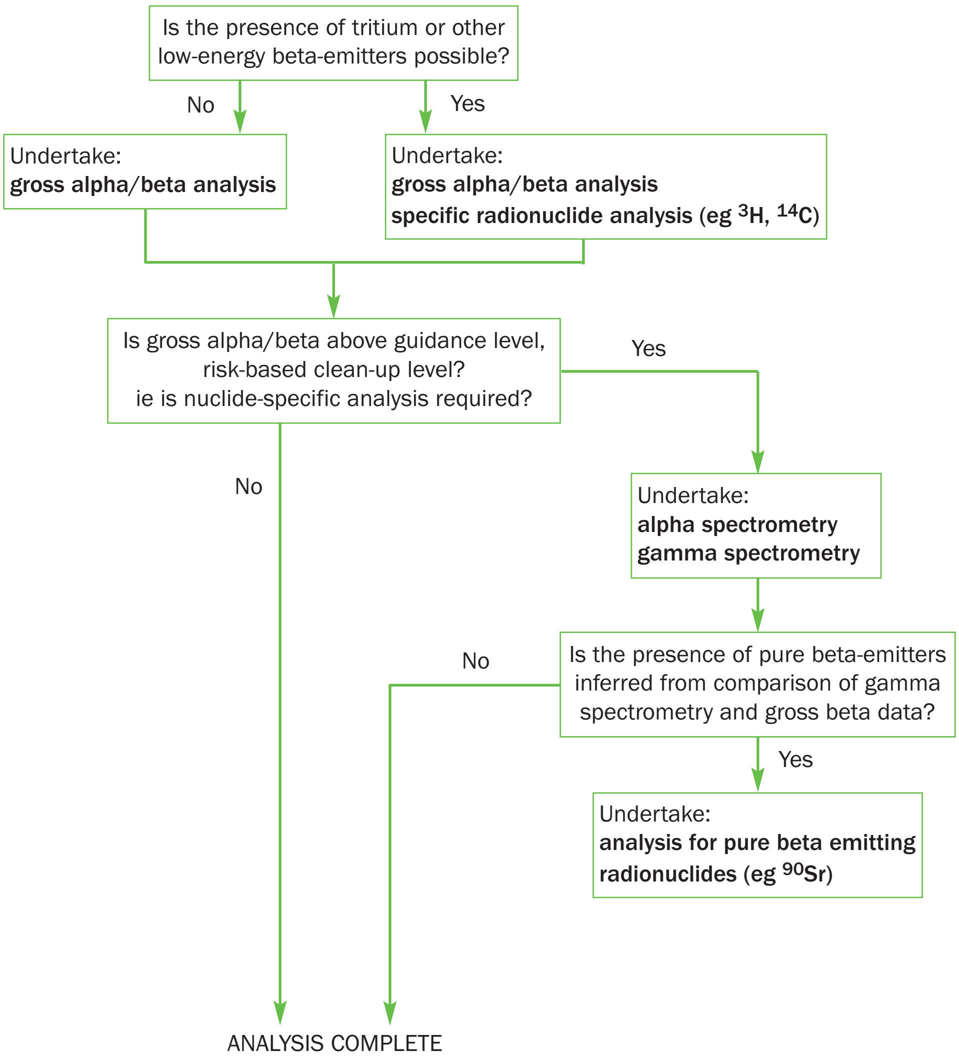


Figure 8.2 ***Water analysis (for radionuclide determination)***

8.8.7 Quality control

The confidence that can be placed in any chemical or radiochemical analytical result is influenced by two factors:

1. The precision and accuracy of the analytical technique ("analytical errors").
2. The extent to which the sample submitted for analysis is representative of the sample supplied to the laboratory ("sub-sampling errors").

Analytical errors are evaluated and controlled by the testing laboratory through the application of a quality control (QC) system. Guidance on QC is given in EURACHEM/CITAC (2007), Ramsey (1993) and ISO 5667-14:1998 for water sampling and ISO/DIS 13530-2:1997 for water analysis, further specific information is given by the EA (2003b).

Details will vary, but use of the types of QC samples described in Box 8.2 should be standard practice both for radiochemical and non-radiochemical analysis. Obtaining reproducibility particularly of radiochemical analyses from site derived samples, can be problematic and expensive. The use of external quality control samples in such instances may help reduce uncertainty. Uncertainty is further discussed in Chapter 11.

Agree in advance with the laboratory the method and format of analytical results delivery to minimise transcription errors and resources required to manipulate data. Use AGS-M format where appropriate (see Section 7.5.1).

Adding to QA/QC procedures, the checking of analytical results for internal consistency and against previous history or expectations are important steps. This must be done promptly after results receipt, because if repeat analyses are required laboratories typically only hold spare sample for 30 days after reporting results.

Box 8.2 ***Quality control samples***

Use of the types of QC samples, concealed from the laboratories, described here should be standard practice:

Blanks: materials that do not (or should not) contain the chemical or radionuclide being analysed for. Ideally, the blank should be of a similar material ("matrix") to the samples being tested. A variety of blanks may be used to determine the potential for contamination of the samples at various stages of the sample collection and analysis procedure.

Field/method blank (typically applicable to water sampling): a radionuclide/chemical-free sample that is taken to the field and then processed, transported and analysed in the same manner as the actual samples.

Analytical blank: a radionuclide/chemical free material used in analytical testing laboratory to evaluate background contamination and cross-contamination.

Duplicate/triplicate samples: samples taken to assess reproducibility of the field sampling procedure ("field duplicate"), to enable inter- or intra-laboratory comparison ("split samples"), and to determine sampling bias. Note: it is very difficult to collect duplicate/triplicate soil samples as contaminant concentrations may vary over small distances, however, duplicate samples of waters should yield the same result.

Standard samples: samples that contain known concentrations of the chemical or radionuclide being analysed for. These samples may be used by the analytical testing laboratory as a check on analytical results or may be submitted with the batch of samples for analysis. Typically, only standard solutions would be submitted in the latter case because of the difficulty of preparing homogenous soil samples.

External quality control samples: Samples of material spiked with a level of radioactivity known only to an external laboratory. These are tested alongside the field samples to provide reassurance that the analyses are correct.

8.8.8 "Non-detect" results

Consideration needs to be given to the management of "non-detect" results, especially for radiochemical analyses where the detection limit is close to values of interest and is sample specific.

All radiochemical analyses should be reported with their estimates of uncertainty. Professional judgement is required to assess the impact of the uncertainty on the interpretation of the non-detect results. So where the limit of detection is at an activity that is not significant then this should be specified. The limit of detection is the lowest activity, which provides 95 per cent confidence of detection given the background in a sample. "Non-detects" will imply a 95 per cent certainty that the activity of the sample is below this activity.

9 Waste management and transport of radioactive materials

Box 9.1 ***Aims of Chapter 9***

> This chapter describes the sources of waste that can arise in site characterisation and how wastes should be categorised and sentenced to appropriate disposal routes. The main issues for managing wastes on potentially radioactively contaminated sites are then summarised. This chapter also presents the special requirements that apply to transporting radioactive materials, such as samples, off-site and the impact this can have for a characterisation project.

9.1 Waste management

Both radioactive waste and non-radioactive waste will be generated by site characterisation. The management of these wastes should be addressed in project specific plans, as part of the overall SAFEGROUNDS approach. These plans then need to be integrated with the site waste management procedures, and where management routes are not available, then new ones will need to be established. For non-radioactive waste the development of a site waste management plan on construction sites is good practice (Section 9.3), and on nuclear-licensed sites and defence sites it is recommended that this should be integrated with radioactive wastes management plans. Further guidance, particularly in the context of managing decommissioning wastes, of which site characterisation wastes may be a part, is given in Miller and Tooley (2005) and Hill (2007a and b).

9.1.1 Sources of waste

It is likely that both solid and liquid wastes will be produced from the site investigation. Typical solid wastes include:

- solid wastes from initial site clearance activities, such as vegetation (which may need to be removed to allow adequate access to the site) and surface wastes (such as metallic items, which may interfere with geophysical surveys)
- spoil that cannot be backfilled into inspection pits, boreholes or trial pits
- used personal protective equipment and respiratory protective equipment
- disposable items used during sample collection, preparation and packaging
- waste from the site accommodation and hygiene facilities
- residues from samples sent for laboratory analysis.

Typical liquid wastes include:

- water produced from wash-down facilities (ie water used for cleaning and decontaminating plant and sampling equipment)
- water produced from operations in the hygiene and change facilities
- water produced from abstraction of groundwater from trial pits, trenches and boreholes on the site
- residues from samples sent for laboratory analysis.

9.1.2 Waste minimisation

Licence Condition 32 of a nuclear site licence requires that production of radioactive wastes be minimised. So, subject to achieving the objectives of the site characterisation project, there may be a requirement to use intrusive techniques that minimise waste production, where their use will not compromise the objectives of the site characterisation project. On both nuclear-licensed sites and defence sites it is good practice to consider options for minimising the generation of waste. It will also be necessary on all sites to segregate wastes into various waste streams defined by radioactivity so that they can be managed correctly. It may be appropriate (or a requirement specified by the client) to appoint a member of the project team with responsibility for minimising and segregating radioactive wastes. On some sites, this role is referred to as the waste minimisation officer.

9.2 Management of active waste

9.2.1 Waste categorisation

In the context of site investigations on potentially radioactively contaminated sites, wastes fall into two categories, as defined under RSA93: radioactive waste and non-radioactive waste. The definitions of radioactive waste are explained in Hill (2007b). Non-radioactive wastes are further categorised by the Environment Protection Act 1990 into *controlled wastes* and hazardous waste (see Section 9.3).

This is a complex area and while a summary of the main points follows, it is always recommended that the actual regulations are checked for any specific situations and advice sought from a suitable expert. Further guidance is given in *Clearance and exemption – principles, processes and practices for use by the nuclear industry – a nuclear industry code of practice* (CEWG, 2006). One of the aims of this code of practice is to build confidence among stakeholders because the disposal of waste containing any level of radioactivity can often lead to concern among some non-statutory stakeholders if not carefully explained.

Disposal of radioactive waste is legislated under RSA93. Schedule 1 of RSA93 defines the concentrations of naturally occurring radionuclides above which liquid wastes are to be dealt with as radioactive. The Radioactive Substances (Phosphatic Substances, Rare Earths etc) Exemption Order 1962 may also be relevant to site characterisation because it allows water containing insoluble particulates with less than 14.8 Bq $g^{-1}$of the Schedule 1 elements to be disposed of without an authorisation under RSA93. In some areas, the natural background concentrations of uranium- and thorium-series radionuclides in groundwaters are close to or above Schedule 1 levels, which can lead to problems in disposing of any water abstracted from boreholes etc.

There is no corresponding definition for artificial radionuclides, so all liquid wastes that contain artificial radionuclides at above background levels must, in principle, be dealt with as radioactive wastes. The relevant environment agency must be consulted to agree the background levels to be used for a specific site.

Exemption orders exist that specify the conditions under which materials or wastes defined as radioactive under RSA93 can be made “exempt”, ie excluded from some or all of the provisions of the Radioactive Substances Act. There are two key exemption orders that are particularly relevant to radioactively contaminated land:

1 Radioactive Substances (Substances of Low Activity) Exemption Order 1986 and 1992 (amended) (SI No 1002 and SI No 647) (SOLA)

2 Radioactive Substances (Phosphatic Substances, Rare Earths etc) Exemption Order 1962 (SI No 2648).

The SoLA Exemption Order 1986 specifies that solid radioactive waste is excluded from the provisions of Section 6 (1) and (3) of RSA93, provided that it is substantially insoluble in water and has an activity that does not exceed 0.4 Bq g^{-1}. These provisions include the requirement to have an authorisation from the relevant environment agency to dispose of the waste. This order is particularly relevant to wastes that contain any manmade radionuclides (CEWG, 2006). In practice, this exemption order means that solid wastes containing less than 0.4 Bq $g^{-1}$of manmade radionuclides (and containing natural radionuclides below levels relevant to other exemption orders) can be dealt with as if they were exempt (Hill, 2007b).

However, while the current radiological protection regime views materials below 4 Bq/g as being below regulatory concern, some stakeholders may conclude that this represents a relatively arbitrary limit, and the free release of this manmade radioactively contaminated material could still prove harmful to humans and the environment.

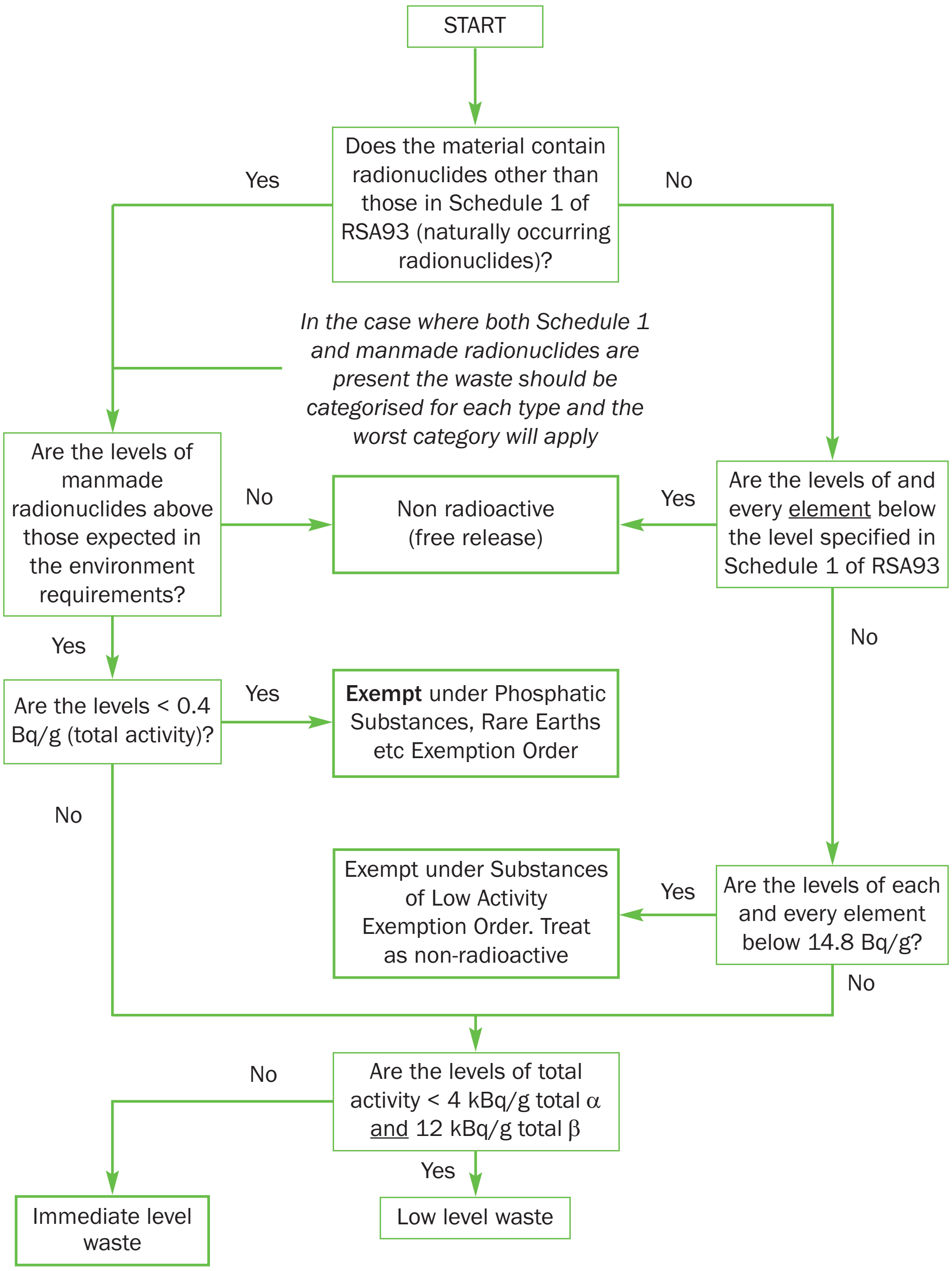
The Phosphatic Substances, Rare Earths etc Exemption Order 1962 states that material that is radioactive solely because of the presence of one or more of the Schedule 1 elements, ie Ac, Pb, Po, Ra, Rn, Th and U, and is substantially insoluble in water, is unconditionally exempted from the provisions of RSA93 provided that the specific activity of each of the Schedule 1 elements present does not exceed 14.8 Bq g^{-1}. This exemption includes waste disposal. This exemption order is particularly relevant to wastes arising from operations involving naturally occurring radionuclides, and is very widely used. Difficulties with it include the lack of a clear definition of "substantially insoluble" and the absence of activity levels for disposal of liquid wastes (as opposed to suspensions of particulates).

Guidance on the interpretation of Schedule 1 is given in DEFRA (2000b) and in the internal guidance issued by the Environment Agency (Chapters 2 to 4) that can be downloaded from the EA website: <www.environment-agency.gov.uk>. The relevant environment agency should be consulted on the interpretation of the Radioactive Substances (Phosphatic Substances, Rare Earths etc) Exemption Order 1962, which is now under review.

Interpretation of the limits to be applied for the various categories of wastes, which contain radionuclides in concentrations above those occurring in the natural background, are summarised in Table 9.1. A flow chart summarising the waste categorisation process is given in Figure 9.1.

Table 9.1 ***Specific activity limits to be applied in determining categories of solid wastes that contain above background levels of radionuclides and that are essentially insoluble in water***

	Waste characteristics	Specific activity, Bq g^{-1}	Waste category
1	Wastes containing manmade radionuclides	≤ 0.4	Deal with as non-radioactive
		> 0.4	Low level waste (LLW)
2	Wastes containing mixtures of Schedule 1 elements only	≤ (Schedule 1, Column 2, RSA93 limit for each element)	Deal with as non-radioactive
		> (Schedule 1, Column 2, RSA93 limits) and ≤ 14.8	• exempt • confirm against phosphatic substance EO • if applicable waste may be disposed at landfill.
		> 14.8	LLW
3	Wastes containing mixtures of manmade radionuclides and Schedule 1 elements	≤ 0.4 (**excluding** contributions from all Schedule 1 elements and their daughters, **provided** none exceed their schedule 1 Column 2 limits)	Deal with as non-radioactive
		> 0.4 (**excluding** contributions from all Schedule 1 elements that do not exceed their Schedule 1 Column 2 limits, and their daughters)	LLW
4		> 4000 alpha >12 000 beta/gamma	Intermediate level waste (ILW)



Note: where the term "element" is used this should be taken to mean the total activity of all the radio isotopes of that element, eg U238 + U235 + U234.

Figure 9.1 ***Flow chart for categorising solid wastes that are essentially insoluble in water***

In March 2007 the UK Government published a policy statement entitled *Policy for the long term management of solid low level radioactive waste in the United Kingdom* (Defra, 2007). This policy refines the definition of low level waste and introduces the concept of very low level radioactive waste (VLLW) and high volume VLLW. This means that some waste generated from the remediation of contaminated land could be disposed of to landfill rather than to the low level waste repository. The environment agencies are now developing an implementation policy for the permitting of such disposal and further guidance is expected to be published in 2009. However, it is noted that there is reluctance on the part of many landfill owners and operators to accept radioactive waste of any type and that such disposals can lead to concern within some stakeholder groups if not carefully explained.

Again, this is a complex area and it is vital to seek expert advice from regulators, owner/operator waste management teams, possible waste management contractors and waste recipients before disposing of any radioactive waste.

9.2.2 Key issues for waste management

The main issues for waste management on potentially radioactively contaminated sites are summarised in Box 9.2.

Box 9.2 ***Key issues for waste management on potentially radioactively contaminated sites***

Averaging volume: this is the volume of waste over which the activity concentration of radionuclides is averaged. Categorisation of waste (as follows) is made on the basis of the averaging volume, which is a vital parameter in the design of a site characterisation and any later remediation. The averaging volume of any waste produced from the site characterisation or later remediation should be agreed with the relevant environment agency during the survey design stage. Guidance on this and other aspects of sampling statistics can be found in CEWG (2006).

Waste minimisation: operators of nuclear-licensed sites will have both environmental policies and site licence conditions, which state that waste production should be minimised. Strategies for intrusive investigations should be selected with this requirement in mind.

Categorisation of wastes: definition is firstly in terms of radioactivity (see Section 9.2.1) but should include other aspects, such as the water or leachable oil content of solid wastes and the hydrocarbon content of liquid wastes. Ensure that disposal routes are available for all wastes that will be produced.

Define responsibilities for wastes: define responsibilities for the characterisation, packaging and storage/disposal of radioactive and non-radioactive wastes. Note that this applies both to wastes produced on the site and to wastes arising from the laboratory analysis of samples.

Waste segregation: health physics monitoring during the site investigation should be used to make an initial segregation into the radioactive and non-radioactive waste streams required by the site operator. Waste segregation is crucial to minimise production of radioactive wastes.

Mixed wastes: it should be noted that where segregation of hazardous chemical and radioactive wastes is not possible there may be no disposal route.

Confirmatory analysis of wastes: before final sentencing of waste, laboratory analysis should be undertaken to confirm the waste category and to ensure it conforms to acceptance criteria.

Waste disposal: ensure that wastes are disposed of in accordance with site operating procedures (if available) and legislation. Ensure duty of care for non-radioactive wastes.

Exempt wastes: while the current radiological protection regime views materials below 4 Bq/g as being below regulatory concern, it should be understood that some stakeholders may conclude that this represents a relatively arbitrary limit, and the free release of this manmade radioactively contaminated material could still prove harmful to humans and the receiving environment.

The level of relative improvement of any wastes above background levels needs to be determined. Cases have arisen where elevated natural levels of radiation have resulted in problems over the sentencing of waste arisings.

Some of these issues are explored in more detail in the following sections.

9.2.2.1 On-site facilities for management of radioactive wastes

Operational nuclear-licensed sites will have facilities for the management of both solid and liquid radioactive wastes. Typically on such sites, the site operator will retain responsibility for the storage and ultimate disposal of any solid radioactive wastes produced during the site investigation. Under this arrangement, the contractor would be responsible only for the packaging of the solid radioactive wastes in containers to be approved by the site operator. It would be for the site operator to ensure that disposal routes are available for both solid and liquid radioactive wastes, and this may include obtaining variations to existing authorisations under RSA93.

Facilities for the treatment and disposal of many liquid wastes are available on operational nuclear-licensed sites. Different categories of liquid waste are primarily defined by radioactivity limits. However, because the waste treatment plants will have been designed to treat the principal waste streams produced during routine operations on the site, and not with contaminated land investigations in mind, there may be the requirement to pre-treat site investigation wastes before disposal in the liquid effluent treatment plant.

When abstracted groundwater is pumped the groundwater quality may change over time. Real time monitoring of water quality for both radioactive and non-radioactive contaminants should be considered to manage and minimise volumes of water requiring specialist treatment.

Pre-treatments of abstracted groundwater may involve reducing suspended solid load, by processes such as flocculation/coagulation, settling and filtration, and reduction of dissolved or free-phase hydrocarbon or solvent contamination, by treatment with granular activated carbon. It is important to determine the acceptance criteria for liquid wastes, and also the requirements for any pre-treatment, during the planning phase of the site investigation.

On non-licensed defence sites where no facilities are available for the treatment or disposal of solid or liquid radioactive wastes, the site owner will need to make appropriate arrangements and obtain the necessary authorisations under RSA93 for waste accumulation and disposal. The treatment and packaging requirements for solid wastes will depend on the route for their eventual disposal (see Section 9.2.2.2). A mobile effluent treatment plant may be required if authorisation cannot be obtained for direct discharge of liquid wastes into the environment.

9.2.2.2 *Disposal of radioactive waste*

The available disposal routes in the UK for solid radioactive wastes are:

- the low-level radioactive waste repository (LLWR)
- disposal to an authorised landfill under an exemption order to the RSA93
- on-site burial at a facility authorised under the RSA93.

The principal disposal site for solid low-level radioactive waste in the UK is operated on behalf of the NDA near Drigg in Cumbria. Details of the acceptance criteria for solid low-level radioactive waste at LLWR (defining the physical and chemical requirements for the waste, in addition to the nature and specific activity of the radionuclide component) are given in *Conditions For Acceptance* by LLW Repository Ltd of *Radioactive Waste For Disposal at the Low Level Waste Repository* with associated guidance. Both are available from: <www.llwrsite.com/customers/customer-guidance>.

Note that LLWR will not accept wastes that can go to landfill. A few nuclear-licensed sites have on-site disposal facilities licensed to accept certain categories of solid radioactive waste. These facilities can only accept waste at the lower end of the LLW category. So there may be a requirement to segregate radioactive wastes into categories suitable for on-site and off-site disposal. If waste is exempt from the requirements of Sections 13 or 14 of RSA93, and has one or more of the hazardous properties (eg toxicity due to the uranium content being >0.1 per cent), this waste will be classified as hazardous waste.

Solid depleted uranium encountered in quantities greater than specified in exemption orders made under the RSA93 poses a significant disposal problem. This is because it is characterised as an intermediate-level waste (ILW) for radioactivity purposes but is also categorised as a special waste under the Environmental Protection Act 1990 (see Box 4.3 for discussion of EPA 1990). So, it can only be disposed following the disposal and transport procedures for both ILW and special waste.

On both nuclear-licensed sites and defence sites, there can be a problem in returning any radioactively contaminated spoil or abstracted groundwater to trial pits and boreholes. Contaminated spoil or water, once removed from its original location, is radioactive waste and its return for disposal requires authorisation under RSA93. However, it is pragmatic to discuss these issues with the relevant environment agency before starting the site investigation and obtaining any authorisations in advance. Failure to do so could, at best, delay the site investigation and, at worst, result in prosecution for a breach of RSA93.

There may be some wastes that have no currently identified or authorised disposal routes and in this case it may be necessary to obtain approval for their safe interim storage on site until such time as a disposal route is available.

9.2.2.3 *On-site segregation of wastes for radioactivity*

The radionuclide fingerprint of the potentially contaminated material should be known to select appropriate instruments and methodologies for assigning wastes to the different categories. Wastes in which fission products (such as Cs-137) or radium are the principal contaminants can be segregated using certain hand-held gamma detectors, for example a 7 cm × 7 cm sodium iodide detector. Calibration of the detector for the particular nuclide and geometry (eg a semi-infinite plane or an excavator bucket full of waste) will be required.

It is not adequate or appropriate to segregate alpha- or beta-contaminated wastes using hand-held instrumentation. It will either be necessary to use an on-site laboratory to carry out gross alpha and gross beta screening analysis of representative samples of the waste or to categorise wastes after the laboratory radiochemical analyses of soil samples become available.

9.3 Management of non-active waste

In the UK, the majority of non-reactive wastes, including waste from household, commercial and industrial premises are termed “controlled wastes”. What is and what is not waste is defined in both UK legislation by the Controlled Waste Regulations 1992 and EU legislation by the Waste Framework Directive 2006 but these definitions are not unambiguous and have been widely challenged in the courts. If the producer of a waste has no further use for it and needs to discard it, then it is a controlled waste. An example of particular relevance in the situation described here is the case where clean soil is excavated from one site and reused on another. While the regulating authority might accept that the soil was not being discarded, so it is not waste, it is the person actually excavating the soil who must decide whether it is waste or not.

Some wastes require more careful handling and greater control such that they fall under specific control. These are described in English or Welsh law as “hazardous”, or in Scottish law as “special”, however, they are still “controlled” waste. All “hazardous waste” is “controlled waste”, although, not all controlled waste is hazardous.

Non-active wastes derived from site investigations are controlled waste. The ways of managing these wastes are rapidly changing, with more emphasis on reducing the volumes sent to landfill by reuse/recycling, and then pre-treating that which is to be landfilled.

Site waste management plans (SWMPs) introduced by the Clean Neighbourhoods and Environment Act 2005, became mandatory in England and Wales for all construction projects over £300 000 in April 2008[16]. They are designed to ensure that wastes generated by construction activities are properly managed, improve environmental performance, help regulation and provide evidence to regulators (EA, SEPA, NIEHS) and clients. If site characterisation works are classed as part of major construction and demolition projects on nuclear-licensed sites and defence sites then SWMPs can be expected to be required, or adhered to as part of the management of a larger project. Alignment of SWMPs with the CDM Regulations has been favoured by the construction industry.

9.3.1 Classification of non-active waste

The provisions of the Landfill Directive are now implemented in England and Wales by Schedule 10 of Regulation 35 of the Environmental Permitting (England and Wales) Regulations 2007 (as yet Scottish equivalent has not proceeded to a harmonised permitting system) and these will continue to have a significant impact on the management of wastes. The main impacts on waste producers are that:

- many wastes cannot be deposited in landfill (eg liquids, chemical substances arising from research and development that are not identified, and explosive and reactive materials)
- biodegradable waste are to be increasingly diverted from landfills
- landfills are classified according to whether they can accept hazardous, non-hazardous or inert wastes. Wastes can only be accepted at a particular landfill if they meet the relevant waste acceptance criteria (WAC) for that class of landfill
- most wastes must be treated before they can be landfilled.

The person/organisation that will take the responsibility for the wastes produced during site characterisation should be identified at an early stage in the project. This is most likely to be the consultants managing the project, but in some circumstances it may be either the site investigation subcontractor or the site management. The waste producer is responsible for ensuring that basic characterisation of the waste is undertaken to establish its main characteristics, as specified by the Regulations. In particular, details of the chemical composition and leaching behaviour of the waste are required to establish whether the waste is hazardous, non-hazardous or inert.

To determine whether the waste is hazardous waste or non-hazardous waste, the producer should first consult the Hazardous Waste List[17] derived from the *European waste catalogue*. This lists all waste streams and marks waste streams that are hazardous with an asterisk. There are two types of hazardous waste entries in the list: absolute entries and mirror entries.

If the waste stream in question is an absolute entry (such as 09 01 01* water-based developer and activator solutions in wastes from the photographic industry), it is always hazardous waste. If the waste is a mirror entry it has a corresponding non-hazardous waste entry. These can usually be identified as they use the word “containing”.

16 SWMPs are not mandatory in Scotland, but are advised as “good practice” by SEPA, Scottish Government and Scottish planning policies.

17 List of Wastes (England) Regulations 2005 (no Scottish equivalent).

Examples include:

- 17 05 03* Soil and stones containing dangerous substances
- 17 05 04 Soil and stones other than those containing dangerous substances.

In the case of a mirror entry, dangerous substances need to be assessed. Details of this assessment are provided by the Environment Agency (EA, 2006d).

Having identified whether the material is hazardous or not, if the producer wishes to dispose of the material at landfill, further characterisation is likely to be required against the waste acceptance criteria (WAC) to determine if it is acceptable at a given landfill. WAC testing will be required for hazardous waste, and it may also be prudent to undertake the WAC test to establish the organic content to discriminate between non-hazardous and inert. Disposal of acceptable wastes to an inert site will inevitably be the cheaper option. There are no leaching limit values for non hazardous waste, because the primary aim is to ensure that the waste is not hazardous. The waste should then be periodically checked to ensure that those properties have not changed. When treated waste is consigned to a landfill, the landfill operator will carry out on-site verification on each load to ensure that the waste is as described by the producer.

The full WAC consists of:

- a list of acceptable inert wastes
- leaching limit values
- analysis of various organic compounds including mineral oil, polycyclic aromatic hydrocarbons and polychlorinated biphenyl, as well as total organic carbons and/or loss on ignition.

For inert waste there is a list of acceptable wastes (Table 5.1 and EA, 2005a). If the waste is a single waste stream comprising waste on the list of acceptable inert waste, and uncontaminated by other materials, then it may be accepted at an inert landfill without testing. For wastes that may be inert but are not on this list, then testing must be undertaken against leaching limit values, and also limit values for other criteria including total organic carbon, to demonstrate that it is inert.

Guidance on definition and classification of hazardous waste (EA, 2006d) and on sampling and testing of wastes for each classification is provided by the Environment Agency (2004c).

Once the waste is characterised, management options can be considered in accordance with the waste hierarchy. Waste minimisation, reuse, recovery and final disposal should be considered in that order. Where disposal by landfill is identified for all or part of the waste, the producer will need to consider appropriate treatment options. If it is not practicable to treat the waste then it should be recorded on the disposal notice, however segregation and sorting are considered to be treatment processes.

9.3.2 Treatment

The Landfill (England and Wales) Regulations 2002 provide a definition of treatment from which the following test (the "three-point test") has been derived. Any potential treatment must fulfil all of these three criteria but need only meet one of the four objectives of the third point:

1 It must be a physical/thermal/chemical or biological process including sorting.

2 It must change the characteristics of the waste.

3 It must do so in order to:

   a reduce its volume

   b reduce its hazardous nature

   c facilitate its handling

   d enhance its recovery.

The waste producer makes the initial decisions about the management of their waste and so is in the best position either to treat or secure its treatment by others. If waste is to be sent to landfill after treatment then, depending on the treatment, testing to confirm whether the material should still be classified as hazardous waste must be carried out to establish its acceptability at landfill.

Of particular relevance to site characterisation generated wastes is that simple physical dilution, without any concurrent chemical or physico-chemical changes, is not an acceptable treatment process. So the dilution of contaminated soil with other soils to lower the concentrations of contaminants of concern below those for hazardous waste is unacceptable. Mixing waste to achieve a physico-chemical change, in pursuance of the third *criterion*, is acceptable.

9.4 Transport and disposal

All waste must be stored, transported, reused or disposed of in compliance with relevant EU and UK legislation.

In 2008 the Environmental Permitting (England and Wales) Regulations 2007 came into force, replacing much of the earlier legislation dealing with the control of waste, ie Environmental Protection Act 1990, Environment Act 1995, the control of more difficult wastes remain under the Hazardous Waste (England and Wales) Regulations 2005. SEPA and the Scottish Government are committed to waste regulatory reform, and implementation is now through the Waste (Scotland) Regulations 2005 and the Special Waste Amendment (Scotland) Regulations 2004.

Section 34 of the Environmental Protection Act 1990 imposes a duty of care on the holder of controlled waste, ie the person who produces, imports, carries, keeps, treats or disposes of waste, or to a broker who has control of such waste. The duty requires that anyone who has a responsibility for controlled waste must ensure that it is managed properly and recovered or disposed of without causing environmental pollution or harm to human health.

There are four main requirements of this duty of care:

1 To prevent any other person committing the offences of depositing, disposing or recovering controlled (or hazardous) waste without a waste management licence, contrary to the conditions of a licence, or in a manner likely to cause environmental pollution or harm to health.

This will be achieved by:

- the use of a reputable waste disposal contractor appropriately registered for disposal operations
- verification that the waste management licence permits the disposal operation to be undertaken

- conducting an audit trail on the disposal operation.

2 To prevent the escape of waste.

This will be achieved by:

- the use of appropriate transport containers
- each container (sealed drum or closed skip) will be labelled in accordance with Carriage of Dangerous Goods and Use of Transportable Pressure Equipment Regulations 2007.

3 To ensure that if the waste is transferred it goes only to an authorised person or to a person for authorised transport purposes.

This will be achieved by:

- the use of a reputable waste disposal contractor who is a registered waste carrier
- verification of the validity and currency of the waste carrier registration
- conducting an audit trail on the disposal operation.

4 When the waste is transferred, to ensure that there is also transferred a written description of the waste, a description good enough to enable each person receiving it to avoid committing any of the offences under point 1 and to comply with the duty at point 2 to prevent escape of waste.

This requires a waste transfer note, which should include the appropriate EWC code, to be prepared and for this to accompany each load of waste that is to be disposed of. Written information regarding treatment should be contained on or with the duty of care transfer note. The Hazardous Waste (England and Wales) Regulations 2005 set out the regime for the control and tracking of the movement of hazardous waste from the producer to the disposal facility.

9.5 Off-site road transport

9.5.1 Radioactive material movements

The transport of radioactive materials is subject to legislation relating both to radioactive content and to any chemical or physical hazards, namely:

- Carriage of Dangerous Goods and Use of Transportable Pressure Equipment Regulations 2007[18]
- Environmental Protection Act 1990: Part II, Hazardous Waste Regulations (England and Wales) 2005 and the Special Waste Amendment (Scotland) Regulations 2004.

Other regulations apply to Northern Ireland and to shipment across international frontiers. However, these are of less relevance to contaminated land investigations, and are not discussed further in this guidance.

In the context of a site investigation, these regulations may be relevant to the movement of solid and liquid samples to a testing laboratory or archive and to the movement of waste to a disposal facility.

18 Applies to Great Britain.

The legislation regarding radioactive material movements (or "RAM transfers") requires understanding of radiation protection issues. Specialist advice from a radiation protection adviser should be sought to ensure that all transfers of radioactive materials are in accordance with this legislation. It should be noted that materials that are "exempt" under RSA93 may still be considered as radioactive under transport legislation.

The consignor responsibilities are given in Box 9.3. In general, the main aspects of the legislation of relevance to contaminated land investigations are as follows:

- the Carriage of Dangerous Goods and Use of Transportable Pressure Equipment Regulations 2007 details individual radionuclide specific activity concentration limits and total activity limits for exempt consignments
- the types of materials that will be produced from the site investigation are radioactively contaminated soils, engineering materials and waters. These materials are likely to be classified as low specific activity (LSA) materials under the Carriage of Dangerous Goods and Use of Transportable Pressure Equipment Regulations 2007
- small volumes of radioactively contaminated materials (for example, samples being transported to a testing laboratory) will be transported using excepted packages (assuming that the material does not exceed the limits, both in terms of specific activity and total activity, which is unlikely). Larger volumes (waste being sent for disposal) will be transported in industrial packages (iso-containers)
- radioactive material should not be transported in a public service vehicle, ie passenger trains, buses, taxis
- radioactive material should not be sent through the post without prior approval in writing from the Post Office.

There are five criteria for the transport of a radioactive material in an excepted package:

- external dose rate at the surface of the package is less than 5 µSv/hr
- external dose rate at 10 cm from the unpacked "instrument or article" (eg the contaminated soil) will not to exceed 0.1 µSv/hr
- while the package is not required to bear a radiation trefoil the items inside should be marked "radioactive"
- the non-fixed[19] contamination levels on the surface of the package are less than 4 Bq/cm^2 beta gamma emitters and low toxicity alpha emitters and 0.4 Bq/cm^2 all other alpha emitters
- activity of the package does not exceed the radionuclide-specific limits given in the Carriage of Dangerous Goods and Use of Transportable Pressure Equipment Regulations 2007.

If any of these limits is exceeded, the radioactive material must be transported in an approved package.

Given the requirements of the Carriage of Dangerous Goods and Use of Transportable Pressure Equipment Regulations 2007 and the expense of RAM transfers, it is advisable to avoid off-site movements of radioactive materials where possible. Indeed some carriers will not accept radioactive materials even at very low levels. The use of on-site

19 "Non-fixed contamination" means contamination that can be removed from a surface during routine conditions of transport and "fixed contamination" means contamination other than non-fixed contamination.

laboratories for characterising samples containing higher levels of radioactivity should be considered. The requirement for waste minimisation has already been discussed (Section 9.1.2).

Box 9.3 ***Responsibilities under the Carriage of Dangerous Goods and Use of Transportable Pressure Equipment Regulations 2007***

In general duty the consignor, who is responsible for transporting the radioactive material, should exercise reasonable care, and must also ensure that:

- if this is the first shipment using a specific type of package that the relevant authorisations have been obtained from the competent authority
- the correct package type is used for the radioactive material (the total activity, external dose rate and surface contamination levels are appropriate to the package type)
- the package is correctly labelled
- the package is transported in accordance with the legislation (eg public transport is not used for the transport of RAM)
- the documentation complies with all the relevant legislation and relevant information is provided to the carrier
- the consignor maintains a quality assurance programme
- the consignee, who receives the radioactive material, is authorised to accept the radioactive material (ie it is a nuclear-licensed site or they have an authorisation under RSA93 to accumulate and dispose of radioactive material)
- that emergency arrangements are in place.

If the consigning site is licensed under the Nuclear Installations Act (as amended) 1965, extra record-keeping requirements will apply.

9.5.2 Nuclear materials

EURATOM safeguards apply to the civilian use of radioactive materials in the UK. One of the requirements is a system of accountancy and control of all nuclear materials subject to the legislation. "Nuclear materials" refers to any ore, source or special fissile material as defined in Part VI of the Commission Regulation (EURATOM) 1976. For organisations handling only small quantities of these materials (such as potentially being produced from a contaminated land investigation), only special fissile materials (Pu-239 and uranium enriched in U-235 or U-233) are subject to the legislation. Also, plutonium with an isotopic concentration of Pu-238 in excess of 80 per cent by activity is exempted.

It is possible that samples produced from the investigation of a site contaminated with fissile radionuclides may require registration under the nuclear materials accountancy system (see previous paragraph). It is not clear whether there is any "de-minimis" level below which the samples can be exempted from this system. Advice on the storage and transport of such material should be sought from the site operator who will take advice from the Department for Business Enterprise and Regulatory Reform (BERR) <www.berr.gov.uk/>.

9.5.3 Non-radioactive material

Not all "environmental" samples will need to be transferred as excepted packages. After health physics monitoring and clearance it is possible to submit very low activity samples via normal courier and postal services. However, the terms and conditions of the chosen courier service should be checked regarding the transport of such materials, as some companies exclude the transport of radioactive materials.

10 Record-keeping

Box 10.1 ***Aims of Chapter 10***

> Record-keeping is one of the SAFEGROUNDS key principles, and site characterisation acquired data and its interpretation should be stored in a SAFEGROUNDS land quality file. This action will ensure its longevity and sustain corporate memory of the owning organisation. Reporting of site characterisation work should be considered in a two volume format with separate factual and interpretative reports, which can be combined where required.

10.1 Site characterisation records

SAFEGROUNDS Key Principle 5 requires site owners/operators to make comprehensive records of the nature and extent of contamination, the process of deciding on the management option for contaminated land and the findings during implementation and validation of the option. It also states that all records should be kept and updated as necessary.

Participating organisation in the site characterisation process are likely to be committed to quality management consistent with the requirements of BS EN ISO 9001:2000, and as such will need to comply with the reporting requirements of these systems. The records should cover all site characterisation work, the process of deciding how to manage the contaminated land, implementing the chosen strategy, validation and interactions with stakeholders throughout the process. As characterisation proceeds all project related documentation should be filed and careful records should be kept of agreed changes, particularly when working on the site. Unless this level of detail is recorded the reasons for small changes due, for example, to operational reasons, will be lost to posterity. As with all good record-keeping, the files should be reviewed and filtered before final archiving.

At the start of the project, plans should be made for record-keeping that are compliant with the quality management programme used for the site characterisation works. Consideration should also be given at an early stage by both the commissioners and the implementation team of the site characterisation works as to the longevity of the materials and devices to be used to store data, because these factors have time and cost implications for project deliverables.

Practical guidance on land quality records management is given in a separate SAFEGROUNDS document (Cruickshank and George, 2007) available on: <www.safegrounds.com>. This guidance recommends that a land quality file (LQF) is set up for each nuclear licensed site or defence site so that information about contaminated land can be held in a formalised structure. The LQF should be part of the record management system of the organisation that owns or operates the site and should be accessible to stakeholders.

A fixed structure for each LQF is recommended for use across an organisation to capture the required information and to allow any gaps in information to be easily identified (Box 10.2). For smaller or more straightforward sites not all the sections may be relevant and its use in these instances should be appropriate to the issues concerned. The file comprises 12 sections and six annexes. The file may be used either as a source of information to feed into site characterisation in Chapters 3 to 7, or as a repository for site characterisation acquired data and its interpretation in Chapters 8 to 11.

The overall aim of Chapters 8 to 11 is to develop a comprehensive body of information including a realistic conceptual model and a robust risk-based analysis of the data. Chapter 9 is intended to be a live document that keeps track of knowledge on areas of potential concern, some of which may have been identified in a desk study then closed out in later investigation or remediation.

Chapter 10 enables build-up of a time-series picture which includes changes in land quality on sites that have a groundwater and/or soil gas monitoring programme. The results of these should be used to update, confirm or challenge the interpretations and assessments in Chapter 11. Chapter 11 will contain the records that document the site's understanding of the significance of ground contamination. The iteration of a conceptual model and other assessments and interpretations should be recorded so that any developments can be recorded and tracked through the initial overview document.

In Chapter 12 further supplementary characterisation information may be included as part of the implementation and verification of the land management options. As well as providing relevant background on the site, the annexes provide a logical and comprehensive record of the processes used to characterise and manage the land quality interest. Annex 3 will hold all the desk study and investigation data.

Overall, the contents of the LQF provide an audit trail for the land quality management process followed as applicable from SAFEGROUNDS land management guidance (Hill *et al*, 2009a) and CLR11 (EA, 2004a). It should enable stakeholders to find out the extent of available information, to understand what has been done and be involved in the future management.

The LQF can also be subdivided by area for complex sites or where site responsibility is split up to cope with fragmentation of the landholding for delicensing or redevelopment.

Box 10.2 ***Content of the land quality file (more detail can be added as on pp 17–19 of the record-keeping guidance (Cruickshank and George, 2007)***

1 Overview document.
2 Document management information.
3 Land referencing information.
4 Current and *future land-use.*
5 Surrounding land.
6 Surface and groundwater.
7 History.
8 Desk study and factual investigation information.
9 Live index of areas of potential concern.
10 Time series monitoring results.
11 Interpretations and assessments.
12 Management of contaminated land.
Annex 1 Record of regulatory information relevant to the land.
Annex 2 Record of site owner requirements/contractual information.
Annex 3 Record of desk studies and investigations.
Annex 4 Record of stakeholder involvement.
Annex 5 Other references.
Annex 6 Copies of other important documents.

10.2 Site characterisation reporting

Delivery of investigation reports may be required for different purposes to serve different audiences. So it may be useful to consider the reporting structure provided in Table 10.1.

Guidance produced in BS 10175:2001 deals solely with the preparation of a factual report, either as a separate volume, or in a single volume in combination with an interpretative report. The approach to risk assessment and its reporting is set out in CLR11 (EA, 2004a). A detailed breakdown of a report structure is provided in DETR (1997).

Consideration should be given to standardisation of data format. For example, the Association of Geotechnical and Geoenvironmental Specialists have a format (commonly known as AGS[20]) for recording and reporting data, including that derived from site characterisation programmes.

Table 10.1 ***Suggested reporting structure***

Report	Audience
Summary report	A brief non-technical summary of the whole investigation for a lay audience. Such a document is particularly useful to supply as part of stakeholder involvement.
Preliminary investigation report with initial conceptual model	To be completed before the next stage of investigation, and useful for circulation to all technically involved parties, and to supply with tender documents for the next site investigation stage.
Exploratory and main report	It is recommended that reports from these investigations are split according to potential audiences.
• factual	From a business point of view the commissioning organisation may wish to release factual information only to potential buyers or developers and allow them to place their own interpretation and cost analysis on the findings.
• interpretative	The interpretative report can be produced giving details of the risk assessment and may be for a limited audience.
Supplementary reports	These reports tend to be short and target particular issues, and there is no particular merit in splitting the facts from the interpretation.

20 <www.ags.org.uk>.

11 Uncertainty

Box 11.1 ***Aims of Chapter 11***

The aim of reducing uncertainty in site characterisation is to provide data with known confidence for input to risk assessment, options comparison or verification activities. Two aspects of uncertainty that are most important to site characterisation are:

- the conceptual model
- estimates of contaminant concentration and distribution.

Guidance to limit this uncertainty is summarised and signposted.

11.1 Uncertainty

It should be recognised that there will always be an element of uncertainty in site characterisation. This needs to be acknowledged in the reporting and quantified where possible. The significance of the uncertainty, the methods of reducing it and optimising investigations should also be explained to stakeholders. Much of the literature on uncertainty is focused on risk assessment (Smith, 2007, Petts *et al*, 1997 and UKCIP, 2003), but the two aspects of uncertainty that are important to site characterisation are:

- development of a representative conceptual model
- estimates of contaminant concentration and their distribution.

Conceptual model uncertainty: the initial conceptual model of the site will have formed the basis for identification of potential pollutant linkages and for the design of the survey. Adopting a worst case approach to contamination scenarios can ensure adequate site characterisation coverage. With a phased approach to investigations the uncertainties in the conceptual model can be reduced to focus characterisation on the most significant pollutant linkages. Nevertheless, some residual uncertainty will remain at the end of the site characterisation process. For example, there may be uncertainty regarding the presence of preferential flow paths at the site (perhaps associated with subsurface services or made ground).

Areas of remaining uncertainty should be identified for further investigation or other potential uncertainty reducing measures, such as increased numbers of samples, real time data collection to identify target areas or use of the Triad approach (Crumbling *et al*, 2005).

Estimates of contaminant concentration and their distribution: only a very small fraction of the site will have been directly sampled. It is important to evaluate the nature of the uncertainty associated with the characterisation elements of sampling, sample preparation and analysis to determine whether the measurements are fit for purpose for their specified use. Typically each element of the characterisation process is undertaken by different individuals and organisations. An awareness of the whole process is important to estimate uncertainty irrespective of the division of effort, and also to optimise the data gathering. Real time sampling and analysis is a comprehensive approach, and although the precision and accuracy of the analyses may be lower than the laboratory other aspects of uncertainty may be better controlled. Guidance on methods to estimate uncertainty for sampling and analysis is given by EURACHEM/ CITAC (2007).

Examples of possible areas of uncertainty are given in Table 11.1 together with possible solutions cross-referenced within this guidance and elsewhere.

Outstanding uncertainty should be recorded related to precision, bias, representativeness, completeness, comparability and sensitivity so that the significance can be treated in later data assessments.

Table 11.1 ***Examples of uncertainties arising during site characterisation, and possible actions that can be taken to reduce uncertainty and other impacts***

Site characterisation activity	Examples of uncertainty	Possible actions to reduce uncertainty and other impacts	Guidance section
Preliminary investigation • desk study	Access or supply of historical information on site history limited by site owner/ occupier. Leads to failure to identify potential radioactive and chemical contaminants, jeopardising HSSE management and scope of investigation (conceptual model uncertainty).	Assume worst-case history, particularly for defence site, and take client through an iterative process to try to establish all relevant sources of information. Prepare contingency plans for HSSE management and site investigation procedures.	5.3.1 5.5.1
	Inadequate information retained by client in plans and demolition records. Potential presence of *in situ* buried structures (eg foundation, services) on the site (conceptual model uncertainty).	Incorporate exploratory investigation stage, using non-invasion geophysical surveying. Limited intrusive investigations to prepare main investigation plans.	6.3 5.3.3
	Poor conceptual model developed and/or lack of link with later survey design. Results in poor quality investigation and poor quality HSSE management (conceptual model uncertainty).	Consult conceptual model checklist to ensure adequacy of model. Review conceptual model and site investigation objectives at regular intervals throughout project.	5.3.2 5.3.2
	Failure to set objectives, eg required risk target.	Ensure that risk targets are set. Use conceptual model of site and required level of confidence in output to design an appropriate sampling strategy.	4
	Failure to appreciate chemical and radioactive characteristics of waste that will be produced. Could lead to production of waste (eg mixed radioactive and organics-contaminated waste) for which no disposal route exists.	Evaluate potential characteristics of waste, and ensure disposal routes available.	9
Preliminary investigation • site reconnaissance	Failure to appreciate requirement of site operating procedures. Could limit technical scope of investigation (eg cannot investigate close to services) or could cause extensive delays to project schedule.	Ensure that, during site visit, appropriate staff are interviewed who can brief and supply contractors with necessary site operating instructions and documentation.	5.1
	Failure to identify protected flora or fauna, leading to possible delays in site characterisation programme, possible prosecution and failure to identify sensitive receptors.	Incorporate ecological surveys in preliminary stages of investigation, and adopt environmental protection measures if appropriate.	3.6.2

Table 11.1 (contd) ***Examples of uncertainties arising during site characterisation, and possible actions that can be taken to reduce uncertainty and other impacts***

Site investigation • exploratory • main • supplementary	Uncertainty in conceptual model and so poor understanding of contamination occurrence.	Use a phased investigation approach, real time sampling to focus investigation, or collect large number of samples.	5.3 and 8.3
	Failure to locate services, both inside and outside site boundary. This could lead to damage to services, possibly resulting in injury/death to site staff and/or disruption to site operations. Extensive delays and project schedule uncertainty.	Ensure that excavation procedures on the client's site are in accordance with site procedures and HSSE guidance. For off-site excavations, ensure that national utilities are contacted.	7.2.1
	Inconsistent positioning information, leads to uncertainty in locations of contaminated ground, sampling points, services etc (data uncertainty).	All investigations or surveys should be topographically surveyed to ordnance datum and National Grid reference. The accuracy of the survey method should be reported.	5.5.6
	Poor quality management of investigation resulting in unreliable data (eg poor sampling and logging data). Further verification works may then be necessary to satisfy stakeholders (data uncertainty).	Ensure that all work is undertaken in accordance with quality management system, and to AGS format.	7.5.1
	Inappropriate sample packaging, storage and speed of transport leading to sample deterioration.	Ensure that all work is undertaken in accordance with quality management system.	5.1.2
	Uncertainty in sample heterogeneity.	Ensure representative sample mixing, splitting and sub-sampling.	8.8.7
	Uncertainty in spatial variability.	Employ appropriate sampling strategies and other approaches.	5.5.2
	Uncertainty due to systematic measurement bias.	Use laboratory quality control practices to reduce uncertainty.	8.8.1
	Uncertainty in analytical data (data uncertainty).	Check QA/QC procedures, analyse more samples, duplicate analyses, use different preparation methods, use different analytical methods with lower limits of detection, look for related contaminants.	8.8.7
	Poorly transcribed digital data from field and laboratory.	Check QA/QC data procedures and use AGS format.	8.8.7

References

ASTM (2000)
Standard guide for developing conceptual site models for contaminated sites
American Society for Testing and Materials (E-1689-95)

BAVERSTOCK, K (2008)
"Implications of new radiobiological insights for the long-term management of high level radioactive waste"
Energy & Environment, vol 19, no 3–4, July 2008, pp 497–514 (18)

BDA (2002)
Health and safety manual for land drilling: a code of safe drilling practice
British Drilling Association

BRE (1999)
Radon: guidance on protective measures for new dwellings
Third edition, BRE Report 21, Construction Research Communications Limited

BURGESS, P H (1998)
Handbook on measurement methods and strategies at very low levels and activities
European Commission Nuclear Safety and the Environment. Report EUR 17624. NRPB
<http://ec.europa.eu/energy/nuclear/publications/doc/eur17624.pdf>

BURGESS, P H (2001)
Guidance on the choice, use and maintenance of hand-held radiation monitoring equipment
NRPB-R326n, Health protection Agency, London (ISBN: 0-855951-461-7). Available from:<www.hpa.org.uk/radiation/publications/archive/reports/2001/nrpb_r326.pdf>

CEWG (2006)
Clearance and exemption – principles, processes and practices for use by the nuclear industry – a nuclear industry code of practice
Clearance and Exemption Working Group, August 2006. Available from:
<www.cewg.safety-directors-forum.org/>

CLARK, L (1988)
The field guide to water wells and boreholes
Open University Press, Milton Keynes (ISBN: 0-33515-203-1) and Halstead Press, New York (ISBN: 0-47021-074-5)

CL:AIRE (2008)
Guidance on comparing soil contamination data with a critical concentration
The Chartered Institute of Environmental Health (ISBN: 978-1-904306-79-5).
Available from: <www.claire.co.uk>

COLLIER, D (2005a)
SAFEGROUNDS: *Community stakeholder involvement*
W16, CIRIA, London. Available from: <www.safegrounds.com>

COLLIER, D (2009c)
SAFEGROUNDS: *Approach to managing contaminated land on nuclear-licensed and defence sites – an introduction*
W27, CIRIA, London. Available from: <www.safegrounds.com>

COTTON, D P (2005)
An aerial survey of the area surrounding and encompassing the Rocky Flats Environmental Technology Site, Jackson County, Colarado
National Nuclear Security Administration DOE/NV/11718/1153, Dec 2005
<http://rockyflats.apps.em.doe.gov/references/189-Bechtel%20Aerial%20Survey.pdf>

CRUICKSHANK, J and GEORGE, S (2007)
SAFEGROUNDS: *Good practice guidance for land quality records management for nuclear licensed and defence sites*
W21, CIRIA, London, Available from www.safegrounds.com

COMARE (2006)
The distribution of childhood leukaemia and other childhood cancers in Great Britain 1969–1993
11th Report, HPA, London

CLG (2004)
Planning Policy Statement 23: *Planning and pollution control. Annex 2: Development on land affected by contamination*
Communities and Local Government, London (ISBN: 978-0-11753-927-3)

CRUMBLING, D (2004)
Summary of the Triad approach
US Environmental Protection Agency, Washington, USA <www.triadcentral.org>

CRUMBLING, D, HAYWORTH, J, JOHNSON, R and MOORE, M (2005)
"The Triad approach: a catalyst for maturing remediation practice in remediation"
The Journal of Environmental Cleanup Costs, Technologies & Techniques, vol 15, **1**, pp 3–19

DEFENCE ESTATES (2007a)
Contaminated land management: Land Quality Assessment (LQA) management guide
Practitioner Guide PG01/07. Available from: <www.defence-estates.mod.uk/publications/practitioner_guides/2007/PG_01_07.pdf>

DEFENCE ESTATES (2007b)
Duty holders guide on the assessment and management of land contaminated
IN 07/08. Available from:
<www.defence-estates.mod.uk/publications/information _notices/2008/IN0708.pdf>

DEFRA (2006a)
Industrial activities which have used materials containing radioactivity
Industry Profile. Available from:
<www.defra.gov.uk/environment/radioactivity/conland/pdf/industryprofile.pdf>

DEFRA (2006b)
Using RCLEA – the radioactively contaminated land exposure assessment methodology
Contaminated Land Report 13 (CLR 13). Available from: <www.environment-agency.gov.uk/static/documents/Research /clr13_1851717_1884705.pdf>

DEFRA (2006c)
Environmental Protection Act 1990: Part 2A Contaminated Land
Defra Circular 01/2006, September 2006. Available from:
<www.defra.gov.uk/environment/ land/contaminated/pdf/circular01-2006.pdf>

DEFRA (2007)
The radioactively contaminated land exposure assessment methodology – technical report
Contaminated Land Report 14 (CLR 14) interim report, January 2007

DETR (1997)
A quality approach for contaminated land consultancy
Contaminated Land Report 12 (CLR12), report by the Environmental Industries Commission in association with the Laboratory of the Government Chemist, Department of the Environment Transport and the Regions, London

DETR (2000a)
Guidelines for environmental risk assessment and management
Revised Departmental Guidance. Department of the Environment Transport and the Regions, Environment Agency, Institute for Environmental Health

DoE (1994a)
A framework for assessing the impact of contaminated land on groundwater and surface water
Contaminated Land Report 1 (CLR 1), HMSO Department of the Environment, London

DoE (1994b)
Guidance on preliminary site investigation of contaminated land
Contaminated Land Report 2 (CLR 2), HMSO Department of the Environment, London

DoE (1994c)
Documentary research on industrial sites
Contaminated Land Report 3 (CLR 3), HMSO Department of the Environment, London

DoE (1994d)
Sampling strategies for contaminated land
Contaminated Land Report 4 (CLR 4), HMSO Department of the Environment, London

DoE (1995)
Industry profiles covering 53 contaminative land uses
DEFRA, Publication Sales Centre, Rotherham

DIGBY, A J (2001)
A general guide to current geophysical borehole logging (for non-oil industry users)
BEL Geophysical, Fugro

ERSKINE, A D, GREEN, H R and HEATHCOTE, J A (1998)
Review of LNAPL monitoring techniques in groundwater
Project Record P2/080/1/M. Environment Agency 1998

EUROPEAN COMMITTEE ON RADIATION RISK (ECRR) (2003)
The health effects of ionising radiation exposure at low doses and low dose rates for radiation protection purposes
Recommendations of the ECRR, Regulators' Edition, C Busby, R Bertell, I Schmitz-Feuerhake, M Scott Cato and A Yablokov (eds), European Committee on Radiation Risk, Comité Européen sur le Risque de l'Irradiation, Brussels

EC DIRECTIVE (1996)
Laying down basic safety standards for the protection of the health of workers and the general public against the dangers arising from ionizing radiation
Council Directive 96/29/EURATOM

EA (1999a)
Technical support material for the regulation of radioactively contaminated land
R&D Technical Report P307, Environment Agency, Rotherham

EA (1999b)
Decommissioning redundant boreholes and wells
National Groundwater and Contaminated Land Centre, Environment Agency, Rotherham

EA (2000a)
Secondary model procedures for the development of appropriate soil sampling strategies for land contamination
R&D Technical Report P5-066/TR, Environment Agency, Rotherham

EA (2000b)
Some guidance on the use of digital environmental data
National Groundwater and Contaminated Land Centre Project NC/06/32, March 2000, Environment Agency, Rotherham

EA (2000c)
Review of non-invasive investigation techniques for groundwater pollution studies
R&D Report P2-178, Environment Agency, Rotherham

EA (2000d)
Guidance on the assessment and monitoring of natural attenuation of contaminants in groundwater
Report no P238, Environment Agency, Rotherham

EA (2001a)
Guide to good practice for the development of conceptual models and selection and application of mathematical models of contaminant transport processes in subsurface
National Groundwater and Contaminated Land Centre Report NC/99/38/2, Environment Agency, Rotherham

EA (2001b)
Secondary model procedure for the development of appropriate soil sampling strategies for land contamination
R&D Technical Report P5-066/TR, Environment Agency, Rotherham

EA (2002)
Guidance on the characterisation and remediation of radioactively contaminated land
Environment Agency, Rotherham

EA (2003a)
Hydrogeological risk assessment *for* landfills
LFTG No1, March 2003, Environment Agency, Rotherham

EA (2003b)
Guidance on the monitoring of landfill leachate, groundwater and surface water
Landfill Technical Guidance Note 02, Environment Agency, London

EA (2003c)
Development of a methodology for selection of determinant suites and sampling frequency for groundwater quality monitoring
Environment Agency, Rotherham

EA (2003d)
Performance standard for laboratories undertaking the chemical testing of soil (version 2)
Monitoring Certification Scheme: MCERTS, Environment Agency, Rotherham

EA (2004a)
Model procedures for the management of land contamination
Contaminated Land Report 11, Environment Agency, Rotherham

EA (2004b)
Technical aspects of site investigation
R&D Technical Report P5-065/TR, vol 1, Environment Agency, Rotherham

EA (2004c)
Guidance on sampling and testing of wastes to meet landfill waste acceptance procedures
Environment Agency, Rotherham

EA (2005a)
Guidance for waste destined for disposal in landfill
Interpretation of the waste requirements of the The Landfill (England and Wales) (Amendment) Regulations 2004, Environment Agency, Rotherham. Available from: <www.environment-agency.gov.uk/static/documents/Business/wacv2_1006008.pdf>

EA (2005b)
A framework for technical decisions and technical guidance on radioactive substances regulation
Radioactive Substances Regulation Environmental Principles (Interim), version 1, Environment Agency, Rotherham

EA (2006a)
Remedial targets methodology: hydrogeological risk assessment for land contamination
Environment Agency, Rotherham

EA (2006b)
Guidance on the design and installation of groundwater monitoring points
Science Report SC020093, January, Environment Agency, Rotherham

EA (2006c)
Chemical testing data on contaminated soils – qualification requirements
Policy No. 307-03 v2, 31 May 2006, Environment Agency, Rotherham

EA (2006d)
Hazardous waste. Interpretation of the definition and classification of hazardous waste
Second edition, Technical Guidance WM2, v2.1, Environment Agency, Rotherham

EA (2007)
Best practice techniques for environmental radiological monitoring
Science Report, SC030308/SR, Environment Agency, Rotherham

EA (2008)
Guidance for the safe development of housing on land affected by contamination
R&D Publication 66, Environment Agency, National House-building Council, Chartered Institute of Environmental Health

EA, NIEA, FSA and SEPA (2007)
Radioactivity in food and the environment 2006
RIFE-12 . Available from: <www.sepa.org.uk>

EURACHEM/CITAC (2007)
"Measurement uncertainty arising from sampling. A guide to methods and approaches"
First edition, *EURACHEM/CITAC Guide,* M H Ramsey and S L R Ellison (eds). Available from: <www.measurementuncertainty.org/mu/guide/>

FETTER, C W (1998)
Contaminant hydrogeology
Second edition, Prentice Hall (ISBN: 978-0-13751-215-7)

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 (ISBN: 978-0-86017-398-4)

HILL, M D (2005)
SAFEGROUNDS: *Briefing note on the Energy Bill*
W19, CIRIA, London. Available from: <www.safegrounds.com>

HILL, M D (2007)
SAFEGROUNDS: *The regulatory framework for contaminated land on nuclear-licensed sites and defence sites*
Version 4, W17, CIRIA, London. Available from: <www.safegrounds.com>

HILL, M D (2007a)
SD:SPUR: *Good practice tools for use in the development of strategies, plans and procedures for the management of decommissioning wastes and redundant buildings, plant and equipment on nuclear sites*
W22, CIRIA, London <www.sd:spur.com>

HILL, M D (2007b)
SD:SPUR: *The UK regulatory framework for decommissioning and management of decommissioning wastes*
W23, CIRIA, London <www.sd:spur.com>

HILL, M, PENFOLD, J, HARRIS, M, BROMHEAD, J, COLLIER, D, MALLET, H and G SMITH (2002)
SAFEGROUNDS: *Good practice guidance for the management of contaminated land on nuclear and defence sites*
W13, CIRIA, London. Available from: <www.safegrounds.com>

HILL, M, PENFOLD, J, WALKER, R, EGAN, M, COLLIER, D, ESLAVA-GOMEZ, A, KRUSE, P, RANKINE, A and TOWLER, P (2009a)
SAFEGROUNDS: *Good practice guidance for the management of contaminated land on nuclear-licensed and defence sites*
Version 2, W29, CIRIA, London. Available from: <www.safegrounds.com>

HSE (1991)
Protection of workers and the general public during the development of contaminated land
HS(G) 66, HMSO, London

HSE (1997)
Avoidance of danger from overhead lines
GS6, HMSO, London (ISBN: 0-71761-348-8)

HSE (1999)
Work with ionising radiations. Ionising radiation regulations approved code of practice and guidance
HMSO, London

HSE (2000a)
Work with ionising radiation: Approved code of practice and guidance
HSE Books, Sudbury (ISBN: 0-71761-746-7)

HSE (2000b)
Avoiding danger from underground services
HS(G)47, HSE Books, Sudbury (ISBN: 0-71761-744-0)

HSE (2001a)
Reducing risks, protecting people
HSE Books, Sudbury (ISBN: 0717621510)

HSE (2001b)
Decommissioning on nuclear-licensed sites
HSE, Bootle. Available from: <www.hse.gov.uk/nuclear/decomm1.pdf>

HSE (2002)
Guidance for inspectors on the management of radioactive materials and radioactive waste on nuclear licensed sites
Nuclear safety directorate, T/AST/024, HSE, Bootle. Available from: <www.hse.gov.uk/nuclear/waste1.pdf>

HSE (2005)
HSE criterion for delicensing nuclear sites
HSE, Bootle. Available from: <www.hse.gov.uk/nuclear/delicensing.pdf>

HSE (2006)
Safety assessment principles for nuclear facilities
Version 1, HSE, Bootle. Available from: <www.hse.gov.uk/nuclear/saps/saps2006.pdf>

HSE (2007a)
Managing health in construction. The Construction (Design & Management) Regulations 2007. Approved Code of Practice
L144, HSE Books, Sudbury (ISBN: 978-071766-223-4)

HSE (2008)
Delicensing guidance: Guidance to inspectors on the interpretation and implementation of the HSE policy criterion of no danger for the delicensing of nuclear sites
HSE, Bootle. Available from: <www.hse.gov.uk/nuclear/delicenceguide.pdf>

HSE (2009)
Nuclear site license conditions summary
Available from: <www.hse.gov.uk/nuclear/silicon.pdf>

HSE/CITB (2007b)
The Construction (Design and Management) Regulations 2007. Industry guidance for CDM co-ordinators
CDM07/2, Construction Industry Training Board (ISBN: 978-1-85751-234-2). Available from: <www.citb-constructionskills.co.uk>

HSE/CITB (2007c)
The Construction (Design and Management) Regulations 2007. Industry guidance for designers
CDM07/4, Construction Industry Training Board (ISBN: 978-1-85751-236-26). Available from: <www.citb-constructionskills.co.uk>

HSE/CITB (2007d)
The Construction (Design and Management) Regulations 2007. Industry guidance for principal contractors
CDM07/5, Construction Industry Training Board (ISBN: 978-1-85751-237-3). Available from: <www.citb-constructionskills.co.uk>

HSE/CITB (2007e)
The Construction (Design and Management) Regulations 2007. Industry guidance for contractors
CDM07/3, Construction Industry Training Board (ISBN: 978-1-85751-235-9). Available from: <www.citb-constructionskills.co.uk>

HSE/CITB (2007f)
The Construction (Design and Management) Regulations 2007. Industry guidance for workers
CDM07/6, Construction Industry Training Board (ISBN: 978-1-85751-238-0). Available from: <www.citb-constructionskills.co.uk>

IAEA (1999)
Assessment of occupational exposure due to external sources of radiation
RS-G-1.3, International Atomic Energy Agency and the International Labour Office, Vienna. Available from:
<www-pub.iaea.org/MTCD/publications/PDF/Pub1076_web.pdf>

IAEA (2003)
Extent of environmental contamination by naturally occurring radioactive material (NORM and technological options for mitigation
Technical Reports Series no. 419, International Atomic Energy Agency, Austria (ISBN: 92-0-112503-8)

IAEA (2004)
Radiation, people and environment
International Atomic Energy Agency, Austria. Available from:
<www.iaea.org/Publications/Booklets/RadPeopleEnv/pdf/radiation_low.pdf>

ICRP (1991) 1990
Recommendations of the International Commission on Radiological Protection
ICRP Publication 60, vol 21, No 1–3 (1991)

ICRP (2007)
"The 2007 Recommendations of the International Commission on Radiological Protection"
Annals of the ICRP, Publication 103, Elsevier BV, The Netherlands

KEAREY, P, BROOKES, M and HILL, I (2002)
An introduction to geophysical exploration
Third Edition, Wiley Blackwell Science, West Sussex (ISBN: 978-0-63204-929-5)

MALLET, H (2004)
SAFEGROUNDS: *Technical options for managing contaminated land*
W18, CIRIA, London. Available from: <www.safegrounds.com>

MCDOWELL, P W *et al* (2002)
Geophysics in engineering investigations
C562, CIRIA, London (ISBN: 978-0-86017-562-9)

MICHAELIS, J, KELLER, B, HAAF, G and KAATCH, P (1992)
"Incidence of childhood malignancies in the vicinity of West German nuclear power plants"
Cancer Causes Control, vol 3, pp 255–263

MILLER, W and TOOLEY (2005)
SD:SPUR: *Site decommissioning: sustainable practices in the use of construction resources*
W009, CIRIA, London <www.sd:spur.com>

MINISTRY OF DEFENCE (2005)
Sustainable development and environment manual
JSP 418, Directorate of Safety and Claims, London.
Available from: <www.mod.uk/NR/rdonlyres/F32B94CE-6620-40E8-A1D2-230EA43AEDD0/0/jsp418_whole.pdf>

MISSTEAR, B D R, BANKS, D and CLARK, L (2006)
Water wells and boreholes
WileyBlackwell, West Sussex (ISBN: 978-0-470-84989-7)

NATHANIAL, J, BARDOS, P and NATHANIAL, P (2002)
Contaminated land ready reference
Land Quality Press, EPP Publications Release 1, Northampton (ISBN: 1-90099-506-9)

NEXIA SOLUTIONS and GEOSCIENCES ADVISORY UNIT, UNIVERSITY OF SOUTHAMPTON (2008)
Electronic site investigation handbook
Available from: <www.nexiasolutions.com>

NATIONAL HOUSE-BUILDING COUNCIL (2007)
Guidance on evaluation of development proposals on sites where methane and carbon dioxide are present
Report no 4, NHBC, Bucks. Available from: <www.nhbcbuilder.co.uk>

NPL (2002)
Good practice guide (30) on practical radiation monitoring
MGPG 30, National Physical Laboratory, Middlesex

NPL (2008)
Recommended nuclear decay data
NPL Report IR6, National Physical Laboratory, Middlesex

NATIONAL RADIOLOGICAL PROTECTION BOARD (NRPB) (1998a)
Living with radiation
Fourth edition, Health Protection Agency, London (ISBN: 0-85951-419-6)

NATIONAL RADIOLOGICAL PROTECTION BOARD (NRPB) (2003)
Environmental radioactivity surveillance programme. Results for 2002
W47, Health Protection Agency, London

OATWAY, W M and MOBBS, S F (2003)
Methodology for estimating the doses to members of the public from the future use of land previously contaminated with radioactivity
W36, Health Protection Agency, London

OFFICE OF GOVERNMENT COMMERCE (OGC) (2002)
How to manage performance
Format Publishing, Norwich (ISBN: 978-1-90309-113-5)

PENFOLD, J (2009)
SAFEGROUNDS: *Guide to the comparison of contaminated land management options*
W28, CIRIA, London. Available from: <www.safegrounds.com>

PETTS, J, CAIRNEY, T and SMITH, M (1997)
Risk-based contaminated land investigation and assessment
J Wiley & Sons, West Sussex (ISBN: 0-471-96608-8)

RAMSEY, M H (1993)
"Sampling and analytical quality control (SAX) for improved error estimation in the measurement of heavy metals in the environment, using robust analysis of variance"
Applied Geochemistry, 2, pp 149–153

RAMSEY, M H, TAYLOR, P D and LEE, J-C (2002)
"Optimised contaminated land investigation at minimum overall cost to achieve fitness-for-purpose"
J Environ. Monit. 4, Royal Society of Chemistry, London, pp 809–814

RUDLAND, D J, LANCEFIELD, R M and MAYELL, P N (2001)
Contaminated land risk assessment. A guide to good practice
C552, CIRIA, London

SCOTTISH ENTERPRISE (1994)
How to investigate contaminated land. requirements for contaminated land site investigations
Scottish Enterprise, Glasgow

SCOTTISH EXECUTIVE (2006)
Environmental Protection Act 1990: Part IIA Contaminated Land
Second edition, paper SE/2006/44, statutory guidance

SCOTTISH EXECUTIVE (2000)
Planning Advice Note 33 (PAN 33): *Development of Contaminated Land*
Available from: <www.scotland.gov.uk/Publications/2000/10/pan33>

SMITH, G (2005)
SAFEGROUNDS: *Assessments of health and environmental risks of management options for contaminated land*
W15, CIRIA, London. Available from: <www.safegrounds.com>

SNIFFER (1999)
Communicating understanding of contaminated land (currently being updated)
Available from: <www.sniffer.org.uk>

STEEDS, J E, SHEPHERD, E and BARRY, D L (1996)
A guide for safe working on contaminated sites
Report 132, CIRIA, London

STONE, K, MURRAY, A, COOKE, S and FORAN, J (2009)
Unexploded ordnance (UXO) – a construction industry guide
C681, CIRIA, London

TUBIANA, M, AURENGO, A, AVERBECK, D, BONNIN, A, LE GUEN, B, MASSE, R, MONIER, R, VALLERON, A J and DE VATHAIRE, F (2005)
Dose–effect relationships and the estimation of the carcinogenic effects of low doses of ionizing radiation
Edition Nucleon, Joint Report no. 2, Academie Nationale de Medecine, Institut de France—Academie des Sciences, 30 March 30, French Academies of Medicine and Science, Paris (ISBN: 2-84332-018-6). Available from: <www.academie-medecine.fr/Upload/anciens/rapports_227_fichier_lie.rtf>

UKCIP (2003)
Climate adaptation: Risk, uncertainty and decision making
UK Climate Impacts Programme, Technical Report May 2003 (ISBN: 0-95448-300-6).

UNSCEAR (2000)
"Sources and effects of ionising radiation"
United Nations Scientific Committee on the Effects of Atomic Radiation, United Nations

USEPA (2000)
Multi-agency radiation survey and site investigation manual (MARSSIM)
Report EPA 402-R-97-016, US Environmental Protection Agency, Washington, DC
<www.epa.gov>

USEPA (2002)
Guidance on choosing a sampling design for environmental data collection (for use in developing a quality assurance project plan)
EPA QA/G-5S, US Environmental Protection Agency, Washington DC <www.epa.gov>

USEPA (2006)
Guidance on systematic planning using the data quality objectives process
QA/G-4, US Environmental Protection Agency Washington DC <www.epa.gov>

WARWICK, P (2007)
Environmental radiochemical analysis III
Royal Society of Chemistry, London, (ISBN: 978-0-85404-263-0)

WATSON, S J, JONES, A L, OATWAY, W B and HUGHES, J S (2005)
Ionising radiation exposure of the UK population: 2005 review
HPA-RPD-001, Health Protection Agency, Chilton (ISBN: 0-85951-558-3)

WELSH ASSEMBLY GOVERNMENT (2006)
Part 2A Statutory guidance on contaminated land (2006)
Available from: <http://wales.gov.uk/?lang=en>

WILSON, S, CARD, G and HAINES, S (2007)
Ground gas handbook
Whittles Publishing (ISBN: 978-1-90444-568-5)

WILSON, S, OLIVER, S, MALLETT, H, HUTCHINGS, H and CARD, G (2007)
Assessing risks posed by hazardous ground gases to buildings (revised)
C665, CIRIA, London

WLGA (2006)
Land contamination: A guide for developers
Jointly with the Environment Agency and Welsh Assembly Government, Welsh Local Government Association. Available from:
<www.cardiff.gov.uk/ObjView.asp?Object_ID=6848>

WILLIAMS, S M, GALAIS, N C M, LENNON, C P and TRIVEDI D P (2007)
ReCLAIM v2.0: "A spreadsheet tool for calculating doses and soil/water radionuclide screening levels for assessment of radioactively contaminated land"
J. Radiol. Prot. 27, Nexia Solutions Ltd, Warrington pp 87–93

Legislation

Acts

Clean Neighbourhoods and Environment Act 2005 No Scottish equivalent

Health and Safety at Work etc Act 1974 Applies to England and Wales, and Scotland

Environmental Protection Act 1990: Part IIA Contaminated Land (inserted by the Environment Act 1995) Statutory guidance, Edition 2 (ISBN: 0-7559-6097-1) Applies to England and Wales, and Scotland

Nuclear Installations Act 1965 (Repeal and Modifications) Regulations 1990 (SI No.1918) Applies to England and Wales, and Scotland with modifications made in Scotland as proposed under the Scotland Act 1998

Radioactive Substances Act 1993 (RSA93) Applies to England and Wales, and Scotland

Water Resources Act 1991

Water Environment and Water Services (Scotland) Act 2003

Water (Scotland) Act 1980 and Sewage (Scotland) Act 1968

Water Services etc (Scotland) Act 2005

Orders

Radioactive Substances (Phosphatic Substances, Rare Earths etc) Exemption Order 1962 (SI No 2648)

The Radioactive Substances (Phosphatic Substances, Rare Earths etc) Exemption Order 1962 Scotland (SI No 2769)

Radioactive Substances (Substances of Low Activity) Exemption Order 1986 (SI No 1002) Applies to England and Wales, and Scotland

Part III of the Waste & Contaminated Land (Northern Ireland) Order 1997

Directives

EC Habitats Directive, Council Directive 92/43/EEC on the on the conservation of natural habitats and of wild fauna and flora

Environmental Liability - Directive 2004/35/EC

Groundwater Directive 1980 80/68/EEC

Regulations

Carriage of Dangerous Goods and Use of Transportable Pressure Equipment Regulations 2007 (SI No 1573) Applies to England and Wales, and Scotland

Commission Regulation (Euroatom) 1976 No 3227/76

Construction (Design and Management) Regulations 2007 (SI No 320) Applies to England and Wales, and Scotland

Control of Substances Hazardous to Health Regulations 1999 (SI No 437) Applies to England and Wales, and Scotland

Contaminated Land (England) Regulations 2000 (SI No 227)

Contaminated Land (Scotland) Regulations 2000 (SSI No 178)

Contaminated Land (England) Regulations 2006 (SI No 1380)

Contaminated Land (Scotland) Regulations 2005 (SSI No 658)

Environmental Permitting (England and Wales) Regulations (SI No 3538)

Environmental Protection Act 1990: Part II: Hazardous Waste Regulations (England and Wales) 2005

Groundwater Regulations 1998 (SI No 2746)

In Scotland, the requirements of the Groundwater Regulations have been included in the Water Environment (Controlled Activities) (Scotland) Regulations 2005 (SSI No 348)

Hazardous Waste (England and Wales) Regulations 2005 (SI No 894)

The Special Waste Amendment (Scotland) Regulations 2004 (SSI No112)

Ionising Radiations Regulations 1999 (SI No 3232) Applies to England and Wales, and Scotland

List of Wastes (England) Regulations 2005 (SI No 895)

Nuclear Industries Security Regulations 2003 (SI No 403) Applies to England and Wales, and Scotland

Nuclear Reactors (Environmental Impact Assessment for Decommissioning) Regulations 1999 (SI No 2892) Applies to England and Wales, and Scotland

Radioactive Contaminated Land (Enabling Powers) (England) Regulations 2005 (SI No 3467)

Radioactive Contaminated Land (Modification of Enactments) (England) Regulations 2006 (SI No 1379)

Radioactive Contaminated Land (Scotland) Regulations 2007 (SI No 179)

Special Waste Regulations 1996 (as amended) (SI No 972)

Town and Country Planning (Environmental Impact Assessment, England and Wales) Regulations 1999 (SI No 293)

Water Environment (Controlled Activities) (Scotland) Regulations 2005 (SSI No 348)

Waste (Scotland) Regulations 2005 (SSI No 22)

Standards

BS 10175:2001 *Investigation of potentially contaminated sites. Code of practice* (ISBN: 0-5803 3090-7)

BS 6068-2.2:1983-2000 *Water quality sampling*. Part 1 to Part 19

BS 7022:1988 *Guide for geophysical logging of boreholes for hydrogeological purposes* (ISBN: 0-58016-871-9)

BS 5930:1999 *Code of practice for site investigations* (ISBN: 0-58033-059-1)

BS 8485:2007 *Code of practice for the characterisation and remediation of ground gas in brownfield developments*

BS 1377-9:1990 *Methods for test for soils for civil engineering purposes. In-situ tests categories*

BS 7755-2.6:1994 *Soil quality. Sampling. Guidance on the collection, handling and storage of soil for the assessment of aerobic microbial processes in soil*

BS EN ISO 9001:2000 *Quality management systems. Requirements*

BS EN ISO 14001:2004 *Environmental management systems. Requirements with guidance for use* (ISBN: 0-58044-771-5)

BS EN ISO 14001:1996 *Environmental management systems. Specification with guidance for use* (ISBN: 0-580-26708-3)

BS ISO 10381-1:2002 *Soil quality. Sampling. Part 1: Guidance on design of sampling programmes*

BS ISO 10381-3:2001 *Soil quality. Sampling. Part 3: Guidance on safety*

BS ISO 10381-5:2005 *Soil quality. Sampling. Part 5: Guidance on the procedure for the investigation of urban and industrial sites with regard to soil contamination*

BS EN ISO 14688-2:2004 *Geotechnical investigation and testing. Identification and classification of soil. Part 2: Principles for a classification*

ISO/DIS 13530-2:1997 *Guidance on analytical quality control for chemical and physicochemical water analyses*

ISO/CD TS 13530 *Water quality. Guidance on analytical quality control for chemical and physicochemical water analysis*

Eurocodes

BS EN 1997-2:2007 *Geotechnical design. Ground investigation and testing*

Websites

<www.marssim.com>

<www.environment-agency.gov.uk>

<www.epa.com>

<www.iaea.org>

<www.hpa.org.uk>

<www.who.int/>

<www.defra.gov.uk>

<www.sepa.org.uk/>

<www.hanford.gov/dqo>

<www.chemistry.about.com>

<www.food.gov.uk>

Glossary

Key:

Bold = terms with special meanings in the SAFEGROUNDS context

Underlined = terms with defined meanings in other contexts (eg regulatory contexts or units definitions).

Plain text = technical terms to assist non-technical audiences.

Absorbed dose	A measure of the energy from ionising radiation deposited in a unit mass of any specified material. The unit of *absorbed dose* is the *Gray*, equal to 1 joule per kg.
Absorption	Process where material in contact with the skin may pass through the pores on the skin's surface and enter the bloodstream. Identified as a possible route for *contaminant* entry into the body.
Activation	Process where a *neutron* is captured by a nucleus to form a new isotope (often a *radionuclide*).
Activation product	An isotope created by *activation*.
Activity	See *Radioactivity*.
Activity concentration	Terminology used to describe *radioactivity* levels relative to the mass or volume of the sample matrix (eg Bg kg^{-1} in soil, Bg L^{-1} in water).
ALARP	As low as reasonably practicable. A standard for assessing necessary control measures taking into account the practicalities of the task in hand. Note: "reasonably practicable" has a defined legal meaning in the UK. ALARP incorporates this legal meaning as opposed to any other meaning that may be implied from technical publications such as those by the International Commission on Radiological Protection (ICRP).
Alpha decay	A form of *radioactive decay* resulting in the emission of a positively charged particle containing two neutron and two protons (a helium nucleus).
Anthropogenic radionuclides	Artificially produced *radionuclides*, by means of *activation* or *nuclear fission*.
Approved Dosimetry Service (ADS)	A dosimetry service approved by HSE (or a body specified by HSE) for measuring, assessing and recording radiological doses to workers. The aim of approval is to ensure, as far as is possible, that doses are assessed on the basis of accepted national standards.
Assumption	**A supposition to provide a clear and well defined basis for the options comparison. Assumptions are necessary where there is some uncertainty concerning factors that have the potential to influence the options assessment, eg the availability of particular waste management routes.**
Atmospheric fallout	Deposition of *radionuclides* to the ground following release to the atmosphere. Normally refers to the effects of atmospheric nuclear weapons testing or large accidents with widespread impact such as the accident at Chernobyl.
Averaging volume	The volume of waste over which the *activity concentration* is determined and averaged to give an average activity concentration for waste sentencing purposes.
Background radioactivity	Radioactivity from *naturally occurring radionuclides*, and *anthropogenic radionuclides* from manmade sources (such as

	global fallout as it exists in the environment from the testing of nuclear weapons or from accidents like Chernobyl) that are not under the control of the owner/operator.
Becquerel (Bq)	The International System (SI) unit of *activity* equal to one nuclear transformation (disintegration) per second.
Beta decay	A form of *radioactive decay* resulting in the emission of an electron or positron.
Classified worker	A category of worker defined under the Ionising Radiations Regulations 1999. Any person who, during the course of their work, is likely to receive an annual *effective dose* in excess of 6 µSv or three-tenths of the appropriate dose limit should be a classified worker.
Collimation	Elimination of the peripheral (more divergent) portion of a useful beam by means of metal tubes, cones, or diaphragms interposed in the path of the beam.
Conceptual model	A representation of the characteristics of the site in diagrammatic or written form that shows the possible relationships between contaminants, pathways and receptors.
Constraint	**Any factor that limits the range of options that can be considered in the options comparison, and is outside the control of those with responsibility for making the decision about the management of the contaminated land. Financial issues should not be used as constraints unless all stakeholders agree.**
Contaminant	**A substance that is in, on or under the land and that has the potential to cause harm or to cause pollution of controlled waters.**
Contamination	**The presence of a substance that is in, on or under the land and that has the potential to cause harm or to cause pollution of controlled waters.**
Contaminated land	**Any land in, on or under which there are radioactive or non-radioactive contaminants at levels above the natural and artificial background levels that are typical of the area of the UK in which the site is located.**
Context	**A definition of the existing situation in which the decisions on the management of the contaminated land need to be taken. The context will include information about the contamination and its status, timescales, regulatory factors and stakeholders and any issues of particular importance.**
Controlled area	Any area where the annual *effective dose* to persons working there is likely to exceed 6 µSv or three-tenths of the appropriate dose limit. Defined within the Ionising Radiation Regulations 1999. Controlled areas have special procedures in place to restrict the possibility of significant exposure. Areas in excess of 7.5 microsieverts per hour when averaged over an eight hour working day should be designated.
Controlled waste	The UK term for wastes controlled under the Waste Framework Directive: any household, industrial or commercial waste.

Controlled waters	Defined in Part III (Section 104) of the Water Resources Act 1991, which includes all groundwater, inland water, estuaries and coastal water to three nautical miles from the shore.
Cosmogenic radionuclides	*Radionuclides* produced by the interaction of cosmic rays with terrestrial matter (eg in the atmosphere).
Cross-contamination	A process whereby, during a series of intrusive investigations or within a single investigation, contaminated material from one area comes into contact with material from another area, thereby potentially affecting the results of any analyses being carried out.
Criterion	**A property or measure of an option's performance that is relevant to the comparison of options. Criteria should be capable of being objectively quantified for all options under consideration (even if only with a simple scoring or ranking scheme). Criteria should also be unique and independent of one another and be defined at a similar level of detail. Criteria are sometimes referred to as "attributes".**
Daughter nuclide	See *Decay product*.
Decay chain	A series of *radionuclides*, each of which decays into the next *radionuclide* in the series until a stable nuclide is reached.
Decay product	The nuclide produced following a *radioactive* decay. Also called a *daughter nuclide*.
Decision making	**The process of deciding which option should be implemented. A major input into decision making is a formal comparison of options. However, other factors may play a role in determining which option is to be implemented.**
Decommissioning	The set of actions taken at the end of a nuclear facility's operational life to take it permanently out of service. It includes actions to systematically and progressively reduce the level of hazard on a site and may include the physical dismantling of facilities. The ultimate aim of decommissioning of a *nuclear-licensed site* is to make the site safely available for other purposes. The endpoint for decommissioning may be *delicensing* or re-use of the site for nuclear purposes, or the keeping of the site under institutional control.
Defence site	**In this guidance, defence sites include: non-nuclear sites that have been or are being used for defence activities and nuclear sites that are operated for MoD by contractors and that are licensed and regulated by HSE under the Nuclear Installations Act (*nuclear-licensed sites*).**
Desk study	Interpretation of historical, archival and current information to establish where previous activities were located, and where areas or zones containing distinct and different types of contamination may be expected to occur, and to understand the environmental setting of the site in terms of *pathways* and *receptors*.
Delicensing	The process of releasing a *nuclear-licensed site* from regulation under the Nuclear Installations Act and of releasing the operator from his period of responsibility for any nuclear liability.

Detailed quantitative risk assessment	*Risk assessment* carried out using detailed site-specific information to estimate risk or to develop *site-specific assessment criteria*.
Discharge	Any emission of a *contaminant* into the environment.
Dose constraint	A target maximum individual dose set by an employer or *radiation protection adviser* for any project involving the use of ionising radiations. The target is set on the basis of what can be achieved by best practice and helps to keep doses *ALARP*. The Regulators can also set dose constraints for the site and specific operations on the site in terms of dose impact to members of the public.
Effective dose	A radiation dose quantity that is a modification of *equivalent dose*, which take into account the susceptibility of different organs and tissues in the body to stochastic effects such as cancer induction, as well as the different radiation types included in the definition of *equivalent dose*. The unit of *effective dose* is the *Sievert*.
Environment	**The environment includes land, water (including groundwater), air, flora, fauna, buildings, animals, crops and sites of historical and cultural importance. In this guidance, people are regarded separately from the environment. The distinction is made for consistency with health and safety, and radiological protection, terminology.**
End state	**The state beyond which no further regulatory controlled action by the current site owner/operator is required.** **Note this differs from the NDA definition:** **"The 'end state' of a site is the physical condition of the site at the point at which the NDA has finished its business"** **Note that with this definition it does not necessarily require all radiological material to be removed from the site, because it is possible for the site to remain under long-term institutional control even after the NDA has finished its work.** **It is possible that a site end state may be mixed – it may consist of several areas remediated to standards appropriate for differing potential reuses.**
Equivalent dose	A radiation dose quantity, which is a modification of the absorbed dose that takes into account the different amounts of damage done by different *radioactive decay* types (see *quality factor* and *absorbed dose*). The unit of *equivalent dose* is the *Sievert*.
Exempt waste	Radioactive waste that is exempt from some or all of the requirements of the Radioactive Substances Act 1993. Such wastes are defined in *Exemption Orders* made under the Act. See also SoLA.
Exemption Orders	Subsidiary legislation, operating under the Radioactive Substances Act 1993, that "exempts" certain materials and forms up to prescribed activity concentrations from some or all of the requirements of the Act.
External radiation	In relation to a person means *ionising radiation* coming from outside the body.

Fingerprint (radiological)	A distinctive or identifying characteristic set of radioactive isotopes that distinguish a particular emission.
Fission product	A nuclide produced as a result of *nuclear fission*.
Future land use	**The range of uses the *contaminated land* will be able put to be put to after the selected *option* has been implemented successfully. The range of future uses may be restricted to reduce the potential hazards associated with residual contamination. Alternatively, the site may be made available for any future use, in which case lower levels of residual concentrations of contaminants are likely to be required.**
Gamma radiation	Penetrating high-energy, short-wavelength electromagnetic radiation (similar to X-rays) emitted during *radioactive decay*. Gamma rays are very penetrating and usually require dense materials (such as lead or steel) for shielding.
Gas-filled detector	Radiation detector consisting of a tube filled with ionisable gas. When the gas is ionised by radiation, the ions are detected by electrodes.
Generic assessment criteria	Criteria derived using general assumptions about the characteristics and behaviour of sources, pathways and receptors. These assumptions will be protective in a range of defined conditions.
Generic quantitative assessment	Risk assessment carried out using generic assumptions to estimate risk or to develop *generic assessment criteria*.
Geophysics	The science of detecting geological structure and buried objects using a variety of (normally non-intrusive) investigative techniques.
Geotechnical testing	Determination of the physical properties of soil/rock.
Gray (Gy)	The unit of absorbed energy dose (J kg^{-1}) or Joules per kilogram.
Groundwater	All water that is below the surface of the ground in the saturation zone and is in direct contact with the ground or subsoil.
Half-life	The time required for one-half of the atoms of a particular *radionuclide* present to decay (disintegrate).
Harm	Adverse effect on the health of living organisms, or other interference with ecological systems of which they form a part, and, in the case of humans, including property.
Hazard	A property of situation that in particular circumstances could lead to harm or pollution.
Hectare	A unit of area, equivalent to 10 000 m^2.
High level of protection	**The level of potential impacts on people and the environment that all stakeholders agree can be tolerated. SAFEGROUNDS does not recommend a particular level of protection, rather it is recommended that the level of protection should be defined on a case-by-case basis.**
Hold point	Exposure limit specified for a particular project, which cannot be exceeded without re-assessment of working practices, including any PPE and RPE requirements.

Ingestion	*Contaminant* entering the stomach and gastrointestinal tract through eating contaminated food, imbibing fluids or hand to mouth contact.
Inhalation	Breathing *contaminant* (eg particulate material, vapour, gas) in through the mouth or nose.
Injection	*Contaminant* entering the body tissue and blood stream directly through cuts and abrasions.
Internal radiation dose	Exposure received internally to the body via inhalation, *absorption*, *ingestion* or *injection* routes.
Ionising radiation	Any form of radiation that is capable of ionising matter. Typically this ionisation takes the form of displacing an electron from an atom.
Irradiation	The process of subjecting an entity to *radiation*.
Involvement	The processes of communication, consultation and participation of stakeholders.
Key principle	**A fundamental principle that should be adhered to during *land management*. Through consultation, SAFEGROUNDS has developed five key principles on the protection of *people* and the *environment*, *stakeholder* involvement, the identification of the preferred *land management option*, taking immediate action and record-keeping.**
Land quality	**The condition of ground (soil, water and buried structures) due because of to natural or manmade factors that could have an impact on people or the environment.**
Land quality management strategy	**A document (or document suite) setting out a framework of arrangements, processes and broad objectives for all aspects of management of contaminated land on a site (or part of a site).**
Licensee	The organisation that is the holder of the nuclear site licence on a *nuclear-licensed site*. The licensee is responsible for nuclear safety on the site and for discharging all the obligations and liabilities associated with the nuclear site licence.
Made ground	Ground produced by infilling with material from outside the site or from another part of the site. Typically this could include rubble, gravel or sand or waste materials.
Management of contaminated land	**Aspects of taking of any actions to assess, characterise, control, monitor or remove (wholly or partially) contamination in on or under land, and all the processes that lead up to decisions to take such actions to protect people and the environment. This includes, but is not limited to, development of a conceptual model and undertaking a risk assessment and a structured comparison of potential management options.**
Monitoring	**A continuous or regular period check to determine the presence or absence of contamination, its nature and the performance of any remediation works. This includes measurements undertaken for compliance purposes, and those undertaken to assess remedial performance.**
Naturally occurring radionuclides	*Radionuclides* and their associated progeny produced during the formation of the earth or by interactions of terrestrial matter with cosmic rays.

Neutron	Uncharged sub-atomic particle, constituting about 50 per cent by mass of most atomic nuclei.
Neutron flux	A measurement of the intensity of a neutron source (measured in J cm^{-2} s^{-1} or neutrons cm^{-2} s^{-1}).
Non-radioactively contaminated land	**Any land in, on or under which there are non-radioactive contaminants at levels above the natural and artificial background levels that are typical of the area of the UK in which the site is located.**
Nuclear fission	Process by which an atom splits into two or more pieces, each being an entirely separate nuclide.
Nuclear-licensed site	Sites that are regulated by HSE under the provisions of the Nuclear Installations Act 1965 (as amended) with a nuclear site licence. The Act applies to fixed sites for the purposes of constructing and operating nuclear reactors and other prescribed nuclear installations. The guidance applies to operating sites and those being *decommissioned*, whether or not they are to be *delicensed*.
Objectives	**This is what management of contaminated land is intended to achieve. Objectives are set by considering factors such as government policy, corporate/organisational policy and the views of *stakeholders*. It is recommended that environment, and health and safety objectives are established separately from those of a commercial and administrative nature.**
Option	**Any potential method of managing the contaminated land that is relevant to the objectives. Options can include, but may go further than, some or all of the actions defined as "remediation" in Part 2A of the Environmental Protection Act, 1990. In evaluating options, consideration should always be given to "doing nothing more" to the contamination or to removing contamination to background levels.**
Optimisation	The form, scale and duration of the intervention (remedial action) that maximises the net benefit. The principle of optimisation means that there is no predetermined end point for remediation that is applicable in all circumstances. In the extension to Part 2A, where a remediation scheme addresses significant pollutant linkages, some but not all of which relate to lasting exposure, any intervention should be optimised having regard to their benefit in respect of any remedial treatment actions relating to non-radioactive significant pollutant linkages. Within a radiation protection context optimisation is an essential part, and in practice the most important part of a system of dose limitation because reliance on dose limits is not enough to achieve an acceptable level of protection. Safety shall be optimised so that the magnitude size of individual doses, the number of people exposed and the likelihood of incurring exposures all be kept as low as reasonably achievable. Economic and social factors are taken into account, within the restriction that the doses to individuals delivered by the source be subject to dose constraints as defined in the *International Basic Safety Standards for protection*

	against ionizing radiation and for the safety of radiation sources (IAEA, 1996).
Owner/operator	**The organisation with responsibility for the site and any associated *contaminated land*. At *nuclear-licensed sites* the operator is the licensee. Owners/operators are responsible for taking final decisions to implement the *proposed option* for land management.**
Pathway	A route or means by which a *contaminant* can reach, or be made to affect, a *receptor*.
People	**Those individuals that could be affected by *contaminated land*. People are distinguished from *environment* following health and safety and radiological protection convention. Separate consideration may be given to "workers" (who receive a direct financial benefit from the *owner/operator*) and the public (who do not). Consideration should also be given to people at present and in the *future*.**
Permeability	The relative ease with which a porous medium can transmit a fluid under a hydraulic gradient.
Pollutant linkage	The relationship between a *contaminant*, a *pathway* and a *receptor*.
Possible options	**All the options that would be effective for managing the *contaminated land*.**
Preferred option	**An option which, on the basis of the options comparison, represents the best balance of features to achieve the overall objectives for the management of the *contaminated land*.**
Preliminary risk assessment	**First tier of risk assessment that develops the initial conceptual model of the site and establishes whether or not there are any potentially unacceptable risks.**
Primordial radionuclides	*Radionuclides* produced during the initial formation of the earth. Those of the *radionuclides* that remain have very long *half-lives*, of possibly the order of billions of years or more.
Proposed option	**The *option* that is formally submitted by an *owner/operator* to regulators and decision makers for approval to implement, following the comparison of options, identification of a preferred option, and consideration of this *preferred option* in regulatory and other acceptance procedures.**
Putrescible waste	Organic waste that may decompose or rot.
Quality factor	A factor applied to the *absorbed dose* in tissue to take account of the different levels of harm inflicted by different types of *radioactive decay*. Used to calculate *equivalent dose*.
Radiation	Normally used in place of ionising radiation, radiation is the emission of energy by means of particles or waves.
Radiation protection adviser (RPA)	An appointment required under the Ionising Radiations Regulations 1999 for all companies involved in work with ionising radiations. The RPA is registered with the HSE and provides advice on all aspects of radiological protection. The RPA will set *dose constraints* on workers and specify *hold points* for use during the work.
Radiation protection supervisor (RPS)	An appointment required under the Ionising Radiations Regulations 1999 for all companies involved in work with

	ionising radiations. An RPS must have received training related to radiological protection and ensures that the specified safety restrictions are observed.
Radioactive decay	The spontaneous transformation of an unstable atom into one or more different nuclides accompanied by either the emission of energy and/or particles from the nucleus, nuclear capture or ejection of orbital electrons, or fission. Unstable atoms decay into a more stable state, eventually reaching a form that does not decay further nor has a very long *half-life*.
Radioactive material	Often used to describe any material containing *radionuclides*. The statutory definition of *radioactive material* is given in the Radioactive Substances Act 1993.
Radioactively contaminated land	**Any land in, on or under which there are radioactive contaminants at levels above the natural and artificial background levels that are typical of the area of the UK in which the site is located.** **The phrase "in, on or under" includes soils, rocks groundwater and below ground structures but excludes authorised disposals of radioactive and non-radioactive wastes. These definitions are for the purposes of SAFEGROUNDS only. They have been chosen because they best reflect the views of stakeholders on the levels of contamination with which the SAFEGROUNDS guidance should be concerned.** **The term radioactively contaminated land also has a precise legal definition taken from the EPA 1990 Part 2A, which is applicable to defence sites.**
Radioactivity	The mean number of nuclear transformations occurring in a given quantity of radioactive material per unit time. The International System (SI) unit of radioactivity is the *Becquerel* (Bq).
Radionuclide	An unstable nuclide that undergoes *radioactive decay*.
Receptor	An entity (persons, living organisms, ecological systems, controlled waters, atmosphere, structures, utilities) that may be adversely affected by a *contaminant*.
Records	**Information including details of site characterisation work, the process of deciding on the land management option/strategy, implementing the option/strategy and validating its implementation, as well as interaction with stakeholders throughout the process. There is a key principle about the keeping of records.**
Remediation	**Any measures that may be carried out to reduce the risks from existing contamination of land areas through action applied to the contamination itself (the *source*) or to the exposure *pathways* to humans or other receptors.**
Remediation (Part 2A, Environmental Protection Act 1990)	Defined in Section 78A(7) as: a) The doing of anything for the purpose of assessing the condition of: (i) the contaminated land in question (ii) any controlled waters affected by that land (iii) any land adjoining or adjacent to that land

	b) The doing of any works, the carrying out of any operations or the taking of any steps in relation to any such land or waters for the purpose: (i) of preventing or minimising, or remedying or mitigating the effects of any significant harm, or any pollution of controlled waters, by reason of which the contaminated land is such land (ii) of restoring the land or waters to their former state c) The making of subsequent inspections from time to time for the purpose of keeping under review the condition of the land or waters. OR with respect to radioactive contamination defined in Section 78A(7)(as modified) as: a) The doing of anything for the purposes of assessing the condition of: (i) the contaminated land in question (ii) any land adjoining or adjacent to that land. b) The doing of any works, the carrying out of any operation or the taking of any steps in relation to any such land for the purpose: (iii) of preventing or minimising, or remedying or mitigating the effects of any harm by reason of which the contaminated land is such land (iv) of restoring the land to their former state c) The making of subsequent inspections from time to time for the purpose of keeping under review the condition of the land.
Remediation strategy	A strategy to organise and manage the action taken to prevent, minimise, remedy or mitigate the effects of any unacceptable risks.
Risk	A combination of probability, or frequency of occurrence, of a defined hazard and the magnitude of the consequences of the occurrence.
Risk assessment	The formal process of identifying, assessing and evaluating the health and environmental risks that may be associated with a hazard.
Risk management	The processes involved in identifying, assessing and determining risks, and/or the implementation of actions to mitigate the consequences or probabilities of occurrence.
Safety case	Documentation for a nuclear installation that demonstrates safety. Safety cases must be produced and maintained during the design, construction, manufacture, commissioning, operation and *decommissioning* of the installation. It is a requirement in the SAPs for contaminated land on a nuclear-licensed site.
Scintillation detector	*Radiation* detector relying on the property of certain materials to fluoresce when ionised by *radiation*. The light produced is measured using a photomultiplier.
Screening	**The process of excluding characterisation from detailed consideration. Screening is usually undertaken with techniques that have higher limits of detection are more**

	rapid and so are usually cheaper.
Sievert	The name for the International System (SI) unit of *equivalent dose* or *effective dose*, abbreviated to Sv. Fractions of a sievert follow conventional nomenclature with one thousandths of a sievert called a millisievert (mSv) and one millionths of a sievert called a microsievert (microSv or μSv)
Site	**A contiguous area of land on which *contamination* is known or suspected to be present. In most cases, a site will have a single *owner/operator*. Sites considered in this guidance are further classified as *nuclear-licensed sites* or *defence sites*.**
Site characterisation	**The process of gathering information about a site (or group of sites) and its setting(s) for the purposed of assessing and, where necessary, managing health and environmental risk. Guidance on site characterisation has been developed by SAFEGROUNDS.**
Site investigation	On-site investigation that involves the collection and analysis of soil, surface water, groundwater and/or soil gas as a means of further informing the site *conceptual model* and the *risk assessment*. The investigation may be undertaken in a single number of successive stages.
Site reconnaissance	A walkover survey of the site.
Site-specific assessment criteria	Values for concentrations of contaminants that have been derived using detailed site-specific information on the characteristics and behaviour of contaminants, pathways and receptors and that correspond to relevant criteria in relation to harm or pollution for deciding whether there is an unacceptable risk.
Source	A hazardous substance or agent (for example a contaminant) that is capable of causing harm.
Source (radioactive)	Radioactive dealed source specifically manufactured, obtained, or retained for the purpose of using the emitted radiation.
Stakeholder	**A person or organisation that has an interest in the management of the *contaminated land*. There are various groups of stakeholders: institutional stakeholders include the *owner/operator*, regulators, government departments and local authorities. External stakeholders are all those outside the owner/operator organisation. Those stakeholders involved in decisions on the management of contaminated land are participating stakeholders and may include local residents, CBOs and NGOs.**
Supervised area	Any area where the annual *effective dose* to persons working there is likely to exceed 1 mSv or one-tenth of the appropriate dose limit.
Supplementary investigation	Investigation carried out following a detailed investigation for the purpose of refining risk estimates, to assist in the selection of an appropriate remedial strategy, or for detailed (remedial) design purposes.
Topographical survey	A survey of the physical features of a site in three dimensions.

Uncertainty	A lack of knowledge about specific factors in a risk or exposure assessment including parameter uncertainty, model uncertainty and scenario uncertainty.
Validation of remediation	**The process of demonstrating, by means of inspection, sampling, testing and recording, that the risk has been reduced to meet remediation criteria and objectives based on a quantitative assessment of remediation performance.**
Weighting factor (radiation)	**Dimensionless factors developed for radiation protection to assess health risks from radiation doses that take into account the biological effectiveness of different types of radiation.**
Whole body dose	See *Effective dose*.

Acronyms and symbols

AGS	Association of Geotechnical and Geoenvironmental Specialists
ALARA	As low as reasonably achievable
ALARP	As low as reasonably practicable
BNFL	British Nuclear Fuels plc
BPEO	Best practicable environmental option
Bq	Becquerel – a unit of radioactivity (one nuclear transformation per second)
CBO	Community based organisation
CDM	Construction (Design and Management) Regulations 2007
CERRIE	Committee Examining Radiation Risks of Internal Emitters
CL:AIRE	Contaminated Land: Applications in Real Environments
COSHH	Control of Substances Hazardous to Human Health (COSHH) Regulations consolidated 2002
DE	MoD Defence Estates Organisation
DEFRA	Department for Environment, Food and Rural Affairs
DETR	Department of the Environment, Transport and the Regions (no longer exists. Most of its responsibilities relevant to this guidance have been transferred to DEFRA, the remainder to DTLR)
DNAPL	Dense non-aqueous phase liquid
DNSR	Defence Nuclear Safety Regulator
DRO	Diesel range organics
DRPS	Dstl Radiological Protection Services (formerly Defence Radiological Protection Services)
DTI	Department of Trade and Industry
DTLR	Department for Transport, Local Government and the Regions
EA	Environment Agency
ECRR	European Committee on Radiation Risk
EHS(NI)	Environment & Heritage Service (Northern Ireland)
EIA	Environmental impact assessment
EIAD	Nuclear Reactors (Environmental Impact Assessment for Decommissioning) Regulations, 1999
EHSNI	Northern Ireland Environment and Heritage Service
FSA	Food Standards Agency
GC	Gas chromatography
GIS	Geographical information system
GPS	Global positioning system
HDPE	High density polyethylene
HPA	Health Protective Agency
HSE	Health and Safety Executive
HSSE	Health, safety, security and environmental protection
HSAWA	Health and Safety at Work etc Act, 1974
IAEA	International Atomic Energy Agency

IBC	Intermediate bulk carrier
ICP-OES	Inductively Coupled Plasma Optical Emission Spectrometry
ICRP	International Commission on Radiological Protection
IRR	Ionising Radiations Regulations, 1999
IRSN	Institut de Radioprotection et de Suret Nuclaire
IWS	Integrated Waste Strategy
J	Joules
J/Kg	Joules per kilogram
LLW	Low-level radioactive waste
LQA	Land quality assessment
LQS	Land quality statement
MADA	Multi-attribute decision analysis
MCERTS	Environment Agency Monitoring Certification Scheme
MoD	Ministry of Defence
MOX	Mixed oxide reactor fuel
MHSW	Management of Health and Safety of Work Regulations 1999
NAPL	Non-aqueous phase liquid
NDA	Nuclear Decommissioning Authority
NEPLG	Nuclear Emergency Planning Liaison Group
NGO	Non-governmental organisation
NIA	Nuclear Installations Act, 1965 (as amended)
NII	Nuclear Installations Inspectorate, part of HSE
NORM	Naturally Occurring Radioactive Material
NRPB	National Radiological Protection Board
Part 2A	Environmental Protection Act, 1990: Part 2A Contaminated Land (inserted by the Environment Act, 1995)
PAH	Polyaromatic hydrocarbon
PCB	Polychlorinated biphenyl
PCOC	Potential contaminants of concern
PID	Photo-ionisation detector
PPC	Pollution prevention and control regime
PPE	Personal Protective Equipment
PRO	Petroleum range organics
RCA	Radiation controlled area/ reactor controlled area
QA	Quality assurance
QC	Quality control
RCEP	Royal Commission on Environmental Pollution
RIFE	Radioactivity in Food and the Environment
RPA	Radiation protection advisor
RPE	Respiratory protective equipment
RPS	Radiation protection supervisor
RSA	Radioactive Substances Act, 1993
ROV	Remotely operated vehicle
RWG	Recovery Working Group

SAFEGROUNDS	SAFety and Environmental Guidance for Remediation Of Uk Nuclear and Defence Sites
SAGTA	Soil and Groundwater Technology Association
SAP	Safety Assessment Principles
SEPA	Scottish Environment Protection Agency
SI	Statutory Instrument
SiLC	Specialist in Land Condition
SERMG	Southern England Radiation Monitoring Group
SNIFFER	Scotland & Northern Ireland Forum For Environmental Research
SoLA	Substances of Low Activity Exemption Order (made under RSA)
SQEP	Suitably Qualified and Experienced Personnel
Sv	Sievert, a unit of dose from ionising radiation
SWMP	Site waste management plan
TENORM	Technically Enhanced Naturally Occurring Radioactive Material
UKAS	UK Accreditation Scheme
UXO	Unexploded ordnance
VLLW	Very low level radioactive waste
VOC	Volatile organic compounds

Symbols

μ	micro
α	alpha
β	beta
γ	gamma

A1 Decision flow diagram

Notes on the flow diagram

The SAFEGROUNDS decision flow diagram is based on the process of managing land contamination outlined in the Contaminated Land Report 11 prepared by the Environment Agency (EA, 2004a) with some modifications. As such, CLR11 should be consulted when interpreting the decision flow diagram. The modifications incorporate the SAFEGROUNDS key principles and highlight other to be considered on nuclear sites (civil and defence), particularly in relation to managing radiological hazards, which may also be pertinent to non-nuclear defence sites.

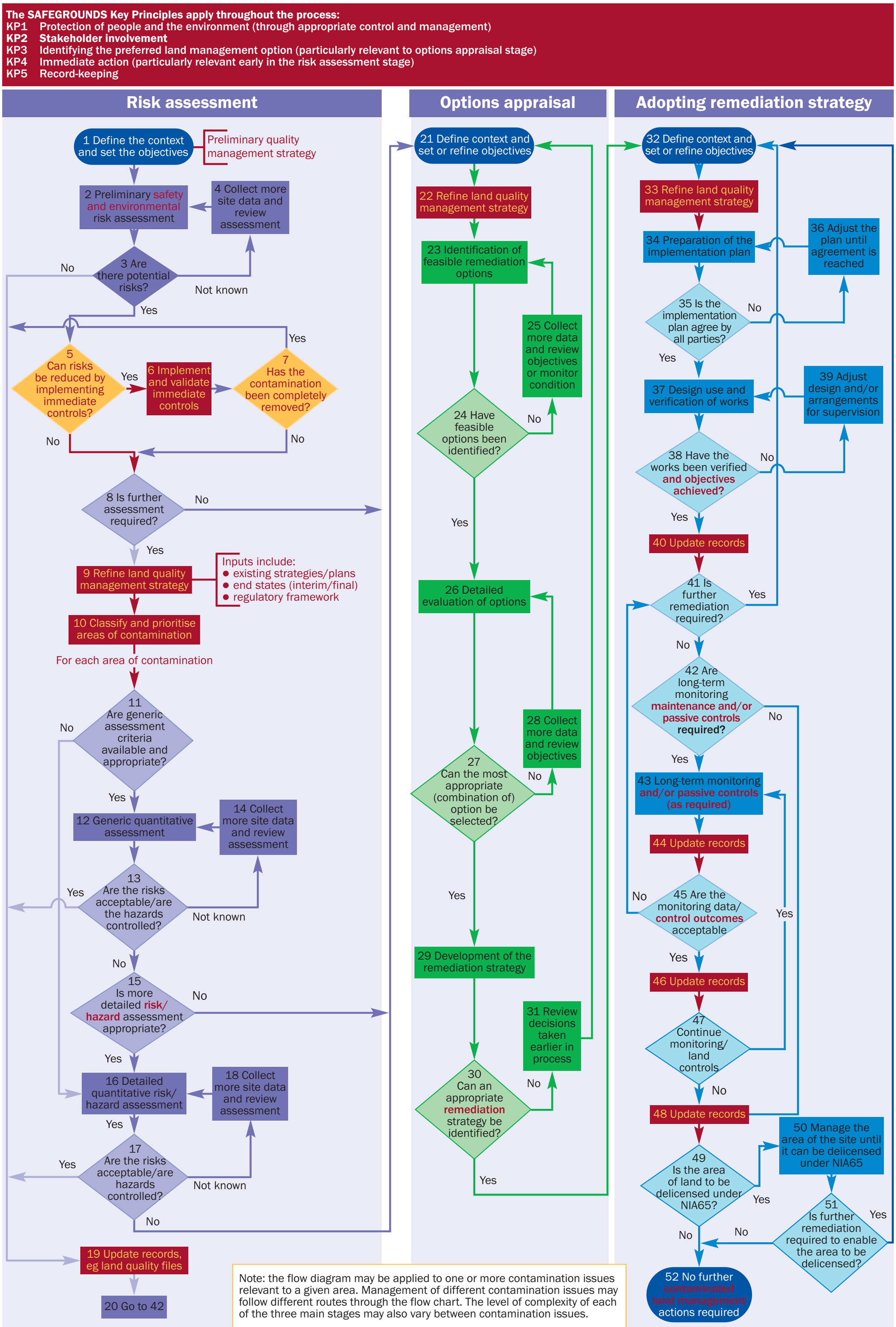
The modifications (highlighted in **dark red boxes** with tan lettering on the decision flow diagram Figure A1.1) are discussed as follows:

- stakeholders are involved throughout the process, in line with SAFEGROUNDS Key Principle 2. A broader cross-section of stakeholders is likely to be involved with the strategic development compared with the development of technical plans
- land quality records will be updated throughout the process, in line with SAFEGROUNDS Key Principle 5
- a land quality management "strategy" is developed at the earliest stages of the process (Element 1) and is refined as more information becomes available and more is known of management/remediation options (Elements 9, 22 and 33)*
- the preliminary risk assessment at Element 2 refers to a preliminary hazard assessment and the potential impacts on safety and the environment
- Elements 5 to 7 highlight the potential introduction of immediate control measures in line with SAFEGROUNDS Key Principle 4
- areas of contaminated land are prioritised for management based on potential risk (Element 10) and the remainder of the decision flow diagram is followed for each area of contamination
- the long-term management of risks associated with contaminated land may involve passive control of the land with or without monitoring contamination (Elements 43–47). For example, it may be necessary to manage the way in which the land is used in accordance with a planning application for site development
- asking whether further remediation is required (Element 41) before asking whether monitoring is required recognises that the remediation strategy may involve a combination of remediation, long-term monitoring and long-term passive control before the final *end state* can be reached. It is also implied that the remediation strategy may involve several elements (the remediation option implemented at Element 37 may only be a provisional measure, eg containing contamination until it can be accessed safely, and further elements may need to be implemented).

Note:

* The land quality management strategy at Element 1 is a brief "statement of intent", which outlines the context of the strategy, preliminary objectives are listed and the approach is summarised, including stakeholder involvement.

At Element 9 the land quality management strategy is a more developed document, which refines the objectives and context following information gathered about potential contamination on the site. This document will also include the regulatory framework, the site context in terms of end states (interim and final) and any planned end uses for the site. It will also include schedules for site developments, decommissioning and restoration, of which land quality management is an integral part. It will also include the strategy for stakeholder involvement.



Note: the modifications to the CLR 11 decision flow diagram for SAFEGROUNDS are highlighted in **dark red** boxes with tan lettering

Figure A1.1 ***Decision flow diagram***

A2 Regulatory framework

Once it has been established that there is, or could be, radioactively contaminated land on a site, the site characterisation team should identify the relevant regulatory regime, legislation and statutory, government and regulatory guidance. Then appropriate objectives to achieve compliance should be set. The justification for the identified regulatory framework and the associated objectives of the site characterisation should be documented.

Table A2.1 shows the UK regulatory regimes for radioactively and *non-radioactively contaminated land*, Table A2.2 shows the principal regulators, and regulatory guidance is summarised in Table 2.3. Further details on the legislation and the different definitions involved are given in the SAFEGROUNDS *Briefing note on the Energy Bill* (Hill, 2005) in the SAFEGROUNDS regulatory framework paper (Hill, 2007), and in the regulatory area of the SAFEGROUNDS website[21].

Nuclear safety on non-licensed nuclear defence sites is regulated by MoD's Defence Nuclear Safety Regulator (DNSR), using essentially the same principles as in the HSE SAPs (HSE, 2006). Part 2A for radioactive and non-radioactive contamination also applies with the environment agencies as regulators.

The situation on other sites with long-standing contamination is as for non-nuclear defence sites. Also, the Radioactive Substances Act 1993 (RSA93) also applies for the disposal of radioactive wastes generated from land investigations and remediation.

Land contaminated by a radiological emergency would be regulated under Part 2A by the environment agencies, if it met the criteria for "radioactive contaminated land" under Part 2A, after all immediate control measures have been implemented.

To implement the various regulatory regimes, the measurement of the nature and extent of contamination is common to all investigations, and it is then followed by an assessment process defined by the regulatory guidance.

Note:

21 For more information consult: <www.safegrounds.com/pdf/reg_frame_for_contam_land_v4.pdf> and <www.safegrounds.com/pdf/energy_act.pdf>.

Table A2.1 ***Regulatory regimes***

	Type of site	Radioactive contamination	Non-radioactive contamination	Mixed contamination
1	Nuclear-licensed sites	NIA, (RSA) (planning regime)	Part 2A, (planning regime)	NIA, (RSA), Part 2A, (planning regime)
1.1	Operational sites			
1.2	Sites to be delicensed			
2	Defence sites (non-nuclear)			
2.1	No change of land use proposed	Part 2A, (MoD),	Part 2A	Part 2A, (MoD)
2.2	Change of land use proposed	Planning regime, (RSA)	Planning regime	Planning regime, (RSA)
3	Non-licensed nuclear defence sites	MoD, Part 2A	Part 2A	MoD, Part2A
4	Other sites (not covered by SAFEGROUNDS guidance) with long-standing radioactive contamination			
4.1	No change of land use planned	Part 2A, (RSA)	Part 2A	Part 2A, (RSA)
4.2	Change of land use planned	Planning regime, (RSA)	Planning regime	Planning regime, (RSA)

Key

NIA: Nuclear Installations Act 1965 (as amended), Radioactive Substances Act 1993 (as amended).

Part 2A: Part 2A of the Environmental Protection Act 1990 (and associated regulations, including the Radioactive Contaminated Land (Modification of Enactments) (England) Regulations 2006 and statutory guidance) or Part III of the Waste and Contaminated Land (Northern Ireland) Order 1997. In Scotland Part 2A is implemented through the Contaminated Land (Scotland) 2005 Regulations. The 2005 Regulations amend Part 2A of the Environmental Protection Act 1990 and the 2000 Regulations in the light of the Water Environment and Water Services (Scotland) Act 2003. The Radioactive Contaminated Land (Scotland) Regulations 2007 provide for identification and remediation of radioactive contaminated land.

Planning regime: See PPS 23 for England, PAN 33 for Scotland, WLGA (2006) guidance for Wales. Regimes in parenthesis are relevant but subsidiary.

Table A2.2 ***Principal regulators***

	Radioactive contamination	Non-radioactive contamination	Mixed contamination
Nuclear-licensed sites	HSE	Environment Agency, SEPA	HSE, Environment Agency, SEPA
All defence sites (non-licensed)	Environment Agency, SEPA, EHS(NI), MoD, HSE	Environment Agency, SEPA, EHS(NI)	Environment Agency, SEPA, EHS(NI), MoD, HSE
Other sites with long-standing contamination	Environment Agency, SEPA, EHS(NI), local authorities	Local authorities (environment agencies on "special sites")	Environment Agency, SEPA, EHS(NI), local authorities

Key

HSE: Health and Safety Executive (in Great Britain, Northern Ireland has its own agency, the Health and Safety Executive for Northern Ireland (HSE(NI))

SEPA: Scottish Environment Protection Agency

MoD: Ministry of Defence

EHS(NI): Environment and Heritage Service (Northern Ireland)

Note:

There are no nuclear-licensed sites in Northern Ireland.

Table A2.3 ***Statutory, government and regulatory guidance***

Regime	Guidance documents	
	Short reference	***Full reference***
NIA65	HSE SLC	HSE *Site licence conditions*
	HSE SAPs (2006)	HSE SAPs (2006) *Safety assessment principles for nuclear facilities*, version 1
	HSE (2002)	HSE (2002) *Guidance for inspectors on the management of radioactive materials and radioactive waste on nuclear licensed sites*, Nuclear safety directorate, T/AST/024
	HSE (2005, 2008)	HSE (2005) *HSE Criterion for delicensing nuclear sites* HSE (2008) *Delicensing guidance*
	HSE (2001b)	HSE (2001b) *Decommissioning on nuclear-licensed sites*
Part 2A	Defra (2006)	Defra (2006) Environmental Protection Act 1990: Part 2A *Contaminated Land*. Statutory guidance, Edition 2, Defra, London
	Defra (2006)	Defra (2006) CLAN 5/06 revised. The extension of Part 2A to include Radioactivity, July 2006
	SE (2006)	Scottish Executive (2006) Environmental Protection Act 1990: Part 2A *Contaminated Land*. Statutory guidance, Edition 2. Paper SE/2006/44.
	WAG (2006)	Welsh Assembly Government (2006) Part 2A *Statutory guidance on contaminated land*
Planning	PPS 23	CLG (2004) Planning Policy Statement 23: *Planning and pollution control. Annex 2: Development on land affected by contamination*
	PAN 33	Scottish Executive (2000) Planning Advice Note 33 (PAN 33): *Development of Contaminated Land*
	WLGA *et al* (2006)	Welsh Local Government Association, Welsh Assembly Government and Environment Agency (2006) *Land contamination: a guide for developers*
RSA	EA (2002)	Environment Agency (2002) *Guidance on the characterisation and remediation of radioactively contaminated land*
	REPs	Environment Agency (2005b) *Radioactive substances regulation environmental principles (interim). A framework for technical decisions and technical guidance on radioactive substances regulation*, version 1
Part 2A and planning, non-radioactive contaminated land	CLR11	Environment Agency (2004a) *Model procedures for the management of land contamination*, Contaminated Land Report 11