



# **SAFEGROUNDS**

## **Best practice guidance for site characterisation**

*Managing contaminated land on nuclear-licensed and defence sites*

*A report prepared by AEA Technology for the SAFEGROUNDS Learning Network*

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## Summary

This document presents current best practice guidance for the characterisation of 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 there is a potential for radioactive contamination to be present. These two categories of site are grouped together in this best practice guidance principally because of the issue of contamination of land by radioactivity. However, there are also other issues common to both categories of site, which may distinguish them from “conventional” contaminated land. Examples include increased client involvement, heightened public awareness and increased security requirements.

The report has been produced as the first technical task of the SAFEGROUNDS Learning Network, a project managed by CIRIA, in association with WS Atkins and the Environment Council, on behalf of stakeholders concerned with the health, safety and environmental management of contaminated land on nuclear-licensed sites and defence sites.

Most of the site characterisation technologies described in this guidance are conventional and well established. Many have been used extensively for the characterisation of chemically contaminated land and will be familiar to most readers. The technologies and instruments that may be less familiar are those concerned with the measurement of radioactivity. However, these are all conventional health physics equipment, with a long record of successful use.

In particular, this guidance focuses on those areas where site investigations on nuclear-licensed sites and defence sites differ from those on “conventional” contaminated land sites:

- nuclear-licensed and defence sites have a more complex regulatory regime. There is a need for site characterisation on such sites to satisfy a number of regulators, who regulate under different legislation and who may have different perspectives on the management of contaminated land
- because of the different regulatory regimes, the required endpoints of site characterisation on nuclear-licensed and defence site and on “conventional” contaminated sites may be different
- there will be greater client involvement on nuclear-licensed sites, primarily driven by nuclear site licence requirements
- site characterisation on nuclear-licensed sites and defence sites will 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 “conventionally” contaminated sites) is essential
- radioactive contamination is potentially present at all nuclear-licensed sites and defence sites. Best practice for characterisation of such sites is that Radiation Protection Advisers and Radiation Protection Supervisors are appointed to provide advice to the employer on compliance with the Ionising Radiations Regulations 1999 and with the Radioactive Substances Act 1993. Note that there is a requirement under IRR 1999 to appoint RPAs and RPSs if working with ionising radiations (ie if radioactive contamination is encountered)

- waste minimisation is a key issue on nuclear-licensed sites. There may be requirements for waste segregation, to ensure arisings of radioactive wastes are minimised
- on nuclear licensed sites, there is a requirement for long-term storage of records. This may influence the extent to which electronic collection and storage of data is used.

References to existing guidance are contained at the end of each chapter.

## Structure of the guidance

Chapter 1 describes the types of site addressed by this guidance and summarises the activities that may cause contamination and the types of chemical and radioactive contamination that may result. Chapter 2 provides a summary for readers who do not have a technical background in issues concerned with radioactivity. It also discusses the concept of background levels of radioactivity, which are unrelated to activities at the site being characterised. Chapter 3 summarises health, safety and environmental protection issues, with emphasis on issues concerned with radioactivity and with issues that are 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. Particular emphasis is given in section 4 to describing the reasons why site characterisation may be required on nuclear-licensed sites and defence sites. It is recognised that the end-point for a site characterisation programme is dependent on the objective (ie the “context” in which the characterisation is undertaken). Chapter 4 also contrasts and compares the management regimes for chemically contaminated land and for radioactively contaminated land, presents the overall sequence of activities required to manage contaminated land and sets site characterisation in the context of these activities.

Chapter 5 emphasises the importance of early communication with stakeholders. Early interaction with regulators is essential, to clarify matters such as statutory ambiguities and methods of approach to characterisation. Early dialogue with the public and with bodies representing the public is also important. This section also presents some of the key technical considerations when planning a site characterisation programme, such as contingency planning, the role of the site conceptual model and the design of sampling strategies. The approach to establishing background environmental quality at a site, in particular background levels of radioactivity, is discussed.

Chapter 6 describes the principal techniques for characterising contaminated land on nuclear-licensed sites and defence sites. As previously, it is not the intention to reproduce this existing guidance in detail; only a summary and signposting is presented. 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 and defence sites. Non-intrusive radiation surveys, geophysical surveys, intrusive investigations and chemical/radiochemical analysis of samples are all discussed. Examples of site characterisations are presented in case studies given in Chapter 9.

Chapter 7 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 8 describes the management of data from site characterisation programmes, and focuses on the need for long-term storage of such records on nuclear-licensed sites. The benefits of electronic storage of data, for example by using geographic information systems (GIS) are given. Examples of uncertainties arising during site investigation, and possible actions that can be taken to reduce such uncertainties, are presented.

Current capabilities and lessons for practice are given in Chapter 9. The key differences between the characterisation of nuclear-licensed and defence sites and the characterisation of “conventional” contaminated sites are summarised. These include the more complex legislative regime on nuclear-licensed and defence sites and the potential or actual presence of radioactive contamination. Areas where there is potential for improving the characterisation of nuclear-licensed sites and defence sites have been identified. The final section of the document describes areas where there is potential to improve best practice in the future.

## Acknowledgements

### Authors

This report was prepared by AEA Technology plc under contract to CIRIA on behalf of the SAFEGROUNDS Learning Network. The project supervisor was Dr N L Jefferies and the principal authors were A C Baker, C J Darwin, N L Jefferies, P A Towler and DL Wade.

### Technical steering group

The project was guided by a technical steering group, and 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 reviewing the drafts of the report:

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\* These members were also members of the SAFEGROUNDS Project Steering Group.

### Additional contributions

Additional review of the draft guidance was provided by the members of the SAFEGROUNDS Project Steering Group. In addition to members of the technical steering group denoted thus (\*), this comprised:

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**SAFEGROUNDS project management**

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## Glossary and abbreviations

This glossary has been produced for the *Best practice guidance for site characterisation on nuclear-licensed sites and defence sites*. Some of the terms listed below may have different meanings in other contexts. Within definitions, words in *italics* are themselves defined in the glossary.

Absorbed dose	A measure of the energy from ionising radiation deposited in a unit mass of any specified material. The unit of <i>absorbed dose</i> is the <i>Gray</i> .
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 <i>contaminant</i> entry into the body.
Accuracy	Level of agreement between true value and observed value.
Activation	Process where a <i>neutron</i> is captured by a nucleus to form a new isotope (often a <i>radionuclide</i> ).
Activation product	An isotope created by <i>activation</i> .
Activity	See <i>radioactivity</i> .
Activity concentration	Terminology used to describe <i>radioactivity</i> levels relative to the mass or volume of the sample matrix (eg Bgkg <sup>-1</sup> in soil, BgL <sup>-1</sup> 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 ( $\alpha$ ) decay	A form of <i>radioactive decay</i> resulting in the emission of a positively charged particle (a helium nucleus).
Anthropogenic radionuclides	Artificially produced <i>radionuclides</i> , by means of <i>activation</i> or <i>nuclear fission</i> .
Approved Dosimetry Service (ADS)	A dosimetry service approved by <i>HSE</i> (or a body specified by <i>HSE</i> ) 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.
Atmospheric fallout	Widespread dispersion of <i>radionuclides</i> . Normally refers to the effects of nuclear weapons testing or events with global impact such as Chernobyl.
Averaging volume	The volume of waste over which the <i>activity concentration</i> is measured and averaged to give an average activity concentration for waste sentencing purposes.

Background radiation	Radiation from <i>naturally occurring radionuclides</i> , and from man-made sources (such as global fallout as it exists in the environment from the testing of nuclear explosive devices or from nuclear accidents like Chernobyl) that are not under the control of the cognisant organisation.
Becquerel (Bq)	The International System (SI) unit of <i>activity</i> equal to one nuclear transformation (disintegration) per second.
Beta ( $\beta$ ) decay	A form of <i>radioactive decay</i> 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 <i>effective dose</i> in excess of 6 mSv or three-tenths of the appropriate dose limit should be a classified worker.
Conceptual model	A textual or schematic hypothesis of the sources and nature of <i>contamination</i> on a site, the pathways and migration mechanisms by which it may be transported, and the receptors that may be affected.
Contaminant	An undesirable concentration or quantity of a substance, or <i>activity concentration</i> of a <i>radionuclide</i> , present in water, atmosphere or soil.
Contamination	Presence of substances or agents as a result of human activity. Note that there is no assumption in this definition that harm results from the presence of the contamination.
Controlled area	Any area where the annual <i>effective dose</i> to persons working there is likely to exceed 6 mSv or three-tenths of the appropriate dose limit.
Controlled waste	Defined for the purposes of the Environmental Protection Act 1990 as comprising household, commercial and industrial waste. Excludes certain categories of waste, such as radioactive waste.
Controlled waters	Defined in Part III (Section 104) of the Water Resources Act 1991, this embraces territorial and coastal waters, inland fresh waters, and groundwaters.
Cosmogenic radionuclides	<i>Radionuclides</i> 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.
Daughter nuclide	See <i>decay product</i> .
Decay chain	A series of <i>radionuclides</i> , each of which decays into the next <i>radionuclide</i> in the series until a stable nuclide is reached.
Decay product	The nuclide produced following a <i>radioactive decay</i> . Also called a <i>daughter nuclide</i> .
Discharge	Any emission of a <i>contaminant</i> into the environment.

Dose constraint	A target maximum individual dose set by an employer or <i>Radiation Protection Adviser</i> 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 <i>ALARP</i> .
Effective dose	The damage sustained by a body by an <i>equivalent dose</i> . Takes into account the susceptibility of different organs to damage from ionising radiation.
Equivalent dose	The sum of the corrected doses (see <i>quality factor</i> ) for each type of radiation. Takes into account the different amounts of damage done by different <i>radioactive decay</i> types. The unit of <i>equivalent dose</i> is the <i>Sievert</i> .
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 <i>Exemption Orders</i> made under the Act. See also <i>SoLA</i> .
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	<i>Radiation</i> from a source outside the body.
Fission product	A nuclide produced as a result of <i>nuclear fission</i> .
Gamma ( $\gamma$ ) radiation	Penetrating high-energy, short-wavelength electromagnetic radiation (similar to X-rays) emitted during <i>radioactive decay</i> . Gamma rays are very penetrating and 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.
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 ( $\text{Jkg}^{-1}$ ).
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 <i>radionuclide</i> present to 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	The potential for harm posed by a <i>contaminant</i> or circumstance, taking no account of the likelihood of exposure.
Hectare	A unit of area, equivalent to 10 000 $\text{m}^2$ .
Heterogeneous	Material with areas of different composition within its volume.
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.

Homogeneous	Material of uniform composition throughout its volume.
Hot spot	An area containing elevated <i>contaminant</i> concentration or <i>activity concentration</i> relative to the surrounding area.
HSE	The Health and Safety Executive.
Ingestion	<i>Contaminant</i> entering the stomach and gastrointestinal tract through eating contaminated food or hand to mouth contact.
Inhalation	Breathing <i>contaminant</i> (eg particulate material, vapour, gas) in through the mouth or nose.
Injection	<i>Contaminant</i> entering the body tissue and blood stream directly through cuts and abrasions.
Internal radiation dose	Dose received internally to the body via <i>inhalation</i> , <i>absorption</i> , <i>ingestion</i> or <i>injection</i> 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.
LLW	Low-level radioactive waste.
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.
MOX	Mixed oxide fuel. A fuel for nuclear reactors that contains both uranium and plutonium oxides.
Naturally occurring radionuclides	<i>Radionuclides</i> and their associated progeny produced during the formation of the earth or by interactions of terrestrial matter with cosmic rays.
Neutron	Uncharged particle, constitutes approximately 50 per cent by mass of most atomic nuclei.
Neutron flux	A measurement of the intensity of a neutron source (measured in $\text{Jcm}^{-2}\text{s}^{-1}$ or neutrons $\text{cm}^{-2}\text{s}^{-1}$ ).
NH	Her Majesty's Nuclear Installations Inspectorate (part of the <i>HSE</i> ).
Nuclear fission	Process by which an atom splits into two or more pieces, each of which is an entirely separate nuclide.
Pathway	A mechanism or route by which a <i>contaminant</i> can reach, or be made to affect, a <i>receptor</i> .
Permeability	The relative ease with which a porous medium can transmit a fluid under a hydraulic gradient.
Pollutant linkage	The relationship of a <i>contaminant</i> , a <i>pathway</i> and a <i>receptor</i> .
PPE	Personal Protective Equipment - equipment used as a "last line of defence" to prevent a person from being exposed to a <i>contaminant</i> or contaminants.
Precision	Level of agreement within a series of measurements of a parameter.
Primordial radionuclides	<i>Radionuclides</i> produced during the initial formation of the earth. Those of the <i>radionuclides</i> that remain have very long <i>half-lives</i> .
Putrescible waste	Organic waste that may decompose or rot.

Quality factor	A factor applied to the <i>absorbed dose</i> in tissue to take account of the different levels of harm inflicted by different types of <i>radioactive decay</i> . Used to calculate <i>equivalent dose</i> .
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 <i>HSE</i> and provides advice on all aspects of radiological protection. The RPA will set <i>dose constraints</i> on workers and specify <i>hold points</i> 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 <i>half-life</i> .
Radioactive material	Often used to describe any material containing <i>radionuclides</i> . The statutory definition of <i>radioactive material</i> is given in the Radioactive Substances Act 1993 (see Box 4.5).
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 <i>Becquerel (Bq)</i> .
Radionuclide	An unstable nuclide that undergoes <i>radioactive decay</i> .
Receptor	An entity (persons, living organisms, ecological systems, controlled waters, atmosphere, structures, utilities) that may be adversely affected by a <i>contaminant</i> .
Risk	An assessment of the potential for harm or damage posed by a <i>contaminant</i> or circumstance taking account of the likelihood, or probability, of occurrence. Risk is the product of <i>hazard</i> and probability.
Risk assessment	Process of establishing the existence, nature and significance of risk.
RPE	Respiratory protective equipment – any equipment designed to prevent a person from inhaling airborne contaminants.
Sampling	Methods and techniques used to obtain a representative sample of the material under investigation.
Scintillation detector	<i>Radiation</i> detector relying on the property of certain materials to fluoresce when ionised by <i>radiation</i> . The light produced is measured using a photomultiplier.
SEPA	Scottish Environmental Protection Agency.
Sievert	The name for the International System (SI) unit of <i>equivalent dose</i> or <i>effective dose</i> .

SNIFFER	Scotland & Northern Ireland Forum For Environmental Research.
SoLA	Substances of Low Activity Exemption Order. This specifies <i>activity concentrations</i> of <i>radionuclides</i> that are deemed to be exempt from all provisions of the Radioactive Substances Act 1993.
Source	A contaminant which is in, on or under the land and which has the potential to cause harm to an identified receptor or to cause pollution of controlled waters.
Special waste	<i>Controlled waste</i> of any kind that is or may be so dangerous or difficult to keep, treat or dispose of that special provision is required to deal with it.
Supervised area	Any area where the annual <i>effective dose</i> to persons working there is likely to exceed 1 mSv or one-tenth of the appropriate dose limit.
Topographical survey	A survey of the physical features of a site in three dimensions.
Whole body dose	See <i>effective dose</i> .

# 1

## Introduction

### 1.1

#### Scope of the document

This document presents current best practice guidance for the characterisation of contaminated or potentially contaminated land on:

- nuclear-licensed sites, including any off-site operational areas (either current or former operations) controlled by the licensee
- sites owned by the Ministry of Defence (MoD) where there is a potential for radioactive contamination to be present. In this guidance, such sites are termed “defence sites”.

These two categories of site are grouped together in this best practice guidance principally because of the issue of contamination of land by radioactivity. However, there are also other issues common to both categories of site, which may distinguish them from “conventional” contaminated land. Examples include increased client involvement, heightened public awareness and increased security requirements. There is some overlap between these two categories. Some MoD sites, such as AWE Aldermaston, are operated by civilian contractors and are licensed under the Nuclear Installations Act. The scope of defence sites addressed by this Guidance is described in Section 1.3.2. The aims of the guidance are summarised in Box 1.1.

Much of the technical guidance on characterisation techniques contained in this report is applicable to other sites at which radioactive contamination may be present (for example, smelting works and oil refineries, where land may be contaminated with naturally occurring radionuclides).

#### Box 1.1

##### *Aims of the guidance*

- describe the types of contaminated land commonly encountered on nuclear-licensed sites and defence sites where radioactivity may be present
- identify the key health, safety and environment issues in site investigations on nuclear-licensed sites and defence sites where radioactivity may be present
- identify the reasons for carrying out investigation of potentially contaminated land on nuclear-licensed sites and defence sites where radioactivity may be present, and the required end-points of those investigations
- describe best practice design of site investigations and the available site characterisation methods
- identify key areas for improvement in current practice.

Other types of contamination (principally chemical, but also ordnance and biological) may be present at nuclear-licensed sites and defence sites. Indeed, experience has shown that chemical contamination of soil and groundwater may be the predominant, or the only, significant problem in areas of some nuclear-licensed sites. Radiological and chemical contamination issues are addressed in detail throughout this guidance document, and reference is made to the issues associated with forms of weaponry. The types of contaminated site addressed in this guidance are shown diagrammatically in Figure 1.1.

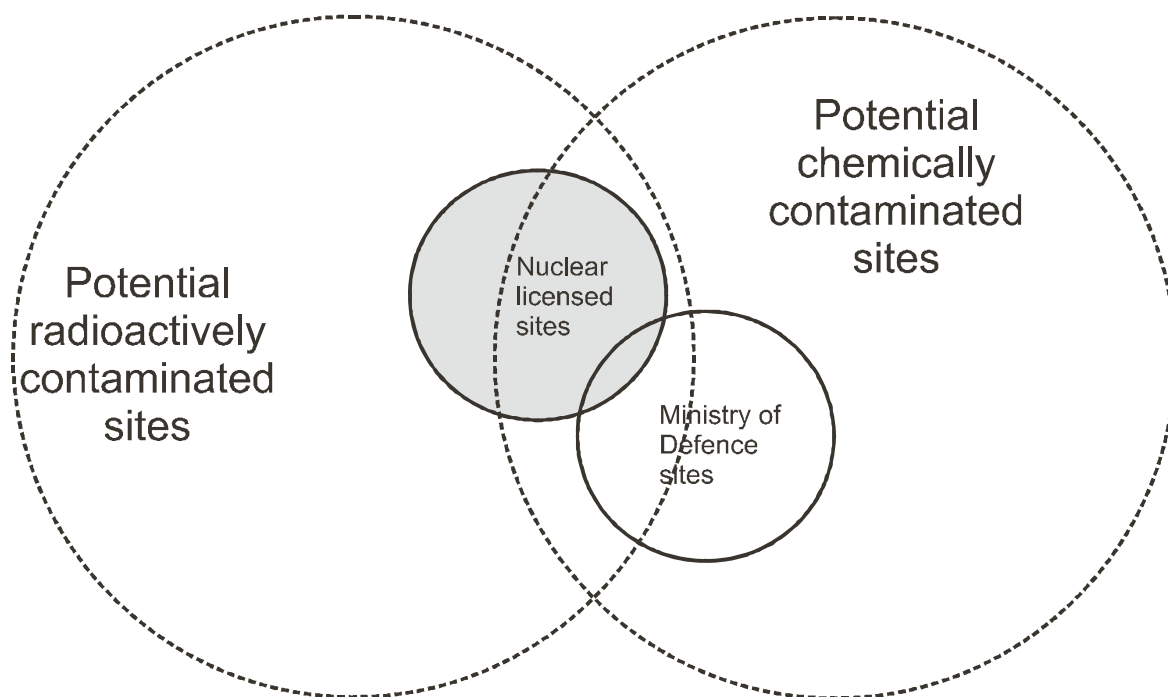


Figure 1.1 Venn diagram of the different categories of site, and the region (in grey) relevant to this guidance

This best practice guidance on site characterisation is intended principally for the following audience:

- liability holders, when designing and specifying site investigations to characterise contamination of land
- regulators, when evaluating the adequacy and conclusions from these site investigations
- consultants and contractors, when undertaking site investigations on nuclear-licensed and defence sites.

In addition, the document is intended to be accessible to other stakeholders, such as local authorities, central government and developers of potentially or actually contaminated sites.

## 1.2 The SAFEGROUNDS Learning Network

The report has been produced as the first technical task of the SAFEGROUNDS Learning Network, a project managed by CIRIA, in association with WS Atkins and the Environment Council, on behalf of stakeholders concerned with the health, safety and environmental management of contaminated land on nuclear-licensed sites and those defence sites where there is a potential for radioactive contamination to be present.

The scope of the site characterisation guidance document was discussed at a workshop in January 2000, facilitated by the Environment Council, to which all stakeholders in the project were invited. Those who attended the workshop are listed in the Acknowledgements. Stakeholders agreed that the document should focus on those areas where site investigations on nuclear-licensed and defence sites differ from those on “conventional” contaminated land sites, and should signpost and summarise key existing site characterisation guidance for contaminated land. A list of the key guidance documents consulted is given at the end of this section.

## 1.3

## Sites addressed by this guidance

### 1.3.1

### Nuclear-licensed sites

All operators of nuclear plant in the UK must, like their counterparts in other industries, conform to the general health and safety standards laid down in the Health and Safety at Work etc Act 1974. In addition, certain parts of the nuclear industry, such as reactor sites and sites that store bulk quantities of radioactive waste or handle and produce items containing enriched uranium and plutonium, must also comply with the Nuclear Installations Act 1965 (as amended). Such sites are classified as nuclear-licensed sites.

The current list of nuclear-licensed sites in the United Kingdom is given in Appendix I. Locations of the sites are shown in Figure 1.2.

In this report, the best practice guidance applies both to the land within the boundary of a nuclear-licensed site and to any off-site operational areas (either current or former operations) controlled by the licensee. This definition has been adopted because those activities that may give rise to contamination, or may have caused contamination in the past, may not all be located within the current boundary of the nuclear-licensed site.

Nuclear-licensed sites in the UK can be divided into the following broad categories:

- operational nuclear power stations generating electricity (operated by organisations such as British Energy Generation (UK) Ltd, British Energy Generation Ltd and Magnox Electric)
- nuclear power stations being decommissioned (operated by BNFL)
- sites used for manufacture, enrichment and reprocessing of nuclear fuel (operated by organisations such as BNFL, Rolls-Royce and Urenco)
- the site used for solid low-level radioactive waste disposal (the Drigg site, operated by BNFL, is currently the only nuclear-licensed disposal site in use)
- sites used for research: nuclear reactors and other facilities either operational or being decommissioned (operated by organisations such as UKAEA, London University and Nycomed Amersham plc)
- sites used for manufacture of radioactive sources, chemicals and pharmaceuticals (operated principally by Nycomed Amersham plc)
- defence sites used for manufacture, assembly and dismantling of nuclear weapons (operated by AWE plc)
- defence sites used for building, maintenance, storage and refuelling of nuclear-powered submarines (eg commercially operated dockyards).

The type and extent of chemical contamination on a nuclear-licensed site will depend both on the current and the former uses of the site. Former uses of nuclear-licensed sites include military airfields, bulk fuel/oil storage, radium luminising work and chemical weapons production. The nature of historical chemical contamination can therefore vary widely from site to site. The potential presence of munitions must also be considered for former military sites.

Chemical contamination that could arise from current and former operations on a nuclear-licensed site is illustrated in Box 1.2. Major activities involving the use of radioactive materials on nuclear-licensed sites are shown in Box 1.3. Different activities produce, or are associated with, different types of radionuclides. It is therefore important to establish the expected radionuclide “fingerprint” for activities undertaken

in an area as a precursor to designing a site investigation. In particular, the radiological risks and consequent protective measures that must be taken are dependent on the type of radiation emitted by the radionuclide.



Figure 1.2

*The locations of UK nuclear-licensed sites*

It is recognised that the concept of a radionuclide “fingerprint” can most easily be applied to sites where there is a single homogeneous source of pollution, and becomes more difficult to apply when there are multiple, heterogeneous sources of pollution. Nevertheless, as with the design of a survey to investigate chemical contamination, it is important to establish the potential contaminants at the site in order to design an appropriate sampling and analysis programme.

1.3.2

**MoD-owned sites where there is a potential for radioactive contamination to be present (“defence sites”)**

This guidance addresses only those sites that are still owned by MoD. Such sites fall into two categories: (i) sites operated directly by the MoD and (ii) sites operated by civilian contractors on behalf of MoD. Sites operated directly by the MoD are excluded from most of the requirements of the Nuclear Installations Act. Those sites that, had they been civilian-operated would have required licensing under the Nuclear Installations Act, are regulated directly by the Ministry of Defence (CNNRP: Chairman Naval Nuclear Regulatory Panel). However, MoD-owned sites that are operated on MoD’s behalf by civilian contractors are subject to the requirements of the Nuclear Installations Act (see previous section).

Notwithstanding the above, it should be noted that all MoD sites are subject to regulation by the Health and Safety Executive (HSE) under the Health and Safety at Work, etc Act 1974 and the regulations made under that Act. In the context of the current guidance, regulation under the Ionising Radiations Regulations 1999 (see Section 1.4.1) is particularly relevant.

MoD-owned sites that are also nuclear-licensed sites were discussed in the previous section. This section is concerned with those MoD-owned sites where radioactive contamination may be present as a result of historical activities.

The most significant historical activity is concerned with the use of radium (a radioactive element) in luminising paints. Radium luminising in the UK was undertaken between 1918 and the 1960s. At the peak of the industry, during the Second World War, there were some 135 luminising workshops and factories in the UK. In addition to potential contamination at the workshops and factories, radium contamination may also be present at sites where equipment containing luminising paint was stored, used or disposed. Thus, there is a potential for radioactive contamination at most MoD sites.

Radioactive contamination at MoD sites may also arise from a number of other activities and processes, although these are of less significance than radium luminising. Depleted uranium is used in airframes and in specialist munitions and armour; thorium has been used in alloys. Radioactive isotopes are also used in personal equipment (such as gaseous tritium light sources: GTLS) and in certain electronic equipment (“radioactive valves”, which may be doped with Cs, U, Th or Kr) and hence may be widely distributed.

**Box 1.2**

***Facilities on nuclear-licensed sites that may be associated with chemical contamination***

Facility	Potential contaminants of concern
<ul style="list-style-type: none"> <li>● heat and power equipment (boilers, generator houses) and associated storage tanks</li> <li>● electrical transformers</li> <li>● R&amp;D facilities eg laboratories and pilot-scale chemical engineering plants</li> <li>● water treatment plants</li> <li>● disposal facilities</li> <li>● incinerators and burning grounds</li> <li>● bulk fuel or chemical storage areas</li> <li>● garages, workshops, maintenance buildings.</li> </ul>	<ul style="list-style-type: none"> <li>● hydrocarbons: diesel, petrol, oils</li> <li>● asbestos</li> <li>● PCBs and PCB-contaminated oils</li> <li>● wide range of solid/liquid inorganic and organic chemicals (including beryllium). Some pilot plants may have involved extensive use of non-aqueous-phase liquids such as organic solvents or mercury</li> <li>● flocculating agents and water purification chemicals, sludges from treatment</li> <li>● wide range of inorganic and organic chemicals, both liquids and solids</li> <li>● organic liquids, explosives, pyrophoric metals</li> <li>● wide range of solid/liquid inorganic and organic chemicals</li> <li>● fuels, solvents, asbestos.</li> </ul>

Box 1.3

**Major nuclear operations on nuclear-licensed sites and associated radionuclides**

Operation	Radionuclides
<ul style="list-style-type: none"> <li>reactor operations (electricity generation for civil and military uses, research reactors)</li> <li>fuel reprocessing</li> <li>fuel fabrication</li> <li>weapons production</li> <li>research and development</li> <li>manufacture of radioactive sources, chemicals and pharmaceuticals.</li> </ul>	<ul style="list-style-type: none"> <li>fission products and activation products (eg Co-60, Cs-137, H-3, actinides). Principally beta- and gamma-emitters</li> <li>fission and activation products</li> <li>uranium, plutonium (MOX) and thorium</li> <li>uranium, plutonium, polonium, americium, tritium (beryllium)</li> <li>various, dependent on nature of research</li> <li>various, including H-3, C-14, iodine isotopes.</li> </ul>

The use of radium in luminising paint was tightly controlled for financial reasons. However, because the full toxicity of radium was not recognised at the time it was being used, control of the workplace was poor and radium contamination was spread within and around buildings. Further, radium wastes were disposed of as non-toxic materials. This usually involved burning the waste and landfilling the resulting ash and debris. Radium-contaminated ash and clinker from such burning may subsequently have been used for a variety of purposes, and has been known to be used for construction of paths and for improving soil quality on allotments. After completion of luminising activities, buildings would have been partially remediated in accordance with accepted practice at the time. Wastes from these activities were again treated as non-toxic and typically buried or burnt on site. Poor records of the use and disposal of radium-bearing materials are characteristic of the practices of the time, which were followed by MoD and the rest of the industry.

In order to understand whether this guidance may be appropriate for a particular defence site, it is first necessary to establish the current and historical activities at the site. This information is obtained as an integral part of the desk study or may already have been produced, in the form of a Land Quality Assessment, on behalf of MoD Defence Estates. Defence Estates may seek advice from DERA Radiological Protection Services (DRPS) on radiological matters. When evaluating such land quality assessments, the potential for incomplete records should be recognised.

**1.4**

**Regulatory aspects**

The regulation of contaminated land on nuclear-licensed sites and defence sites is typically more complex than that of “conventional” contaminated land. Regulators that may be involved include:

- the Health and Safety Executive (of which the Nuclear Installations Inspectorate, NII, is a part)
- the Environment Agency and Environment Agency Wales
- Scottish Environment Protection Agency
- Department of the Environment (Northern Ireland)
- local authorities
- Ministry of Defence.

The legislation that is specifically relevant to potentially radioactively contaminated land is outlined in Section 1.4.1 and that for chemically contaminated land in Section 1.4.2. Other relevant legislation, such as general health and safety legislation, is discussed in Chapter 3.

### 1.4.1

#### Legislation for radioactively contaminated land

There are three principal pieces of legislation.

- 1 Ionising Radiations Regulations 1999, which are concerned with the protection of workers and members of the public from hazards arising from the use of radioactive materials and other sources of ionising radiation in the workplace. The Health and Safety Executive (HSE) is responsible for the enforcement of the Ionising Radiations Regulations.
- 2 Nuclear Installations Act 1965 (as amended), which deals with radioactive waste management and nuclear safety and is the Act under which nuclear-site licences are issued. The Nuclear Installations Inspectorate (NII) of the HSE is the regulator.
- 3 Radioactive Substances Act 1993 (as amended), which deals with protection of the public and the environment from the discharge and disposal of radioactive wastes. The regulators are the environment agencies, ie the Environment Agency and Environment Agency Wales, the Scottish Environment Protection Agency (SEPA) in Scotland and the Department of the Environment in Northern Ireland (DoE(NI)).

On nuclear-licensed sites the HSE is the regulator for land contaminated with radioactivity. While the site is operational, management of land is regulated primarily via conditions in nuclear site licences. The site licence conditions that are of particular relevance to the management of contaminated land are:

- Licence Condition 4(2) which requires adequate arrangements for the storage of nuclear matter
- Licence Condition 6 which requires adequate records
- Licence Condition 23 which requires safety cases
- Licence Condition 32 which requires waste to be minimised
- Licence Condition 34 which requires wastes to be contained.

The Nuclear Installations Act 1965 stipulates that, when a nuclear site licence is in force and has been revoked or surrendered by the licensee, the licensee will remain responsible for the safety of activities on the site. This “period of responsibility” can only end when a new licence has been issued for the site or the NII has given written notice that “in its opinion there has ceased to be any danger from ionising radiations from anything on the site”. The HSE has not yet “de-licensed” any nuclear facility where land is contaminated with radioactive material from operations on the site, but has work in hand to provide guidance on the definition of “no danger”.

The environment agencies have responsibilities for radioactively contaminated land on nuclear-licensed sites under the Radioactive Substances Act 1993 (as amended). These responsibilities are in two areas. Off-site migration of radioactivity, if it occurs, constitutes an unauthorised discharge of radioactive material into the environment. Disposal of any radioactive waste generated by site investigation or land remediation must be authorised by the relevant agency. The environment agencies place requirements in authorisations to ensure that the best practicable means are used to prevent the unnecessary creation of waste for disposal and to limit the amount of activity in waste disposed of into the environment.

DETR and the Scottish Executive are developing a regulatory regime for radioactively contaminated land other than that on nuclear-licensed sites. It is anticipated that a risk-based “suitable for use” approach similar to the contaminated land regime of the Environmental Protection Act 1990 (Part IIA) will be adopted. Until the new regime is in place, the environment agencies will continue to use their powers under the Radioactive Substances Act to regulate contaminated land on non-licensed sites. These powers relate primarily to the generation, accumulation and disposal of radioactive wastes.

Crown immunity applies to sites operated by the MoD (as distinct from sites operated on MoD’s behalf by civilian contractors). Such sites are regulated by MoD, whose policy is to follow the civilian regulatory regime (for example, the Radioactive Substances Act 1993 (as amended)) so far as it is practicable to do so. The Ionising Radiations Regulations apply at nuclear-licensed sites and defence sites. HSE can use their powers under the IRRs to regulate contaminated land on both these types of site.

#### 1.4.2

### Legislation for chemically contaminated land

The management of non-radioactively contaminated land in England and Wales is addressed by the contaminated land regime in Part IIA of the Environmental Protection Act 1990 (inserted by Section 57 of the Environment Act 1995), see Box 1.4. This requires local authorities to identify contaminated land in their areas. Under the legislation, the presence of contaminated land on certain types of site (including nuclear and defence sites) requires the land to be designated as a Special Site and, in this case, the environment agency takes over from the local authority as the enforcing authority. Thus, the principal regulators of non-radioactively contaminated land on nuclear-licensed and defence sites are the environment agencies (the Environment Agency and Environment Agency Wales, the Scottish Environment Protection Agency in Scotland and the Department of the Environment (Northern Ireland) in Northern Ireland).

#### Box 1.4

#### *The contaminated land regime of the Environmental Protection Act 1990 (Part IIA)*

Section 78A(2) of the contaminated land regime defines contaminated land as:

*land which appears...to be in such a condition by reason of substances in, on or under the land that (a) significant harm is being caused or there is significant possibility of such harm being caused, or (b) pollution of controlled waters is being, or is likely to be, caused.*

Risk assessments (using the contaminant-pathway-receptor approach) are to be used to determine the site-specific impact of any contamination and to evaluate whether “significant harm” is being caused or is likely to be caused to human health or to the environment. If the risks to human health and the environment are considered to be acceptable with respect to the current use of the site, no further action is required under the Part IIA regime. Site remediation is required if the risk arising from the current use is unacceptable. In cases of redevelopment, for which planning application is required, the need for any remediation is dealt with as part of the redevelopment process.

The presence of contamination at a site is not sufficient to classify the site as contaminated land under the contaminated land regime. Fundamental to the definition of contaminated land under the regime is the requirement that the contaminant source causes, or has a significant possibility of causing, significant harm to a receptor. Clearly, a pathway (that is, a means by which the contaminant can impact a receptor) and a receptor are pre-requisites for this to be possible.

## 1.5

### List of key available site investigation guidance

DETR (2000)

*Model procedures for the management of contaminated land*

Report CLR11 Contaminated Land Research

Harris, M R, Herbert, S M, Smith, M A (1995)

*Remedial treatment for contaminated land. Volume III: Site investigation and assessment*

Special Publication 103, CIRIA, London

Scottish Enterprise (1994)

*How to investigate contaminated land: requirements for contaminated land site investigations*

ISBN 0-90557-413-3

Welsh Development Agency (1993)

*The WDA Manual on the Remediation of Contaminated Land*

#### British Standards

BS5930:1999 *Code of practice for site investigations*

BS DD 175:1999 *Investigation of potentially contaminated sites – Code of Practice*

(Revision in draft September 1999)

## 2

## Radioactivity in the environment

This section provides a summary for readers who do not have a technical background in issues concerned with radioactivity.

## Box 2.1

### Aims of Chapter 2

- to introduce the principles of radiation and radioactivity
- to identify the principal radionuclides that are of relevance 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.

## 2.1

### Radiation and radioactivity

Atoms, or *nuclides*, can be characterised by the name of the element and the mass number, for example caesium-137, which can be written as  $^{137}\text{Cs}$  or Cs-137. Some nuclides are stable, and are referred to as “stable isotopes” of an element, but many are not. Unstable nuclides are called *radionuclides*. *Radioactivity* involves the spontaneous disintegration (or *decay*) of the nuclide with the emission of *ionising radiation*.

The *activity* of a radioactive material is the rate of radioactive decay, expressed as the number of disintegrations per unit time. The SI unit for activity is the *Becquerel (Bq)*, the number of disintegrations per second. Measurements of radioactivity in soils and waters are expressed as *activity concentrations*, the number of Becquerels per unit mass or volume of the medium. For example, activity concentrations in soil are typically expressed in Becquerels per gram ( $\text{Bqg}^{-1}$ ) of soil; activity concentrations in water are expressed as Becquerels per litre ( $\text{BqL}^{-1}$ ).

The *decay chain* is a series of radionuclides, each of which decays into the next radionuclide in the series until a stable nuclide is reached. The most commonly encountered decay chains are the *natural decay chains* originating with  $^{235}\text{U}$ ,  $^{238}\text{U}$  and  $^{232}\text{Th}$ . The rate of decay of a radionuclide is characterised by its *half-life*, the time taken by the radionuclide to lose half of its activity by decay. Each radionuclide has a unique, and unalterable, half-life, but the half-lives of radionuclides can vary enormously from fractions of a second to millions of years.

The predominant modes of radionuclide decay are *alpha decay* (the emission of an alpha particle from the nucleus) and *beta decay* (involving the emission either of an electron or positron). As a result of either of these forms of decay, the nucleus may be left in an excited state, which will decay to ground state usually with the emission of *gamma radiation*.

The penetrating power of the radiation influences the ease with which it can be detected. For example, measurement of alpha radiation in the field is extremely difficult because of the very short penetration distance in soils and waters, see Table 2.1.

All forms of radioactivity are potentially dangerous to health, depending on the *dose* received, see Box 2.2. *Irradiation* is the exposure of a body or substance to radiation.

Table 2.1

*Penetrating properties of principal types of radiation*

Type	Distance travelled in air	Distance travelled in soil/water
Alpha	~5 cm	<0.5 mm
Beta	Up to ~8 m	~2 cm
Gamma	>100 m	~1 m

Box 2.2

*Radiation dose*

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

**Absorbed doses of radiation**

The various sources of radiation to which a person is exposed give rise to absorption of energy in the body. The amount of energy absorbed in body tissue is expressed in terms of the energy imparted by the radiation per unit mass of matter. The unit of *absorbed dose* is the *Gray (Gy)*. Absorbed dose rate is typically expressed in micrograys per hour ( $\mu\text{Gyh}^{-1}$ ).

**Equivalent and whole body dose**

However, in biological systems, humans for example, different types of radiation (alpha, beta, gamma) produce different degrees of damage for the same absorbed dose. To equalise things a *quality 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. Dose rate is typically expressed in microsieverts per hour ( $\mu\text{Svh}^{-1}$ ).

In radiation protection it is useful to think of radiation dose in terms of the overall impact it may have on the whole body. Since different organs have different susceptibility to damage from radiation, further corrections must be applied. The resulting calculated dose is called the “effective dose” and is often referred to as “*whole body dose*”.

In the context of contaminated land investigations, one should 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 calculated by means of monitoring air contamination levels.

## 2.2

### Principal radionuclides of relevance to contaminated land

Most natural materials contain some radionuclides, although typically at such a low level that sensitive instruments are required to detect them. These radionuclides can be divided into two broad categories.

- 1 *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), see Box 2.3.
- 2 *Anthropogenic radionuclides*, produced by man. In addition to site-specific radioactive contamination, which is the subject of this guidance, anthropogenic radionuclides are widely distributed in the environment as a result of atmospheric nuclear weapons testing, nuclear accidents (of which Chernobyl is currently the most significant in the UK context) and authorised discharges of radioactivity from sites where radioactive materials are handled.

**Primordial radionuclides**

*Radionuclides in the natural decay series originating with U-235, U-238 and Th-232.* The dominant naturally occurring isotope of uranium is U-238 (99.28 % natural abundance by mass). U-235 constitutes essentially all of the remaining 0.72 % by mass of natural uranium. The activity ratio of  $^{238}\text{U}/^{235}\text{U}$  is approximately 22. Crystal rocks, on average, contain approximately  $25 \text{ mBqg}^{-1}$  U-238 (equivalent to 2 ppm U) and  $30 \text{ mBqg}^{-1}$  Th-232 (equivalent to 7 ppm Th). Some rocks in the UK, such as the granites of SW England, contain significantly higher levels of U: typically of order 16 ppm (0.2  $\text{Bqg}^{-1}$  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, a key 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, in turn, decays to stable lead via a series of short-lived, predominantly alpha-emitting, radionuclides.

*Lighter radionuclides, principally K-40.* K-40 has a half-life of  $1.28 \times 10^9$  years, and an isotopic abundance of 0.0118 %. This leads to natural potassium being radioactive, having an activity of approximately  $30 \text{ Bqg}^{-1}$ .

**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 C-14 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 sub-surface.

**C-14.** All living matter contains a C-14 concentration of approximately  $0.23 \text{ Bqg}^{-1}$  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).

**H-3.** Tritium 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 approximately  $200 \text{ BqL}^{-1}$ . At present, tritium activity in precipitation is approximately  $2\text{-}5 \text{ BqL}^{-1}$ .

Anthropogenic radionuclides are produced as a result of either:

- **nuclear fission**, the splitting of a heavy nucleus into two roughly equal fragments as the result either of spontaneous reaction or of bombardment with neutrons or charged particles. This is the process that occurs in a nuclear reactor to generate energy
- or **activation**, the result of irradiation by a flux of 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  $^{60}\text{Co}$  and  $^{14}\text{C}$ . Many radionuclides for medical and industrial use are also produced by this process.

The principal operations on nuclear-licensed sites that produce man-made radionuclides and/or concentrate naturally occurring radionuclides are summarised in Box 1.3. The radionuclide “fingerprint” that is produced from these 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 large 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 areas of, the site.

The fingerprint defines the relative activities of radionuclides at the source of contamination. However, as radionuclides migrate away from the source area, 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 cannot be applied.

Some of the principal longer-lived fission products and activation products, which may be encountered in contaminated land site investigations, are given in Tables 2.2 and 2.3.

Table 2.2

*Principal longer-lived fission products relevant to contaminated land*

Radionuclide	Half-life	Major decay
Sr-90, Y-90	28.64 y, 2.67 d	$\beta^-$ , $\beta^-$
Tc-99	2.1 10 <sup>5</sup> y	$\beta^-$ $\gamma$
Cs-137, Ba-137	30.2 y, 2.55 m	$\beta^-$ $\gamma$

**Note:** where two radionuclides are shown on one line, the second is produced from decay of the first

Table 2.3

*Principal longer-lived activation products relevant to contaminated land*

Radionuclide	Half-life	Major decay
H-3	12.33 y	$\beta^-$
C-14	5730 y	$\beta^-$
Fe-55	2.74 y	Electron capture
Co-60	5.27 y	$\beta^-$ $\gamma$
Ni-63	99 y	$\beta^-$
Cs-134	2.06 y	$\beta^-$ $\gamma$
Pu-241, Am-241	14.4 y, 433 y	$\beta^-$ $\alpha$ $\gamma$
Pu-238	87.7 y	$\alpha$
Pu-239	2.41 10 <sup>4</sup> y	$\alpha$
Pu-240	6.56 10 <sup>3</sup> y	$\alpha$
Pu-242	3.74 10 <sup>5</sup> y	$\alpha$

## 2.3

### Background levels of radioactivity

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

Background levels of radioactivity will vary (i) from site to site and (ii) spatially within a site. 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. Therefore, 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; that is, 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 below that of the natural soil at the site. These variations in natural background level can be detected by some walkover radiation surveys (see Figure 2.1) and should be taken into account when deriving background levels for the site.



Figure 2.1 Variation in background radioactivity at a site

Box 2.4 Background levels of man-made radionuclides in surface soils and sediments

<b>Fallout</b>	
I In areas particularly affected by Chernobyl atmospheric fallout (upland areas of NW England)	
Cs-137	0.01-0.34 Bqg <sup>-1</sup> (modal value in range 0.05-0.1 Bqg <sup>-1</sup> )
II In other areas (eg Oxfordshire)	
Cs-137	<0.003-0.06 Bqg <sup>-1</sup> (modal value <0.003 Bqg <sup>-1</sup> )
<b>Marine discharge</b>	
iii In areas affected by marine discharge (Cumbrian coastline and Ribble estuary). Data from Environment Agency, 2000.	
Co-60	0.006-0.033 Bqg <sup>-1</sup>
Cs-137	0.8-9.8 Bqg <sup>-1</sup>
Pu-238	0.06-1.8 Bqg <sup>-1</sup>
Pu-239/240	0.18-9 Bqg <sup>-1</sup>
Am-241	0.5-12 Bqg <sup>-1</sup>

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. Levels of radioactivity in coastal areas can be influenced by authorised radioactive discharges into the marine and non-marine (eg lakes, streams, rivers) environment, see Box 2.4. “Background” concentrations are influenced by the proximity to the point of discharge, the amounts and concentrations of radioactivity discharged into the marine environment and the prevailing water and sediment movement patterns.

External radiation dose rates from the background levels of radioactivity in rocks and soils depends on the levels and nature of the radioactivity. Typical background dose rates are 0.05-0.1  $\mu\text{Sv}\cdot\text{h}^{-1}$ .

## 2.4

### References

EA (2000)

*Technical support material for the regulation of radioactively contaminated land*

Project P3-055 R&D Technical Report P307. Environment Agency, UK (ISBN: 1 85705 145 9)

## 3

# Health, safety and environmental protection

### 3.1

## Introduction

#### Box 3.1

#### *Aims of Chapter 3*

This section describes the key aspects of health, safety and environmental management on nuclear-licensed and defence sites that are different from those on conventional contaminated sites. The reader is referred to CIRIA Report 132 for guidance on safe working on conventional contaminated sites. This section focuses on health and safety issues concerned with working with radioactivity. The key to ensuring compliance with the principal legislation concerned with radioactivity (the Ionising Radiations Regulations 1999 and the Radioactive Substances Act 1993, as amended) is the appointment of a suitably qualified Radiation Protection Adviser (RPA).

The requirements of environmental management systems are presented.

This guidance focuses on aspects of health, safety and environmental management on nuclear-licensed and defence sites that differ from those on conventional contaminated sites. Detailed guidance of safe working on conventional contaminated sites is already available (CIRIA Report 132). The reader is referred to this report for information.

One of the key aspects of health, safety and environmental management on operational nuclear-licensed sites is that the site operator has well-specified site procedures, which 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.

In contrast to nuclear-licensed sites, few MoD sites have extensive site procedures relevant to the investigation of contaminated land. MoD procedures are more concerned with security and conventional safety. It should be noted that compliance with security procedures is a requirement for contractors and that compliance may have an effect on planned project programmes. Contractors will be permitted to work to their own safety procedures after they have been reviewed and approved by MoD staff.

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

### 3.2

## Summary of key safety legislation relevant to site investigations on contaminated land

The prime legislation for health and safety management is the Health and Safety at Work etc Act (HSAWA) 1974. Under this act are a series of regulations, some of which are of relevance 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.

**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**

- Workplace (Health, Safety and Welfare) Regulations 1992
- Provision and Use of Work Equipment Regulations 1998
- Fire Precautions (Workplace) Regulations 1997
- 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

**Construction**

- Construction (Design and Management) Regulations 1994
- Construction (Health, Safety and Welfare) Regulations 1996
- Construction (Head Protection) Regulations 1989

**Hazards**

- Control of Substances Hazardous to Health Regulations 1999
- Ionising Radiations Regulations 1999
- Electricity at Work Regulations 1989
- Manual Handling Operations Regulations 1992
- Noise at Work Regulations 1989
- Control of Asbestos at Work Regulations 1987
- Control of Lead at Work Regulations 1998

The Ionising Radiations Regulations 1999 (IRR99) are discussed in more detail in the following section because the potential presence of radioactive contamination is one of the issues that distinguishes site characterisation on nuclear-licensed and defence sites from that on most other sites.

Prior to 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. Best practice is that a Radiation Protection Adviser (see below) is appointed to advise on this, and other radiological, issues.

**3.3**

**Radiological safety: Ionising Radiations Regulations 1999**

The main piece of legislation that relates to the health and safety of workers involved with radioactivity on contaminated land is the Ionising Radiations Regulations 1999 (IRR99). IRR99 sets out the general requirements for control of work with ionising radiations. Further guidance is given in *Work with Ionising Radiation*, the approved code of practice and guidance for IRR99. The requirements that are most relevant to contaminated land are summarised below. The key to ensuring compliance with IRR99 is to appoint competent staff (in particular, a Radiation Protection Adviser) at the beginning of the project.

### 3.3.1

## Part II – General principles and procedures

**Regulation 6 – Notification of Specified Work.** For work involving concentrations and quantities of radionuclides greater than specified in the Regulations, there is a requirement to notify HSE 28 days before starting work. This requirement does not apply to work on nuclear-licensed sites. Note that, because of uncertainties in the interpretation of the Regulations with respect to contaminated land, this is an area where advice from the RPA must be sought.

**Regulation 7 – Prior Risk Assessment.** Requirement to carry out a “prior risk assessment” before work with ionising radiations. Compliance with this regulation does not remove the need for compliance with the Management of Health and Safety at Work Regulations.

**Regulation 8 – Restriction of Exposure.** Requirement that doses to employees and others are restricted as far as is reasonably practicable. This embodies the principle of As Low as Reasonably Practicable (ALARP).

**Regulation 9 – Personal Protective Equipment.** Requirement that PPE meets the requirements of the Personal Protective Equipment Regulations 1992.

**Regulation 10 – Maintenance of Controls & PPE.** Requires that any engineering control, design feature or warning device provided to aid restriction of exposure, is properly maintained and where appropriate is subject to thorough examinations and testing.

**Regulation 11 – Dose Limitation.** Requires that dose limits for employees and others, as set out in IRR99, are not exceeded.

**Regulation 12 – Contingency Planning.** Requires that contingency plans are put in place where a risk assessment shows that a radiation accident is reasonably foreseeable.

### 3.3.2

## Part III – Arrangements for the management of radiation protection

**Regulation 13 – Radiation Protection Advisers.** Requires the appointment of a Radiation Protection Adviser (RPA) to advise the employer on general compliance with the regulations (IRR99), see Box 3.3.

**Regulation 14 – Information, Instruction & Training.** Requires that employees are given appropriate training in radiation.

### 3.3.3

## Part IV – Designated areas

**Regulation 16 – Designation of Controlled or Supervised Areas.** Requires the designation of areas as controlled or supervised depending on the results of the prior risk assessment.

**Regulation 17 – Local Rules and Radiation Protection Supervisors.** Requires the production of written local rules to enable work in controlled (also in some circumstances for supervised) areas to be carried out in accordance with the regulations. Radiation Protection Supervisors (RPS) must be appointed to secure compliance with the regulations, see Box 3.3.

**Regulation 18 – Additional Requirements for Designated Areas.** Requires the demarcation of designated areas and restricts access to these areas.

**Regulation 19 – Monitoring of Designated Areas.** Requires that suitable monitoring of designated areas is undertaken.

### 3.3.4

#### Part V – Classification and monitoring of persons

**Regulation 20 – Designation of classified persons.** Requires the employer to designate as classified workers any employees who are likely to receive an effective dose in excess of 6 mSv per year or an equivalent dose that exceeds three-tenths of any relevant dose limit.

**Regulation 21 – Dose assessment and recording.** Requires that the employer of classified workers makes arrangements with an Approved Dosimetry Service (ADS) to assess all significant doses to classified workers.

**Regulation 24 – Medical Surveillance.** Requires that the employer sets up a system of medical surveillance for all classified workers and certain others.

### 3.3.5

#### Part VII – Duties of employees etc

**Regulation 34 – Duties of Employees.** Puts duties on all employees engaged in work with ionising radiation which are consistent with Sections 7 and 8 of the Health and Safety at Work Act 1974.

## 3.4

### Key radiological safety principles

This section discusses some of the basic radiological protection principles that are embodied in IRR99. The principles are discussed in the context of their application to the characterisation of contaminated land on nuclear-licensed and defence sites.

#### Box 3.3

#### *Appointment of staff to ensure compliance with IRR99*

The key to ensuring compliance with the requirements of IRR99 is the appointment of 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. It should be noted that the same RPA should not be appointed for more than one company where a compromise could be envisaged (eg RPA for both the main contractor and the client). However, it may be acceptable for the same RPA body, ie an organisation that employs a number of RPAs, to act for more than one company involved in the project provided that adequate safeguards exist to prevent a conflict of interests.

**Radiation Protection Supervisors (RPS).** All companies involved with the project (and working with ionising radiation) must appoint at least one RPS. In the case of subcontractors with only few personnel on site or on site for a short duration, it may be appropriate for a main contractor's RPS to fulfil this role.

### 3.4.1

#### Hazard identification and risk assessment

All hazards associated with radiologically contaminated land should be considered. Those that apply should be further assessed to establish their nature and magnitude. In considering the hazards that may be present, the issues in Box 3.4 can be used as a guide. Box 3.5 lists some of the outcomes of the risk assessment.

Box 3.4

*Checklist for hazard identification*

- The following issues should be addressed:
- estimated radiation dose rates to which anyone can be exposed
  - estimated levels of airborne and surface contamination likely to be encountered
  - the likelihood of contamination arising and being spread
  - engineering control measures and design features already in place or planned, and the consequence of possible failures of such measures and features
  - the effectiveness and suitability of personal protective equipment (PPE) and respiratory protective equipment (RPE) to be provided
  - possible accident situations, their likelihood and potential severity.

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. An example would be radiation from a nearby facility, which would cause additional dose to workers taking part in site characterisation.

Box 3.5

*Prior risk assessment*

- The result of the prior risk assessment should be used to determine:
- the action needed to ensure that radiation exposure of all persons is kept ALARP
  - the value of any dose constraints that may be set for the work, and the content of a suitable programme of dose assessment
  - the need to designate certain employees as classified persons
  - the need to designate areas as controlled or supervised and to specify local rules
  - the training needs of classified and non-classified employees
  - the type of any PPE/RPE that may be required
  - the maintenance and testing schedules required for any control measures selected.

3.4.2

**Restriction of exposure**

The International Commission for Radiological Protection (ICRP) has set down the general principles of restriction of exposure. They are set in three stages: justification, optimisation and limitation. The justification for characterisation and remediation of contaminated land is generally well established. Dose limits are set in legislation. Therefore, the focus should be on optimising radiological dose, according to the principal of ALARP. The following section describes the techniques that 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 arises principally from contaminated soil and from nearby processes or activities. The main techniques for reducing exposure to external radiation are:

- **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. This can concentrate dose in a small volume where it can do significant damage. In particular,  $\alpha$  particles, which cannot penetrate the skin in external exposure, can cause significant 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 the hierarchy of controls must ensure 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 spraying 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.

## 3.5

### Staff competency and training

The provision of competent employees is a fundamental duty of the employer. On nuclear-licensed sites, the licensee will generally require evidence that staff are suitably qualified and experienced personnel (SQEP) for the tasks that they are required to perform. MoD will also require evidence that competent staff are employed by the contractor. As most MoD sites have no local RPA support, the training and experience requirements for working on MoD sites are given a high priority.

Additional health and safety training specific to the site and to the project will be required. The type and depth of training should be relevant to the type of work being carried out and developed to meet the specific hazards identified during the risk assessment, see Box 3.6.

Box 3.6

*Occasions when health and safety training is to be considered*

Induction training appropriate to the work to be undertaken and the location, eg:

- site induction course, to provide workers with details of site procedures and emergency arrangements (this is a requirement for working on most nuclear-licensed sites)
- project-specific induction training to describe the project objectives, methods and hazards. For example, staff should be aware of the radiological hazards and the measures taken to control them. Staff will also require training if they are issued with any PPE or RPE.

Before exposure to new risks.

Prior to a change of responsibility.

Prior to the introduction of new equipment.

Prior to the introduction of a new system of work.

3.6

**Radiological monitoring**

Under the Ionising Radiations Regulations 1999, there is a legal requirement to carry out health surveillance monitoring. This is achieved through a programme of radiological monitoring. Another aspect of radiological monitoring is to provide information to characterise the site: this is discussed separately in section 6. Health and safety monitoring requirements for other aspects of working on contaminated sites are discussed fully in CIRIA Report 132 *A guide to safe working on contaminated sites*, to which the reader is referred for information. Legislative requirements for health surveillance relevant to site characterisation on contaminated land are given below.

Box 3.7

*What legal requirements are there for health surveillance?*

A number of the health and safety Regulations place a duty on employers to carry out appropriate health surveillance:

- Control of Substances Hazardous to Health Regulations 1999
- Ionising Radiations Regulations 1999
- Control of Asbestos at Work Regulations 1987
- Noise at Work Regulations 1989.

Health and safety monitoring should be both reactive, motivated in response to an event, and proactive, identifying shortcomings that may eventually lead to project loss. If any shortcomings are identified, additional controls should be put in place to mitigate the effect.

3.6.1

**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 outset 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 personnel. This will be based on the outcome from the exposure assessment.

**External dosimetry.** External dosimetry will generally involve the wearing of a suitable whole-body dosimeter, normally a film badge or thermo-luminescent dosimeter (TLD) badge. The dosimeter will usually be worn on the chest/torso area and will be changed and sent for analysis by the ADS on a regular basis. Alternatively, electronic dosimeters,

which provide an immediate indication of dose uptake, can be used. Electronic dosimeters are particularly useful for the early stages of a site characterisation, where a rapid assessment of the suitability of working practices is required.

**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. A number of methods of assessing internal exposure are available. The choice will be determined by the level of risk associated with the particular work being undertaken. Examples are:

- estimating uptake of radionuclides from static air sample data and occupancy times in an area
- 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 change significantly.

It is MoD practice to require that whole body monitoring (WBM) is carried out on contractor's staff before starting and on completion of any work where there is a high probability of encountering loose radioactive contamination. This provides some protection against claims for internal exposure of personnel caused by work on an MoD site. WBM may not be required for site characterisation work but is always carried out where site remediation takes place.

**Radiation passbooks.** All classified workers who may work away from their employer's premises are issued with radiation passbooks. These passbooks record dosimetry data and give medical status. If entry into a radiologically designated area is required when working at a site other than their employer's premises, then the passbook must be submitted to the site operator for scrutiny. The objective is to ensure that the classified worker (who in this case is designated an "outside worker") will not exceed any dose limits as a consequence of the work undertaken at the site. In certain circumstances the HSE may grant an exemption from this requirement for outside workers in IRR99, particularly where those workers are normally resident on the licensee's site, for example tenants.

**Dose constraints.** The project manager, in consultation with the RPA, should establish dose constraints at the outset of the project. Details of the works (specific activities, decontamination methods, numbers of people involved, etc) will be needed in order to set up realistic dose constraints. Dose constraints set should be specified in the relevant local rules. The RPA should regularly review doses and take appropriate action if it appears the restraint may be exceeded.

### 3.6.2

#### Monitoring equipment and programme

Suitable monitoring equipment must be used to achieve accurate monitoring results, in a timely manner and in accordance with the technical objectives of the project. All instruments must be within calibration, and must be functionally tested before each use. When selecting instruments, consideration should be given to the physical conditions in which they will be used. Where possible, instruments should be rugged, waterproof and easily cleaned. The quality management system should contain a procedure for recording instrument defects and tracking their return and repair.

The selection of health physics instruments for measuring direct radiation is discussed in Chapter 6. It is not discussed further here. In addition to this monitoring, static air samplers (SAS) should be used where there is a possibility of airborne radioactivity, for example during excavation works.

At the outset of the project, a monitoring programme should be defined by the project manager, in consultation with the RPA. Issues to address will include the following:

- type of survey (radiation dose rate, contamination, environmental)
- background benchmarks (same background value across site or various values across different parts of the site, background values for different monitor types etc)
- reference levels (to what monitored value are any action levels being set, different values for various monitor types etc)
- function checks (how often, by who, recording results etc)
- maintenance and repair (on-site facilities, storage, booking-in booking-out, cleaning etc)
- calibration and records (availability of calibration certificates, recording faults etc).

Materials contaminated with radium will give rise to the emanation of radon gas. Consequently, on radium-contaminated sites, the monitoring programme should also include radon gas monitoring. When working with radium-contaminated items individuals should be made aware of the likelihood of the presence of alpha contamination in air and of radon daughter precipitation on solid surfaces.

### 3.6.3

#### Designation of areas

The site to be investigated may be radiologically designated before the start of the project. This would be the case if, for example, the site contained facilities that use radioactive materials, or if the presence of radioactive contamination was already known. It is also possible that, during the site investigation, radioactivity is discovered in an area that was previously not radiologically designated. In this case, it may be necessary to define the site as a designated area part way through the site characterisation. Finally, if the possibility of locating radioactive contamination during excavations in a non-designated area is high, it may be appropriate to define the area as a temporary designated area for the duration of the excavation. Note that there is a requirement under IRR99 to consult an RPA prior to designating a controlled or supervised area.

There are two classes of radiologically designated area defined under IRR99, defined by criteria such as: surface contamination levels; airborne contamination levels; accessible dose rates and total radioactivity.

- 1 Supervised area.
- 2 Controlled area.

There are restrictions on access into radiologically designated areas. All staff entering a supervised area should be fully aware of the prevailing radiological conditions and requirements for access. In addition to this requirement, controlled areas must only be entered by classified workers or persons entering under a written system of work (WSoW). The WSoW should be drafted before the project starts and it should be incorporated into the local rules.

Washing and changing facilities should be available for places where contamination is likely. Facilities will vary from normal washing facilities, where only low levels of

contamination are expected, to showers in areas where high levels of re-suspendable loose contamination could exist. The facilities should be situated so that contamination is not spread beyond the area for which they are provided. Where facilities are remote from the contaminated area, a clearly delineated route must exist between them.

### 3.7

## Safety management arrangements

The overall 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, see Box 3.8. These principles are featured in the common law “duty of care” and in occupational health and safety law, such as the Health and Safety at Work etc Act 1974. The safety management arrangements provide the basis for the working procedures used for the work activities.

#### Box 3.8

#### *What forms the “safe system of work”?*

Safe systems of work include development and implementation of all or some of the following:

- safety procedures
- safety instructions
- permit-to-work system
- risk assessments
- method statements
- checklists
- records
- adequate monitoring of the system by management.

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 key elements common to most nuclear-licensed sites.

- safety categorisation of the proposed work by the site operator. A hazard and operability study (HAZOP) may 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 health and safety plan and method statements by the site operator and issue of permit to work and excavation permits (if required)
- completion and closure of permit to work and excavation permits at the end of the project.

On operational MoD sites, the overall responsibility for safety lies with the commanding officer for the site. However, day to day authority may be delegated to Defence Estates or some other technically competent organisation. The Works Services Manager for the site acts as the MoD representative and, after taking the appropriate specialist advice from the Defence Radiation Protection Services (DRPS), ensures that the contractors’ procedures are “fit for purpose”.

Disused or abandoned sites no longer have a commanding officer and responsibility for these sites lies with Defence Estates. 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 seeks advice on radiological issues from the DRPS.

It is best practice that the health and safety plan should conform to the requirements of the CDM Regulations. It should include:

- notification to HSE of the initial intention to work with ionising radiations (if appropriate)
- 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 RPS) and of the Approved Dosimetry Service (if appropriate)
- local rules for all radiologically designated areas
- method statements
- arrangements for monitoring of compliance
- welfare requirements
- communications, co-operation and training arrangements
- emergency procedures
- accident reporting procedures.

In accordance with the CDM Regulations, a health and safety file should be produced and maintained for the duration of the project. This document should include:

- 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 qualified and experienced personnel (SQEP) 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.

## 3.8

### Personal protective equipment

When implementing control measures relevant to hazards identified during the risk assessment stage, personal protective equipment (PPE) should be considered a last resort. However, there are many instances in the characterisation of radioactively and chemically contaminated land where the use of PPE will be necessary. When specifying the PPE requirements for tasks it is important to consider both the radiological and non-radiological hazards. The selection process should consider the compatibility of different PPE; for example, can standard head protection be worn with the required respiratory protective equipment (RPE)?

#### 3.8.1

##### Protective clothing

Before the start of the project, suitable protective clothing should be selected. Influencing factors on the selection will include the following:

- full range of hazards and level of protection required
- compatibility with other PPE
- availability, storage and maintenance arrangements
- cost (eg use of disposable items)
- working environment (dry, wet, muddy etc)
- number of workers
- project duration.

Typical protective clothing for site characterisation projects on contaminated sites would include coveralls, gloves, safety footwear, safety helmet. Examples are shown in Figure 3.1.



**Key to Figure 3.1**

- |                            |   |
|----------------------------|---|
| a) Construction helmet.    | e) High visibility jacket.              |
| b) Steel toe-capped boots. | f) Rubber or chemical resistant gloves. |
| c) Overshoes.              | g) Half-face respirator.                |
| d) Disposable overalls.    | h) Full-face respirator and filter.     |

**Figure 3.1**

*A selection of the PPE that may be required*

It is best practice (and commonly a requirement on nuclear-licensed sites) that separate protective clothing is used for designated and non-designated areas. Typically, the two sets of protective clothing are distinguished by colour-coding or other marking.

### 3.8.2

#### Respiratory protective equipment (RPE)

Before any RPE is used, an exposure assessment should be carried out. A number of assessments may be needed in projects that are of long duration, or where the nature and/or execution of works changes.

All individuals wearing RPE should receive suitable training in its use and they should be aware of its limitations. When not in use, the RPE should be kept in clean, secure and dry storage conditions and it should always be kept fully serviceable (clean, no broken straps etc). RPE must be regularly inspected and tested by qualified personnel, and records kept. A discussion on the selection and use of RPE is given in CIRIA Report 132.

## 3.9

## Environmental protection

### 3.9.1

### Benefits of environmental protection compliance

Participants in site characterisation work will be expected to comply, as a minimum, with the environmental legislation, 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 these organisations will require their consultants and sub-contractors to 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 safety, health and environmental aspects
- management of stakeholder expectations.

### 3.9.2

### 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 sub-contractors 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. The key principles are listed below:

- minimise the direct and indirect adverse environmental effects of site characterisation activities. This should be demonstrated by provision of a safety, health and environment plan for performance of the work (not to be confused with a health and safety plan that may be required by the Construction (Design and Management) Regulations)
- every individual should be suitably qualified, trained and experienced to carry out their work and to understand their responsibility for the environmental effects of their activities
- managers at all levels should understand their responsibilities for the environmental effects of the activities of the employees, contractors and visitors under their control
- all staff should know the environmental objectives and targets relevant to their work, and assume personal responsibility for the environmental effects of their actions
- equipment and facilities used for site characterisation work should be appropriate for the job, adequately maintained and operated to a suitable system of work. This will minimise, as far as reasonably practicable, direct environmental effects
- all staff should know the procedures for reporting accidents and emergencies that have environmental implications, and the actions to be taken to minimise the effect of an accident

- participation in audits, monitoring and review activities to check compliance with environmental legislation and management systems may be expected.

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 summarised in Box 3.9. An environmental protection checklist is given in Box 3.10.

**Box 3.9**

***Some aspects of environmental protection appropriate to site characterisation activities***

Aspect description	Example of activity or process
Waste management	Spoil generation, minimisation and disposal. Requirements related to duty of care. Refer to Environmental Protection (Duty of Care) Regulations 1991 and HMSO (1996).
Water use	Impact of using water flush techniques.
Materials storage and handling including hazardous materials	Fuel storage for equipment.
Air quality	Emissions from generators.
Noise and vibration	Use of heavy plant. Refer to Code of Practice BS 5228 <i>Noise Control on Construction and other Open Sites</i> .
Effluents, including sewerage	Disposal of pumped contaminated water from boreholes, sewerage disposal from site toilet facilities.
Contaminated land	Prevention of spread of contamination as a result of: <ul style="list-style-type: none"> <li>i inadequate borehole construction techniques or</li> <li>ii inadequate decommissioning of redundant boreholes. Refer to Environment Agency (1999).</li> </ul>
Ecology	Careful re-instatement of excavation sites.
Odours	Equipment emissions.
Transport	Vehicle movements.

**Box 3.10**

***Environmental protection checklist***

- check contractual environmental requirements
- check own organisational environmental requirements
- check legislative environmental requirements
- check responsibilities
- produce environmental impacts register for the project
- check personnel competence, equipment suitability and maintenance
- check procedures for monitoring and recording, audits and reviews, for communications and for emergency incidents.

## 3.10

### References

HMSO (1996)

*Waste management “The Duty of Care”, Code of Practice*

HMSO Books

National Groundwater and Contaminated Land Centre (1999)

*Decommissioning redundant boreholes and wells*

Environment Agency

Health and Safety Executive (1999)

*Work with ionising radiation, ionising radiations regulations 1999. Approved Code of Practice and guidance*

HSE Books

## 4

# Objectives of the site characterisation

Box 4.1

### *Aims of Chapter 4*

This section describes why site characterisation may be required on nuclear-licensed sites and defence sites, and defines end-points for different site characterisation contexts.

It contrasts and compares the management regimes for chemically contaminated land and for radioactively contaminated land, presents the overall sequence of activities required to manage contaminated land and sets site characterisation in the context of these activities.

## 4.1

### Reasons for site characterisation

There are several reasons why site characterisation may be required at nuclear-licensed sites and defence sites, see Box 4.2.

Box 4.2

### *Why site characterisation may be required*

- compliance with the requirements of a nuclear site licence
- delicensing of all or part of a nuclear licensed site
- compliance with regulatory requirements under Part IIA of EPA 1990
- other regulatory compliance, including the Radioactive Substances Act
- requisite surveillance
- evaluation of liabilities
- divestment
- redevelopment of land
- design of a remediation strategy
- validation of remediation.

These reasons are discussed in more detail below. Some relate to legislation concerned with radioactivity (eg the Nuclear Installations Act 1965 and the Radioactive Substances Act 1993). Others relate to issues of chemical contamination (eg Part IIA of the Environmental Protection Act 1990 and the Groundwater Regulations 1998).

**Compliance with the requirements of a nuclear site licence.** The Nuclear Installations Act 1965 allows NII to attach conditions to site licences, as outlined in section 1.4.1, with respect to the handling, treatment and disposal of nuclear waste. Furthermore, 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.

**Delicensing of all or part of a nuclear licensed site.** 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 IIA of EPA 1990.

**Compliance with regulatory requirements under Part IIA of EPA 1990.** Part IIA of EPA 1990 places a requirement on local authorities to identify chemically contaminated land on nuclear-licensed and defence sites. If insufficient information is available to determine whether a site should be classified as contaminated, and hence to be treated as a Special Site, then the local authorities have powers to authorise a site inspection to be performed and to recover the costs from an appropriate person. Liability-holders may consider it appropriate to take a pro-active approach and undertake site characterisations themselves in order to evaluate their contaminated land liabilities under Part IIA.

**Compliance with the Radioactive Substances Act.** 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” (unless the site has Crown immunity), 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 (see also section 4.3.2.1).

**Requisite surveillance.** 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 and defence sites where List I and II substances are being handled. The Environment Agency is to publish guidance on “prior investigation” and “requisite surveillance”.

**Evaluation of liabilities.** Site owners or operators of nuclear-licensed sites and 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. It is therefore essential to understand, by site characterisation, the magnitude of such impacts and to estimate actual or potential remediation costs and associated liabilities, thereby budgeting for improvement works or taking account of such liabilities in land valuation.

**Divestment and/or redevelopment of land.** Once site activities have ended, divestment and/or redevelopment may be considered an option. Site characterisation may be required to evaluate the magnitude of any risks posed by radioactive or non-radioactive contamination to human health and the environment, and to determine what management strategy is appropriate. Although RSA93 requirements are not risk-based (in the sense that they do not require a contaminant-pathway-receptor approach), the regulators may encourage such an approach to land remediation.

**Design of a remediation strategy.** If the site is to be remediated, then site characterisation will be required to enable a suitable remediation package to be designed and costed.

A key deliverable from the site characterisation should be an evaluation of the volumes and other characteristics of radioactive waste that may require disposal, because radioactive waste disposal costs are commonly a major component of the project cost. Characterisation should be sufficient to enable disposal routes for radioactive wastes to be identified.

The distribution of radioactive contamination in soil is often heterogeneous. An extreme example is the distribution of radium vials in contaminated soils at former luminising works. Individual vials have activities of order 1 MBq, but they are sparsely distributed in the soil. The volume of soil over which the radioactivity from the vial(s) is averaged for waste categorisation purposes (the “averaging volume”) needs to be defined before the site characterisation is designed. This consideration of averaging volumes is crucial to the design of the site characterisation programme, but is commonly overlooked.

**Validation of remediation.** Characterisation and monitoring for compliance and performance will be necessary during and following remedial action. The precise requirements will depend on the nature of the remedial package. This may involve a single remedial action or a combination of methods and determination that:

- excavation and removal is complete
- *ex situ* treatment is achieving the required performance
- *in situ* treatment is achieving the required performance
- cover or containment measures are performing to design specifications.

## 4.2

### End-points

The reason for undertaking the site characterisation defines its context and enables the required end-points to be specified. Identification of the context and of the end-points is a key issue for any site characterisation, as it enables an appropriate site characterisation design to be developed. Examples of relevant end-points for different site characterisation contexts are given in Box 4.3.

## 4.3

### Comparison of the management of chemically contaminated and radioactively contaminated land

Radioactively contaminated land and chemically contaminated land are regulated under different statutory regimes (see section 1). This section summarises the differences between the definitions of “contaminated land” in the two regimes, and the consequent differences in the roles of site characterisation in land management.

### 4.3.1

#### Chemically contaminated land management

It is not the intention of this document to repeat the extensive guidance on the management of chemically contaminated land, but it is important to set the specific guidance for nuclear-licensed sites and defence sites in the wider context of contaminated land management in the UK. It is recommended that reference should be made to the more extensive guidance cited for further information (CIRIA, 1995; DETR, 2000b; Petts *et al.*, 1997; EA, 1999).

Box 4.3

Examples of end-points for different site characterisation contexts

Context	End-point
Compliance with the requirements of a nuclear site licence	Determination of radioactive contamination and radiation dose to humans. Installation of an appropriate compliance monitoring system.
Delicensing of all or part of a nuclear licensed site	Demonstration of “no danger” from ionising radiations to humans.
Compliance with Part IIA of EPA 1990	Assessment of whether land constitutes “contaminated land” under EPA 1990.
Compliance with RSA93 (as amended)	Determination of presence of radioactive substances on the site (and usually evaluation of radiological risks to humans) and elimination of unauthorised discharges.
Divestment of land	Evaluate whether site is suitable for current or planned use.
Redevelopment of land	Evaluate whether site is suitable for current or planned use.
Remediation	Design remediation programme. Key cost issue for radiation contamination is determining volumes of radioactive waste to be disposed. Averaging volume for calculating activity levels in the soil must be defined at the outset (see Chapter 7).
Validation of remediation	Validation of remedial package implementation.
Post-remediation monitoring	Verification of continued efficacy of remedial strategy and remedial package.

The main objective underlying the introduction of the Part IIA contaminated land regime is to provide an improved system for the identification and remediation of land where contamination is causing unacceptable risks to human health or the wider environment. Risks are assessed in the context of the current use and any planned change of use of the land.

The definition of chemically contaminated land is based upon the principles of risk assessment, including the concept of contaminant-pathway-receptor (DETR, 2000a). There are two steps in applying the definition of contaminated land with respect to chemical contamination.

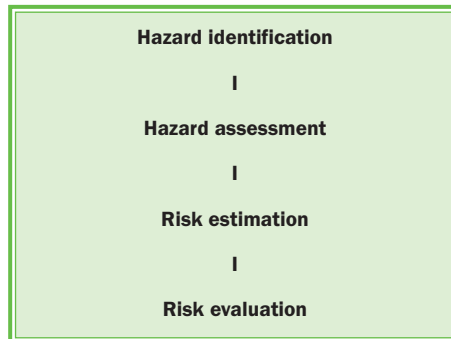
The first step is to identify a contaminant, a pathway (or pathways) and a receptor, with respect to that land. The identification of each of these three elements is linked to the identification of the others. A pathway can only be identified if it is capable of exposing an identified receptor to an identified contaminant. That particular contaminant should likewise be capable of harming or, in the case of controlled waters, be capable of polluting that particular receptor.

The second step in applying the definition of contaminated land is to ascertain that a pollutant linkage (that is, a combination of a contaminant, a pathway and a receptor) exists in respect of a piece of land, which:

- is resulting in significant harm being caused to the receptor
- presents a significant possibility of significant harm being caused to that receptor

- is resulting in the pollution of the controlled waters which constitute the receptor
- is likely to result in such pollution.

To determine that “significant harm is being caused” or that “there is a significant possibility of significant harm being caused”, the regulator will require a scientific and technical assessment of the risks. Risk assessment (DoE, 1995) involves four phases:



**Hazard identification and hazard assessment.** “Hazard” is the property of a substance or situation that has the potential to cause harm. It does not consider the likelihood that harm will occur. Hazard identification involves the initial identification of the potential contaminants, pathways and receptors. The hazard assessment phase of the process involves consideration of plausible pollutant linkages and the determination of the potential for health and environmental risks (DETR, 2000a).

**Risk estimation and risk evaluation.** “Risk” is the combination of the probability, or frequency, of occurrence of a defined hazard and the magnitude of the consequences of the occurrence. Risk estimation and risk evaluation together form the process of risk assessment. Risk estimation is concerned with evaluating the likelihood that contamination on the site will lead to an adverse effect on the receptor. Risk evaluation considers whether the estimated risks are acceptable. It may also include the element of risk perception.

**Risk management** is the process whereby decisions are made to accept a known or assessed risk or to implement actions to reduce the risk. The latter is the process of site remediation.

The main advantages (WDA, 1993) of dealing with contaminated sites using a risk-based approach are:

- adoption of a systematic and objective assessment method
- provision of a rational, consistent, transparent and defensible basis for discussion of a proposed course of action
- provision of an assessment of uncertainties.

#### 4.3.1.1

#### *Risk management process*

The DETR and the Environment Agency and Environment Agency Wales have sponsored research to develop a hierarchy of documents that provide a systematic approach for the management of contaminated land (DETR 2000a). The level of technical detail of this guidance increases as one moves down the hierarchy. The four main tiers are:

- 1 Process for managing contaminated land. This describes the overall approach and decision-making process for dealing with contaminated land.

- 2 Primary model procedures. These describe the procedural approach for the main technical activities involved in managing contaminated land, ie risk assessment, evaluation and selection of remedial measures, and implementation of risk management actions.
- 3 Secondary model procedures. These describe the approach required to support one or more of the three primary model procedures.
- 4 Technical publications. These provide detailed technical advice, guidance and instruction on specific technical matters.

Already a methodology to provide a framework for determining the degree of soil and groundwater remediation that is necessary to protect water resources has been published (Environment Agency, 1999), but that for human health (Ferguson, 1996) is still awaited. In the absence of the latter, various risk assessment tools are being used (Petts, 1999). For example, SEPA has recently commissioned a deterministic approach for calculating human health impacts, entitled *Framework for deriving numeric targets to minimise the adverse human health effects of long-term exposure to contaminants in soil* (SNIFFER, 1999). In addition to government and regulator publications, CIRIA has developed non-statutory guidance (CIRIA, 1995), as have other organisations requiring best practice (WDA, 1993; Scottish Enterprise, 1994).



Figure 4.1

*Phased investigations for risk assessment and remediation selection*

Of the key documents cited, DETR, 2000b provides an overall framework for a risk assessment, including the management of the non-technical project-related risks. Specific guidance by CIRIA in SP103 (CIRIA, 1995) is given on characterisation and formal assessment of potential risks posed by contamination, see Figure 4.1. The

revised draft of DD175 (BSI, 1999) primarily focuses on the characterisation phases, and assumes a level of familiarity with the other two documents and with a risk-based approach. The current guidance will also assume some familiarity with this trilogy of documentation and will highlight specific aspects that are pertinent to the characterisation of nuclear-licensed and defence sites.

4.3.1.2

*Role of site characterisation*

Site characterisation is an integral component of the risk assessment process. It is the determination of the contamination status of a site and its environmental setting by the systematic collection of data through a variety of means, including: document searches, personnel interviews, remote sensing, ground investigation by intrusive means, physical inspection, sampling and testing (WDA, 1993). Its aim is to characterise the contaminant-pathway-receptor elements of the risk assessment framework, and to establish whether the linkage exists.

Specific investigation guidance is given in DD175 (BSI, 1999) as to how the site characterisation findings feed into the risk assessment process. Box 4.4 shows the role of site characterisation within the overall process of managing contaminated land, as recommended by existing guidance.

Box 4.4

*Role of site characterisation in the management of contaminated land*

<b>Generic</b>	<b>CLR 11 (DETR, 2000b)</b>	<b>CIRIA SP 103 (CIRIA, 1995)</b>	<b>DD175 (BSI, 1999)</b>
<b>Hazard Identification:</b> site identification and reconnaissance	Risk assessment Phase 1a: <i>desk study and site reconnaissance</i>	Preliminary investigation: <i>desk study and site reconnaissance</i>	Preliminary investigations: <i>desk study and site reconnaissance</i>
<b>Hazard Assessment:</b> Exploratory to detailed investigation	Risk assessment Phase 1b: <i>additional desk study and exploratory site investigation</i>	Exploratory investigation	Exploratory investigation ( <i>described as optional</i> )
<b>Risk Estimation:</b> Detailed site investigation and site assessment	Phase 2: detailed site investigation including supplementary site investigation	Detailed investigation and assessment	Main investigation including supplementary investigations
<b>Risk Evaluation</b> <b>Site assessment</b>	Phase 2: risk assessment (risk evaluation)	Qualitative, semi-quantitative and quantitative assessment	Not part of the document

This phasing is similar to that adopted in the USA (ASTM, 1993a; ASTM, 1993b). The International Standards Organisation (ISO) uses a four-phased approach, with an initial phase limited to desk study and the following three phases of increased level of sophistication (ISO: DIS 10381-1). In the UK, ecological surveys are referred to as Phase I reconnaissance survey and Phase II detailed survey (NCC, 1990; IEA, 1995).

It can be seen that the nomenclature between the various guidance documents is inconsistent, and a careful check should be taken to clarify exactly what is required if generic terms are used in contractual or reporting documentation.

### 4.3.1.3

#### Assessment

The simplest assessment procedure that will delineate the contamination problem should be used in the first instance. Progression to more complex assessments, with use of detailed site-specific characterisations, is required when contamination is found to have a significant impact on a receptor and the problem needs close definition. More complex assessment methods and detailed site data are obviously more expensive; therefore a phased approach to assessment, as with site characterisations, is recommended. Further guidance on the assessment and interpretation of data derived from site characterisation studies is to be produced within the SAFEGROUNDS Learning Network. However, a brief overview is given here.

There are essentially two assessment phases, a screening assessment and a quantitative risk assessment:

#### 1 Screening assessment

The screening assessment is a relatively simple process, and the objective is to eliminate from further consideration site areas or contaminants that are extremely unlikely to pose a significant risk to any of the receptors identified in the conceptual site model. The assessment is achieved by comparison of measured contaminant concentrations with sets of conservative, environmental- and health-related standards and guidelines. At this stage, no site-specific estimate of the risk is calculated. Some, but not all the standards and guidelines may incorporate nationally or internationally acceptable levels of risk to certain receptors assuming defined exposure scenarios (often worst-case).

Environmental quality standards/guidelines have been published by many organisations including the UK Government, the European Council, the World Health Organisation and professional institutions such as the American Society for Testing and Materials. CIRIA Report 103 (CIRIA, 1995) devotes a whole section to guidelines and standards.

None of the available standards/guidelines provides a fully comprehensive set of screening criteria, which includes all types of contaminants and all types of receptor. In these circumstances, screening criteria may be calculated using similar methodologies as for those criteria that have been defined, or using other appropriate methods (Environment Agency, 1999; ASTM, 1998). Comparison with natural background concentrations should also be considered.

If the contaminant concentrations in the environmental media are within the screening criteria then the assessment need not proceed any further. Any contaminant concentration that is greater than the screening criteria will require further investigation to establish whether it poses a significant risk. In this case, the assessment will proceed to the quantitative risk assessment stage to determine a site-specific estimate of risk.

#### 2 Quantitative assessment

These assessments move progressively towards site-specific analysis and take account of the potential attenuation and dispersion of contaminants as they migrate from the source towards the receptor. Analytical or numerical mathematical models are used to predict contaminant migration and the reduction in concentration that results from physical dispersion processes, such as hydrodynamic dispersion and dilution, and from chemical retardation and attenuation processes, such as contaminant adsorption, precipitation, volatilisation, photo-degradation and biodegradation.

Sometimes, natural dispersion, degradation and retardation processes (which together are termed “natural attenuation”) may be sufficient to protect the identified receptor(s). In these cases, monitored natural attenuation (MNA), which consists of monitoring groundwater to confirm that natural attenuation processes are acting at a sufficient rate to ensure that the wider environment will be unaffected, is an appropriate management option (Environment Agency, 2000). However, where these natural processes are insufficient to reduce contaminant concentrations to acceptable levels, remediation may be necessary. Modelling can be used to establish remediation targets, which act as the basis for the remediation plan, and to design the remediation scheme. It is very important that there is effective communication between those designing and undertaking the site characterisation and those evaluating the data.

#### 4.3.2

### Radioactively contaminated land management

#### 4.3.2.1

#### *Definition of radioactively contaminated land*

There is no specific definition of “radioactively contaminated land” in UK law. The definition currently used in practice is derived from the regime for the control of radioactive substances and radioactive wastes. It is that land is radioactively contaminated if it has substances in, on or under it that are radioactive in the legal sense and that would be radioactive wastes if the land is disturbed. The definitions of radioactive substances and radioactive wastes are given in the Radioactive Substances Act 1993, as amended (see Box 4.5).

The other relevant legislation is the Substances of Low Activity Exemption Order (the SoLA EO) made under RSA93. This allows solid wastes that are “substantially insoluble in water” and in which the activity is less than 0.4 Bq/g to be disposed of as if they were not radioactive. For practical purposes, the SoLA 0.4 Bq/g level serves the same purpose for artificial radionuclides that Schedule 1 of RSA93 does for radionuclides in the naturally occurring uranium and thorium series.

It is important to note that the Schedule 1 levels are for total concentrations of radioelements, ie natural background concentrations and any man-made additions, but the SoLA level is for concentrations additional to any natural background. This is relevant to radionuclides that occur both naturally and artificially, for example tritium and carbon-14.

Neither the Schedule 1 levels nor the SoLA level were originally derived from a risk criterion. The radiation doses and risks implied by the levels have, however, recently been investigated in connection with consultation on whether the levels should be changed as part of the implementation in the UK of the 1996 European Basic Safety Standards Directive. The investigation showed that, as far as contamination of surface soil, concrete, metals and general wastes is concerned, the Schedule 1 and SoLA levels are consistent with a dose criterion of 10  $\mu$ Sv per year, ie a risk criterion of 10<sup>-6</sup> per year (in order of magnitude terms).

There are difficulties in the application of the RSA and SoLA definitions and levels to contaminated land. For example, there are various ways of applying the Schedule 1 radioelement concentrations to radionuclide concentrations. Also, the SoLA definition applies only to insoluble activity (with the implication that all soluble activity consisting of artificial radionuclides is to be regarded as contamination, whether it is above or below 0.4 Bq/g). Some of these difficulties are being addressed in regulatory guidance being developed for the Radioactive Substances Act.

**Radioactive material** is “any substance falling within either or both of the following descriptions:

- a substance containing an element specified in the first column of Schedule 1, in such a proportion that the number of Becquerels of that element contained in the substance, divided by the number of grams that the substance weighs, is a number greater than that specified in relation to that element in the appropriate column of that Schedule
- a substance possessing radioactivity that is wholly or partly attributable to a process of nuclear fission or other process of subjecting a substance to bombardment by neutrons or to ionising radiations, not being a process occurring in the course of nature, or in consequence of the disposal of radioactive waste, or by way of contamination in the course of application of a process to some other substance.”

**Radioactive waste** is “a substance or article which, if it were not waste, would be radioactive material” or “a substance or article which has been contaminated in the course of the production, keeping or use of radioactive material, or by contact with or proximity to other waste”.

**Schedule 1: Radioelement concentrations**

Element		Becquerels per gram (Bq g <sup>-1</sup> )		
		Solid	Liquid	Gas or vapour
1	Actinium	0.37	$7.40 \times 10^{-2}$	$2.59 \times 10^{-6}$
2	Lead	0.74	$3.70 \times 10^{-3}$	$1.11 \times 10^{-4}$
3	Polonium	0.37	$2.59 \times 10^{-3}$	$2.22 \times 10^{-4}$
4	Protactinium	0.37	$3.33 \times 10^{-2}$	$1.11 \times 10^{-6}$
5	Radium	0.37	$3.70 \times 10^{-4}$	$3.70 \times 10^{-5}$
6	Radon	-	-	$3.70 \times 10^{-2}$
7	Thorium	2.59	$3.70 \times 10^{-2}$	$2.22 \times 10^{-5}$
8	Uranium	11.1	0.74	$7.40 \times 10^{-5}$

For the present document, the important point is that “radioactive contamination” is defined in the current UK regulatory framework in terms of a directly measurable quantity (Bq/g). This is quite different from the definition of non-radioactive contamination, which relies on risk assessment using the contaminant-pathway-receptor approach.

4.3.2.2

*Implications for the management of radioactively contaminated land*

The discovery of radioactive contamination implies that the land has to be managed appropriately, but this will not necessarily involve remediation: it could mean simply leaving the contamination where it is (if it is at low levels and contained).

On contaminated nuclear-licensed sites, a risk assessment will often be required to help to determine whether, and if so how, radioactively contaminated land should be remediated. On defence sites that are being characterised as a precursor to sale, a simpler approach is frequently adopted in which it is assumed that all contamination (ie all materials with activities above Schedule 1 and SoLA levels) is to be removed.

4.3.2.3

*Role of site characterisation*

Comparison of Sections 4.3.1 and Sections 4.3.2 shows that site characterisation has a somewhat different role for radioactive contamination to that described for chemical contamination. In the case of radioactive contamination, site characterisation is not an

integral part of risk assessment. The first objective of site characterisation is simply to find out whether the land is contaminated and this only involves measurement. At a later stage site characterisation may feed into risk assessment but this will not always be the case.

#### 4.3.2.4

#### *Investigation framework*

No explicit investigation framework has been devised in the UK for radioactively contaminated land. The following three-stage approach is recommended and expanded upon in Chapter 5.

- 1 **A preliminary investigation** comprising a desk study and site walk over to establish historical activities, current status, and the environmental setting. From this information, an initial conceptual model of the site can be formed and hazards identified.
- 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, such as surface radiation surveys, are very useful at this stage. In existing guidance documents, this phase is seen as an opportunity to gather a limited amount of additional information in order to plan the detailed phase of investigation.
- 3 **A detailed investigation**, mainly using intrusive ground investigation to provide information on the horizontal and vertical distribution of radioactive contamination, together with geological, geotechnical and hydrogeological information. Surface surveys may also be required to provide, for example, ecological and hydrological data. **Supplementary investigations** may be necessary to focus on areas of uncertainty not resolved by the main phase.

## 4.4

## References

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- Standards**
- BSENISO9000:1994 *Quality systems*
- BS DD 175:1999 *Investigation of potentially contaminated sites – Code of Practice*  
(Revision in draft September 1999)
- DIS 10381-1, Part 1: *Guidance on the Design of Sampling Programmes*  
Draft International Standard International Organization for Standardization.
- Acts**
- DETR (2000a)  
*Contaminated Land, Environmental Protection Act 1990: Part IIA*  
DETR Circular 02/2000, Department of the Environment, Transport and the Regions

## 5

# Planning the site investigation

### Box 5.1

#### *Aims of Chapter 5*

This section describes the framework of activities that comprise a site investigation. 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 (or models) to design an appropriate site characterisation programme. It is also important to refine the conceptual model(s) regularly during the investigation programme.

Key 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, the establishment of background levels of radioactivity and the need for waste minimisation.

### 5.1

## Identification of key roles

Contaminated Land Report CLR12 (DETR, 1997) describes the client-consultant relationship, and identifies the key 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. For some site characterisation projects, the Construction (Design and Management) (CDM) Regulations 1994 are applicable.

### 5.2

## Communication with stakeholders

It is important to make and implement at an early stage a communications plan with stakeholders for nuclear-licensed sites and defence sites. The stakeholders may include, but are not limited to, those in Box 5.2.

Early interaction with regulators is essential, to clarify matters such as statutory ambiguities and methods of approach to characterisation. For radioactive contamination on nuclear-licensed sites, this liaison with the HSE will occur naturally in the process of fulfilment of the site licence conditions. On defence sites, a proactive approach with the relevant environment agency is required. 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.

Conveyance of reliable information is essential. At nuclear-licensed sites, the local liaison committee should be the first point of contact. Subsequently, other stakeholders may be encouraged to participate through meetings by invitation, by public open meetings, by information displays in public buildings and by production of leaflets for the local population. The scale of consultation and information exchange is not predictable, and may need to be changed as a project progresses, particularly when work can be seen to be under way. The economic benefit of early stakeholder involvement cannot be underestimated.

Because work on nuclear and defence sites typically has a high public profile, it is desirable that the site characterisation process is well-documented. All meetings, records and information should be available to appropriate persons at the appropriate time and in an appropriate format. Information provided should be authentic, appropriately documented and the decision-making procedure should be technically

defensible. Adherence to best practice and a quality management system at all times should be the aim.

Box 5.2

*Examples of potential stakeholders in the management of contaminated land on nuclear-licensed and defence sites*

Category	Example
Site owner	Ministry of Defence, British Energy
Site occupier	UKAEA, BNFL
Employees	TUC
Regulators	Environment Agency, Health and Safety Executive, local authorities, SEPA
Consultants/contractors	
Neighbours	Residential and commercial/industrial
Insurers/financiers	
Developers	
National environment groups	Friends of the Earth, Greenpeace
Local residential groups	Residents associations
Others	English Heritage, the National Trust, CPRE, Countryside Commission, Countryside Commission for Wales, Scottish Natural Heritage
National utilities	BG Transco plc, BT

### 5.3

### Framework of activities in a site characterisation

A framework for site characterisation, based on the approach in Section 4.3, is given in Figure 5.1. This framework is developed from that provided in the draft edition of DD 175 (BSI, 1999) with greater emphasis placed on the review of safety, health and environmental (SHE) aspects of the characterisation.

The main elements of the framework are:

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

This section of the report expands on the first four steps of the framework and the review activities, which are essential and are undertaken at the end of each major stage of the process. The functions of the field investigations are summarised in Box 5.3 and discussed in detail in Chapter 6.

Box 5.3

Three phases of field investigations

**The exploratory investigation.** This is an optional phase, often suited to non-intrusive investigation methods, or a very limited intrusive investigation. It is used to test areas of greatest uncertainty with respect to the conceptual model of contamination and site characteristics, and the additional information provided aids the design of the detailed investigation(s) and enables SHE requirements to be specified. Sufficient information may be provided to update the risk assessment, for example, by eliminating a particular pollutant linkage because a pathway no longer exists.

**Main investigation.** This phase is designed to assess the nature and extent of contamination, the geology, hydrogeology and hydrology of the site. Other surveys such as ecological studies may be included. The main investigation should provide all necessary data to achieve the project objectives.

**Supplementary investigations.** This is an optional phase to address or clarify particular technical matters with respect to the risk assessment or design of remedial methods.

5.3.1

Determination of characterisation-specific objectives

Objectives for site characterisation may be set at two levels:

- the overall project objective(s) set by the client or commissioning organisation
- the specific objectives of the site characterisation.

The overall project objective(s) is invariably a concise statement of the problem arising from the need for the information. The site characterisation objectives are focused on how to provide the data for an assessment to satisfy the overall project objective(s). Detailed guidance on objective setting for contaminated land investigations is given in BSI (1999) and CIRIA (1995). It is recommended that the following should be included when setting specific objectives for site characterisation:

- overall project aims
- SHE management
- development and testing of the conceptual model
- spatial and temporal boundaries of the characterisation
- specification of data form and accuracy
- quality management.

Overall project aims have been discussed in Section 4.1, and SHE management in Chapter 3. Development and testing of the conceptual model is to be discussed in Section 5.3.3. The three remaining “objective setting” considerations cover the “where”, the “when”, the precision and the accuracy of data collection. Design of the sampling strategy is addressed in Section 5.4.2. Setting limits of detection having regard to the requirements of screening standards, regulators and end-points is discussed in Section 6.4. Quality management issues are summarised in Section 8.3.2.

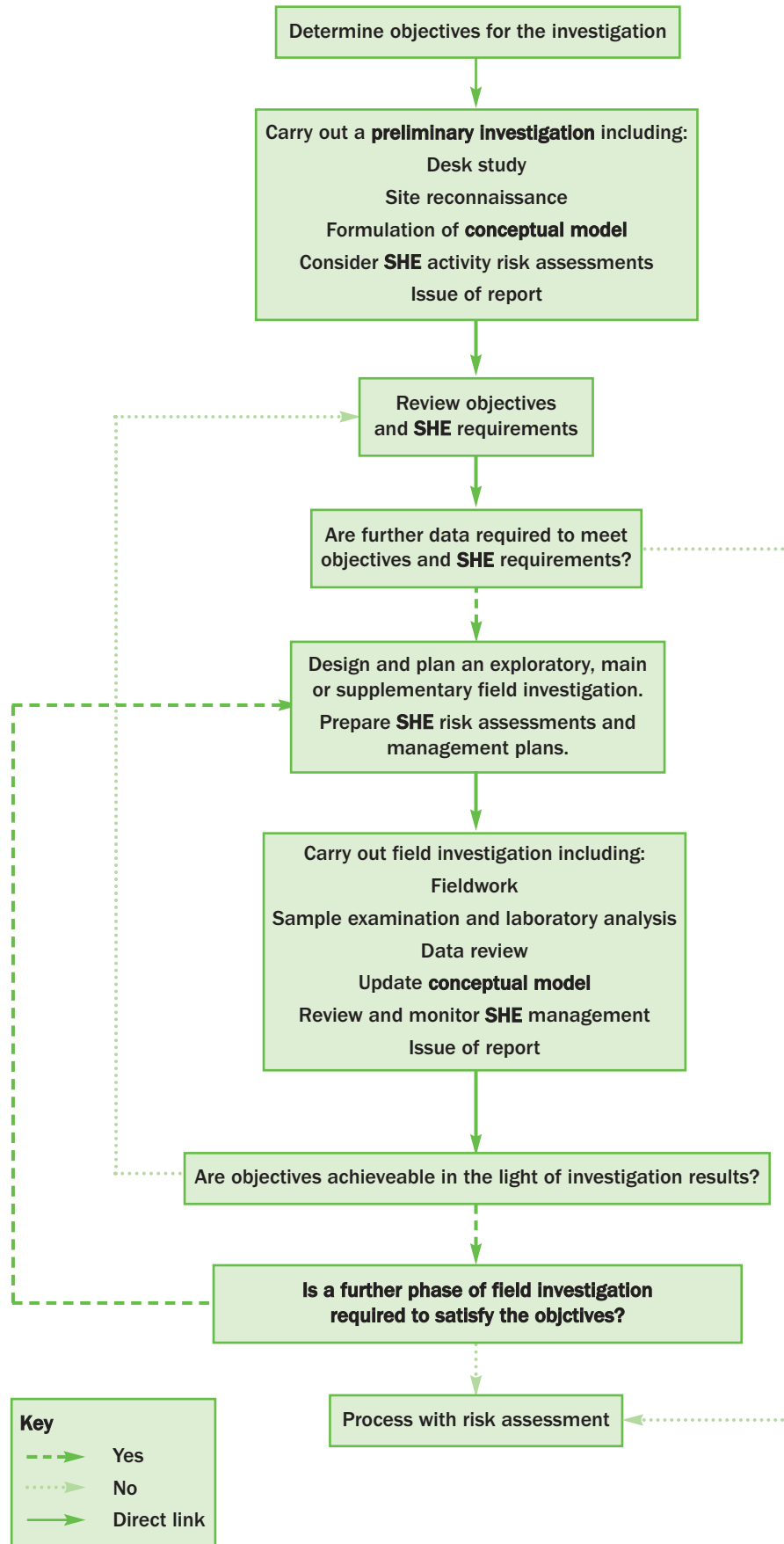


Figure 5.1

Framework for site investigation planning (after BSI, 1999)

### 5.3.2

## Preliminary investigation

The aim of the preliminary investigation is to compile and evaluate the available information on the potentially contaminated site. These data are then used to construct an initial site conceptual model (or models), which is used as a basis for a hazard assessment to design the site investigation phases of work and to develop SHE management plans. Guidance on preliminary investigations of contaminated land is given in (BSI, 1999; CIRIA, 1995; DoE, 1994a, b & c; DETR, 2000; Scottish Enterprise 1994, WDA 1993). In general, the preliminary investigation will consist of three parts:

- 1 Desk study.
- 2 Site reconnaissance.
- 3 Derivation of the conceptual model.

#### 5.3.2.1

### *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 existing literature. For defence sites and nuclear-licensed sites that were at one time defence sites (eg wartime airfields), certain additional information may be held by MoD Defence Estates, DERA Radiation Protection Services, the Imperial War Museum, the Ministry of Defence and various service archives. Site-specific information of relevance to the desk study may be located at the site itself, although widely dispersed (see Box 5.4).

Interviews with current and past employees are often very revealing about actual 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 industry profiles produced by the DETR is strongly recommended as a guide to understanding activities, processes and contaminants on the sites (DoE, 1995). They are not definitive studies but they introduce some of the technical considerations that need to be borne in mind at the start of an investigation for possible contamination. None is specific to nuclear-licensed sites and defence sites, but several are helpful when considering the many possible processes on defence sites: 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 processes have not occurred in the past.

#### 5.3.2.2

### *The site reconnaissance*

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

- collect additional information and visually inspect the site and contaminant sources, the environmental setting and potential receptors
- investigate constraints to investigation, such as the extent of hard cover, overhead cabling, difficulty of access, service runs, and present-day site usage
- establish site operating procedures, which are often complex at nuclear-licensed sites and defence sites.

A number of site-specific data sources on nuclear-licensed sites and defence sites may provide useful historical data. It should be noted that it may be difficult to obtain this information for defence sites, even if it exists. The sources are:

- photographic archives, which include aerial photographs for some nuclear-licensed sites and defence sites and may include photographs taken during construction of facilities
- general site archives
- occupational health archives (individuals' records will not be accessible)
- facilities records, including information on processes and radionuclide inventories
- reports on previous site investigations (geological, hydrogeological, 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 for recent data). The most recent data may already be entered into a geographical information system
- site drawing office records, which will include details of the development of the site, demolition of buildings and the locations and types of underground services
- unusual occurrence/accident reports. These are mandatory on licensed nuclear 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
- current and former employees.

An extensive list of site reconnaissance activities is provided in CIRIA, 1995 and DoE, 1994b. A photographic record is recommended in both these documents, but at some sites this may not be possible due to security restrictions.

A guided tour by a person familiar with the site is desirable. Any unaccompanied personnel 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.

### 5.3.3

#### The site conceptual model

There is growing awareness of the necessity to develop a conceptual model (or models) of a site at an early stage (BSI, 1999; EA, 1999a; ASTM, 1995). It is the essential first step in the assessment process. It is also required to develop site-specific SHE management.

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 outset of a site characterisation programme, it is probable that only limited information is available to develop the initial site conceptual model. As a consequence, 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 textural or schematic description of the site describing or showing the potential contaminant-pathway-receptor linkages (see Figure 5.2). The level of detail and type of information required in a conceptual model is dependent on its intended use. For example, a conceptual model to enable a screening assessment may require only limited site-specific pathway characteristics such as soil organic matter and clay content. A conceptual model to enable quantitative assessment will additionally 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 5.5, and additional checklists are provided in BSI (1999).

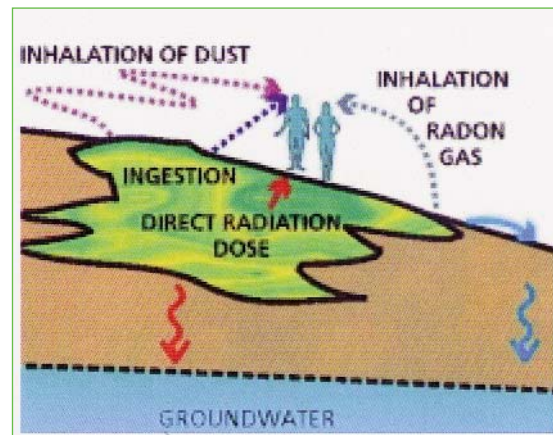


Figure 5.2  
Simple conceptual model (diagram) of contaminant migration pathways in the immediate vicinity of an area of radioactively contaminated land

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.

### 5.3.3.1

#### *How does the conceptual model feed into site characterisation design?*

Having developed the initial site conceptual model, it is important that it is used to design the site characterisation programme. Furthermore, this link should be documented so that other parties can understand why the design was selected. 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. Examples of the links between the conceptual model and the site characterisation design are given in Box 5.6. Potential contamination linkage pathways for a site are identified, and site characterisation activities to investigate these potential mechanisms are listed.

Characterisation data will be used to test and refine the initial site conceptual model or models. Some models may be rejected because they are inconsistent with the new data. Uncertainty in the remaining model(s) will be reduced, and these models will feed back into a review of the forward programme. For example, the locations, numbers and types of intrusive sampling points should be reviewed after evaluation of data from the non-intrusive surveys.

**Source characteristics**

- timing and duration of contamination
- mechanism of contamination: eg fallout from stack discharge, leaking drain, spillages 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 to receptor)
- pathway characteristics and processes (physical, chemical and biological) that will affect rate of migration and contaminant concentrations
- temporal changes in the pathway
- potential for transfer between environmental compartments, eg aqueous to sediment phases or surface soils to airborne dust
- wind direction, velocity and dust loading
- presence of burrowing animals
- surface water flow patterns and distribution of sub-surface drainage systems
- expected groundwater flow patterns and travel times to receptors (including rising groundwater)
- influence of artificial structures facilitating contaminant 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-site public, 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.

5.3.4

**Design and planning of site characterisations**

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 under-estimated, particularly in respect of how the project timescale is affected. For example, on non-licensed sites a 28-day notification period is required by IRR99 for work to start for the first time with ionising radiation, and this could delay the programme of works. Further, on non-licensed sites, an authorisation issued under the RSA may be required for accumulation and disposal of radioactive wastes that will be generated during site investigation (and subsequent remediation). Such authorisations can take several months to obtain and are frequently the rate-determining step in a project.

Box 5.6

Examples of the linkage between conceptual model and site investigation design

Linkage focusing on pathway	Survey design to address potential contamination mechanism
Diffuse airborne contamination	<ul style="list-style-type: none"> <li>walkover radiation surveys</li> <li>surface sampling for radioactive and non-radioactive contaminants on an appropriate sampling pattern</li> <li>or other contaminants, addressed by intrusive investigations on an appropriate sampling pattern.</li> </ul>
Spillage from vehicles during transport operations	<ul style="list-style-type: none"> <li>walkover radiation surveys</li> <li>soil vapour survey</li> <li>surface and shallow sampling adjacent to roads.</li> </ul>
Disposals/spillages/losses associated with former buildings	<ul style="list-style-type: none"> <li>walkover radiation surveys</li> <li>soil vapour survey</li> <li>surface and shallow sampling adjacent to roads</li> <li>trial pits/boreholes located at the positions of known buildings.</li> </ul>
Leakage from drains	<ul style="list-style-type: none"> <li>a drain survey, including sampling of drain sediments</li> <li>trial pits/boreholes located along the line of the drain</li> </ul>
Burial of waste materials	<ul style="list-style-type: none"> <li>walkover geophysics survey prior to intrusive sampling, in order to detect disturbed ground, buried objects and services</li> <li>soil vapour survey</li> <li>walkover radiation surveys</li> <li>intrusive investigations at positions identified by geophysical survey.</li> </ul>

Guidance on planning the characterisations is again given in the key references, but on nuclear-licensed and defence sites there will be additional requirement 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 sub-contractors)
- development of contingency plans in the event that ordnance is discovered (see Section 6.3.1 for safe digging practices on sites where buried munitions may be present)
- locating sub-surface services
- identifying constraints imposed by operational activities.

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 services that:

- could cause harm to the personnel 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 consequence of the above, extensive documentation is typically required prior to characterisation of nuclear-licensed sites and defence sites (see Section 5.3.5).

### 5.3.5

#### Preparation of documentation

The approvals required for documents will be dependent 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 (commonly designated the ATO (Authority to Operate) holder on a nuclear-licensed site) is also required. The following types of documentation are required before starting site works:

- method statements, which 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 accord with project contractual requirements and technical objectives, and should take account of health and safety issues and the need to minimise environmental impacts
- safety, health and environment plan, which describes:
  - arrangements to ensure the health and safety of all workers (including hazard assessment, hazard evaluation and proposed control measures if required)
  - environmental issues
  - management and standards
  - selection of sub-contractors
  - emergency procedures
  - accident reporting
  - arrangements for monitoring of compliance
  - welfare requirements
  - communications, co-operation and training arrangements
- quality programme, which describes the quality assurance system that will be applied to ensure that the site characterisation meets the required quality assurance standards
- quality plan, which demonstrates that work has been undertaken in accordance with the project specification
- environmental impacts register, which identifies the potential environmental impacts that activities will have. The register should cross-refer 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
- project risk assessment, which identifies potential technical and non-technical risks to the project. This enables contingency plans to be developed.

### 5.3.6

#### Review activities

Sufficient time should always be allowed between investigation phases for:

- a review of the project objectives
- a review of SHE management
- updating the conceptual model of the site in the light of 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.

The specification for the next stage of the characterisation may be updated in the light of this review, which should be documented. In many site characterisations, it is appropriate to phase the surveys. More detailed characterisations are deferred until the results of earlier phases of work have been evaluated. This approach ensures that the more detailed investigations are focused on relevant areas.

## 5.4

### Key issues for survey design

#### 5.4.1

#### Contingency planning

Contingency planning should be undertaken during the design of any contaminated land investigation. The project risk assessment enables the key actual and potential risks to be identified, and contingency plans developed. In the context of site characterisations on nuclear-licensed sites and defence sites, additional 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 Section 3.6). Therefore, 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.

Key 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 RSA 93) are unexpectedly produced, are sample analysis and waste disposal routes available? For example, can such waste be replaced in the borehole or will the regulatory authority (the relevant environment agency) deem that it has been “accumulated”? In the latter case on a non-licensed site, is an authorisation necessary to accumulate such material under RSA93? (See also Chapter 7.)
- in the event that the work area requires designation under IRR99, do sub-contractors have the relevant authorisations and qualifications to enable them to continue work?
- what precautions are necessary to minimise spread of contamination?

Key contingency planning issues in the event of discovering buried munitions are:

- can staff safely withdraw from the workplace, leaving it in a safe condition?

- is a specialist munitions adviser available on an appropriate timescale 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 6.3.1).

#### 5.4.2

#### Soil sampling patterns and frequencies

As described in Section 5.3.3.1, the design of the site investigation must be clearly linked to the preliminary conceptual model of the site, and procedures must in place to allow regular and systematic review of the strategy (see Section 9.2). A key aspect of the site investigation plan is 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 (CIRIA, 1995; DoE, 1994d; USEPA, 1997; BSI, 1999). A summary of the key issues discussed in these guidance documents is given below.

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 area or 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:

- what are the principal pathways for contamination (see Box 5.5)?
- for the principal mechanisms of contamination at the site, what are the typical sizes and spacings of the source areas?
- how mobile are the contaminants? For example, is it possible that a contaminant in the soil will also contaminate groundwater?
- how deep are the contaminants likely to penetrate into the sub-surface environment?
- what are the objectives of the site investigation, and what is the required level of confidence in the results?
- if remediation was required, what “averaging volume” would be used for waste characterisation? This issue is of greatest importance on sites where contamination is heterogeneously distributed (ie “hot spots” are present).

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 in order to define the “envelope” of contamination and to provide information on the area 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 available guidance. DD175 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 localized 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 where the density of sampling is likely to be related to the size of the garden area).*

In contrast, DoE, 1994d presents a statistical approach in which the number of sampling points required to detect a certain size of “hot spot” 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:

- a hot spot of specific size (if one exists) will not be missed
- if contamination is not found, a hot spot of at least the specified size does not exist.

The size of the hot spot can be considered in a number of 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 smaller contaminant sources. The statistical approach designed by DoE, 1994d is the more rigorous approach. However, the information needed to parameterise the model can only be obtained from a considered conceptual model of the site. The statistical approach proposed in DoE, 1994d also addresses sampling pattern (eg square grid, random, herringbone), and states 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 1-3 above but, because sampling points are aligned, has a reduced ability to detect elongate 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 6. 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.

### 5.4.3

#### Soil gas surveying

Where spills or leaks of volatile organic compounds have occurred, soil gas surveying is recommended. The Institute of Petroleum, 1998 gives guidance on soil gas surveying. Areas of waste disposal may be identified by soil gas surveying if volatile compounds were known to be deposited, or landfill gas. Extensive guidance on landfill gas monitoring is available (DoE, 1991; CIRIA 1993).

Radium decays to radon, a short-lived radioactive gas. Detection of radon in soil gas may therefore provide information on the presence of buried radium-contaminated materials. Soil 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.

### 5.4.4

#### Depth-dependent sampling of soils

The sampling approaches described above from DD175 and P103 consider only a 2-D (area) distribution of contaminants. It is essential to understand the 3-D 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 depth of boreholes and trial pits and the approach to collecting samples from them.

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 4.1), 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 sub-surface 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 water balance 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, colloids/particulates)
  - the chemical properties of the contaminants (eg its solubility and sorption characteristics in the sub-surface 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
  - 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 additional testing requirements (eg geotechnical characterisation of the site).

## 5.4.5

### Surface water and groundwater characterisation

Sections 5.4.2-5.4.4 have addressed issues concerned with characterising soil contamination. It is also possible that contamination of surface waters and groundwaters may have arisen as a result of operations and activities on the site. Consideration should therefore be given to sampling surface waters and groundwaters and to building understanding of the hydrological and hydrogeological environments. Guidance on the design of such programmes is given by the Environment Agency, 2000 and by DoE, 1994a. Guidance on all forms of water sampling is given in ISO 5667 series. Recently in this series, draft guidance on sampling groundwater on contaminated sites has been produced (ISO, 2000). Sampling of groundwater and non-aqueous-phase liquids is discussed further in section 6.3.6.

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.

Key considerations for the design of a groundwater characterisation programme are given in Box 5.8.

#### Box 5.8

#### *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 and at 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.

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

- the key horizons for contaminant transport should be identified and targeted
- monitoring boreholes should be designed to minimise or prevent vertical flows (“cross-flow”) through the screen or 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 monitoring may be required to:

- evaluate environmental liabilities and their development with time
- ensure compliance with regulatory limits (eg requisite monitoring: see Section 4.1)
- 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 outset of the investigation, the survey design should take account of this.

If long-term monitoring is to be undertaken, it is best 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. These procedures will ensure both that inappropriate data are not collected and that the monitoring programme does not continue beyond the period when it was required.

Best practice procedures for the collection of representative groundwater samples are available (for example, Environment Agency, 2000), and are discussed further in Section 6.3.6. Water abstracted from the boreholes during development and sampling must be managed in accordance with the operating procedures of the site and with UK legislation. It may be necessary to treat water prior to disposal onto the ground surface (for example, using activated carbon to remove organic contaminants) or to transport the waste water 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.

#### 5.4.6

#### Geographical location of survey points

The sites covered by this best practice 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 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, 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.

Data management issues are discussed in Chapter 8. On nuclear licensed sites, there is

a requirement to retain all records relevant to compliance with the site licence for a period of 30 years. As a result, there may be a preference to store data in electronic format using geographical information systems (GIS). Guidance on the use of GIS is given in Environment Agency, 2000.

## 5.4.7

### Establishing background environmental quality

#### 5.4.7.1

#### *Background radioactivity*

For the reasons discussed in Sections 2.3 and 4.3.2, 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 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 all samples analysed; 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 2.3, background levels of radioactivity will vary (i) from site to site and (ii) spatially within a site. Concentrations of naturally occurring radionuclides will be strongly influenced by the composition of the rocks and soils, and by the extent of near-surface weathering effects. Anthropogenic radionuclides derived from global fallout are (with the exception of tritium) unlikely to penetrate significantly below surface soils; it would therefore be inappropriate to use the background levels of such radionuclides in surface soils to derive a background for deeper soils and rocks. In order to determine background levels of radioactivity at a site, it is therefore 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.

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 sufficiently far away that site-derived radioactivity will not have significantly enhanced 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; for example, to distinguish between made ground and natural soils.

#### 5.4.7.2

#### *Background chemical quality*

Similarly, for chemical contamination it is important to establish background quality for soils and groundwaters (Environment Agency, 1999a) and for soil gas (DoE, 1991) because, in some locations the natural background may contain elevated concentrations of a compound or element (see Section 4.3.1). “Background” may also be elevated due

to contamination from a neighbouring site and it is necessary to establish the concentrations to apportion liability. From both the assessment and risk management perspectives, deriving background concentrations are integral to the decision-making process.

#### 5.4.8

#### Waste minimisation

Licence Condition 32 of a nuclear site licence requires that production of radioactive wastes be minimised. Consequently, subject to achieving the objectives of the site characterisation project, there may be a requirement to use intrusive techniques that minimise waste production. This condition does not apply to non-licensed defence sites. On both categories of site, it will be necessary to segregate wastes into various waste streams defined by radioactivity. This is discussed further in section 7. 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.

#### 5.5

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### Standards

BS DD 175:1999 *Investigation of potentially contaminated sites – Code of Practice*  
(Revision in draft September 1999)

## 6

## Characterisation methods

## Box 6.1

## Aims of Chapter 6

This section describes the principal techniques for characterising contaminated land on nuclear-licensed sites and defence sites. Many of the techniques, such as the use of geophysics and the construction of intrusive sampling points, are already described in existing contaminated land guidance. It is not the intention of this section to reproduce this existing guidance in detail. Only a summary is presented; the reader is signposted to existing guidance for 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 and defence sites.

## 6.1

## 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 at some later time through laboratory measurement. As a consequence, non-intrusive radiation surveys (or “radiological surveys”) are a key component of 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 below is not a method statement for carrying out a radiological survey, but a set of pointers to highlight important issues and good practice and to identify some common problems and mistakes.

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

- MARSSIM: *The USEPA Multi-Agency Radiation Survey and Site Investigation Manual* (USEPA, 1997)
- Environment Agency R&D Technical Report - *Technical support material for the regulation of radioactively contaminated land* (Environment Agency, 1999a).

Radiological surveys in the field can be broadly divided into two types: the scanning survey and direct (or point) measurements (USEPA, 1997).

**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 identify rapidly the areal distribution of contamination at a site in order 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.

**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 (in, for example,  $\mu\text{Svhr}^{-1}$ ) 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.

### 6.1.1

#### 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 personnel
- to determine the areal distribution of radionuclides on the site
- to determine the degree of heterogeneity in the distribution of any contamination
- to determine the fingerprint of the radionuclides on the site.

Having identified the objectives, the information in Box 6.2 should be used to design the survey.

Box 6.2

#### *Design issues for radiation surveys*

Which radionuclides are likely to be present on the site?	<ul style="list-style-type: none"> <li>● based on the desk study (previous site usage, records of radionuclide use, environmental monitoring etc)</li> <li>● important because it is the primary driver in the selection of radiological monitoring equipment.</li> </ul>
What are the natural background levels of radioactivity at the site?	<ul style="list-style-type: none"> <li>● from previous monitoring data from the area. If inadequate background information exists, it will be necessary to make measurements to assess this.</li> </ul>
What are the detection limits required for the radionuclides of interest?	<ul style="list-style-type: none"> <li>● based on the derived concentration guideline levels for the radionuclides of interest, SoLA EO or background</li> <li>● if the radionuclide fingerprint is known, it may be possible to infer the presence of a radionuclide by measuring the most-easily detectable radionuclide in the fingerprint.</li> </ul>
What is the size of the area to be surveyed?	<ul style="list-style-type: none"> <li>● the entire area of ground that has the potential to be contaminated (or a sub-set of it)?</li> <li>● important because this will drive selection of the transportation used during surveying and may impact on the grid size selected.</li> </ul>
What are the time/cost limitations on the job?	<ul style="list-style-type: none"> <li>● financial and time constraints will often have a significant impact on the type of survey selected.</li> </ul>

The detailed survey design and equipment selection will depend on the site conditions and the radionuclides expected to be present. In general, three aspects will be considered; the type of radiation detector, its method of use and the scale of the survey grid, see Box 6.3.

Box 6.3

**Key aspects of radiological surveys**

Determination of the type of radiological monitoring instrument to be used (see section 6.1.2)	<ul style="list-style-type: none"> <li>based upon the expected radionuclides present, the required detection limits and cost/time constraints.</li> </ul>
Design of the survey grid (see Section 6.1.4).	<ul style="list-style-type: none"> <li>based on the size of the area to be surveyed and the size of the anomalies expected to be present</li> <li>includes focused surveying of known or suspected problem areas</li> </ul>
Determination of the most effective method of transporting the radiological monitoring equipment during the survey (see Section 6.1.5)	<ul style="list-style-type: none"> <li>based upon grid size, equipment to be used and the availability of equipment</li> <li>overflying restrictions may apply for some nuclear-licensed sites and defence sites - this should be clarified with the site owner</li> </ul>

A conventional design for a radiological survey is presented in Box 6.4. 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 subsequently displayed using GIS. An example of a radiological survey conducted using such a technique is presented in Figure 6.1.

Box 6.4

**A conventional design of radiological survey**

<p>A conventional design of a scanning radiological walkover survey may consist of:</p> <ul style="list-style-type: none"> <li>the gridding of a site at a 5 m spacing</li> <li>a surveyor slowly walking over the whole of each grid square swinging a gamma or beta/gamma monitor a few centimetres above ground</li> <li>recording the locations and magnitude of elevated radioactivity readings by hand in a notebook</li> <li>spray-marking the ground at locations of elevated radioactivity measurements</li> <li>further investigation of suspect areas by swabbing for alpha or beta activity.</li> </ul>
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6.1.2

**Instrumentation**

**Types of instrument**

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 the literature (USEPA, 1997; Environment Agency, 1999a). Figure 6.2 shows a range of radiological monitoring equipment. 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 Radiation Protection Supervisor) who are capable of carrying out the survey whilst adhering to the appropriate quality control and health and safety rules.



Figure 6.1

*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 (see Table 2.1). 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 6.5).

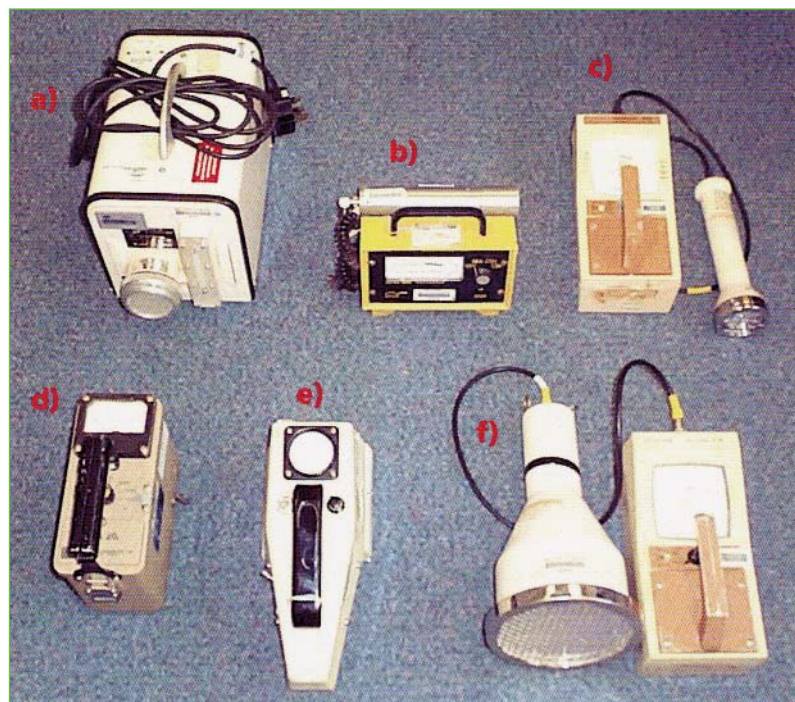
Box 6.5

***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 low-energy beta emitter such as H-3. In addition, it is generally not possible to detect alpha-emitters on rough or wet surfaces because of their extremely low penetration (see Table 2.1). 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 associated radionuclides may be present on a site. This may either be due to the processes carried out at the site or the fact that a decay chain may be present. In these cases, it is possible to look for more easily detectable radionuclides associated with the poorly detectable alpha and low-energy beta- and gamma-emitters.

If radionuclides that are not detectable in the field are believed to be present and are not thought to be associated with detectable radionuclides, sampling and laboratory analysis will be required.



Key

- |  |   |
|--|---|
| a) Dust monitor                                    | d) Ludlum low-level dose meter            |
| b) Mini instruments 5-40 end window Geiger counter | e) Pam 2 alpha scintillation monitor      |
| c) BP4 beta/gamma scintillation detector           | f) 1667 beta/gamma scintillation monitor. |

Figure 6.2

**Examples of radiological monitoring equipment**

There are two main types of radiation detector used for most field radiological surveys. These are:

- gas-filled detectors
- scintillation detectors.

Other radiation detection methods exist (solid state detectors and passive integrating detectors). However, these are not generally used in radiological surveys and hence are not discussed further here.

**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 (see AEA Technology (1998) for details). Common gas-filled detectors include the Geiger-Muller tube and ion chambers, the main characteristics of which are as follows.

Geiger-Muller tubes (example: Mini EP15 alpha and beta contamination meter):

- response is dependent on the energy of the radiation being detected (ie they may give a different reading for the same amount of radioactivity from different radionuclides)
- 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 (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 (see AEA Technology (1998) for details). Common scintillants are:

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

#### **Choice of instrumentation**

Many different instruments are available for radioactivity surveys. Most of these are based upon the detection techniques given above. However, each instrument will be designed to monitor for particular radioactivity types or energies. In addition, 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 listed below:

- 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 (1997) and Environment Agency (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.

#### **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 personnel are not exposed to unacceptable levels of radioactivity
- comply with the Ionising Radiations Regulations (1999).

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  $^{241}\text{Am}$  may indicate that  $^{241}\text{Pu}$ , the beta-emitting parent, is present)
- provide valuable additional 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 (see Section 7.2).

Gamma spectrometry measures the gamma flux at the position at 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.

The conversion from gamma flux to activity per unit volume is undertaken using modelling. There may be uncertainty in the calculated activity per unit volume, because of uncertainty in the input parameters listed above. If this is the case, some limited sampling and laboratory analysis should be undertaken to confirm the quantitative results from the *in situ* measurements.

Two main types of portable gamma spectrometer are available. These are sodium iodide- or caesium iodide-based spectrometers and semiconductor spectrometers. Sodium iodide detectors are generally handheld units that are fairly robust, but with limited spectrometric ability. Semi-conductor 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 is 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 must 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.

### 6.1.3

#### Background radioactivity

As explained in section 5.4.7, in the case of land contaminated with artificial radionuclides, the definition of “contaminated” is land where activity levels are greater than 0.4 Bq/g above background. 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.

#### 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 well 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. The data from the areas outside of the area of contamination can be analysed to determine the distribution of background radioactivity (ie range, mode, mean etc). Background would be recorded in terms of the units used during the screening survey (often counts per second).

#### 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 minimum of ten 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 ten 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. Consequently, more measurements would be required.

### 6.1.4

#### The survey grid

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
- desk study information on potential sources of contamination in the area.

The majority of radiological surveys are carried out using a grid of some type. 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 of the grid may vary over the site of interest, to allow for focused surveying in the areas of most interest. The statistical design of surveys is discussed in Section 5.4.2.

### 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 alternate 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 a number of 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.

In addition, to the above locational techniques, it is also common practice to mark areas of contamination detected on-site using spray paint.

#### 6.1.5

### Transportation used during surveying

There are three main methods by which radiological monitoring equipment may be transported: by hand, in a ground-based vehicle or by air. The relative advantages and disadvantages of each approach are given below:

**The walkover survey.** This consists of a single person carrying up to approximately 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 range of radiological measurements that may be made.

**The vehicle survey.** This consists of a ground-based vehicle, either motorised or hand-pushed, carrying up to approximately 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 a number of 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. The main disadvantage of the vehicle survey compared to the walkover survey is that the site must be flat and open.

**The airborne survey (aeroplane or helicopter).** This consists of an aeroplane or helicopter carrying up to approximately 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. In addition, overflying restrictions may apply on nuclear-licensed and defence sites, limiting the applicability of this technique.

#### 6.1.6

### Quality control

#### Instrument calibration

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

- a battery check

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

### 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.

Advantages of manual recording of data:

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

Disadvantages of manual recording of data:

- human error possible (for example, some radiation detectors have manual switches to change between scales; if the switch is incorrectly set, a reading an order of magnitude too high or too low could be recorded)
- data must be manually transferred from operator notebooks prior to interpretation and presentation
- 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.

Advantages of automated data recording:

- 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 locational and radiological measurements
- data recording in poor weather conditions is possible
- data can be directly transferred to a computer for processing and presentation.

Disadvantages of automated data recording:

- possible to set up data logger incorrectly and hence 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 in order to use the equipment.

## 6.1.7

### Limitations

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

- the type of radionuclides present – in general a non-intrusive survey can only detect high-energy beta and gamma emissions
- the depth of burial/shielding of the radioactivity – a relatively thin layer of soil may shield radioactivity from a detector

- “shine” from nearby buildings/facilities – non-intrusive radioactivity surveys will not be applicable if nearby buildings or facilities are giving rise to elevated 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.

### 6.1.8

#### Common mistakes

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.

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 5.4.7.

Historically, some surveys may have been undertaken using equipment that was not sensitive enough to detect very low levels of radioactivity (for example, close to the SoLA Exemption Order limits). This may have lead to the incorrect conclusion that the sites were not contaminated.

## 6.2

### Geophysics

### 6.2.1

#### The application of geophysical techniques

Geophysical techniques provide an indirect means of characterising a site prior to any intrusive works. For contaminated land sites, geophysical methods that identify variations in the near surface structure or chemistry of the ground are required.

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 sub-surface 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:

- identification of sub-surface services and munitions, which may be a hazard for intrusive investigations
- characterisation of the geological structure of the site and identification of potential waste disposal pits or sub-surface structures (such as buried tanks or foundations).

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

must be employed during the intrusive phases of the work (refer to section 6.3.1 for information on procedures for undertaking excavations and avoiding services).

## 6.2.2

### Commonly used geophysical techniques

The three 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
- ground penetrating radar (GPR).

These techniques provide characterisation of the near-surface environment, typically within 3 m of ground surface. Other techniques, such as seismic reflection/refraction and 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 discussed below 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).

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

**Electrical methods** are divided into two types: electromagnetic surveying and resistivity profiling.

**Electromagnetic surveying** uses electromagnetic induction to measure the sub-surface electrical properties. Electromagnetic surveys generally produce an areal 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 and metallic services. They are significantly affected by surface metallic structures and care is needed to avoid anomalous readings adjacent to features such as fences.

**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.

**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 hence the maximum detection depth for buried objects, depends on the electrical properties of the soil.

### 6.2.3 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 Box 6.7 below.

**Box 6.7** *Typical objectives of geophysical surveys and illustrative techniques to provide the required data*

Objective	Proposed technique
Locate services (note: no technique will guarantee to detect all services. Safe digging practices must be used if services may be present)	<ul style="list-style-type: none"> <li>electromagnetic profiling (both in-phase and out-of-phase components) on a 2 x 1 m grid across all accessible areas of the site to detect metallic services and cables</li> <li>targeted GPR on a 2 x 1 m grid to detect the most significant plastic and ceramic services (such as gas services)</li> <li>cable avoidance tool (CAT) and signal generator, to be used at all proposed excavation positions to confirm absence of services.</li> </ul>
Detection of buried pits	<ul style="list-style-type: none"> <li>electromagnetic profiling on a 2 x 1 m grid across all accessible areas of the site.</li> </ul>
Locate underground structures (eg building foundations)	<ul style="list-style-type: none"> <li>electromagnetic profiling using on a 2 x 1 m grid across all accessible areas of the site</li> <li>ground penetrating radar (GPR) targeted into the areas of interest.</li> </ul>
Locate non-ferrous and ferrous metal items that could relate to buried munitions	<ul style="list-style-type: none"> <li>electromagnetic profiling on a 2 x 1 m grid across all accessible areas of the site</li> <li>metal detector survey at sampling locations.</li> </ul>

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

### 6.2.4 Drains surveys

Drains and sediments within them may be radioactively and/or chemically contaminated. Further, leaks from drains are a potential source of contamination of the surrounding ground. The current and past uses of drains on a site should be determined in order to identify those drains that may have been used to carry chemically or radioactively contaminated liquids. In addition, 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 5.3.2.1) should be designed to obtain such information.

Drain surveys comprise of:

- 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.

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 listed below.

- sediment build-up in drain runs may prevent deployment of in-drain devices. There may be a requirement for washing down the drains prior to the survey. 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 RSA, 1993 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.

## 6.3

### Intrusive investigations

Intrusive investigations are carried out to characterise sub-surface materials in order to obtain information on contaminant distribution and on the geological and hydrogeological environment. In addition, sub-surface investigations may be used to collect samples for geotechnical testing. Geotechnical sampling and testing is beyond the scope of this guidance document. However, limited mention is made later in this section.

Intrusive investigations divide into three main aspects:

- health and safety
- techniques
- sample collection.

Many of the health and safety issues have been covered in previous sections. However, the issue of safe digging practices is an important one that is best covered here. Both intrusive investigation techniques and sample collection methods have been fully described in many other guidance documents (BS5930; British Standards Institution, 1999b; CIRIA, 1995; Scottish Enterprise, 1994). An overview of these issues, with

particular reference to features of nuclear-licensed sites and defence sites, is given in the next section.

### 6.3.1

#### Safe digging practices

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

- avoidance of underground services
- avoidance of buried munitions
- radiological monitoring to protect workers and minimise the spread of contamination.

The avoidance of underground services and munitions are discussed below. Radiological monitoring issues during intrusive investigations are discussed in Section 3.6. In addition to these aspects, hazards appropriate to working on a conventionally contaminated site must also be considered (for example, civil engineering risks and protection against chemical contamination).

#### Underground services

Safe digging practices should be used during the intrusive investigation, as described in the HSE document *Avoiding danger from underground services* (Health and Safety Executive, 1988). Underground services typically present the greatest hazard during the intrusive phase of a site investigation. Because of this, the general process for determining if it is safe to excavate is repeated below:

- 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 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 6.8.

The quality of service plans for land outside the main security fence of a nuclear-licensed site or defence site may be poorer than those for services within the site. If excavating in public access areas owned by a nuclear-licensed or defence site, it is recommended that the main utilities providers for the region be contacted to ensure that their service location plans are in agreement with the site plans.

### 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 put into place to ensure that drilling into such objects does not occur. It is recommended that site-specific advice be sought from a specialist munitions adviser.

Box 6.8

#### *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 services plans of the areas by the licensee.
- 3 Selection of proposed excavation positions by the contractor, taking into account the service plans. Agreement of 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 excavation permit by the licensee. The excavation permit would typically include a second set of services drawings and approvals from all interested parties (health physicists, appropriate buildings managers, ATO holders 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**

In addition to the procedure listed above, a cable avoidance tool should be on site and used regularly during the excavations by a suitably qualified and experienced person (SQEP).

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 present 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.

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 could be rapidly identified and works stopped. A procedure for investigating a site containing munitions is given below.

- 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 for munitions to be 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 6.2. However, advice from a specialist geophysical contractor should be sought in order that the most appropriate geophysical technique for the site is employed. The geophysical survey should produce a map showing the locations of 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 buried metallic objects, or to ensure that, if excavation must be undertaken in the vicinity of 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 object should be undertaken with care. Borehole drilling methods are not appropriate. An appropriate method would be to use an excavator to carefully remove approximately 20 cm thick layers of soil to expose the metallic object(s). A banksman 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, prior to them being 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. It should be noted that the civilian authorities will make the occurrence public, and media interest may result. The licensee should inform the NII if buried munitions are subsequently 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.

### 6.3.2

#### Radiological monitoring during intrusive investigations

Radiological monitoring is undertaken during intrusive investigations for three purposes:

- to protect the health and safety of workers
- to minimise the spread of contamination
- to provide environmental data.

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 is given below.

Selection of appropriate monitoring equipment:

- this should be determined by an appropriately trained person, such as the 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 prior to excavation at that location:

- this should be carried out in addition 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, a probe can be lowered into the excavation to detect if radioactivity is present. 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)
- in temporary shallow boreholes used for soil sampling, an appropriate narrow-diameter probe would be required for down-hole measurement. Although this would provide useful depth-dependent information with better sensitivity than could be achieved from monitoring spoil or samples, it is limited by issues such as borehole stability. Down-hole radiological monitoring is discussed further in section 6.3.4. As with monitoring of trial pits, the background level of radioactivity may alter with depth because different soil horizons are encountered.

Regular monitoring of the spoil generated during the excavation process:

- this will ensure that any buried radioactive contamination will be detected in the spoil produced by the excavation process
- the spoil should 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 6.3.4.

Monitoring on completion of each excavation:

- personnel 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, in addition to 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 personnel.

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) prior to being transported to the laboratory.

### 6.3.3

#### Types of intrusive investigation

Samples collected during the site characterisation will be of the following types: soils and rocks; surface waters and groundwaters; soil gases. Soil samples are collected either manually, by hand-digging or by using an auger, or mechanically, using an excavator (for trial pits) or drilling rig (for boreholes). Groundwater samples are generally collected from boreholes that are either temporarily or permanently cased, or on occasion from trial pits. Gas samples are generally collected from temporary shallow probes or from boreholes completed as soil gas monitoring points.

### 6.3.4

#### Methods of intrusive investigation

There are several methods of excavating into the sub-surface. Many of these methods have been described in great detail in other guidance (BS5930; British Standards Institution, 1999b; CIRIA, 1995; Scottish Enterprise, 1994). An outline of the methods that are applicable to nuclear-licensed sites and defence sites is given in Box 6.8. 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.

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

#### Field logging

It is important to log all relevant information when carrying out an intrusive investigation. Such information should consist of, as a minimum:

- location of excavation and location number
- depth of excavation
- 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
- field monitoring information (gamma monitoring, dose monitoring)
- backfilling details
- photographs taken.

An example field logging form is presented in Figure 6.3.

### 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:

- if trial pitting using an excavator, take large bucket scoops and collect soil samples from the centre of the bucket (ie the soil that has not had contact with the excavator bucket)
- if drilling, use a method that installs a temporary casing to isolate different soil layers
- 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.

Excavation type		Excavation number		Date/time		
Location				Monitoring details		
				Beta/Gamma (cps)	Dose ( $\mu\text{Svhr}^{-1}$ )	Other
Depth (mbgl)		Soil/rock description	Sample number/type	Probe type/no.	Probe type/no.	Probe type/no.
From	To					
Further information (backfilling details, photographs taken etc):				Logged by:		

Figure 6.3 Example field logging proforma

### Backfilling with and disposal of spoil

Spoil will be generated during intrusive investigations. Small quantities will be generated by drilling boreholes; 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). Therefore, the approach to backfilling excavations with spoil should be 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 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).

Contingency plans should be prepared for the case where subsequent laboratory analysis indicates that radioactive wastes have been backfilled into the excavation. This could be where alpha-emitting or low energy beta-emitting radionuclides are present. 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 Box 6.8).

In certain circumstances, it may be necessary to replace spoil into the trial pit from which it was obtained even though it is known to be significantly contaminated. If, for example, the external doses being received from the material were excessive, the material may be returned to the trial pit (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 (Environment Agency 1999c).

Surplus drilling spoil and samples not required for analysis are waste materials and should be disposed of appropriately (see section 7 for a discussion of waste management procedures).

### 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.

### Downhole radiological measurements

Downhole radiological measurements complement non-intrusive radiological surveys (see section 6.1) and radiological monitoring during intrusive investigations (see Section 6.3.2). 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 (for example, 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 6.3.2).
- 3 In conjunction with temporary percussive holes from which no waste or samples are produced at surface (for example, cone penetrometer testing).

Downhole radiological measurements can be used to improve targeting of samples taken for subsequent laboratory analysis or to provide interpolation between sparse data from borehole samples (for example, 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). In addition, the third situation, above, 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 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 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 best practice to undertake downhole radiological measurements prior to groundwater sampling. Where this is not possible, data from downhole radiological measurements should be interpreted with caution.

### 6.3.5

## Sampling of soil and rock

### Sample selection

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:

- sampling from predefined depth intervals
- sampling based on visual features (ie from different geological units or different layers of made ground)
- 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 approximately inversely proportional to the weight of sample analysed. In general, it is sufficient to collect approximately 500–1000 g of sample in an appropriate container for gamma spectrometry analysis.

Box 6.9

Techniques for intrusive sampling

Technique	Outline of method	Advantages	Disadvantages
Soil gas probing	<ul style="list-style-type: none"> <li>gas sample probe inserted into soil to a depth of &lt;0.5 m</li> </ul>	<ul style="list-style-type: none"> <li>simple method of obtaining the areal soil gas data.</li> <li>no spoil generated</li> <li>low potential for contamination to be spread.</li> </ul>	<ul style="list-style-type: none"> <li>only suitable for gas sampling</li> <li>can only be used at shallow depth.</li> </ul>
Hand-digging	Use of trowel to collect samples to <0.5 m depth.	<ul style="list-style-type: none"> <li>samples can be collected from any surface location</li> <li>base of hole can be monitored during excavation</li> <li>little equipment is required</li> <li>low potential for contamination to be spread</li> <li>low risk of damaging services</li> <li>cheap.</li> </ul>	<ul style="list-style-type: none"> <li>maximum depth of sampling -0.5 m</li> <li>disturbed samples are collected.</li> </ul>
Hand augering	Use of hand auger to drill holes in soft materials to a depth of approximately 1m.	<ul style="list-style-type: none"> <li>little equipment is required</li> <li>cheap</li> <li>samples can be collected in areas with poor access.</li> </ul>	<ul style="list-style-type: none"> <li>maximum depth of sampling 1 – 2 m</li> <li>samples are significantly disturbed and there is a high potential for cross contamination of layers</li> <li>only appropriate for fine grained soft sediments.</li> </ul>
Trial Pitting	Use of tracked or wheeled excavator to dig trial pit to <6 m depth.	<ul style="list-style-type: none"> <li>large volume of soil exposed - sampling and logging more representative</li> <li>observations of base of trial pit can be used to identify potential hazards</li> <li>base of excavation may be monitored for services and contamination as trial pit progresses.</li> </ul>	<ul style="list-style-type: none"> <li>large quantities of potentially contaminated waste materials brought to ground surface</li> <li>medium risk of damaging services (unless banksman identifies marker tape etc.)</li> <li>maximum depth 6 m – note that the trial hole will often collapse when groundwater is encountered.</li> </ul>
Borehole drilling	Cable percussive drilling in soils/weak rocks.	<ul style="list-style-type: none"> <li>suitable for a wide range of materials</li> <li>suitable for <i>in situ</i> geotechnical testing and geotechnical sampling</li> <li>good definition of depth of materials</li> <li>little or no use of drilling fluid</li> <li>suitable for the installation of permanent groundwater or gas monitoring installations</li> <li>possible to use low-head room rigs for sampling in difficult area.</li> </ul>	<ul style="list-style-type: none"> <li>drilling process produces relatively large quantities of spoil (although less than trial-pitting)</li> <li>driller's mate is closely involved with the drilling process and has a relatively high potential to become contaminated</li> <li>relatively slow</li> <li>maximum depth tens of metres depending on material.</li> </ul>

Box 6.9

*Techniques for intrusive sampling*

Technique	Outline of method	Advantages	Disadvantages
Borehole drilling (contd)	Solid stem rotary augering in soils/weak rocks	<ul style="list-style-type: none"> <li>relatively fast</li> <li>little or no drilling fluids required</li> <li>suitable for the installation of permanent groundwater or gas monitoring installations</li> <li>can undertake inclined drilling for sampling under buildings etc.</li> </ul>	<ul style="list-style-type: none"> <li>high potential for cross-contamination of samples</li> <li>depth resolution poor</li> <li>not appropriate for coarse gravelly materials.</li> </ul>
	Hollow stem rotary augering in soils/weak rocks	<ul style="list-style-type: none"> <li>relatively fast</li> <li>good quality samples</li> <li>good depth definition</li> <li>suitable for the installation of permanent groundwater or gas monitoring installations</li> <li>can undertake inclined drilling for sampling under buildings etc.</li> </ul>	<ul style="list-style-type: none"> <li>not appropriate for coarse gravelly materials.</li> </ul>
	Rotary drilling in rock (truck- or mini-rig mounted)	<ul style="list-style-type: none"> <li>rapid drilling possible</li> <li>can be used to drill through overburden using rotary-percussive drilling</li> <li>maximum depth hundreds of metres</li> <li>good quality core and samples</li> <li>suitable for the installation of permanent groundwater or gas monitoring installations.</li> </ul>	<ul style="list-style-type: none"> <li>expensive</li> <li>drilling fluids may contaminate sampled and surrounding rock</li> <li>difficult to control and dispose of drilling fluids and cuttings</li> <li>difficult to monitor drilling cuttings</li> <li>truck-mounted rigs not suitable in restricted space areas.</li> </ul>
	Windows sampling	<ul style="list-style-type: none"> <li>small quantities of waste produced</li> <li>core can be produced in clear plastic sleeves</li> <li>simple to monitor cores to select samples and for health and safety purposes</li> <li>relatively quick</li> <li>cheap</li> <li>possible to use in restricted space areas</li> </ul>	<ul style="list-style-type: none"> <li>maximum depth usually less than 5 m</li> <li>samples are usually compacted</li> <li>small quantities of sample are recovered</li> <li>samples are not suitable for many geotechnical tests</li> <li>difficult to identify water strikes</li> <li>not very reliable in granular soils.</li> </ul>

Certain other analyses require additional 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. For example, this approach has been used to determine the average contaminant concentrations in  $\sim 30 \text{ m}^3$ -sized disposal pits.

### Sample collection

Disturbed soil may be brought to ground surface using any of the intrusive investigation techniques listed in Section 6.3.3. 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). In this case, samples that are representative of the entirety of the ground cannot be collected because of the presence of coarse gravels, cobbles and boulders. It is neither practicable nor appropriate (given that any contamination will be concentrated within the finer-grained fraction) to analyse these coarse-grained components of the soil. In this case, the coarse-grained fraction should be discarded, and only the finer-grained fraction sent for chemical and radiochemical analysis. The approximate 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 best 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.

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.

## 6.3.6

### Liquid and gas sampling

#### Installation of permanent monitoring points

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

- 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 (for example 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 (for example, Environment Agency, 1999b; CIRIA, 1993a).

### Groundwater sample collection

Groundwater sampling methodologies are described in detail in a number of other guidance documents (for example, CIRIA, 1993; Environment Agency, 1999b). An outline of the methodology is given below.

Groundwater samples are generally collected by one of two methods:

- pump sampling
- 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 prior to collecting the sample, ensuring that the sample is representative of the groundwater in the rock mass rather than that in the borehole. It is best practice to withdraw three borehole volumes of groundwater prior to collecting samples, or to carry out in-line monitoring (for electrical conductivity, pH etc) and to sample after measurements have stabilised.

When pump-sampling a borehole on a nuclear-licensed or defence site, adequate provision should be made for disposal of the waste-water generated (see Section 5.4.5). Direct disposal of radioactively contaminated water to ground, or by a surface water body, will not be possible unless covered by the site's authorisation under RSA93 (see Chapter 7). Similarly, disposal of chemically contaminated water to ground or by a surface water body would require authorisation from the environment agency.

Radiological monitoring using standard field instruments will typically not detect contamination in water samples, because the radionuclides are typically 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 and defence sites, see section 6.4.4. 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 Environment Agency, 1999b, and is not considered in detail here. All groundwater samples should be filtered (typically to 0.45 µm) in the field prior to addition of the preservative. It is good practice (i) to refrigerate groundwater samples to approximately 4°C after collection and prior to 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 5 litres) for radionuclide analysis is impracticable and is not necessary. An illustrative groundwater sample storage and preservation scheme is shown in Box 6.10.

Box 6.10

*Illustrative scheme for storage and preservation of water samples*

Determinand	Container	Preservation
All radionuclides except tritium	5 litre HDPE	50 ml HNO <sub>3</sub>
Tritium	0.5 litre glass	None
Metals	1 litre HDPE	Hardness, HNO <sub>3</sub>
Cyanide	0.1 litre HDPE	NaOH
Chloride, sulphate etc, alkalinity	250 ml HDPE	None
Non-volatile and semi-volatile organics	1 litre amber glass	None
Volatile organics	Glass serum vials (sealed with PTFE-faced rubber septum)	None

**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 more dense than water respectively and hence will either sink through or float on 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 will not be discussed further here. Further information on DNAPLs is provided elsewhere (for example, Fetter (1992)).

The sampling of LNAPL may be carried out in a number of 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.

### Soil gas sampling from permanent monitoring points

The sampling of permanently installed gas monitoring points is generally used for monitoring methane production from landfilled putrescible wastes. It is unlikely that such monitoring will be required on nuclear-licensed sites or defence sites. Extensive guidance on the identification of landfill gas already exists (see for example the series of CIRIA reports on methane (CIRIA, 1992; CIRIA, 1993a; CIRIA 1993b; CIRIA 1995)) and is therefore not repeated here.

### Soil gas surveying

Soil gas surveying provides information on volatile or gaseous contaminants within the near-surface soils. It is 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 soil 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 soil gas to migrate. In addition, results are commonly influenced by meteorological factors, such as the extent of recent rainfall, barometric pressure and windspeed.

Soil gas surveying may be used as an indicator of the presence a number of contaminants, including:

- volatile organic compounds (VOCs) such as petroleum hydrocarbons or organic solvents
- organic compounds that are not VOCs, but that produce CO<sub>2</sub> 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 soil 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.

#### Box 6.11

#### Soil gas surveying

Ground-probing soil gas surveys typically involve the following stages:

- determination of the sampling pattern based on the size of the site, the quantity of information required, the desk study and walkover survey information, cost implications
- insertion of the sampling probe at each location
- purging of atmospheric gases from the sampling probe
- withdrawal of soil gas sample
- analysis of the soil gas either on site using portable instruments (eg photo ionisation detector or gas chromatograph) or in the laboratory (following storage in a suitable gas tight container).

Soil gas surveying is a screening technique. Therefore, the analysis is usually completed in the field using on-site instrumentation. Areas within the highest concentration contours (“hot spots”) are targeted for more exhaustive soil sampling and analysis. More detailed descriptions of soil gas surveying techniques are provided in guidance produced for Scottish Enterprise (1994).

Advantages of soil gas surveying are that it is a rapid screening technique which can aid in the identification of areas of chemically (or radioactively, in the case of radon) contaminated land and it is relatively inexpensive.

Limitations of soil gas surveying are that migration of soil gas may be significantly affected by the near surface geological and man-made structures. Because of this the soil 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.

### 6.3.7 Sample labelling and transport

Samples should be clearly labelled in a manner that 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. Advice on storage conditions should be sought from the analyst.

Radioactively contaminated samples containing greater than 70 Bqg<sup>-1</sup> total radioactivity become subject to the Radioactive Substances (Road Transport) Regulations. 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 it is analysed. If it is suspected that some samples may contain greater than 70 Bqg<sup>-1</sup> of radioactivity, it may be necessary to undertake on-site screening analysis, for example using a portable gamma spectrometer, to determine the appropriate method of transport. If this is not possible, then samples should be transported in accordance with the requirements of the Radioactive Substances (Road Transport) Regulations. Waste management and transport of radioactive materials is discussed further in Chapter 7.

### 6.3.8 Geological logging/geotechnical testing

#### Geological logging

All boreholes and trial pits should be logged following BS 5930:1999. In addition, the following information should be recorded:

- depth and results of any *in situ* radiological or chemical monitoring
- depths and depth ranges and type of any samples collected for chemical or radiochemical analysis
- depths of any man-made features (BS 5930 logging will only record such features as made ground).

### Photography

Photographs 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. Prior to use of a camera on these sites, permission should be sought from the site operator. Ideally photographs should be taken of:

- all sampling locations
- trial pit walls
- any exposed *in situ* geological materials
- cores samples prior to them being divided up for analysis.

### Geotechnical testing

In some circumstances it may be possible to combine a contaminated land survey with a geotechnical survey. However, a number of points should be borne in mind:

- 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 must be tested for contamination prior to the geotechnical testing being carried. 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 6.4.1) from the relevant environment agency, and notification under IRR99 if activities involved are above exemption levels.

Geotechnical testing methods are described in detail in BS1377, 1990 *Methods of test for soil for civil engineering purposes*. Some examples of common tests are given in Table 6.1.

Table 6.1

**Common *in situ* and *ex situ* tests**

<i>In situ</i> tests	<i>Ex situ</i> tests
Standard penetration test	Liquid and plastic limits tests
<i>In situ</i> California bearing ratio test	Moisture content
Hand shear vane test	Undrained triaxial compression tests
Perth penetrometer test	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 foundation to occur.

## 6.4 Chemical and radiochemical analysis

### 6.4.1 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 of the laboratory by NAMAS (under the auspices of the United Kingdom Accreditation Service, UKAS). It is, however, important to confirm that accreditation is held for the specific analyses required. The testing laboratory should be committed to the implementation of effective and efficient quality management systems consistent with the requirements of BS EN ISO9001, 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 Health and Safety Executive, the AquaCheck scheme organised by WRc Ltd and CONTEST (CONtaminated land TESTing) organised by the Laboratory of the Government Chemist.

The sites that are being considered by this best 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.

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.

### 6.4.2 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. Subsequent to 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 will be discussed in Section 7.1.

### 6.4.3 Analytical testing strategy

It is not possible to analyse all samples for all possible contaminants, and a strategy is therefore needed to prioritise and sequence the chemical and radiochemical analyses undertaken. The strategy would take into account:

- the objectives of the site investigation (for example, is it to determine if a site is chemically or radioactively contaminated or to design 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.

A phased approach is generally taken to the chemical and radiochemical testing. This is likely to involve:

*on-site screening of samples*, 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 example:

- gross alpha/beta
- gamma spectrometry (which also provides detailed analysis for specific radionuclides)
- tritium
- hydrocarbon analyses (eg diesel range organics (DRO: C1 – ~C35) and petrol range organics (PRO: C4–C10))
- polyaromatic hydrocarbon (PAH) and polychlorinated biphenyl (PCB) screens
- beryllium.

*detailed laboratory analysis*, for example:

- alpha spectrometry to determine activities of uranium and plutonium isotopes
- chemical separation followed by specific radionuclide analysis (for example, 90Sr)
- trace metal analyses (eg Hg, Pb, Zn, hexavalent chromium)
- 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 (CO<sub>2</sub>, methane, sulphide)
- 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 Radioactive Materials Road Transport Regulations (see Section 7.2).

#### 6.4.4

#### Analysis of radioactivity in soils and waters

The 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 in Boxes 6.12 and 6.13 below. The analysis of tritium in soils and waters is also discussed.

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 BqL<sup>-1</sup> can be achieved. For comparison, these levels are below the Guideline Values produced by the World Health Organisation for radioactivity in drinking water.

In practice, however, 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 Bqg<sup>-1</sup> 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 only the fine-grained (<200 µm) portion of the soil. This can introduce a systematic bias in the result, because any radioactive 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 prior to analysis.

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

Tritium is common contaminant on nuclear-licensed sites. It is present as tritiated water, which behaves in a chemically identical way to naturally occurring water (H<sub>2</sub>O). 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.

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 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 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, in order to evaluate whether a potential problem exists. If tritium contamination below the groundwater table is detected, it is best practice to install groundwater monitoring boreholes and to obtain groundwater samples for further analysis.

Gamma spectrometry detects gamma radiation, which is produced during the decay of most radionuclides. However, as shown in Boxes 2.2 and 2.3, there are some potential radioactive contaminants, such as  $^{90}\text{Sr}$ , that do not produce gamma radiation on decay and whose presence cannot be inferred from short-lived gamma-emitting daughter radionuclides.

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

However, because 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.

In **waters**, gamma spectrometry is typically used to provide more detailed analysis of contaminated samples. This is principally because gross alpha/beta analysis of waters provides accurate and precise measurement to detection limits below activity levels that are of radiological concern. Indeed, the detection limits of gamma spectrometry typically exceed those of the gross alpha/beta technique.

Flowsheets suggesting possible strategies for gross radioactivity and radiochemical analysis of soils and groundwaters are given in Figures 6.4 and 6.5.

# This version is now superseded by version 2 (W30)

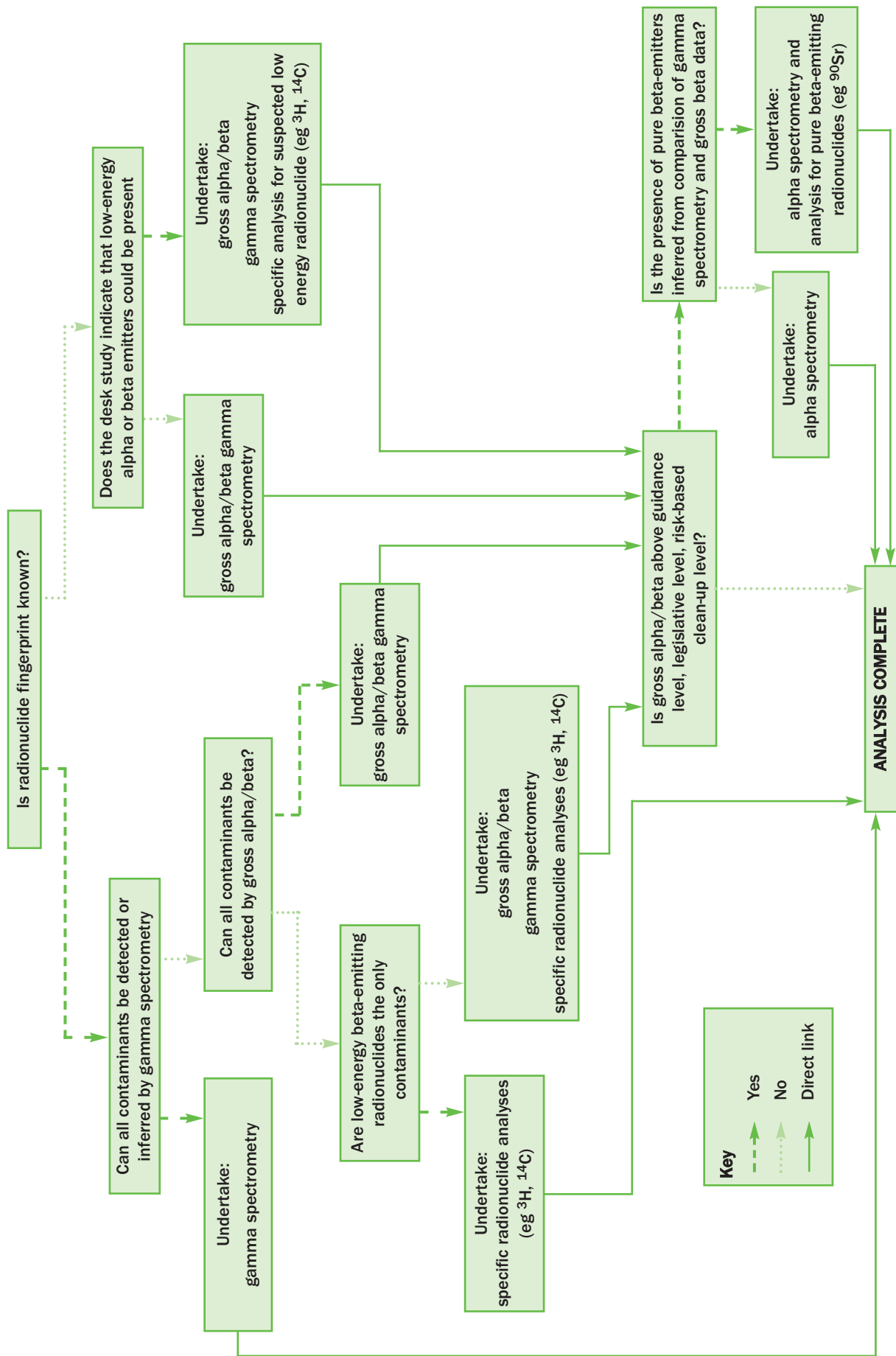


Figure 6.4

Soil analysis (for radionuclide determination)

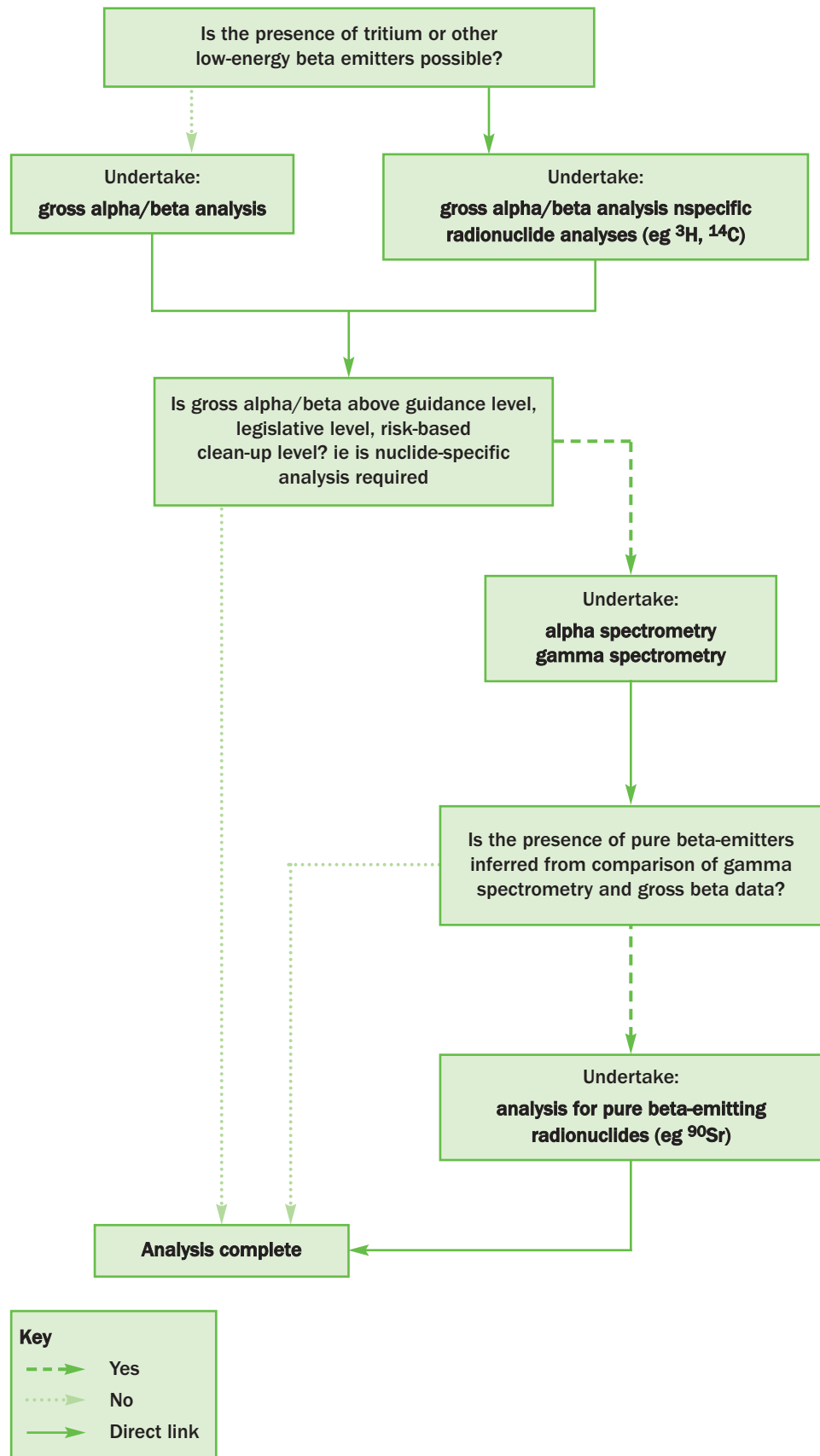


Figure 6.5

Water analysis (for radionuclide determination)

## 6.4.5

### Assessment of errors

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

- the precision and accuracy of the analytical technique (“analytical errors”)
- 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. Details will vary, but use of the types of QC samples described in Box 6.14 should be standard practice.

#### Box 6.14

#### Quality control samples

Use of the types of QC samples described below 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 the analytical testing laboratory to evaluate background contamination and cross-contamination.

**Duplicate samples.** Samples taken either to assess reproducibility of the field sampling procedure (“field duplicates”) or to enable inter- or intra-laboratory comparison (“split samples”). Note: it is very difficult to collect duplicate soil samples as contaminant concentrations may vary over very 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 homogeneous 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.

## 6.5

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(Revision in draft September 1999)

## 7

# Waste management and transport of radioactive materials

### Box 7.1

#### *Aims of Chapter 7*

This section describes the sources of waste that can arise in site characterisation and how wastes should be categorised, which will define which disposal routes need to be available. The key issues for managing wastes on potentially radioactively contaminated sites are then summarised.

This section also describes the special requirements that apply to transporting radioactive materials, such as samples, off-site and the impact this can have for a characterisation project.

## 7.1

### Waste management

### 7.1.1

#### 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 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.

### 7.1.2

#### Waste categorisation

##### Solid wastes

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 definition of radioactive waste is given in Section 4.3.2. Non-radioactive wastes are further categorised by the Environment Protection Act 1990 into controlled wastes and special wastes.

Exemption orders exist which 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.

- Statutory Instrument 1986, No. 1002 and amended 1992, No. 647. The Radioactive Substances (Substances of Low Activity) Exemption Order; and
- Statutory Instrument 1962, No. 2648. The Radioactive Substances (Phosphatic Substances, Rare Earths etc) Exemption Order.

The SoLA Exemption Order specifies that solid radioactive waste is excluded from the provisions of Section 6(1) and (3) of RSA, provided that it is substantially insoluble in water and has an activity that does not exceed 0.4 Bq/g. These provisions include the requirement to have an authorisation from the environment agency to dispose of the waste. This order is particularly relevant to wastes that contain any man-made radionuclides (see Section 4.3.2.1). In practice, this exemption order means that solid wastes containing less than 0.4 Bq/g of man-made radionuclides (and containing natural radionuclides below levels relevant to other exemption orders) can be dealt with as if they were not radioactive.

The Phosphatic Substances, Rare Earths etc Exemption Order 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 RSA provided that the specific activity of *each* of the Schedule 1 elements present does not exceed 14.8 Bq/g. 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).

A major practical problem in the interpretation of Schedule 1 of RSA93, and the Phosphatic Substances, Rare Earths etc Exemption Order limits, has been the lack of guidance about the treatment of daughter products. However, guidance on interpretation of Schedule 1 is available from DETR (DETR, 2000). The relevant environment agency should be consulted on the interpretation of the Phosphatic Substances Exemption Order, which is currently 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 Box 7.2. A flow chart summarising the waste categorisation process is given in Figure 7.1.

Solid waste materials with radionuclide concentrations as specified in Box 7.3 can also be categorised as very low level waste (VLLW) and can be disposed with ordinary refuse (HMSO, 1995). The categorisation of VLLW is a working practice adopted by the environment agencies but is not part of the provisions of the Radioactive Substances Act. VLLW disposal is subject to standard authorisation conditions.

Schedule 1 of RSA93 defines the concentrations of naturally occurring radionuclides above which liquid wastes are to be dealt with as radioactive (see Box 4.5). The Phosphatic Substances, Rare Earths etc Exemption Order may also be relevant to site characterisation because it allows water containing insoluble particulates with less than 14.8 Bq/g 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.

**Box 7.2**

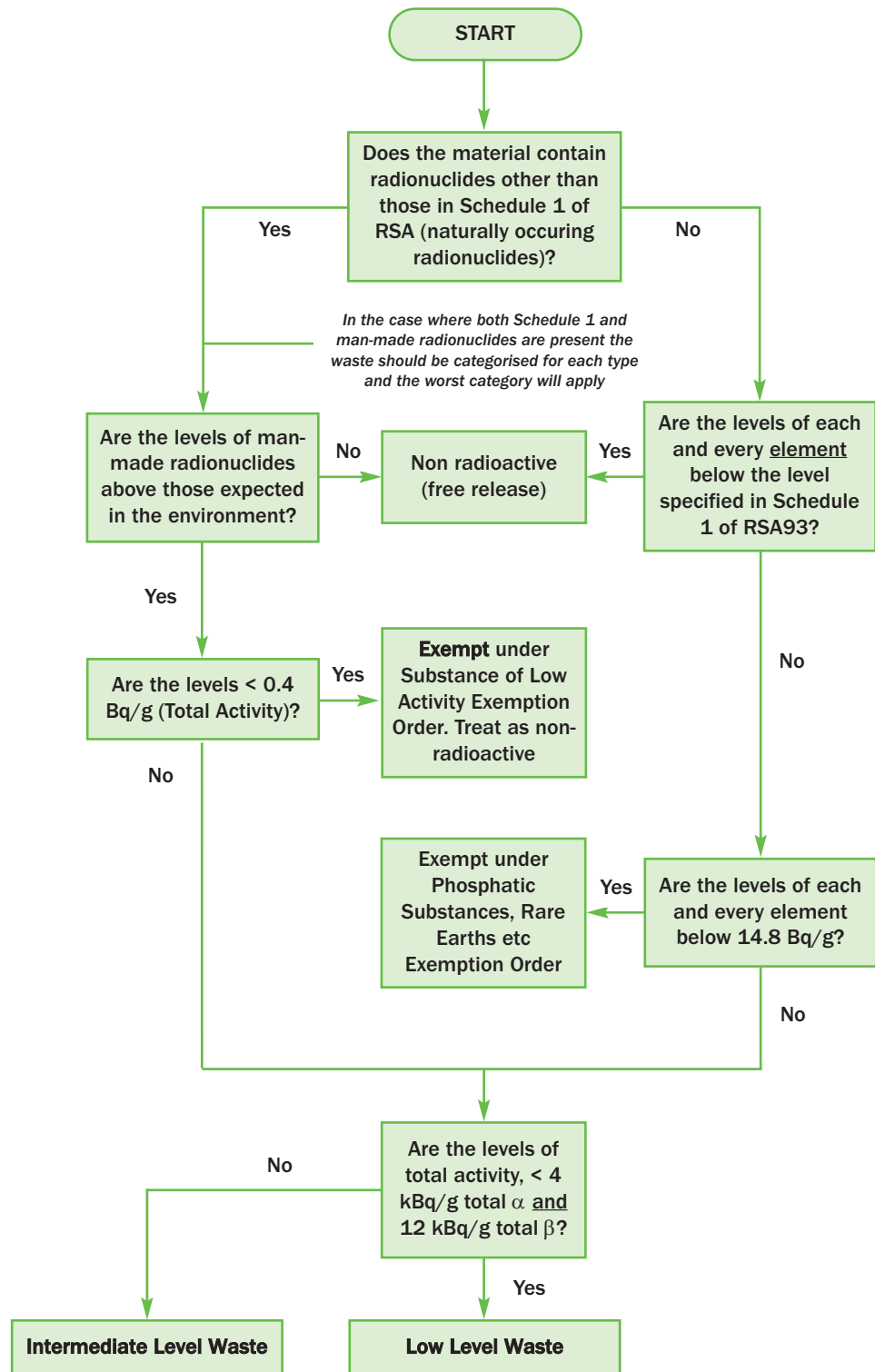
**Specific activity limits to be applied in determining categories of solid wastes that contain above background levels of radionuclides and that are essentially insoluble in water**

Waste characteristics		Specific Activity, Bq/g	Waste category
1	Wastes containing man-made 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. Refer to Phosphatic Substances etc EO; may go to landfill
		> 14.8	LLW
3	Wastes containing mixtures of man-made radionuclides and Schedule 1 elements	≤ 0.4 ( <b>excluding</b> contributions from all Schedule 1 elements and their daughters, <b>provided</b> none exceed their Schedule 1 Column 2 limits)	Deal with as non-radioactive
		> 0.4 ( <b>excluding</b> contributions from all Schedule 1 elements, which do not exceed their Schedule 1 Column 2 limits, and their daughters)	LLW
4		> 4000 alpha > 12 000 beta/gamma	Intermediate level waste (ILW)

**Box 7.3**

**Activity concentration specified in standard authorisations for VLLW disposal**

Radionuclide	Activity concentration, kBq m <sup>-3</sup>
β/γ emitting*	< 4000
Carbon-14 or Tritium**	< 40 000
* single item limit of 40 kBq	
** if there are no other radionuclides, single item limit of 400 kBq	



**Note:** Where the term “element” is used this should be taken to mean the total activity of all the radion isotopes of that element, eg U238 + U235 + U234

Figure 7.1

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

### 7.1.3

## Key issues for waste management

The key issues for waste management on potentially radioactively contaminated sites are summarised in Box 7.4.

#### Box 7.4

#### *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 (see below) is made on the basis of the averaging volume, which is therefore a key parameter in the design of a site characterisation and any subsequent remediation. The averaging volume of any waste produced from the site characterisation or subsequent remediation should be agreed with the relevant environment agency during the survey design stage.

**Waste minimisation.** Operators of nuclear-licensed sites will have both environmental policies and site licence conditions that state that waste production should be minimised. Strategies for intrusive investigations and for other aspects of the site investigation should be selected with this requirement in mind.

**Categorisation of wastes.** Definition is firstly in terms of radioactivity (see Section 7.1.2) but must 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.

**Confirmatory analysis of wastes.** Prior to 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 in accordance with site operating procedures (if available) and legislation. Ensure duty of care for non-radioactive wastes.

Some of these issues are dealt with in more detail below.

### 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; this may include obtaining variations to existing authorisations under the Radioactive Substances Act.

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. Pre-treatments 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 hence 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 below). Mobile effluent treatment plant may be required if authorisation cannot be obtained for direct discharge of liquid wastes into the environment.

### Disposal of radioactive waste

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

- the low-level radioactive waste disposal site at Drigg, Cumbria
- 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 by BNFL plc at Drigg. Details of the acceptance criteria for solid low-level radioactive waste at Drigg (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 BNFL of Solid Waste at Drigg*, issued by BNFL Waste Management and Decommissioning. A Guidance Note to the *Conditions For Acceptance* (CFA) is also available.

Note that Drigg 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. Such on-site facilities typically can only accept waste at the lower end of the LLW category. Thus, there may be a requirement to segregate radioactive wastes into categories suitable for on-site and off site disposal. The Special Waste Regulations 1996 (see below) apply to radioactive wastes that are covered by an exemption order (ie exempt) under RSA93. Note that radioactivity in itself is not sufficient to make a substance a special waste; the waste will need to have some other property, such as toxicity due to the uranium content being >0.1 per cent, to qualify as a special 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 below for discussion of EPA 1990). Consequently, 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 may be a problem in returning any radioactively contaminated spoil or abstracted groundwater to trial pits and boreholes. This is because the relevant environment agency may regard the spoil or water, once removed from its original location, as an accumulation of radioactive waste and its return as disposal that requires authorisation under RSA93. It is important to discuss these issues with the environment agency before starting the site investigation and obtain 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.

### On-site segregation of wastes for radioactivity

The radionuclide fingerprint of the potentially contaminated material must be known in order to select appropriate instruments and methodologies for assigning wastes to the different categories. Wastes in which fission products (such as Cs-137 or Co-60) or radium are the principal contaminants can be segregated using certain hand-held gamma detectors, for example a 3 in × 3 in 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.

### Disposal of non-active waste

In the UK, wastes are defined under the Environmental Protection Act 1990 by two broad categories:

- controlled waste
- special waste.

The former category covers most non-active wastes that would be produced during the characterisation of a contaminated site. Special waste is defined as “controlled waste of any kind (that) is or may be so dangerous or difficult to keep, treat or dispose of that special provision is required for dealing with it.” Consequently, there are additional requirements (above those required for controlled waste) for disposal of special waste. The contractor will probably be responsible for disposal of non-radioactive waste produced during the characterisation of a nuclear-licensed site or defence site.

Wastes shall be disposed in accordance with the relevant UK legislation, ie Environmental Protection Act 1990, Environment Act 1995, Water Resources Act 1991, Special Waste Regulations 1996 and Health and Safety at Work etc Act 1974. section 34 of the Environmental Protection Act 1990 imposes a duty of care on persons concerned with controlled and special waste. The duty applies to any person who produces, imports, carries, keeps, treats or disposes of controlled or special waste, or to a broker who has control of such waste. It requires that anyone who has a responsibility for controlled or special waste ensures that it is managed properly and recovered or disposed safely. Under the duty of care, there are four main requirements:

- 1 To prevent any other person committing the offences of depositing, disposing or recovering controlled (or special) 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 The Carriage of Dangerous Goods (Classification, Packaging and Labelling) and Use of Transportable Pressure Receptacles Regulations, 1996.
- 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 (1) above and to comply with the duty at (2) above to prevent escape of waste.

This is achieved by raising a consignment note for each consignment of liquid, or solid waste, that is disposed. The Special Waste Regulations 1996 have amended the Environmental Protection (Duty of Care) Regulations 1991 such that a duty of care waste transfer note is not required when a special waste consignment note is raised.

## 7.2

### Off-site road transport

#### 7.2.1

#### Radioactive material movements

The transport of radioactive materials by road is subject to legislation relating both to radioactive content and to any chemical or physical hazards, namely:

- Radioactive Material (Road Transport) Act 1991
- Radioactive Material (Road Transport) (Great Britain) Regulations 1996 (RAMROAD)
- Environmental Protection Act 1990: Part II, Special Waste Regulations 1996.

Other regulations apply to Northern Ireland, to off-site transport by air, sea and rail 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.

The legislation regarding radioactive material movements (or “RAM transfers”) requires understanding of radiation protection issues. Specialist advice from a Radiation Protection Adviser should therefore be sought to ensure that all transfers of radioactive materials are in accordance with this legislation. In general terms, the key aspects of the legislation of relevance to contaminated land investigations are:

- materials with activities greater than 70 Bq/g are subject to the RAMROAD legislation
- 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 RAMROAD
- 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 given below, 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 the prior approval in writing of the Post Office.

There are four criteria for the transport of a radioactive material in an excepted package:

- the external dose rate at the surface of the package is less than 5  $\mu\text{Sv/hr}$
- the external dose rate at 10 cm from the unpacked “instrument or article” (eg the contaminated soil) will not to exceed 100  $\mu\text{Sv/hr}$
- the loose contamination levels on the surface of the package are less than 0.4 Bq/cm<sup>2</sup> beta and 0.04 Bq/cm<sup>2</sup> alpha
- the activity of the package does not exceed the radionuclide-specific limits given in Schedule 36 of RAMROAD.

If any of these limits is exceeded, the radioactive material must be transported in an approved package.

Given the requirements of RAMROAD and the expense of RAM transfers, it is clearly desirable to avoid off-site movements of radioactive materials where possible. The use of on-site laboratories for characterising samples containing higher levels of radioactivity should be considered. The requirement for waste minimisation has already been discussed (Section 5.4.8).

Box 7.5

***Responsibilities under the Radioactive Material (Road Transport Great Britain) Regulations 1996***

The consignor, who is responsible for transporting the radioactive material, must ensure that:

- 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
- 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 RSA 93 to accumulate and dispose of radioactive material).

If the consigning site is licensed under the Nuclear Installations Act (as amended) 1965, additional record-keeping requirements will apply.

7.2.2

**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) No 3227/76, 1976. For organisations handling only small quantities of these materials (such as potentially could be produced from a contaminated land investigation), only special fissile materials ( $^{239}\text{Pu}$  and uranium enriched in  $^{235}\text{U}$  or  $^{233}\text{U}$ ) are subject to the legislation. Further, plutonium with an isotopic concentration of  $^{238}\text{Pu}$  in excess of 80% 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 above. 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 in turn will take advice from the DTI.

### 7.3

### References

DETR (2000)

*Interpretation of Schedule 1 of the Radioactive Substances Act 1993 and related issues*

DETR/RAS/00.003, DETR, London

HMSO (1995)

*White Paper. Review of Radioactive Waste Management Policy*

Cm2919, HMSO, London

## 8

# Data management

Box 8.1

### Aims of Chapter 8

This section provides guidance on structuring site characterisation reports, on the importance of storing information so as to comply with nuclear site licence conditions, on the use of geographical information systems and on the uncertainties inherent in interpreting site characterisation data and the measures that can be taken to reduce this uncertainty.

## 8.1

### Reporting

Investigation reports may be required for different purposes and to serve different audiences. Therefore it is useful to consider the following reporting structure provided in Box 8.2.

Box 8.2

### 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 in response to enquiries from the public and senior management.
Preliminary investigation report with initial conceptual model	To be completed prior to the next stages 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 investigation 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 more 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.

Guidance produced in BS DD175 (BSI, 1999) deals solely with the preparation of factual reports, either as a separate volume, or in a single volume in combination with the interpretative report. DoE, 1994 gives brief guidance on project reports together with the health and safety plan, the environmental protection plan and the preparation of licences and permits. A checklist of key features of a report is given in Box 8.3.

<b>Summary</b>	A concise non-technical summary of the report and its conclusions is highly desirable.
<b>Contents page</b>	An index of the report contents is helpful.
<b>Terms of reference</b>	Client terms of reference should be clearly stated.
<b>Objectives</b>	Should be clearly stated and linked to the terms of reference.
<b>Structure</b>	Consistent use of paragraph, table and figure numbering should be maintained with a clear layout.
<b>Methods/results/ Interpretation</b>	Methods, results and interpretation should be clearly stated and identifiable. Opinions should be justified, drawing on published information and guidance where possible.
<b>Conclusions</b>	Should be clear, derived from the previous text, and relevant to the original objectives.
<b>Recommendations</b>	Should be clear (and often costed, timetabled) and justified in relation to the clients's overall, and agreed project objectives.
<b>Abbreviations and glossary</b>	Should be applied consistently, always introduced and, where widely used, a separate list of abbreviations and a glossary should be included in the report.
<b>Charts/graphs/ diagrams/photographs</b>	Should be used to support text where they assist in understanding results. However, too many graphs with information not directly relevant to the text can be confusing.
<b>Cross references</b>	Should be checked for accuracy and consistency.
<b>References</b>	The work of other parties reported or used in the interpretation must be referenced and a separate reference list provided.
<b>Appendices</b>	Supporting data should be held in appendices and identified in the report text.

Use should be made of high-quality figures wherever possible, to enable the results from the investigation to be readily understood by a wider audience. Geographical information systems may be valuable in this context.

Consideration should also be given to standardisation of data format. For example, the Association of Geotechnical and Geoenvironmental Specialists has proposed a format (commonly know as the AGS Format) for recording and reporting data from site characterisation programmes (Association of Geotechnical and Geoenvironmental Specialists, 1999).

## 8.2

### Corporate memory

Under Nuclear Site Licence Condition 6, there is a requirement on the licensee to “make adequate records to demonstrate compliance with any of the conditions attached to (the) licence”. Such records must be preserved for a period of 30 years. Site characterisation reports may fall into this category. See section 4.1 for a summary of the reasons why site investigations may be undertaken on nuclear licensed sites.

Maintenance of paper-based systems is costly in time, space and effort. Computerised geographical information systems (GIS) or equivalent electronic systems, such as the combination of AutoCad and a database, can provide significant advantages. These systems can store historical site maps, old plans, service layouts, photographs and

investigation data. The ease of use enables frequent interrogation for SHE management as well as for the purposes of representing site investigation data. Often the value of information in old records is overlooked because of the difficulty of access.

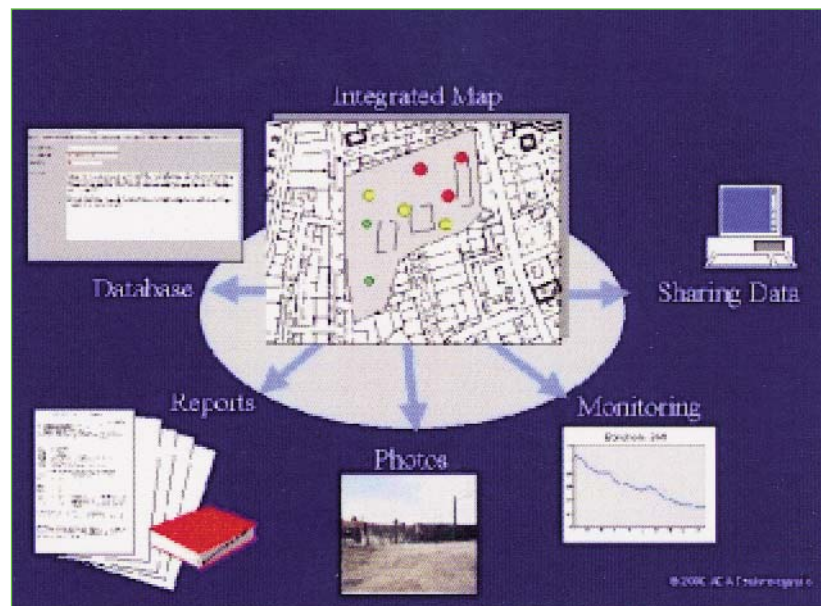


Figure 8.1

*Illustrative output from a geographical information system*

Placing data on common scales and overlaying different types of information has proved very useful on sites with complex histories. It can highlight discrepancies in surveying, changes of use and areas of uncertain information. In addition to historical information, data about the current situation, site investigation information and proposed changes of use can be layered on top to provide an integrated information source. Investment in converting records to electronic format and developing a site-specific GIS may be significant, but the benefits for corporate memory are:

- co-ordination of records
- ease of retrieval
- ease of updating
- rapid production of all aspects of site information
- traceability and auditability
- fulfilling record-keeping requirements of management systems.

An example of the illustrative output from a GIS is given in Figure 8.1. Guidance on the use of digital data in site characterisation programmes is given in Environment Agency, 2000.

## 8.3 Evaluation of data

### 8.3.1 Uncertainty

It should be recognised that there will always be an element of uncertainty in the interpretation of site characterisation data. This needs to be acknowledged in the reporting and quantified where possible. There are two aspects to this uncertainty.

**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. The site characterisation will have focused on reducing those uncertainties in the preliminary conceptual model that are of greatest significance to possible adverse impacts on receptors. 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 flowpaths at the site (perhaps associated with sub-surface services or made ground). Areas of remaining uncertainty should be identified in the site characterisation report, in order that their significance can be treated in the subsequent assessment of the data.

**Data uncertainty.** Only a very small fraction of the site will have been directly sampled. It is important to evaluate the extent to which data obtained are representative of the site. Key issues to consider for the acquired data are: sample heterogeneity (sub-sampling errors: Section 6.4.5); spatial variability of the property being measured and systematic measurement biases (for example, gross alpha/beta analysis of soil is discussed in Section 6.4.4).

Examples of possible areas of uncertainty are given in Box 8.5.

### 8.3.2

#### Data quality

Throughout the site investigation process, it is necessary to have confidence that the procedures used to collect samples and to determine contaminant levels are fit for purpose, and that the procedures described in the method statements are followed. This is achieved by adherence to quality management systems.

Organisations commissioning site characterisation work are likely to hold company accreditation to BS EN ISO 9000 (BSI, 1994). It therefore follows that 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 given in Box 8.4.

It is essential that quality procedures are applied at all stages of the investigation. The procedures used should be capable of confirming the reliability and robustness of the investigation carried out and the data produced. Detailed guidance on quality management can be found in the BSI publications, and specifically related to contaminated land in CIRIA (1995), DETR (1997) and British Standards Institution (1999).

#### Box 8.4

##### *Quality management issues (from British Standards Institution, 1999)*

- qualifications and experience of personnel carrying out work
- qualifications, accreditation and experience of sub-contractors
- chain of custody procedures
- QA/QC for sampling and analyses
- accurate record-keeping and suitable data storage
- review and audit of all works carried out at all stages of the investigation, including reporting and interpretation.

Box 8.5

*Examples of uncertainties arising during site investigation, and possible actions that can be taken to reduce uncertainty*

Site characterisation activity	Examples of uncertainty	Possible actions to reduce uncertainty
<u>Preliminary investigation</u> <ul style="list-style-type: none"> <li>desk study</li> </ul>	Access or supply of historical information on site history limited by site owner/occupier, leading to failure to identify potential radioactive and chemical desk study contaminants, jeopardising SHE management and scope of investigation (conceptual model uncertainty).	Assume worst-case history, particularly for defence sites, and take client through an iterative process to try to establish all relevant sources of information.  Prepare contingency plans for SHE management and site investigation procedures.
	Inadequate information retained by client in plans and demolition records.  Potential presence of <i>in situ</i> buried structures (eg foundations, services) on the site (conceptual model uncertainty).	Incorporate exploratory investigation stage, using non-invasive geophysical surveying.  Limited intrusive investigations to prepare main investigation plans.
	Poor conceptual model developed and/or lack of link with subsequent survey design. Results in poor quality investigation and poor quality SHE 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.
	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.
	Failure to appreciate chemical and radioactive characteristics of waste that will possibly leading 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.
<u>Preliminary investigation</u> <ul style="list-style-type: none"> <li>site reconnaissance</li> </ul>	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 personnel are interviewed who can brief and supply contractors with necessary site operating instructions and documentation.
<u>Site investigation</u> <ul style="list-style-type: none"> <li>exploratory</li> <li>main</li> <li>supplementary</li> </ul>	Failure to locate services, both inside and outside site boundary. This could lead to damage to services, possibly resulting in injury/death to site personnel an/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 HSE Guidance. For off-site excavations, ensure that national utilities are contacted.
	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 surveying method should be reported.
	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.

## 8.4

### References

Association of Geotechnical and Geoenvironmental Specialists (1999)  
*Electronic transfer of geotechnical and geoenvironmental data. Version 3*

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.

Department of the Environment (1994)  
*Guidance on preliminary site investigation of contaminated land*  
CLR 2, DoE, HMSO, London

Department of the Environment, Transport and the Regions (1997)  
*A quality approach for contaminated land consultancy*  
CLR 12, DETR, London

Environment Agency (2000)  
*Some guidance on the use of digital environmental data*  
National Groundwater and Contaminated Land Centre, Project NC/06/32, March 2000

### Standards

BS EN ISO 9000:1994 *Quality systems*

BS DD 175:1999 *Investigation of potentially contaminated sites – Code of Practice*  
(Revision in draft September 1999)

## 9

# Current capabilities and lessons for practice

### Box 9.1

#### Aims of Chapter 9

This section brings together a summary of the key differences between the characterisation of nuclear-licensed or defence sites and the characterisation of “conventional” sites. Three case studies of characterisations are presented, with lessons for practice drawn from each one. The SAFEGROUNDS Learning Network would be pleased to consider further case studies for inclusion in a later edition of this guidance.

Finally, this section summarises the key points from the best practice guidance and indicates some areas where future technological or process developments have the potential to improve current best practice.

### 9.1

## Current capabilities

This guidance has summarised current best practice for the investigation of nuclear-licensed sites and defence sites. Many of the project management and legislative issues are specific to such sites, although the general technical approach and characterisation techniques have broader application to potentially radioactively contaminated land.

Most of the site characterisation technologies described in this guidance are conventional and well established. Many have been used extensively for the characterisation of chemically contaminated land and will be familiar to most readers. The technologies and instruments that may be less familiar are those concerned with the measurement of radioactivity. However, these are all conventional health physics equipment, with a long record of successful use.

The key differences between the characterisation of nuclear-licensed and defence sites and the characterisation of conventional contaminated sites are summarised below:

- nuclear-licensed and defence sites have a more complex regulatory regime. There is a need for site characterisation on such sites to satisfy a number of regulators, who regulate under different legislation and who may have different perspectives on the management of contaminated land
- because of the different regulatory regimes, the required endpoints of site characterisation on nuclear-licensed and defence site and on “conventional” contaminated sites may be different
- there will be greater client involvement on nuclear-licensed sites, primarily driven by nuclear site licence requirements
- site characterisation on nuclear-licensed sites and defence sites will 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 conventionally contaminated sites) is essential
- radioactive contamination is potentially present at all nuclear-licensed sites and defence sites. Best practice for characterisation of such sites is that Radiation Protection Advisers and Radiation Protection Supervisors are appointed to provide advice to the employer on compliance with the Ionising Radiations Regulations 1999 and with the Radioactive Substances Act 1993. Note that there is a requirement under IRR99 to appoint RPAs and RPSs if working with ionising radiations (ie if radioactive contamination is encountered)

- waste minimisation is a key issue on nuclear-licensed sites. There may be requirements for waste segregation, to ensure arisings of radioactive wastes are minimised
- on nuclear-licensed sites, there is a requirement for long-term storage of records. This may influence the extent to which electronic collection and storage of data is used.

## 9.2

### Case studies

Case studies, which demonstrate current practice for the characterisation of nuclear-licensed and defence sites, are presented below. In each case study, some or all of the following information is presented. Additional case studies would be welcomed by the SAFEGROUNDS Learning Network for consideration for future editions of this guidance.

- description of the site
- driver for the site characterisation
- outline of the scope of characterisation (eg desk study, non-intrusive surveys etc)
- health, safety and environmental issues
- derivation of the preliminary conceptual model and link with the design of subsequent parts of the site investigation
- areas of the site characterisation that are considered to represent good practice
- outcome of site characterisation and use of data in decision making
- lessons learned.

### 9.2.1

#### Characterisation of the F2 chemicals facilities, BNFL Springfield

This case study is based on a paper by Dr D. Simister (HSE) and Mr W Denison (F2 Chemicals) (Simister and Denison, 1999).

##### Site description

The site for the work was F2 Chemicals Ltd at the Springfield nuclear-licensed site. F2 was formerly known as BNFL Fluorochemicals Ltd. F2 is involved with the manufacture of non-nuclear products based on fluorine, for use in the medical, pharmaceutical, agrochemicals, electronics and other sectors.

The area of the F2 site is approximately 3 ha. There is no information to suggest that nuclear materials were processed, transported or stored in the area of the Springfield site occupied by F2. However, a sealed radioactive source is used. Previously, the F2 site was used for non-nuclear ceramics development (and known as REFEL silicon carbide).

##### Drivers for the site characterisation

The driver for the site investigation was that BNFL wished to divest itself of the F2 facilities. In order to do this, it was necessary to delicense the area of the F2 facilities.

##### Date of the site characterisation

The site characterisation work was primarily carried out during 1998. Some work was begun in 1994, but then discontinued for commercial reasons.

##### Outline of scope of investigation (eg desk study, non-intrusive surveys etc)

The site characterisation was broken down into two stages:

- a desk study
- site investigation.

A desk study was carried out that reviewed historical information from 1944 onwards (ie the start of nuclear activities at Springfield). The following information was compiled:

- site plans from 1944 to 1998 showing the positions of buildings on the F2 site through time
- historical data describing the activities performed within the buildings on the site
- anecdotal evidence from interviews with people who have historical knowledge of the area
- information from the Springfield works Site Safety Committee minutes
- data from a search of the UKAEA Springfield safety archive
- information from review of the REFEL Management Safety Committee minutes
- information from review of the Springfield site Health Physics and Safety Department data
- information from the Springfield site incident and event files

These records did not indicate that nuclear materials had been used, processed or stored within the area of the F2 facilities. They also indicated that there had been no incidents or events that may have led to the area becoming contaminated with radioactive material.

A desk study was also carried out to review available hydrogeological data and information on the physical interactions between the F2 area and the rest of the Springfield site. It was found that the primary controls on groundwater flow were:

- the abstraction from the four BNFL process supply boreholes
- the clay layers that cause perched water and thus lateral flow to occur above the regional groundwater table.

The only physical interaction between the F2 site and the main Springfield site that could potentially act as a conduit for future contamination of the F2 site was the trade effluent drainage system. At the time of the study, this system was used to provide drainage of the F2 quality control and research and development laboratories.

The site investigation consisted of a surface radioactivity survey and intrusive investigations:

- radioactivity survey - this consisted of a gamma dose survey using Mini-Instruments Type 6-80 meters at 1m above ground. The instruments were calibrated by the NRPB using traceable national standard sources. The survey demonstrated that the range of gamma dose was 0.05  $\mu\text{Gyh}^{-1}$  to 0.09  $\mu\text{Gyh}^{-1}$ , which is consistent with the natural background for the area.
- intrusive investigation - the outline of the sampling and analyses carried out is highlighted in Box 9.2.

#### Outcome of the site characterisation, use of data in decision-making

None of the samples collected during the intrusive investigation exceeded acceptance criteria and the radiological survey did not demonstrate any radiation levels above background.

In order to delicense a site, NII needs to be satisfied that the site is radiologically “clean” and that there is no danger from ionising radiations. The site characterisation works, along with independent checks commissioned by NII and the safety case put forward by BNFL, satisfied HSE that this was the case. The Springfield nuclear site licence was therefore varied in February 1999 to exclude the land associated with F2 Chemicals Ltd.

Box 9.2

*The sampling strategy employed at the F2 site characterisation, Springfield*

The intrusive investigation consisted of the collection of 40mm diameter core samples at the locations described below:

- 1 The three hectares of the F2 site were divided into 10 m grids. At most locations sampling was carried out at the intersection of the grids and consisted of two samples being collected, one at 0.5 m depth and one at 1 m depth.
- 2 At the location of an infilled pond samples were collected on a 5 m grid at depths of 0.5 m, 1.0 m, 1.5 m, 2.0 m, 2.5 m and 3.0 m.
- 3 A number of 2m-high landscaped mounds occur in the F2 area. These were sampled along their centre lines at 5 m intervals, at depths of 1.0 m, 2.0 m, 2.5 m and 3.0 m below the top of the mounds.
- 4 A large 0.5 m high mound is present in the F2 area. This was sampled on a 10 m grid, but at depths of 0.5 m, 1.0 m and 1.5 m below the top of the mound.
- 5 Approximately 10% of the area sampled in 1994 was re-sampled for comparison.
6. In total, 1300 samples were analysed for uranium isotopes by delayed neutron counting and 130 samples were analysed for total beta activity.

Acceptance criteria were derived for uranium from Schedule 1 of RSA 93 (11.1 Bq uranium per gramme) and for beta activity by taking a value of double the predicted background beta activity.

**Lessons for practice**

The site characterisation works was carried out in two stages:

- the undertaking of a desk study
- the site investigation.

The desk study did not identify any potential or actual source areas of areas radioactive contamination. Hence, a non-targeted sampling grid was used for most of the area. Focusing of the site investigation did occur in some areas: the infilled pond and various mounds. This was a sensible approach, as these were areas that had been disturbed in the past and there would have been a higher potential for contamination to be present. The grid spacing for the majority of the site was set at 10 m, which gave rise to approximately 300 sampling locations within the 3 ha area. This was a higher density of sampling than may be considered necessary for a site where all existing information indicated that there was no contamination (see section 5.4.2 for discussion of sampling patterns and frequencies). However, a 10 m sampling grid gives a higher degree of confidence in the results of the survey than a larger grid size.

For site delicensing, NII has a responsibility to ensure that there is no danger from ionising radiations if it is to delicense a site. Hence, a survey for delicensing purposes only has to identify the presence of radioactive contamination. However, if the site is to be redeveloped, the status of the land with respect to chemical contamination would be required. On certain sites, non-radioactive contaminated land can be more widespread and may represent a greater risk to health than non-radioactive contamination.

## 9.2.2

### Characterisation of the Catapult Pit, UKAEA Harwell

This case study is based on work undertaken by AEA Technology on behalf of UKAEA.

#### Site description

The Catapult Pit is the name generally given to the remains of an installation constructed at RAF Harwell during 1939-1940. It is located outside the Harwell Main Site, and underlies part of the playing field area to the north of the proposed Chilton Field housing development.

The Mark III Catapult Installation was designed by the Royal Aircraft Establishment (RAE) as part of its work into the ground-accelerated launching of bombers. This work did not come to fruition, and the installation was partially decommissioned during or after the Second World War, leaving a circular pit, 3.5 m deep and lined with reinforced concrete, and two 3 m-deep reinforced concrete-lined trench arms. This structure was completely backfilled some time during the 1940s and 1950s. However, there are no detailed records of the types of materials used to backfill the pit and trenches. It is, therefore, possible that some chemical and/or radioactive wastes generated at the Harwell site may have been disposed into the pit during the backfilling process.

#### Drivers for the site characterisation

There were four main drivers for characterising the materials within the Catapult Pit. These were that:

- the Catapult Pit lies outside the Harwell nuclear-licensed site
- it was backfilled during early 1950s, potentially with contaminated materials
- there is public access to site, which is currently used for recreation
- the site is adjacent to UKAEA-owned land scheduled for housing redevelopment.

#### Date of the site characterisation

The site characterisation works were carried out in two phases during 1997.

#### Outline scope of the characterisation

The characterisation of the Catapult Pit consisted of the stages set out below.

**Desk study** – to identify the original structure of the Catapult Pit, the date and nature of infill and potential contaminant migration pathways and receptors. The following data sources were searched:

- RAF records
- UKAEA records
- UKAEA reviews of disposal practice at Harwell (from interviews with staff and written documents)
- site-specific geological and hydrogeological information
- previous site investigation records.

The data collected during the desk study did not indicate the presence of significant levels of contamination within the Catapult Pit. During the previous site investigation works in 1991 13 trial pits were excavated into the Catapult Pit and did not identify any radioactive contamination. The geological and hydrogeological data indicated that,

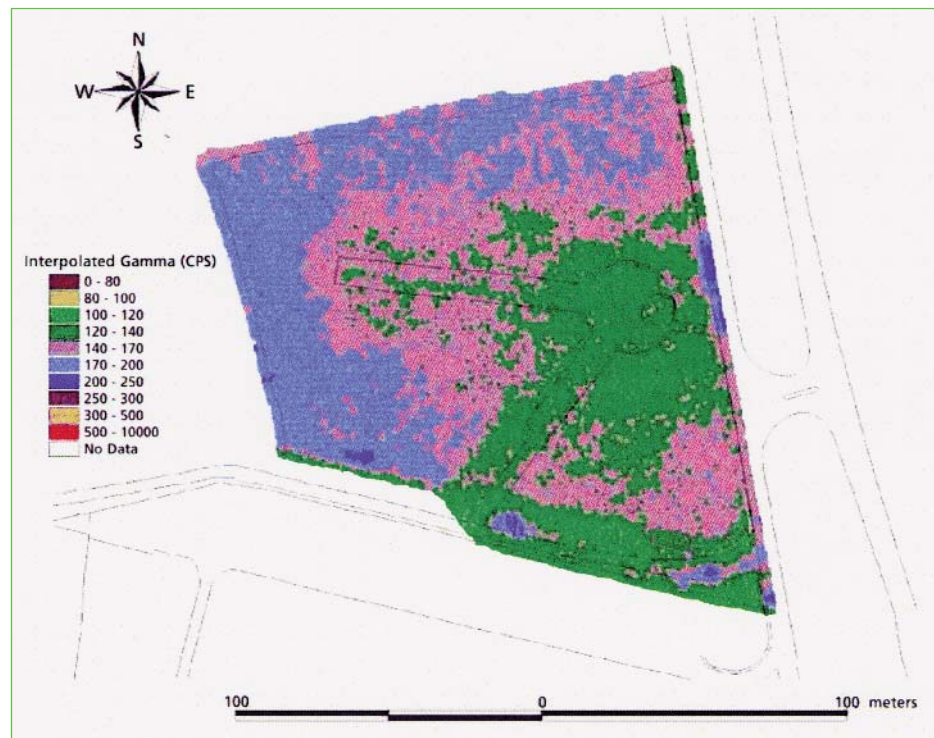
as for the rest of the Harwell site, the site overlies chalk and that groundwater flow is predominantly to the south-east.

**Geophysical surveys** – to confirm the existing structure of the Catapult Pit, identify any sub-surface services in area and identify discrete waste items in the Catapult Pit. A previous survey using electromagnetic methods and ground penetrating radar (GPR) had been used and had identified certain features relating to the Pit. However, the previous GPR survey was incomplete. Hence an additional, full-coverage GPR survey of the Catapult Pit was carried out. The surveys clearly identified the boundary of the Catapult Pit and a number of anomalies (representing objects) within the Pit.

**Walkover gamma radiation survey** – to determine the location of any areas of elevated gamma radiation. The survey undertaken was:

- a 100% coverage gamma survey of the Catapult Pit and surrounding area using the Groundhog TM system (a 75 mm diameter sodium iodide detector linked to a data logger and to the global positioning system)
- dose rate measurements ( $\mu\text{Svhr}^{-1}$ ) at spot locations.

The results of the gamma survey are presented in Figure 9.1. This plot was produced from approximately 30 000 total gamma measurements and demonstrates that the surface gamma radiation over the catapult pit is equal to or less than that of the areas outside of the Catapult Pit.



**Note:** The outline of the Catapult Pit (the circular pit and two long “trench arms” is shown). There are no increased levels of radioactivity over the area of the Catapult Pit.

Figure 9.1

**GROUNDHOG™ total gamma radiological survey of the Catapult Pit and surrounding area**

**An intrusive investigation programme** – this consisted of:

- production of method statements, health and safety plans and risk assessments
- construction of trial pits and trenches
- chemical and radiochemical analysis.

The initial plan was to:

- dig 20 trenches/trial pits to the concrete base of the Catapult Pit
- dig ten trial pits into the trench arms
- target geophysical anomalies
- locate some trial pits away from geophysical anomalies
- collect homogenised soil samples over 1 m intervals
- individually sample discrete waste items
- sample standing water
- undertake a broad range of chemical and radiochemical analyses (gross alpha/beta, toxic metals, volatile organic compounds).

#### **Results of the intrusive investigation**

The trenches proved that the following waste types were present:

- limited ash and domestic waste
- industrial waste (chalk spoil)
- industrial waste (uranium-contaminated material).

There was no standing water present.

Near the base of the fourth trial pit radioactive contamination was identified. This was giving rise to dose rates in excess of the hold-point for the project of  $7.5 \mu\text{Svhr}^{-1}$  (although note that none of the doses received by the workforce was of radiological significance). Work was stopped and the RPA and appropriate UKAEA staff informed.

It was decided to backfill the radioactive spoil into the excavation as this would present significantly less hazard than the material remaining at ground surface. The material was returned to the excavation, and covered with uncontaminated soil. A final radiological survey was undertaken, which demonstrated that the capping layer of soil had reduced doses to background levels.

The analysis regime was extended to include gamma spectrometry, alpha spectrometry and beryllium. Samples of the radioactively contaminated material were found to contain up to 10% by mass uranium. Radionuclide analysis confirmed that the uranium was of natural origin (as opposed to chemically processed or isotopically separated material): most probably, it comprised uranium ore that had been transported to the Harwell site for research purposes.

The lack of water within the Catapult Pit indicated that the drainage system was still functioning and hence that there was potential for groundwater pollution to occur. Three groundwater monitoring boreholes were therefore constructed and are now included in the site groundwater monitoring regime. Monitoring of these boreholes demonstrated that no contamination of the groundwater had occurred.

The previous site investigation did not discover any radioactive contamination within the Pit, indicating that the radioactive contamination is limited in extent.

#### Outcome of the site characterisation

At present, although natural uranium is present within the Catapult Pit, it presents no risk to human health. In the short term UKAEA has instigated a groundwater monitoring programme. In the longer term UKAEA plans to remediate the Catapult Pit by:

- removal and off-site disposal of the infilling materials
- decontamination of the concrete structure (if necessary)
- removal of contaminated material from drains (if necessary)
- re-instatement of the Catapult Pit with clean fill material.

#### Lessons for practice

Based on desk study information and previous site investigation data, the Catapult Pit was thought to be essentially clean of contamination prior to the start of this characterisation programme. This raises three important points:

- desk study data may not give the complete story of a site and, unless information is very detailed, it should be assumed that significantly more contamination may be present than the data indicate
- no matter how detailed a site investigation programme is, it is still possible to miss localised patches of contamination
- hold-points and contingency plans should be put into place in case significantly more contamination is detected than expected.

### 9.2.3

#### Characterisation and assessment of hydrocarbon-contaminated land at UKAEA, Dounreay

This case study is based on work undertaken by AEA Technology on behalf of UKAEA.

##### Site description

The site for the work was the land adjacent to the Dounreay Fast Reactor (DFR) Diesel Generator House (D1110) at UKAEA Dounreay. A number of previous site investigations in the vicinity of the DFR Diesel Generator House had shown the presence of hydrocarbons in shallow trial pits and boreholes. UKAEA considered that the source of the hydrocarbon contamination was likely to be from either, or both of, the bulk storage tanks at D1116 or the underground storage tanks adjacent to D1110. These storage facilities were therefore the focus of the site characterisation.

The area of the site was crossed by a number of major services and facilities, including operational radioactive drains, services to the DFR and the D1225 Shaft.

##### Drivers for site characterisation

There were two main drivers for the site characterisation programme:

- the need to comply with Scottish and UK legislation. In particular, it is an offence under the Control of Pollution Act 1974, as amended by the Environment Act 1995 to “cause or knowingly permit” any poisonous, noxious or polluting matter to enter controlled waters. In this context, both groundwaters and coastal waters are defined as “controlled waters”

- the need to understand the potential impact that the hydrocarbon contamination may have on the shaft waste retrieval programme.

#### Objectives of the site characterisation

- to determine the nature, extent and severity of contamination in the soil and groundwater at the site
- to identify, characterise and assess potential sources of contamination and migration pathways
- to identify and evaluate the risks and likely impacts associated with the presence of the contamination
- to assess the need for remedial action and to evaluate the options available.

#### Date of the site characterisation

The site characterisation works were carried out during June 1999.

#### Outline scope of the characterisation

This project involved the following principal phases:

##### Desk study

- a preliminary conceptual model of the site was developed, and potential pollutant linkages were identified
- the positions of subsurface services at the site were identified by reference to site services plans, to allow locations for intrusive investigations to be selected.

##### Surface geophysical surveys

- sub-surface services at the site were located using a combination of electromagnetic (EM) profiling and ground-penetrating radar (GPR)
- information on the thickness of superficial deposits at the site was provided by GPR

##### Geochemical surveys

- VOC soil gas surveys were undertaken to detect areas of near-surface hydrocarbon contamination.
- a sulphur hexafluoride soil gas survey was undertaken to detect leakages from an underground diesel pipeline.

##### Intrusive investigations

- safety documentation, including health and safety plans, method statements and local rules/emergency procedures for the site investigation, was produced
- twenty trial pits and five groundwater monitoring boreholes were constructed, logged (to BS 5930) and sampled to provide direct observation of the extent of soil and groundwater pollution at the site
- groundwater monitoring boreholes were hydrogeologically tested, to provide input data for the environmental risk assessment
- all sampling was undertaken under the supervision of a qualified health physics surveyor
- soil and groundwater samples were analysed for potential contaminants of concern (both radioactive and chemical contaminants).

### Results of the site characterisation

The desk study confirmed that there were three principal uses of hydrocarbons in the vicinity of D1110:

- diesel for the diesel generators, supplied from the main diesel storage tanks at DN020, some 300 m south of D1110. An underground pipeline carried diesel to the D1116 Bulk Storage Tanks, from where underground pipelines connected to D1110 and the Sea Water Pump House;
- lubricating oil for the diesel generators, stored in two 2,000 gallon storage tanks located immediately to the northwest of D1110;
- transformer oil for the electrical transformer.

Two potential migration pathways for hydrocarbons were identified from the desk study: (i) within the superficial deposits and ground disturbed by construction activity and (ii) within the Caithness flagstones, either as a floating product on the groundwater surface or dissolved in the groundwater. The D1225 Shaft and the foreshore were identified as potential receptors.

The geophysical surveys were successful at locating underground services. The results were invaluable for confirming that the service plans were correct and for increasing confidence that intrusive investigations would not hit services. The geophysical surveys did not provide readily interpretable information on the nature and depth of the superficial deposits, or on the presence of hydrocarbons in the near-surface soils.

The site investigation demonstrated that there is widespread low-level near-surface contamination of the D1110 site by a mixture of variably degraded oil and diesel. Higher concentrations of degraded oil and diesel appeared to indicate that sub-surface leaks from underground storage tanks to the rear of D1110 and the D1116 Bulk Storage Tanks had occurred.

Perched groundwater was shown to be of limited extent in the coarse-grained superficial deposits (being found only in approximately 10% of excavations). This perched water is probably ephemeral, being most significant in the winter months, when seepages may issue from the cliffline. Sheens of LNAPL are visible in the shallow groundwater, which is significantly contaminated by variably degraded diesel.

Highest concentrations of diesel range organics in the Caithness flagstone occur immediately down-gradient of the underground storage tanks, suggesting this is the major source of hydrocarbon contamination. The distribution of contaminants in the Caithness flagstone groundwaters suggests that the capture zone of the D1225 Shaft extends across much of the investigated area. However, some contaminated groundwater does discharge from the cliff face and into the lower part of the beach sediments.

### Outcome of the site characterisation

The data produced by the site characterisation were used as input into a risk assessment. The risk assessment used the RBCA (risk-based corrective action) methodology. The risk assessment demonstrated that no remediation of the hydrocarbon-contaminated source area is required on human health grounds.

Concentrations of organic contaminants (specifically diesel range organics) entering the Dounreay Shaft are currently acceptable for discharge through the UKAEA Liquid Effluent Treatment Plant (LETP). Although it is not expected that contaminant concentrations will rise in the future, it was recommended that continued monitoring

of the shaft monitoring boreholes be undertaken to give advance warning of any adverse trends and frequent analysis of groundwater abstracted from the shaft be undertaken to ensure that acceptance criteria for the LETP continues to be met.

The estimated flux of dissolved hydrocarbons from the site onto the foreshore is very small and hence the environmental impact on controlled waters is negligible.

A risk management plan, including remediation of limited areas of the site, has been formulated.

### Lessons for practice

Careful examination of services plans, followed up by geophysical surveys gave confidence that the locations of services in the area of investigation were known, even though the area contained many services. The positions of the intrusive investigations could then be selected to avoid the possibility of interaction with the services.

Geophysical investigations to determine geological features or the extent of ground contamination are often inconclusive, particularly in area where disturbed ground may be present.

Procedures were established for the treatment of hydrocarbon-contaminated borehole effluents, using granular activated carbon, prior to the disposal of liquid wastes at the Liquid Effluent Treatment Plant.

## 9.3

### Lessons from experience

This section brings together the key points from the best practice guidance as a series of Dos and Don'ts, see Table 9.1. Areas where there is potential for improving best practice are given in section 9.4.

## 9.4

### Possible future improvements to site characterisation best practice

This final section of the document describes areas where there is potential for technological or process developments to improve best practice for characterising nuclear-licensed sites and defence sites.

In future, greater use will probably be made of rapid, on-site techniques for quantifying levels of radioactivity. This development will minimise the need for off-site transport of radioactively contaminated samples. Similarly, more use will probably be made of in-field instrumentation for quantifying concentrations of chemical contaminants in soils and waters. Portable X-ray fluorescence (XRF) and gas chromatography (GC) is already commonly used in the USA, and is becoming more widely used in the UK. There is also potential for wider use of plants as indirect indicators of soil or water contamination.

Ecotoxicological testing offers a potentially better way to determine directly the impact of contamination on ecosystems. However, at present such testing cannot relate observed harm to a particular component in the contaminated soil or water. In future, ecotoxicological testing via DNA and genetic markers may enable the impact of specific contaminants on ecosystems to be directly measured.

Table 9.1

Summary of key points for best practice

Do	Consult with all stakeholders at the planning stage of a major characterisation project, including the public, to achieve buy-in to your process and to understand the points of view of other people. Arrange early dialogue with the regulators.
Do	Arrange for the data you collect to be stored in a way that enables long-term record-keeping, and use graphical presentation to make results accessible to the widest group of stakeholders. This may mean using a Geographical Positioning Systems (GPS) to survey control points and Geographical Information System (GIS) to record data.
Do	Where possible, use monitoring techniques that enable data to be captured electronically and transferred to the storage system without re-keying. This will minimise the opportunity for human error.
Do	Make sure you understand what the legislation actually says, not what you think it says.
Do	Prepare a conceptual model of the site to aid the design of a characterisation process. Make sure this model is “fit for purpose” and that it addresses both radioactive and chemical contamination. Make sure the model is continually refined during the characterisation work.
Do	Make sure that RPAs and RPSs are appointed whenever there is the potential for radioactive contamination to be found.
Do	Make contingency plans, for example to be able to deal with unexpected contaminants.
Do	Make sure you take account of all constraints on your method of working, for example being aware of site licence conditions and taking these into account.
Do	Establish the sampling and analysis protocols at the outset of the characterisation.
Do	Liaise with the relevant environment agency to determine averaging volumes for categorisation of wastes.
Do	Make sure the end-points of the characterisation are discussed and agreed between the client and contractor. Hold points that may come into effect during the characterisation also need to be defined and agreed.
Don't	Assume that all radioactive contamination is at or near the surface. For example, be aware of contamination from drains or underground pipes, or the impact of deep contaminated horizons in radioactively contaminated made ground.

The need to minimise waste production on nuclear-licensed sites may result in the wider use of invasive sampling technologies that reduce or eliminate wastes. Coupling of advanced sampling techniques with *in situ* contaminant measurement will further reduce production of wastes. In general, there will probably be a greater need to minimise the overall environmental impact of a site characterisation programme, which will also influence the production of wastes and the types of equipment used during the programme.

In the future, there will probably be improved use of statistical methods for designing and interpreting site characterisation surveys. This will enable the level of confidence in the conclusions drawn from the survey to be better expressed. The use of statistical methods, together with use of better decision-making tools, will ensure that sufficient data to reach the required end-point is collected, and that the collection of unnecessary data is minimised.

Finally, there is the need for a better understanding of potential interactions between radioactive and chemical contaminants in the environment. UK and international radioactive waste management R&D clearly demonstrates the potential enhanced mobilisation of some radionuclides, particularly actinides, with certain organic complexants. Further, enhanced transport of radionuclides associated with colloidal material has also been demonstrated. There is a need for further research in this area specifically targeted on contaminated land, and for the results from this research to be used in remediation decisions for such land.

## 9.5

### References

Simister, D N, and Denison, W, 1999

“Delicensing of the F2 Chemicals Limited Facilities from the nuclear site at BNFL  
Springfield, UK”

In: Proc. Conf *Decommissioning, Decontamination and Reutilisation, Knoxville, Tennessee, 12-  
16 September 1999*

## A1

# List of nuclear-licensed sites in the United Kingdom

### A1.1

## Nuclear site licences in England and Wales (as of July 2000)

Licence no. Site	Address	Licensee
7	Consort Reactor Silwood Park, Buckhurst Road, Sunninghill, Ascot, Berkshire, SL5 7TE	Imperial College of Science & Technology University of London
13	Zero Energy Experimental Reactor (Neptune), Moor Lane, Raynesway, Derby, DE24 8BJ	Rolls-Royce Marine Power Operations Ltd
28	Capenhurst Works Chester Capenhurst, Cheshire, CH1 6ER	British Nuclear Fuels Ltd
29	Drigg Storage Site Drigg, Cumbria	British Nuclear Fuels Ltd
30	Springfield Works (Uranium Fuel Manufacture Fuel Storage and Processing) Salwick, Preston, Lancashire, PR4 0XJ	British Nuclear Fuels Ltd
31	Sellafield (Windscale Works and Calder Works) Sellafield Seascale, Cumbria, CA20 1 PG	British Nuclear Fuels Ltd
32	Amersham Laboratories Amersham, Bucks, HP7 9LL	Nycomed Amersham plc
33	Isotope Production Unit [Bldg 443.26], Harwell, Didcot, Oxon, OX11 0RA	Nycomed Amersham plc
34	Isotope Production Unit [Bldg 10.23], Harwell, Didcot, Oxon, OX11 0RA	Nycomed Amersham plc
38	Cardiff Laboratories – Processing of Nuclear Material Whitchurch, Cardiff, South Glamorgan, CF4 7YT	Nycomed Amersham plc
42	Devonshire Dock Complex Barrow-in-Furness, Cumbria, LA14 1AF	BAE Systems Marine Ltd
43	Triga Reactor and Isotope Preparation Facility, Research Reactor, Billingham Cleveland TS23 1JB	ICI Chemicals & Polymers Ltd
44	Harwell Laboratory Harwell, Didcot, Oxfordshire, OX11 0RA	UKAEA
46	Windscale Nuclear Licensed Site Windscale Seascale, Cumbria, CA20 1PF	UKAEA
47	Winfrith Technology Centre A32 Winfrith, Dorchester, Dorset, DT2 8DH	UKAEA

48	Capenhurst Works Capenhurst, Chester, Cheshire, CH1 6ER	URENCO (Capenhurst) Ltd
49	Nuclear Fuel Production Plant Raynesway, Derby	Rolls-Royce Marine Power Operations Ltd
50	Devonport Royal Dockyards, Devonport, Plymouth, PL1 4SG	Devonport Royal Dockyard Ltd
51	Sizewell A NPS Leiston Suffolk IP16 4UE	Magnox Electric plc
52	Hinkley Point A NPS Stogursey West Somerset, TA5 1ND	Magnox Electric plc
53	Bradwell NPS Bradwell-on-Sea, Maldon, Essex, CM13 7HP	Magnox Electric plc
54	Berkeley NPS & Berkeley Centre Berkeley, Gloucestershire, GL13 9PA	Magnox Electric plc
55	Dungeness A NP Dungeness, Shepway, Kent, TN29 9PP	Magnox Electric plc
56	Trawsfynydd NPS Trawsfynydd, Gwynedd, LL41 4DJ	Magnox Electric plc
57	Oldbury NPS Oldbury-on-Severn, Avon, BR12 1RQ	Magnox Electric plc
58	Wylfa NPS Cemaes Bay, Anglesey, LL67 0DH	Magnox Electric plc
59	Hartlepool NPS Hartlepool, Cleveland TS25 2BZ	British Energy Generation Ltd
60	Heysham NPS Heysham, Lancashire LA3 2XQ	British Energy Generation Ltd
61	Dungeness B NPS Dungeness, Shepway, Kent, TN29 9PP	British Energy Generation Ltd
62	Hinkley B NPS Stogursey West, Somerset TA5 1ND	British Energy Generation Ltd
63	Sizewell B NPS Leiston, Suffolk IP16 4UE	British Energy Generation Ltd
77	AWE Aldermaston Atomic Weapons Establishment, Aldermaston, Reading Berkshire RG7 4PR	AWE plc
78	AWE Burghfield Atomic Weapons Establishment, Aldermaston, Reading Berkshire RG7 4PR	AWE plc

**A1.2**

**Nuclear site licences in Scotland (as of July 2000)**

Sc 2	Scottish Universities Research Reactor Centre, East Kilbride, Glasgow, G75 0QU	University of Glasgow
Sc 3	Chapelcross Works Annan, Dumfries, DG12 6RF	British Nuclear Fuels plc
Sc 6	Dounreay Licensed Nuclear Site, Thurso Caithness, KW14 7TZ	UKAEA
Sc 8	Rosyth Royal Dockyard Rosyth, Fife, KY11 2YD	Rosyth Royal Dockyard Ltd
Sc 9	Hunterston A NPS Hunterston, West Kilbride Ayrshire, KA23 9QT	Magnox Electric plc
Sc 10	Torness NPS Torness, Dunbar, East Lothian, EH42 1QZ	British Energy Generation (UK) Ltd
Sell	Hunterston B NPS Hunterston, West Kilbride, Ayrshire, KA23 9QT	British Energy Generation (UK) Ltd