Final Report **Project UKRSR03**

Development of a Framework for Assessing the Suitability of Controlled Landfills to Accept Disposals of Solid Low-Level Radioactive Waste: Principles Document

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EXECUTIVE SUMMARY

This report is the initial report of a research project aimed at establishing a framework for assessing the suitability of controlled landfills to accept disposals of solid low-level radioactive waste. The disposal of radioactive waste alongside other wastes at landfill sites is a disposal route aimed at small users rather than at the nuclear industry, and it is restricted to relatively low activity wastes. For the purpose of this project, it has been assumed that all SPB disposals will be made to non-hazardous landfill sites. The framework therefore may not be applicable to inert and hazardous landfill sites.

This document presents the key principles on which the framework will be based. These principles include high-level principles applied to all aspects of managing risks to the public, and also principles used to establish appropriate approaches to environmental, and specifically radiological, risks.

The framework comprises the overall process for determining the suitability of landfill sites for accepting certain types of low-level radioactive waste. The framework comprises four principal stages:

- Initial screening for potentially suitable sites.
- Development of the assessment context and methodology.
- Calculation.
- Authorisation decision and conditions.

The framework is aimed at assessing new sites, or sites that have not previously accepted radioactive waste. The screening stage is intended to quickly determine whether a proposed site is worth a more detailed assessment. The principles of this screening process are discussed.

The framework has been developed to ensure that, as far as possible, a consistent approach is used for all the assessments undertaken. Many of the overall constraints and objectives (the assessment context) are therefore generic. The report identifies and discusses these aspects and identifies where site-specific details will be required to complete the assessment context for individual sites.

Assessments of landfill sites in terms of their environmental impacts require the identification of the sources, pathways and receptors through which environmental harm could arise. The report identifies a generic set of these that encompasses the activities and environmental setting of landfill sites. The framework will include protocols for determining which of these is applicable at any specific site. The detailed questions and protocols that will be used to guide the user through the process will be developed at a later stage of the project.

The report describes the process by which calculations of environmental impact (dose to humans) will be used to determine the radiological capacity of a site. The relationship between the overall radiological capacity and the disposal capacity is discussed. Authorisation conditions, which are outlined in this report, will be an important part of the risk management process.

TABLE OF CONTENTS

Development of a Framework for Assessing the Suitability of Controlled Landfills to Accept Disposals of Solid Low-Level Radioactive Waste: Principles Document

1 Introduction

1. The Scottish Environment Protection Agency (SEPA), and the Environment and Heritage Service, Northern Ireland (EHS) and the Environment Agency for England and Wales (EA) are responsible for the regulation of radioactive waste disposal in the UK. The Scotland and Northern Ireland Forum for Environmental Research (SNIFFER) has commissioned research on behalf of these UK regulatory agencies to establish a framework for assessing the suitability of controlled landfills to accept disposals of solid low-level radioactive waste from small users.

2. This document presents the key principles on which the framework will be based, and also presents a top-level description of how assessments in support of this framework will be conducted. More detailed descriptions of the protocols, models, equations and data to be used in the assessments will be presented in further reports.

3. This document has been prepared by Galson Sciences Ltd. as a contractor report for submission to the Project Board for review and discussion. It is also intended that this document will be used for consultation with both internal and external consultees once it is approved by the Project Board. At a later stage of the project, the principles and description of the framework and Assessment Methodology set out in this report will be incorporated into Guidance Documents to be issued by SNIFFER.

4. This document is structured as follows:

- Chapter 2 sets out the purpose of developing this framework and outlines the types of waste and facilities that will be evaluated. This Chapter also describes the key principles that underlie the framework and its application, and identifies and describes the key stakeholders for the assessment process.

- Chapter 3 gives an overview of the proposed framework, describing the initial screening principles that will be applied to each application of the framework, and how a more detailed assessment will be formulated for appropriate sites. This Chapter also demonstrates how the framework conforms with national and international guidance on best practice for environmental risk assessment.

- Chapter 4 presents further details of the Assessment Methodology for the analysis of each landfill, describing the scenarios to be considered, and the conceptual models for the various source-receptor-pathways associated with low-level radioactive waste in a landfill.

- Chapter 5 discusses how the assessment calculations undertaken for particular landfills can be used with information on any past disposals to establish the potential for future disposals of wastes from small users. This Chapter also describes the types of authorisation conditions that may be required to ensure the site continues to meet regulatory requirements.

2 Regulatory Background

2.1 Radioactive Waste and Disposal Routes

5. Radioactive waste arises from all uses of radioactive materials, both within the nuclear industry and in hospitals, universities, research laboratories and non-nuclear industries. These non-nuclear industry users (known collectively as small users). require authorisations under the Radioactive Substances Act 1993 (RSA 93) both to keep radioactive materials and to dispose of the associated wastes. Wastes can be disposed of to the atmosphere, as liquid discharges, or as solid material sent to an appropriate disposal site. The majority of the solid radioactive wastes generated by small users falls within the category known as low-level radioactive waste (LLW), and could, therefore, be disposed of at the national disposal facility at Drigg, Cumbria, currently operated by BNFL. However, many small users do not generate sufficient waste to make effective or economic use of Drigg, which normally receives waste in half-height ISO containers, each containing some 8 m^3 of waste and costing at least £30,000 to dispose of. Waste from these small users also tends to be at the lower end of the activity range acceptable for disposal at Drigg. There is therefore a need for alternative disposal routes for the radioactive wastes generated by small users.

6. Some radioactive waste generated by small users is of sufficiently low activity and sufficiently small in volume that it is classified as very low level radioactive waste[1] (VLLW) and can be disposed of alongside other domestic and commercial wastes at ordinary landfill sites. This so-called “dustbin disposal” still requires an authorisation from the appropriate environment agency, but no further authorisations, approvals or conditions are required for the disposal site. There are also categories of radioactive waste (for example radioactive material in discarded devices such as smoke detectors or tritium light sources) that are exempt from the requirements for authorisation[2]. Much of this material is also likely to be disposed of at ordinary landfill sites.

7. A further route for the disposal of some categories of LLW from small users is through special precautions burial (SPB) at controlled landfill sites[3]. This route requires that the regulator must satisfy itself that the physical and engineered characteristics of the site are suitable for disposal of these wastes, subject to conditions. The assessment approach described in this report is intended to inform the environment agencies in making these decisions. For the purpose of this project, it has been assumed that all SPB disposals will be made to non-hazardous landfill sites. The assessment approach therefore may not be applicable to inert and hazardous landfill sites.

8. SPB was identified as a disposal route for LLW in the 1982 guide to the RSA 60. The 1982 guide proposed controls over SPB disposal of LLW by placing conditions and limitations in the authorisation granted to the waste producer[4]. These include:

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[1] The activity limit for waste disposed of with ordinary refuse is less than 400 kBq beta/gamma activity waste in each 0.1 m^3 of material (or single items containing less than 40 kBq beta/gamma activity).

[2] The series of Exemption Orders applying to these categories is under review (Thorne and Smith-Briggs, 2002).

[3] Radioactive Substances Act 1960, A Guide to the Administration of the Act, Department of the Environment et al., HMSO, 1982.

[4] This describes current (2003) practise throughout the UK. However, for future disposal sites, the Environment Agency intends to change to a procedure whereby waste producers will transfer wastes to a

- the identity of the specific landfill site to which disposals are authorised,
- an overall activity concentration limit of 4 megabecquerels per 0.1 m^3 for radionuclides with a half life greater than one year and 40 megabecquerels per 0.1 m^3 for radionuclides with a half life of less than one year[5],
- limits on the amounts of specific radionuclides present in the waste,
- the requirement to bury the waste to a depth of at least 1.5 m amongst other waste which is not radioactive,

9. In addition to the authorisation conditions placed on the waste producer, the landfill site operator must also comply with conditions related to the disposal of the waste. In particular, records relating to the date and the precise location of disposals must be kept, so that waste can be recovered if required.

10. The RSA60 was replaced by the RSA 93. The 1982 guide to the RSA 60 was not updated and is not strictly applicable to the RSA 93. However the SPB of LLW was confirmed as being in accord with government policy in the White Paper *Review of Radioactive Waste Management Policy Final Conclusions* (Cm 2919) published in 1995. CM2919 identified SPB as a potential disposal route for LLW[6] and but did not re-state the more restrictive activity concentrations given in the 1982 guide to the RSA 60 Act (see para. 8). However the conditions given in the 1982 guide may still be applied when SPB of LLW is considered or reviewed by regulators.

11. The principal intended use of SPB disposal is for waste from users outside the nuclear industry. There are currently sites in England that accept nuclear industry wastes for SPB disposal, but Cm 2919 states that further use of this route by the nuclear industry will not be encouraged.

12. A consultation on radioactive waste management has recently been initiated by the Department for Environment, Food & Rural Affairs (DEFRA) and the devolved administrations. The principal focus of this consultation is on wastes for which there is currently no long-term management strategy. Nevertheless, this consultation may eventually lead to changes in government policy that affect the management of LLW. In the meantime, SPB is still regarded as an appropriate disposal route for certain wastes from small users. In practice, however, the availability of approved sites has declined because sites have not been replaced when they have closed.

13. There are currently only two landfill sites in Scotland that are approved by SEPA for special precautions burial and the available capacity for further disposals at these sites is very limited. This decline in the number of approved landfill sites available for disposal of SPB wastes is a significant concern, potentially limiting the sustainable development of existing and future practises generating these wastes. The situation in England and Wales and in Northern Ireland has not reached the same level of concern, but without new sites and further capacity, the

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landfill operator who will hold a disposal authorisation, with associated conditions and limitations. This type of disposal will be termed controlled burial.

[5] The guide to the administration of the Radioactive Substances Act allows for a further relaxation for special precautions burial of waste containing carbon-14 and/or tritium to 200 megabecquerels per 0.1 m^3.

[6] LLW is classified as radioactive material not exceeding 4 GBq/t of alpha or 12 GBq/t of beta/gamma activity.

current situation is not sustainable. For many small users, the scattered distribution of approved sites already results in unnecessary transport and handling of the waste.

14. One factor that can inhibit the development of new sites is the public's perception of the risks associated with radioactive waste. Public opposition to many conventional waste disposal facilities and industries is even more pronounced in relation to radioactive waste disposal, and the pressure of public opinion during the planning process could lead to applications for planning permission being refused. Understanding why public attitudes harden against such facilities and being able to anticipate where public concerns are most likely to arise therefore becomes important. Openness and transparency are essential to avoid public mistrust preventing meaningful dialogue – but a robust method of site assessment and regulatory control is also required in order to provide confidence in the Agencies' role as regulators.

15. The potential for objections and protest from local stakeholders, together with perceived problems regarding contamination and ongoing liabilities at site closure, can make private operators developing new landfill sites reluctant to accept radioactive wastes. Although there are powers to require local authorities to accept these types of waste, there is also a reluctance by the Government to use them. The preferred approach is to establish a dialogue with regulators, site operators, local authorities, waste producers and other stakeholders. A consistent framework that provides assurance on the safety of SPB disposals at landfill sites will be a key part of this dialogue.

16. The framework must fit in with established principles and methodologies for developing regulations and regulatory decision-making. Section 2.2 describes the key principles that underlie these regulatory activities. There are also existing regulations and guidance for related practices, including both radiological issues and the relationships with the landfill licensing regime, that help to form a framework for the Agencies' assessment of potential SPB sites. These are described in Section 2.3. Key stakeholders are described in Section 2.4. Chapter 3 shows how the proposed approach fits in with other environmental assessment methodologies.

2.2 Regulatory Principles

High-level principles

17. The Government's Strategy Unit study "Risk: Improving government's capability to handle risk and uncertainty" (Strategy Unit Report November 2002) recommended that government should follow five high-level principles in managing risks to the public:

- Openness and Transparency
- Engagement
- Proportionality and precaution
- Evidence
- Responsibility

18. These overarching principles are intended to complement existing published frameworks such as the Freedom of Information Act, the Code of Practice on Access to Government Information, the Principles of Good Regulation, and guidance on the production of Departmental risk frameworks. They are also intended to ensure that government is open and transparent about its understanding of the nature of risks to the public and about the process(es) that it follows in handling them. It is intended that government will seek the involvement of those stakeholders affected by risks in the decision process. Action to tackle risks to the public are to be proportionate to the level of protection needed consistent with other action, and targeted to the risk. The commitment is to base decisions on all relevant evidence, including perceptions of

risks faced, and public concerns and values. Finally, the principles seek to balance risk and responsibility by ensuring that responsibility for managing risks is allocated to those best placed to control them.

Operational principles

19. Sitting underneath the five high-level principles for handling uncertainty and managing risks to the public are a number of well-established operational principles. These guide environmental, health and safety regulation, and need to be considered in any new approach to providing an assessment framework and methodology for SPB sites. Radioactive waste management policy and strategy should be based on the same principles that apply to more general environmental policies and strategies.

Sustainable development

20. The guiding principle of sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. Achieving such development requires, at the least, that a number of supporting principles are considered. Cm 2426, *Sustainable Development – the UK Strategy,* sets out the following supporting principles:

- decisions should be based on the best possible scientific information and analysis of risks;
- where there is uncertainty and potentially serious risks exist, precautionary action may be necessary;
- ecological impacts must be considered, particularly where resources are non-renewable or effects may be irreversible;

In addition, the cost implications should be addressed directly by those responsible - the 'polluter pays' principle.

21. Other tools that contribute to the Government's drive towards sustainable development for waste management include best practicable means (BPM), best practicable environmental option (BPEO), waste minimisation, and the proximity principle (ensuring that developments are as close as possible to the source of the waste).

22. These principles and tools are discussed in more detail in this section. Overall, Government policy is to ensure that radioactive waste is managed safely and that the generation that receives the benefit meets its responsibilities to future generations.

Best Practicable Environmental Option

23. The Best Practicable Environmental Option (BPEO) was defined by the Royal Commission on Environmental Pollution, and discussed in detail in their twelfth report, published in 1988 (RCEP, 1988).

24. The Royal Commission report states that, "A BPEO is the outcome of a systematic consultative and decision-making procedure which emphasises the protection and conservation of the environment across land, air and water. The BPEO procedures establish, for a given set of objectives, the option that provides the most benefits or least damage to the environment as a whole, at acceptable cost, in the long term as well as the short term".

25. BPEO implies that decisions on waste management are based on an assessment of alternative options evaluated on the basis of factors such as occupational and environmental risks, the environmental impacts, the costs and the social implications. This requires

determining what alternatives exist for the disposal of radioactive waste and evaluating these, taking into account all relevant factors in order to identify the option with the least environmental impact, whilst considering other constraints such as safety, legal, financial and social factors.

26. Applications under RSA 93 will be assessed in order to determine if the applicant should submit a BPEO statement. For non-nuclear premises this is likely to be required only for significant waste disposal practices.

Best Practicable Means

27. The Basic Safety Standards Directive and the resulting Directions to the Agencies require that the exposure of members of the public to radiation resulting from the disposal of radioactive waste are kept as low as reasonably achievable (ALARA). A key mechanism for ensuring that doses are kept ALARA is the inclusion of conditions in authorisations requiring operators to:

> "… take all reasonably practicable measures in the design and operational management of their facilities to minimise discharges and disposals of radioactive waste, so as to achieve a high standard of protection for the public and the environment. BPM is applied to such aspects as minimising waste creation, abating discharges, and monitoring plant, discharges and the environment. It takes account of such factors as the availability and cost of relevant measures, operator safety and the benefits of reduced discharges and disposals." (Cm 5552, *Managing the Nuclear Legacy: A strategy for action*).

28. Resources required for determining whether a particular aspect of a proposal represents the BPM should not be disproportionate to the benefits likely to be derived.

Waste minimisation and waste hierarchy

29. Improved process and resource management can lead to the minimisation of the radioactivity of the waste produced as well as the volume of radioactive waste produced. The avoidance or reduction of waste at source can result in significant cost reduction for operators both in terms of raw material usage and waste disposal costs. Additionally, reduction in the quantity of radioactive waste produced may preserve the capacity of scarce waste disposal facilities. Government policy states that radioactive wastes should not be created unnecessarily. Reduction in all types of waste can be achieved by employing effective waste separation and waste characterisation practices and by encouraging minimum use of raw materials. Recycling and re-use may also be possible by employing effective decontamination practices in certain circumstances.

The 'Polluter Pays' Principle

30. The 'polluter pays' principle states that the polluter should bear the full costs of their actions, including those costs which radioactive waste management imposes on society and the environment. The costs associated with authorisations granted under RSA 93 are set in order to recover the costs of environmental regulation. This is therefore an example of the application of the 'polluter pays' principle.

31. The producers and owners of radioactive waste are responsible for the costs of managing and disposing of radioactive waste. All producers and owners should make financial provision for the costs of radioactive waste management and disposal before they are incurred.

The Proximity Principle

32. The proximity principle requires that wastes are disposed of as close to the point of production as possible. The application of this principle takes into account the safety and environmental impact of the wastes and the techniques applied to its management. The aim of the proximity principle is to avoid the adverse environmental impact of unnecessary transport; however, application of the principle must be balanced against economies of scale and transport options and availability.

33. In addition, given the potential difficulty in establishing new landfill sites that are suitable for accepting LLW, there is a strong possibility that wastes will need to be transported some distance from their site of arising. This implies a relaxation of the proximity principle at those sites that are suitable, allowing them to accept LLW that has arisen outside the normal regional catchment area of the site.

The Precautionary Principle

34. The precautionary principle was defined by the UN Conference on the Environment and Development as: “where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation”. In practice this means that precautions may need to be taken now in order to avoid possible environmental damage or harm to human health in the future, even though the scientific basis for taking precautions is not proven.

35. UK Government commitments under the OSPAR convention, which is the convention for the Protection of the Marine Environment of the North-East Atlantic, impose a duty to apply the precautionary principle when considering radioactive waste discharges to the marine environment.

36. Government is also committed to applying the precautionary principle where there is good reason to believe that harmful effects might occur, and where scientific evaluation of the consequences and likelihood reveals such uncertainty that it is impossible to assess the risk with sufficient confidence to inform decision-making. Where decisions are reached by invoking the precautionary principle, there is also a commitment to actively review and revisit the decision when further information becomes available that reduces the uncertainty.

Radiation dose limits and constraints

37. The conceptual framework and key principles of radiation protection are based on the recommendations of the International Commission on Radiological Protection (ICRP). These recommendations are adopted in the European Community through basic safety standards for the protection of the health of workers and the general public against the dangers arising from ionising radiation. Directive 80/836/Euratom (the Basic Safety Standards (BSS) Directive) was largely implemented in the UK by the Ionising Radiations Regulations 1985, with the Radioactive Substances Act 1960 (RSA 60) covering those aspects of the Directive concerned with the protection of the public and the environment from the discharge or disposal of radioactive waste.

38. New general recommendations from ICRP in 1990 (ICRP 1991) led in turn to a revised BSS Directive which took account of the ICRP recommendations on how to improve protection. The revised Directive 96/29/Euratom was adopted in May 1996. The Radioactive Substances Act 1993 (RSA 93), as an enabling act, required only minor changes to take account of the revised Directive. Several Articles of the Directive impose requirements relevant to the administration of

RSA 93. The majority of these requirements were already undertaken by the Agencies, but have been made binding through the issuance of Directions to the Agencies.

39. The Directions require: that all exposures to ionising radiation of any member of the public, and of the population as a whole, resulting from the disposal of radioactive waste are kept as low as reasonably achievable, economic and social factors being taken into account; and that the sum of the doses resulting from the exposure to ionising radiation of any member of the public should not exceed the dose limits specified in the BSS Directive.

40. The principal annual dose limit for members of the public is 1 mSv.

41. Because members of the public may be exposed to more then one source of radiation arising from radioactive waste disposal, the Directions require that the Agencies should, at the planning stage for radiological protection, use the following maximum doses resulting from defined sources:

- 0.3 mSv y^{-1} from any source from which radioactive discharges are first made on or after 13 May 2000: or
- 0.5 mSv y^{-1} from discharges from a single site.

42. It is generally accepted that existing facilities should be able to be operated to comply with the 0.3 mSv y^{-1} dose constraint. The Government has accepted that, where realistic assessment of doses suggest that a facility could not be operated within this figure, the operator must demonstrate that the doses resulting from continued operation of the facility are ALARA and within dose limits (Cm 2919).

43. Facilities that meet the dose constraint must still demonstrate that doses are ALARA, which for existing facilities may involve active steps to reduce the exposures (optimisation). However, the Government has proposed a lower bound for optimisation of 0.02 mSv y^{-1} (Cm 2919). In accordance with this policy, if exposures are calculated to be below this threshold, the Agencies will not seek to secure further dose reductions to members of the public provided they are content that the operators are using best practicable means (Environment Agency et al. 1997).

44. The dose constraints listed above are maximum values to be considered by the Agencies. The Agencies also have the flexibility to set lower constraints for different practises and facilities (Cm 2919).

2.3 Regulatory Constraints

UK Landfill Licensing Regime

45. The regulatory framework for licensing landfills in the UK has recently been revised, largely to implement the European Commission Landfill Directive (99/31/EC). The regulatory agencies responsible for regulation of radioactive waste disposal are also responsible for licensing landfills, i.e., EA in England and Wales, SEPA in Scotland, and EHS in Northern Ireland.

46. In England and Wales, waste management licensing was previously regulated under either the Waste Management Licensing Regulations 1994 implementing the Environmental Protection Act 1990, or the Pollution Prevention and Control (PPC) Regulations 2000. The Landfill (England and Wales) Regulations 2002 (SI 1559) came into force in July 2002, and amend the previous regulations so as to apply the PPC Regulations to all landfills. In this way all landfills will eventually be regulated for non-radioactive waste under a single regime with a permit that complies with both the Landfill Directive and the Integrated Pollution Prevention and Control

(IPPC) Directive. Existing landfills are in the process of being re-licensed under the new regulations.

47. In Scotland, landfill sites were previously licensed under the Waste Management Licensing Regulations 1994 and the Pollution Prevention and Control (Scotland) Regulations 2000. The Landfill Directive is implemented in Scotland through the Landfill (Scotland) Regulations 2003, which came into force in April 2003. As in England and Wales, these regulations amend the PPC regulations and will bring landfills under a single permitting regime.

48. In Northern Ireland, the Pollution Prevention and Control Regulations (Northern Ireland) 2003 and the Landfill Regulations (Northern Ireland) 2003, which came into force in January 2004, implement the requirements of the IPCC and Landfill Directives. Responsibility for waste disposal licensing has been transferred from the District Councils to the Environment and Heritage Service (EHS).

49. The new regulations in all parts of the UK that implement the Landfill Directive will classify landfills as either:

- landfills for hazardous waste (as defined in the Article 1(4) of the EC Hazardous Waste Directive 91/689/EEC);
- landfills for non-hazardous waste; or
- landfills for inert waste[7].

50. These classifications are exclusive, so that hazardous waste sites will not be permitted to co-dispose non-hazardous waste. A pre-requisite for determining whether wastes are hazardous waste as defined by the EC Hazardous Waste Directive is that they are controlled waste (Environment Agency et al. 2003). Radioactive wastes, along with certain agricultural and quarry wastes, are currently excluded from the definition of controlled waste, even if other characteristics of the wastes would cause them to be classified as hazardous, however this is not the case in Scotland where the amendment of the Landfill (Scotland) Regulations 2003 brought such wastes within its scope. Some clarification of the definitions of different waste types is required to determine whether such excluded wastes can nevertheless be co-disposed with hazardous wastes, or whether they must be disposed, with conditions, at non-hazardous or inert waste sites.

51. The Assessment Methodology described in this report is independent of the waste classification, although differences in site characteristics between the different landfill types are likely to affect the calculated radiological capacity of a particular site.

Regulatory Constraints for Radioactive Waste Disposal to Landfill

52. The disposal of LLW to controlled landfill sites for SPB is currently regulated through authorisations to waste producers. Unlike disposal to specialised facilities (e.g., Drigg), there is no separate authorisation for the disposal facility, but conditions applied to the disposal authorisation and the licensing of the landfill site through the PPC process will help to ensure that the hazard posed by SPB disposal of radioactive waste is minimised.

[7] Inert waste is defined as material which does not undergo any significant physical, chemical or biological transformations; does not dissolve, burn or otherwise physically or chemically react, biodegrade or adversely affect other matter with which it comes into contact in a way likely to give rise to environmental pollution or harm to human health; and whose total leachability and pollutant content and the ecotoxicity of its leachate are insignificant and, in particular, do not endanger the quality of any surface water or groundwater.

53. The PPC permit may include conditions relating to site management, and conditions related to the disposal of SPB waste need to be compatible with these conditions and practices at the landfill site. However, SPB waste is not controlled waste and cannot be controlled through the PPC permit. Thus, because there is no ongoing regulatory control over radioactive waste once it has been disposed of at an SPB site, the Agencies take the view that the maximum dose potentially arising from these disposals should be consistent with the maximum dose from wastes that are exempt and disposed of without authorisation, or with the maximum dose from wastes consigned to a specialised facility once control has been lost.

54. There are a number of sources for determining a dose criterion that would satisfy these requirements, including the Basic Safety Standards, the Agencies' own guidance for specialised facilities, and Government policy for radioactive discharges.

55. The Basic Safety Standards set out in EU Directive 96/29/Euratom introduce the concept of clearance for low-activity radioactive materials and wastes. The Directive permits Member States to set levels of radioactivity below which materials can be disposed of, recycled and re-used without needing prior authorisation. This concept is known as clearance, with clearance levels setting a threshold at or below which the levels of radioactivity are small and pose negligible radiological risk, irrespective of the volume or future use of that material. The criteria used to establish these clearance levels are a maximum effective dose to any member of the public on the order of 10 μSv y^{-1}, and either an annual collective dose no more than about 1 man Sv or an assessment that shows that exemption is the optimum option.

56. There is no direct provision in RSA93 for setting clearance levels, but Schedule 1 of RSA 93 defines the levels at which naturally occurring substances are considered radioactive, and the Substances of Low Activity (SoLA) Exemption Order under RSA 93 provides unconditional exemption for solid materials meeting specified concentration limits. Following research and consultation on how the Basic Safety Standards should be implemented into regulations in England and Wales, the Department of the Environment, Transport and the Regions (DETR) concluded that materials meeting these provisions would give rise to doses of less than 10 μSv y^{-1} and would therefore satisfy the requirements of the Directive (Hill et al., 1998).

57. For radioactive waste disposal in a specialised facility, the Guidance on the Requirements for an Authorisation (GRA) (Environment Agency et al. 1997) sets a dose constraint while control of the facility is maintained and a risk target for the period after closure and after control of the facility has been relinquished. The dose constraint is a total permissible annual dose of 0.3 mSv y^{-1} to an individual of the critical group (i.e., the group receiving the maximum exposure). The risk target is an annual risk of death or severe hereditary defect for a representative member of the potentially exposed group at greatest risk of 10^{-6} y^{-1}. This is equivalent to an annual dose target of around 0.02 mSv y^{-1} (20 μSv y^{-1}), assuming that the receptor is exposed to the dose. The GRA notes that the long-term target is lower than the constraint for the controlled period to account for the greater uncertainty in the assessment, particularly into the far future.

58. Cm 2919 requires the Agencies to consider whether dose constraints lower than the maximum should be defined for particular types of disposal. Overall, the Agencies have determined that a dose criterion of 0.02 mSv y^{-1} for the most exposed individuals is appropriate for satisfying themselves that disposals to SPB sites will not have unacceptable radiological consequences. The assessments of potential SPB sites outlined in this report therefore use this value for determining how much radioactive waste could be consigned to a site by various

routes and not pose a significant hazard to either workers[8] on the site, members of the public living around the site, or people living and growing crops on the site after closure.

59. A landfill operator remains liable for the landfill until the landfill no longer poses a risk and can be surrendered. The Agencies have determined that, provided all assessments show doses of less than 0.02 mSv y^{-1} the risks posed by any SPB waste disposed of at the site are not unacceptable in either the operational or post-closure phases without aftercare. This means in turn that the SPB content is not a relevant consideration in determining when a PPC permit can be surrendered.

OSPAR and the UK Discharge Strategy

60. The UK is a signatory to the OSPAR convention, which imposes general obligations on all contracting parties to take all possible steps to prevent and eliminate pollution. The OSPAR Strategy aims to ensure that by 2020 discharges of radioactive substances are reduced to levels whereby additional concentrations in the marine environment above historic levels are close to zero. The requirement to reduce discharges to the marine environment applies to non-nuclear premises as well as to nuclear premises.

61. Following consultation, the UK has laid out its strategy for complying with the requirements of the OSPAR convention with respect to radioactive substances (DEFRA 2002). This strategy builds on the commitment to reduce discharges to the marine environment by the application of best available techniques.

62. One of the aims of the Government's strategy for radioactive discharges over the next two decades (DEFRA 2002) is a progressive reduction of the doses received as a consequence of such discharges. The objective is to reduce liquid discharges to the marine environment from 2020 onwards such that a representative member of a critical group of the general public will be exposed to an estimated mean dose of no more than 0.02 mSv y^{-1} from such sources. However, this level of exposure is the result of the planned reductions in discharges and it is not intended to impose it as an annual dose limit or constraint (DEFRA 2002).

2.4 Key Stakeholders

63. Although the principal user of the approach described here for assessing potential SPB sites will be the Environment Agencies, it is important that the needs of other stakeholders are considered in establishing the overall framework. The key stakeholders identified as having an interest in the process are described in this section. Other stakeholders will be involved in site-specific assessments (e.g., the water industry)

Regulatory Staff

64. Regulatory staff need to have the confidence to apply the methodology when assessing potential sites. This is important where decisions involve several types of uncertainty and raise concerns among public and other key parties. The overall framework and the Assessment Methodology are intended to provide them with that confidence in a robust and traceable manner.

[8] General site workers are subject to the same criteria as members of the public. Higher dose criteria might apply for workers directly involved in the handling of radioactive material.

Waste Producers

65. The disposal of LLW to SPB sites is a route aimed at small users on non-nuclear premises, rather than at the nuclear industry. The major producers of LLW from non-nuclear premises are:

- NHS Trusts,
- higher education organisations, and
- research institutes and industry.

66. These waste producers will have an interest in how the assessment approach might affect their disposal authorisations.

Local Authorities

67. Local authorities have a particularly important role to play in the SPB disposal route. They are the statutory planning authority, and therefore can influence the waste disposal facilities available within their local authority area. This is particularly relevant for disposal of LLW, as all landfill sites and other facilities will require planning permission. It is possible that potential disposal routes for LLW may be prevented by prohibition clauses within the planning consent.

68. Local planning authorities will have an interest in the assessment approach because they need to have the information and guidance to determine whether it is appropriate in principle to allow the disposal of radioactive waste at the disposal site seeking planning consent.

69. Local authorities also play an important role because they may be landfill site operators, and so some of the landfill sites assessed as potential SPB sites could be owned and operated by local authorities.

Waste Management Industry

70. The waste management industry provides a variety of services relating to the disposal of LLW, such as waste collection, treatment and disposal facilities. Often the services provided for LLW run in parallel with those for conventional waste. The waste management industry ranges from small operators who may own and run a single landfill site, to companies offering an integrated waste management service.

71. There is a declining number of routes available for the disposal of LLW. There has been a reduction both in the number of landfill sites available to receive LLW, and in the number of incinerators that are suitable for burning radioactive clinical waste.

72. The waste management industry will have an interest in how the assessment approach could be used to review a range of sites and help them to develop or expand business opportunities

Central Government

73. The UK Government is responsible for developing policy to ensure the implementation of international protocols and EU legislation. The Devolved Administrations have responsibility for ensuring that environmental policy, including policies relating to radioactive waste management, are in place. For England and Wales, DEFRA leads on policy initiatives related to radioactive waste management. Scottish Executive has this role in Scotland, and in Northern Ireland the Department of Environment/Northern Ireland has responsibility.

74. In 1999 the House of Lords Select Committee published its report on Radioactive Waste Management (House of Lords Select Committee, 1999). One of the recommendations of the report was that there should be public consultation on issues relating to radioactive waste management (see para. 12).

75. The Government's advisory committee, the Radioactive Waste Management Advisory Committee (RWMAC)[9], has recently published report dealing with the specific problems of small users (RWMAC 2000) and on the management of low activity wastes (RWMAC 2003). Both the RWMAC reports and the Government consultation document Managing Radioactive Waste Safely (DEFRA et al. 2001) have been drawn upon in the development of this document.

76. Central Government will have an interest in the framework for assessing the suitability of potential SPB sites because its application could have significant effects on the availability, or otherwise, of economic disposal routes for small users, which may affect the services provided by them to society at large. Government policy on radioactive waste management and the development of new specialised facilities will need to consider the needs of these users alongside those of the nuclear industry.

[9] In March 2004, the Government put RWMAC into abeyance for 2-3 years while the consultation on issues relating to radioactive waste management is in progress.

3 Structure of the Assessment

3.1 Overall Structure

77. Any assessment of environmental performance comprises a set of activities and documents. For the assessments of potential SPB sites, it is important that the same structure and methodology is applied to all the assessments. This Chapter therefore outlines the overall framework within which these assessments will be conducted.

78. The overall framework for the assessment of an SPB site is illustrated in Figure 1. The principal stages of the approach are:

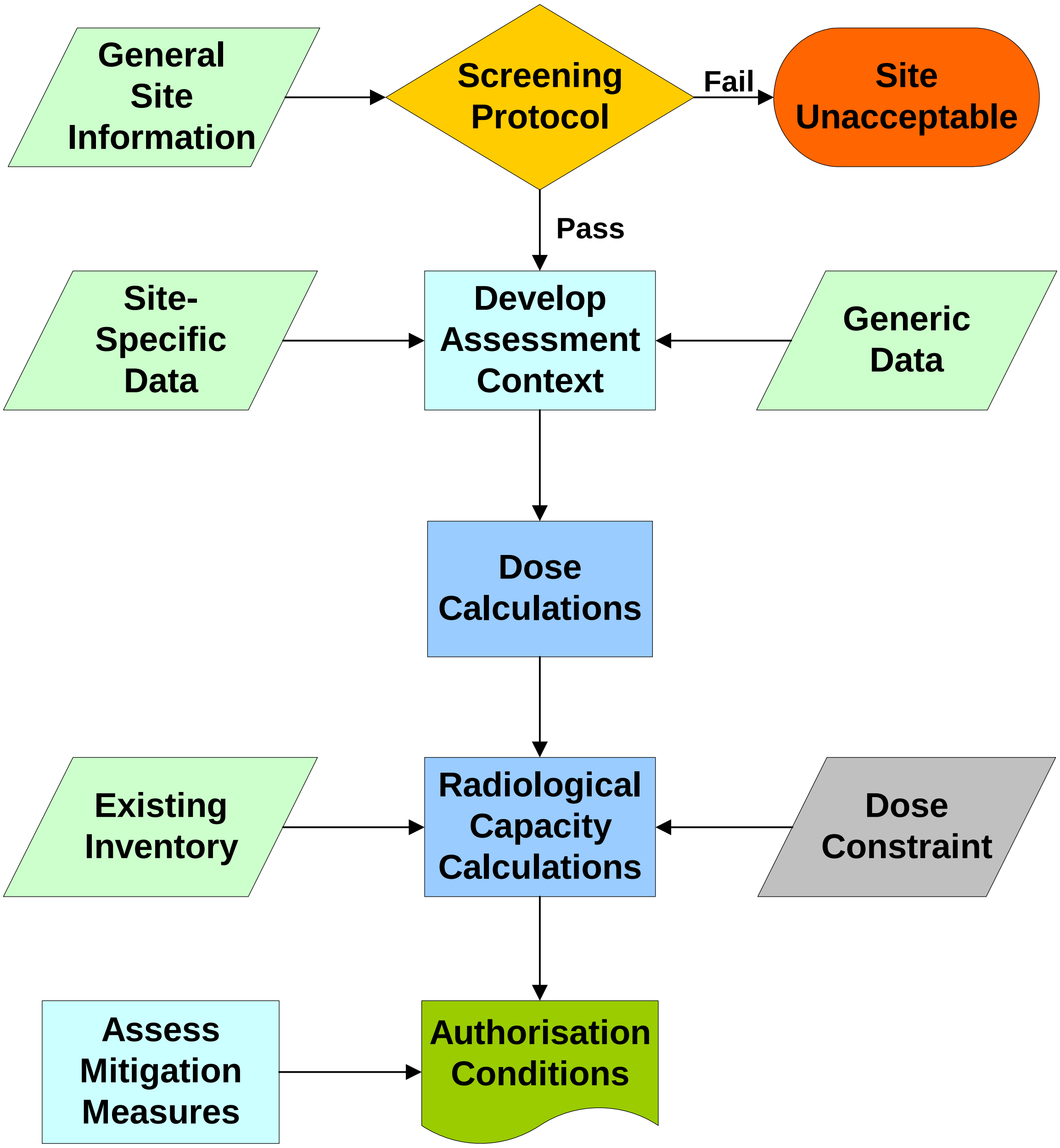
- an initial screening stage, intended to determine whether a more detailed assessment is justified (see Section 3.2);
- establishing the assessment context (see Section 3.3);
- undertaking dose calculations (see Chapter 4);
- calculating the potential radiological capacity for a site (see Section 5.2); and
- determining the implications of the assessment for the authorisation of disposals at the site (see Sections 5.3 and 5.4).

79. The adoption of a screening stage in this framework, which ensures that the level of effort put into assessing each landfill is proportionate to its potential suitability, conforms with the tiered approach advocated in UK Government guidelines for environmental risk assessment and management (Figure 2; DETR et al. 2000; Environment Agency 2000).

80. A key part of the framework is a description of the top-level constraints and objectives of the assessment. In part, these are dependent on the details of the site concerned (site-specific) and in part on the general purpose and scope of the assessment (generic). Generic information may also be used where site-specific information is not available or is difficult to obtain. Overall, this description is referred to as the assessment context, and the framework will guide the user in taking the generic assessment principles and site-specific information to define the site-specific assessment context. Both the generic and site-specific aspects of the assessment context are outlined in Section 3.3.

81. The calculation of potential doses arising from radionuclides in a landfill site will be based on a set of models and scenarios that represent key activities at the site and other aspects of the assessment context. The scenarios identified as potentially important are described in the following Chapter, along with descriptions of the conceptual models that could be used to assess these scenarios. Details of the mathematical and numerical models that, in combination with generic and site-specific assessment data, can be used to implement the conceptual models will be described in companion reports.

Figure 1: Overall approach to the assessment of SPB sites.



82. The scenarios and conceptual models described in this report will not necessarily apply to all sites considered. In particular, other licensing requirements should ensure that new landfills are not sited in sensitive locations with respect to groundwater resources. Having guided the user through setting the site-specific assessment context, the framework will, therefore, guide the user through identification of the potential source-receptor-pathways at a particular site. From this description of the disposal system, the appropriate scenarios and conceptual models for the assessment can be determined, and the data required for the assessment calculations can be identified.

83. The conceptual models and the model development process are consistent with UK regulatory principles for assessment of public doses from radioactive waste discharges (Environment Agency et al. 2002), and with regulatory guidance for the hydrogeological assessment of landfills (Environment Agency 1999, 2002a; SEPA 2002).

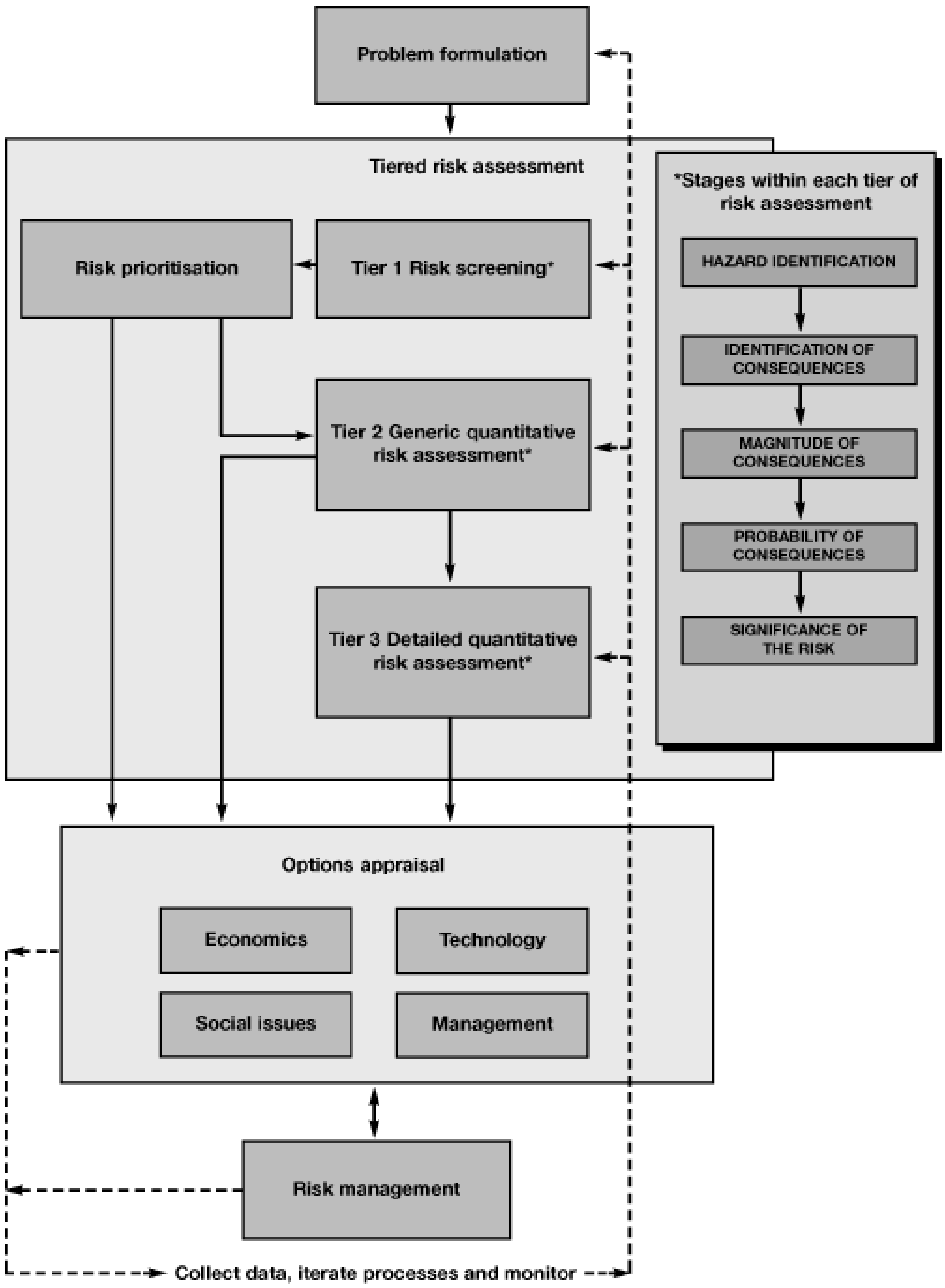
84. The composition of wastes that could potentially be authorised for SPB disposal differs between waste generators, and hence the potential radiological inventory will differ between disposal sites. There may also be differences in the amounts of radionuclides entering the site through routes other than special precautions burial. Instead of making assumptions about site-specific inventories, the dose calculations that form part of the assessment are therefore based on fixed amounts (10^6 Bq) of key radionuclides. These calculations, together with the overall dose constraint, will be used to determine an overall radiological capacity for the site. This capacity is defined in terms of categories of radionuclides, each category grouping radionuclides whose properties (e.g., half-life, mobility, dose coefficients) result in their contributing to peak dose during a particular period in a similar manner.

85. Determining the potential for future SPB disposals at a particular site involves modifying the overall radiological capacity to take account of any existing radiological materials at the site (both earlier authorised disposals and material that did not require an authorisation). Account must also be taken of potential future non-SPB disposals.

86. Setting conditions in the authorisations to waste producers is the principal method for regulatory control of SPB sites. The key authorisation conditions will be those related to the amount of waste that can be disposed of. These conditions will be based on the assessment results for the different categories of radionuclides, the assumptions made in deriving the assessment results, and the level of uncertainty in the assessment. Other authorisation conditions might relate to the timing of disposals, record-keeping and the methods used for disposal. These measures could reduce the potential for doses to arise and/or develop confidence in the assessment.

87. The current regulatory approach of authorising the waste producer and not the disposal site for SPB prevents the direct use of authorisation conditions to control site management. There will, however, be conditions in the landfill operator's PPC permit relating to site management, and it is important that the determination of the potential for future SPB disposals at a particular site takes account of these.

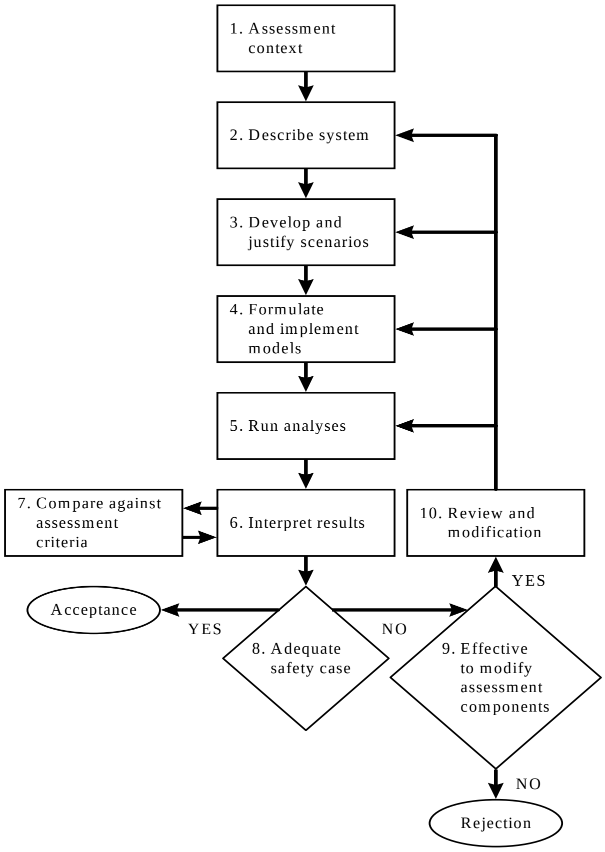
Figure 2: The Environment Agency risk assessment framework (from DETR et al. 2000).



88. In addition to the overall approach outlined above conforming to the UK government risk assessment framework, the detailed Assessment Methodology proposed also reflects best practice for the assessment of near-surface radioactive waste disposal facilities. The assessment of potential sites for SPB disposals need not be as detailed or comprehensive as assessments of specialised radioactive waste disposal facilities because of the limited inventory proposed, and the controlled emplacement of the radioactive waste along with larger volumes of other wastes. Nevertheless, confidence in the more limited assessments will be enhanced if the overall structure and key elements of a more detailed assessment are addressed, but in a simplified form. In the development of the framework and Assessment Methodology described here, the approach established by the International Atomic Energy Agency's International Safety

Assessment Methodologies (ISAM) Working Group (Figure 3; IAEA 1997) has been incorporated into the SPB assessment framework.

Figure 3: IAEA ISAM Safety Assessment Methodology (IAEA 1997).



3.2 Site Screening

89. The methodology being developed for assessing the suitability of landfill sites for the disposal of SPB wastes is simplified in comparison to the approach that might be used for assessing a specialised radioactive waste disposal facility. Nevertheless, this Assessment Methodology will still require a significant amount of information from the assessor, which could be time-consuming to collect and collate even for a single landfill site. However, some sites may be unsuitable for obvious reasons, and so an initial screening phase has been incorporated into the overall framework to identify such sites and exclude them from further consideration.

90. The Assessment Methodology described in this report, including the site screening, is intended to be applied to sites for which risk assessments have been conducted and that fulfil the requirements of both the Landfill and PPC Directives. The screening criteria are intended to apply only to aspects of the site and its evolution relevant to radiological impacts.

91. The screening process, and the other elements of the Assessment Methodology, are intended only for new sites, or for sites that have not previously accepted SPB wastes. It is not intended that screening or the Assessment Methodology should be applied retrospectively to existing SPB sites. Sites that already accept SPB disposals have been assessed previously and appropriate conditions are attached to the disposal authorisations for these sites to ensure that any public exposure is below the dose constraint.

92. Screening is envisaged as a desk-based review of available information. It is intended that screening of individual sites would be undertaken by an Agency Inspector as an initial step in the Assessment Methodology. The screening principles could also be applied to several sites by other users (e.g., site operators) as a means of determining which sites might be potential SPB sites. A primary screening principle for a candidate site is that it is appropriately licensed as an operational waste disposal facility, i.e. currently the site has either a waste management license or a PPC permit. Similarly, suspension of SPB disposals is likely to be warranted at a site that does not continue to operate under the appropriate licensing e.g., if its license or permit is revoked or suspended.

93. The necessary information on the characteristics of the site should be available as a result of the requirements under waste management licensing regimes, e.g., for a site description and a hydrogeological assessment.

94. The general principles against which a site will be screened are such that, if a site fails to conform with a principle, it is either unsuitable or is highly likely to prove unsuitable for SPB disposal of radioactive waste in the future. The principles relate to the site characteristics, rather than to the characteristics of the SPB waste being consigned to the site. Any differentiation according to the radionuclides or groups of radionuclides that could be consigned to a particular site can only be made on the basis of more detailed information than is available at the screening stage.

95. The principal characteristics used for site screening are those that could lead to high environmental risk. As examples of factors that could be used as screening criteria, proposals for sites close to a groundwater resource to start accepting SPB wastes might be screened out. Such sites will have to conform with the groundwater protection criteria in the waste management licensing procedures. However, the radiological assessment will have to consider longer timescales, when any engineered barrier designed to protect groundwater may have degraded. Similarly, existing sites that have received a large number of unauthorised disposals (e.g., exempt wastes or VLLW permitted at ordinary landfill sites) will have a large uncertainty associated with any radiological capacity calculations. Such sites may be excluded from further assessment if the uncertainty is likely to preclude authorisation for future SPB disposals.

96. A further category of screening criteria that relate indirectly to environmental risk are those concerning site management. For example, where past failure(s) of leachate control systems or breaches of waste management conditions have lead to the suspension of relevant licensing to operate as a waste disposal facility (see para. 92), this could be taken as evidence of potential future problems at the site.

97. For the purposes of a *regulatory* assessment of the potential suitability of sites for SPB disposals, only technical criteria are used. Societal issues may be important in the final decision-making regarding the authorisation of SPB disposals. Such decision-making is the responsibility of policy makers (Ministers), and should be informed by a technical assessment. Other users of the Assessment Methodology may wish to include additional screening criteria, such as economic and societal issues, to ensure that sites considered for SPB disposal would have broad acceptance.

3.3 Setting the Assessment Context

98. As mentioned above, the development of the framework and Assessment Methodology described here aims to address the overall structure and key elements of a more detailed assessment, but in a simplified form. The approach developed by the IAEA's ISAM Working Group has been used as the basis for this simplification. A key element of the ISAM approach

is the development of the assessment context, and this section describes the application of this to the assessment of SPB sites.

99. The notion of an assessment context arises because an assessment of the performance of a disposal facility can be undertaken for a number of purposes, including optimisation of the design, application for licensing, regulatory review, and confidence building. The level of detail of an assessment will vary according to its purpose, as may other aspects of the system analysed. The assessment context sets out the top-level constraints and objectives for the assessment so that the purpose and scope are clearly defined and helps to ensure that the results of one type of assessment are not used or misinterpreted in another context.

100. As developed by the IAEA, the assessment context is aimed at describing individual assessments. A key feature of the framework described in this report is that it can be applied to a number of facilities (i.e., potential SPB sites), and an overall assessment context would ensure that all such assessments were conducted in a consistent manner, even if undertaken at different times or by different agencies. However, an overall assessment context cannot be established for all sites because some elements are necessarily site-specific. The approach adopted, therefore, is to identify as many aspects of the assessment context that are common to all the sites and develop a generic assessment context for these, and to provide guidance to the user on developing the site-specific elements as required.

101. The following key areas should be addressed by the assessment context (IAEA1999):

- assessment purpose and audience;
- assessment endpoints;
- assessment philosophy and basis;
- environmental system of interest;
- site context;
- nature of the wastes to be considered;
- assessment timescales;
- assumptions regarding society habits and futures;

102. The following sections set out the constraints and objectives of the framework under these headings, identifying in particular those aspects where a generic context can be established and where site-specific information will be required.

Assessment Purpose and Audience

103. The assessment purpose and audience are generic, common to all the assessments of potential SPB sites.

104. The overall purpose of the assessment is to determine the suitability of a landfill to accept disposals of solid LLW in accordance with Government policy. The calculational part of the assessment is specifically concerned with determining the radiological capacity of a landfill by means of dose calculations for fixed inventories (10^6 Bq) of key radionuclides or groups of radionuclides.

105. The principal assessment audience is inspectors of the UK Environment Agencies, who will use the framework to determine if sites could potentially accept disposals of LLW. In addition, other audiences may wish to review the assessments in order to understand how decisions have been made and to establish confidence in the results. These other audiences may include waste producers, site operators and the public. The framework has been developed both to guide the principal audience through the technical complexity of the

assessment, and to present the development and results of the assessment for other audiences in a transparent and traceable manner.

Assessment Endpoints

106. The assessment endpoints are generic, common to all the assessments of potential SPB sites[10].

107. The assessment endpoint required is the potential inventory that can be authorised for SPB disposal at a particular landfill site. This cannot be determined directly, because there are other sources of radionuclides (non-SPB disposals) that may contribute to the dose received by people living or working near the site. Together, these different sources of radionuclides must be less than the radiological capacity of the site, defined (see Section 2.3) as the inventory that could give rise to an annual dose to individuals of 0.02 mSv y^{-1}. Because the inventory is unknown, the endpoint of the assessment calculations is the peak annual dose that might result to individuals from a unit disposal of radioactive waste (10^6 Bq) to a landfill. Taking account of the potential non-linearities and other assumptions, this dose for a unit disposal can be converted to a radiological capacity and thence, with additional assumptions about other sources, to an authorised SPB disposal inventory.

108. Other assessment endpoints are feasible. There is an increasing awareness of the potential for environmental harm to arise even if humans are not directly affected. Such harm could arise through impacts to non-human species (Environment Agency 2001), or simply as increased concentrations of radionuclides in environmental media. Although the Agencies have a duty to consider the potential harm, these other endpoints are not currently included in the framework because there is no specific regulatory constraint or target against which they might be compared. The overall methodology would, however, need little modification to determine these endpoints if required. In the case of impacts to non-human species, the key additional requirement would be the factors relating environmental concentrations to dose for these species.

Assessment Philosophy and Basis

109. The assessment philosophy and basis are generic, common to all the assessments of potential SPB sites.

110. This framework described here is intended to address the specific issues associated with the disposal of radioactive wastes. Any landfill at which such disposals are considered will already have been through the PPC permitting process and detailed hydrogeological risk assessments will have been undertaken. However, the SPB assessment considers a wider range of potential pathways and is intended to be in addition to the PPC assessments and not a replacement or alternative to them. Where possible, information used in the PPC process for the site should also be used in the assessment of suitability of the site to receive SPB to ensure consistency between the assessments.

111. The methodology for assessing potential SPB sites comprises a set of dose calculations based on simplified representations of the hydrogeology around the site and of other pathways. The calculations use a combination of generic and site-specific data and are deterministic. This type of calculation is considered appropriate in terms of the potential environmental impact of SPB disposals at landfill sites.

[10] In this context, assessment endpoint refers to the parameter that is calculated, not the value of that parameter for a particular assessment.

112. The level of complexity required has been considered in the development of the Assessment Methodology for SPB disposals. A probabilistic approach was rejected for several reasons:

- The potential environmental impact of the inventories considered is low.
- Key uncertainties, such as the extent of non-SPB disposals, are treated separately from the calculations of radiological impact.
- A cautious approach (as defined in Environment Agency et al. 2002), is used to represent the source-pathway-receptors in the assessment.
- Although probabilistic techniques could be used to estimate environmental impacts, the calculation of radiological capacity is more appropriately done deterministically.

113. Overall, the representation of the system is such that the assessment results can be used with confidence to make robust decisions concerning the radiological capacity of a landfill. A more complex risk assessment is not considered warranted for this purpose.

Environmental System of Interest

114. The environmental system of interest is specific to each potential SPB site considered.

115. Geology and hydrogeological characteristics are specific to each landfill. The aim of the framework is to assist the Agency Inspector in identifying the key geological and hydrogeological features that need to be taken into account in the formulation of conceptual models and in the implementation and parameterisation of the models. The characterisation of the environmental system is recorded in the documentation of the assessment.

Site Context

116. The site context is specific to each potential SPB site considered.

117. The site context includes a range of features of the site and its surroundings that help to define the source-pathway-receptor system(s) used in the assessment calculations. These features include:

- The identity and proximity of potentially affected populations or other environmental receptors.
- Potential exposure pathways associated with the potentially affected populations, such as stream and groundwater discharge points, drinking water wells and irrigation practices, and atmospheric pathways for gas and dust, including point source emissions from combustion of landfill gas.
- Site management practices, such as waste segregation, coverage of waste, liner type, permitted leachate head, and leachate management.
- Past disposals of radioactive wastes (see below) and other wastes that might interact with radioactive wastes (e.g., organic materials).

118. The aim of the framework is to assist the Inspector in identifying and documenting the site features that need to be accounted for in the dose calculations. The information needed on the characteristics of the site should be available to the Inspector as a result of the requirements under waste management licensing regimes, e.g., for a site description and a hydrogeological assessment.

Nature of the Wastes

119. This aspect of the assessment context comprises both generic and site-specific elements.

120. The SPB disposal route is generally available only to small users of radioactive materials, and not to the nuclear industry. The sources of waste authorised for SPB disposal are hospitals, universities, and the like, that use radioactive sources for medical and research purposes, and the volumes of waste consigned will be small in comparison to the overall volume of the landfill sites concerned. The information likely to be available on the waste inventories, and the associated uncertainties, is under review within this project. It is likely, however, that only limited information, such as total measurements of alpha- beta-, and gamma-activity, may be available. Radiological capacity and other calculations will therefore focus on a few key categories of radionuclides with similar properties rather than on a wide range of individual radionuclides. These categories will be generic and common to all the assessments of potential SPB sites.

121. The dose calculations described in Chapter 4 will be based on these generic categories of radionuclides and will also use unit activities (10^6 Bq) rather than any site-specific inventory. In determining the potential for sites to receive SPB disposals, however, there is site-specific information that must be taken into account. This includes the nature (type, activity) of any past disposals of radioactive waste, both SPB and non-SPB, the potential for further non-SPB disposals, and the uncertainties associated with the estimates of these disposals. This information will be used in determining the available radiological capacity for SPB disposals and in establishing authorisation conditions.

Assessment Timescales

122. The assessment timescale is specific to each potential SPB site considered.

123. The dose calculations undertaken for each assessment are intended to determine the peak dose to the receptors via each of the identified pathways. The time at which this peak dose occurs is a function of the properties of the pathways, and so the timescale for the assessment is specific to each site.

124. In all cases, it is necessary to consider the operational period. The peak dose to site workers will occur during operations, and the peak dose to the public around the site may also occur during this period. Depending on the properties of the radionuclides present in the wastes (half-lives, decay products), it is also necessary to consider the post-closure period when the peak calculated dose to members of the public on or off the site may occur. The assessment timescale is then determined either (i) by when the radioactivity has decayed to insignificant levels, or (ii) by when the radioactivity has been dispersed in the environment and the calculated dose is decreasing, i.e., the peak dose has been passed.

125. Dispersal of the radioactivity depends in part on the site-specific assumptions regarding the rate of degradation of the landfill engineering. It is likely that the approved closure plan for a landfill will involve a period of continued control and maintenance until the landfill is considered to no longer pose a pollution hazard to groundwater. There are two ways in which this period can be considered in the Assessment Methodology. The default assumption is that there is no

such control period, i.e., leachate management ceases and the engineered barriers are assumed to start to degrade immediately after closure. The alternative assumption is that post-closure institutional management will last 30 years, during which leachate management is assumed to continue, and occupation or use of the site by members of the public will be prevented. Degradation of the engineered barriers is, however, still assumed to start immediately after closure.

126. The default assumption of no post-closure control ensures that the determined radiological capacity of the landfill is not dependent on a particular closure plan. In the majority of cases, however, it is likely to be a conservative assumption which will reduce the calculated radiological capacity below that which would be calculated if account was taken of a period of post-closure controls. Radiological capacity calculations based on the alternative assumption will be dependent upon a particular closure plan (and its effectiveness) and should therefore be treated with some caution. They will, however, be of value in assessing the sensitivity of the radiological capacity to the presence of controls and in particular determining whether the default assumption of no post-closure control is conservative.

Assumptions regarding Societal Habits and Futures

127. The assumptions regarding societal habits and futures are generic, common to all the assessments of potential SPB sites.

128. Assumptions about future societies are required in assessments for facilities with long-lived radioactive wastes because there is a potential for unintentional human intrusion into a facility after closure and after knowledge of the presence of the facility and the hazard of its contents has been lost. Whether such intrusions take place, and their consequences if they do, depends in part on the level of technology available to future societies and the types of activity carried out. UK and international guidance on best practice for safety assessment of radioactive waste disposal facilities (e.g., Environment Agency et al. 1997, NEA 1995) is that assessments should include scenarios in which future human activities are similar to those currently observed at, or in the vicinity of, the disposal site, and that technology remains at the same level as the present day. Scenarios in which past behaviour is assumed may also be considered, but conjecture about how society or technology might evolve should be avoided. These assumptions help to ensure that the same level of protection is afforded to future generations as is provided at the present day.

129. The shorter periods of time considered in the assessments of SPB sites, which typically do not contain radioactive wastes with such long half-lives as those contained in specialised radioactive waste disposal facilities, means that society and technology will have had less time to change from the present day. The assumption that future human activities are similar to those currently observed at, or in the vicinity of, the disposal site, and that technology remains at the same level as the present day, is therefore appropriate for these assessments.

130. A related assumption is that the long-term safety of a facility should not depend upon actions by future generations. This means that, although it can be assumed that knowledge of the site will persist for some time, and that this will prevent inappropriate activities at the site, eventually some form of site occupation or intrusion may take place.

3.4 Summary

131. The overall framework for conducting assessments of potential SPB sites includes an initial screening stage to determine if a more detailed assessment is warranted. If a more detailed assessment is required, then a site-specific assessment context is developed. This

comprises a number of generic aspects, intended to ensure compatibility between assessments, and site-specific aspects to cover the particular features of the site.

132. Using the terminology established by the IAEA, the generic aspects of the assessment context are the assessment purpose, endpoints, basis, and assumptions regarding future society. The site-specific aspects of the assessment context are the environmental system of interest, site context, nature of the wastes, and assessment timescales.

133. There are two possible approaches to deriving some of the site-specific aspects of the assessment context. The first, or "bottom-up", approach involves deriving information independently for each site. This could involve an amount of repetition if several assessments are conducted, and also the potential for differences or inconsistencies to arise. The alternative, "top-down" approach is to derive a set of generic information that includes all the receptors and pathways identified in establishing the scenarios to be considered. Setting the site-specific context would then involve excluding some of these generic pathway/receptors as being of low consequence or not relevant to a particular site.

134. The "top-down" approach has been adopted in the framework developed for the assessment of potential SPB sites. The range of scenarios, receptors and pathways that will form the basis of the generic dataset from which site-specific contexts will be developed is described in the following Chapter. The methodology will guide the user through this development of the assessment context by a series of questions, resulting in the documentation of the assessment context for each site.

4 Assessment Methodology and Model Development

135. Before assessment calculations can be performed, a structured description of the system to be modelled is required. This involves not only a description of the physical system but also a description of the events to be considered and the processes involved. This description must then be translated into a set of equations and data for use in the calculations. Using the terminology adopted for the ISAM methodology for risk assessment (Figure 3), this process comprises:

- the development of scenarios (broad descriptions of the events and processes that will be considered in the assessment);
- the formulation of the models (more detailed descriptions of how the assessment will be performed); and
- the implementation of models.

136. The scenarios to be considered are described in Section 4.1. In the case of the models, there is a hierarchy of model types, ranging from conceptual models or descriptions to mathematical and computational models used to define calculations. In this report, only conceptual models are described (Section 4.2). Detailed mathematical models, and associated parameter values, which will allow calculations to be undertaken, will be described in companion reports.

137. As discussed in previous sections, one aim of the framework described here is to achieve a consistent and easy to apply methodology for the assessment of potential SPB sites and to develop suitable conditions and controls. Users of the methodology will not, therefore, be required to independently develop scenarios and models for particular sites. Rather, the Assessment Methodology will guide the user through the selection of the appropriate scenarios, models and parameters through a series of questions. As far as possible, these will be simple Yes/No or qualitative (e.g., High - Medium - Low) questions and will not involve the user in detailed modelling decisions.

138. The terms used to describe the components of a landfill in this chapter are explained in Figure 4.

4.1 Scenarios

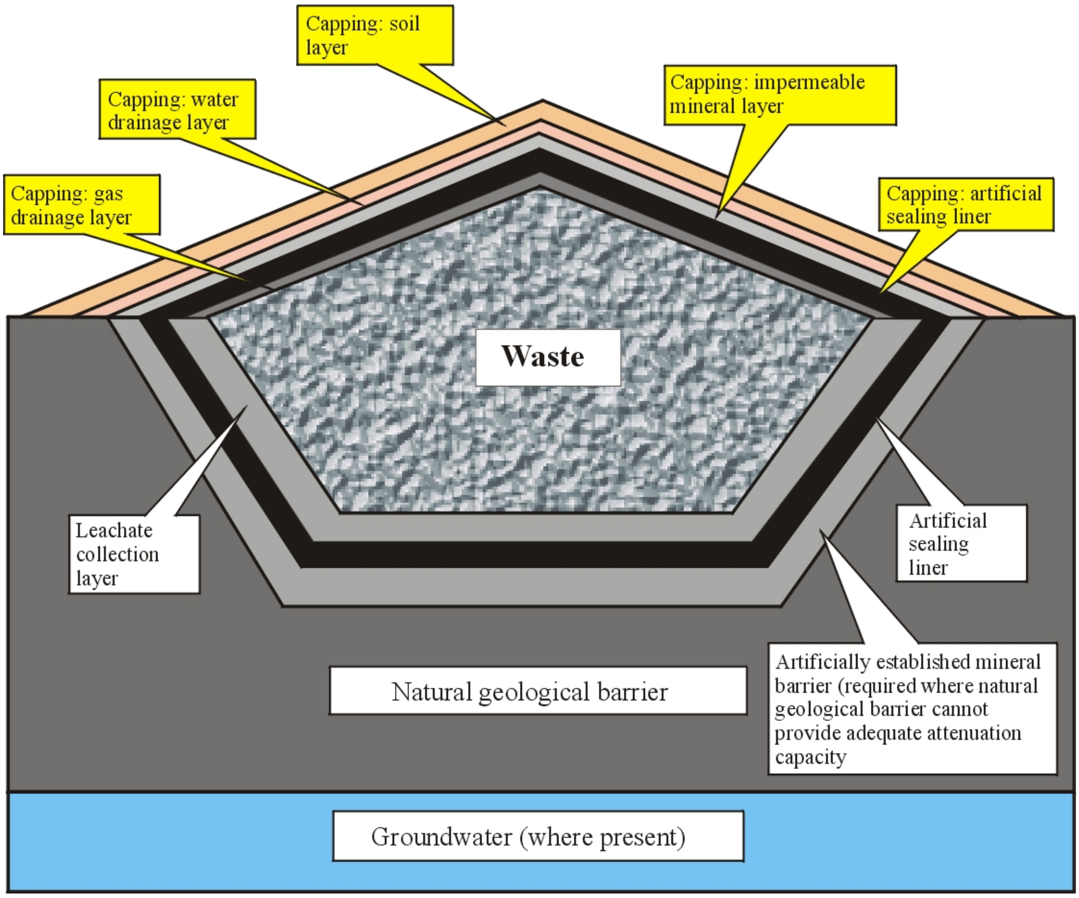
139. In order to cover the full range of events that may affect a potential SPB site, the framework includes two sets of scenarios. These are the expected or normal evolution of the site, and scenarios that assess the consequences of events that are not certain to occur. A further division is made between operational (pre-closure) scenarios (summarised in Table 1) and post-closure scenarios (summarised in Table 2).

140. The waste management license for the site will require a closure plan detailing the cessation of waste disposal and the emplacement of the final cover. This closure plan is also likely to include a period of continued care and surveillance. So as to avoid the calculated radiological capacity being dependent upon the effectiveness of a particular closure plan, the default (and generally conservative) assumption is that there will be no continued period of leachate management or site maintenance following closure. The alternative assumption is for a control period of 30 years after closure during which surveillance would reduce the possibility of intrusion or other accidents. This assumption of continued leachate management or site

maintenance following closure, can be used to assess the sensitivity of the radiological capacity to these controls.

141. The approach to scenario development is in accordance with Agency guidance for hydrogeological assessment of landfills (Environment Agency 2002a) and also with the IAEA scenario derivation methodology for near-surface radioactive waste disposal (IAEA 2001, 2002).

Figure 4: Terminology used to describe the components of a landfill in the development of the Assessment Methodology (after Environment Agency 2002b).



142. During the operational period, the expected evolution of the site, waste, and leachate management is assumed to be as envisaged in the application for a waste management license. Depending on the site and the types of waste accepted, the expected evolution could include the installation / maintenance of boreholes for landfill gas abstraction, flaring of landfill gas, on-site or off-site leachate treatment, or direct discharge of leachate to sewers.

143. During the operational period, four scenarios that are not certain to occur are also considered for releases of radioactivity to the environment:

- Failure of the engineered barrier around and beneath the landfill is considered through a scenario of release of leachate to groundwater.
- Failure of the leachate management is considered through a scenario of spillage of leachate to a nearby surface water body (if one exists).

- Releases to the atmosphere (dust, gases and vapour) are considered through a scenario of a fire in the waste, including spontaneous combustion.

- Exposure of site workers is considered through a scenario covering operations to remediate or re-engineer the site (e.g., to repair a failed barrier or enlarge the site), during which workers handle or are exposed to radioactive waste.

Table 1: Operational scenarios included in the Assessment Methodology and the associated hazards.

Scenario name	Description	Hazards
Normal operations	Expected operation of the landfill up to capping and closure, as approved by the relevant Agency. Doses to site workers and to the public are considered.	Gas Release
		Liquid release (leachate)
		Aerosols (leachate)
		Direct irradiation
Barrier failure	Failure of the artificial sealing liner and geological barrier during operations. Doses to the public are considered.	Liquid release (leachate)
Leachate spillage	Unintentional release of leachate to surface water. Doses to the public are considered.	Liquid release (leachate)
Site remediation or re-engineering	Workers expose waste during operations to remediate containment failure or to enlarge or otherwise re-engineer site.	Solid release (dust while uncovered)
		Direct irradiation
Fire	Fire releases radioactivity. Doses to site workers and to the public are considered.	Solid release (dust), gases and vapour

144. The last two of these scenarios are considered to encompass the range of other events that may result in a site worker being exposed, such as short-term contact with leachate.

145. After site closure, any active leachate management systems maintained after disposal operations have ceased (e.g., pumping, on-site treatment, tankering off-site) will also cease. Passive controls (e.g., infiltration barriers, drainage layers) are assumed to be effective initially, but to then degrade slowly, allowing more leachate to potentially migrate into groundwater. Similarly, although there will probably be controls on site use after closure, the default assumption for calculating radiological capacity is that it would be possible for houses to be built and occupied on top of the landfill cover. Occupants of these houses could be exposed to both gas releases and direct irradiation.

146. Two post-closure scenarios that are not certain to occur are considered:

- An abandoned drainage system may begin to clog and, if this occurs while the seals are still effective, bathtubbing (the build-up of leachate until it flows over the sides of the engineered barriers) might occur, thereby forcing leachate into and over the site cover. This scenario may also arise at the time that control is lost and active leachate management ceases, if there are no effective passive systems in place.

- Knowledge of the former site may be lost, or the risks not appreciated, and the site may be inadvertently excavated during an activity such as road building or residential development.

Table 2: Post-closure scenarios included in the Assessment Methodology and the associated hazards.

Scenario name	Description	Hazards
Normal post-closure evolution	During this time, the landfill engineering is assumed to gradually degrade. Doses to the public are considered.	Gas Release
		Liquid release (leachate)
		Direct irradiation (through cover)
Bathtubbing	Blockage of the drainage system causes overflow of leachate laterally from the landfill onto the soil. Doses to the public are considered.	Liquid release (leachate)
Inadvertent excavation	Waste is inadvertently excavated and re-distributed, e.g., during building or farming. Doses to the intruder and the subsequent user of the site are considered.	Direct irradiation
		Solid release (dust)
		Solid release (waste)

147. The normal operations and normal post-closure evolution scenarios have a high probability of occurrence and, therefore, are given most consideration in the derivation of the radiological capacity. The other scenarios leading to releases to the environment or to direct exposures[11] are of low probability. For some of these scenarios, the probability will vary between sites depending on factors such as geology, thickness of the natural and engineered barriers, and site operations. In other cases, the scenario is dependent on human actions which, because they are conjectural, are assumed to be independent of the particular site. It is possible that the probability of some of these "uncertain to occur" scenarios could be reduced through appropriate mitigation measures, and this potential should be considered in the development of authorisation conditions for SPB disposals.

148. The framework for assessing potential SPB sites does not require the user to actually calculate the consequences of the uncertain scenarios. For each scenario, the consequences of a small-scale event will be similar for each landfill; the key differences between landfills will be the probability of the event and the potential size of the event. Therefore, the consequences of a small-scale event will be calculated in advance for each of these scenarios, using models and parameter values developed as part of the overall methodology. The Assessment Methodology will guide the user in assessing the probability and potential size of uncertain events for each landfill, and in applying the results.

[11] The inadvertent intrusion scenario can result in both releases to the environment and direct exposure.

4.2 Conceptual Models

149. The conceptual model for a dose calculation comprises a description of the source, the pathway and the receptor, and of the processes that take place along this source-pathway-receptor chain. The development of a conceptual model for an overall assessment therefore involves the identification of all the possible sources, pathways, receptors and processes. The source-pathway-receptors considered in the framework are described below.

150. The development of conceptual and mathematical models for the assessment of potential SPB sites is consistent with regulatory guidelines for environmental risk assessment (DETR et al. 2000), guidance on the conduct of present-day dose calculations for radioactive discharges (e.g., NRPB 1996; Environment Agency et al. 2002) and hydrogeological risk assessments for landfills (Environment Agency 1999, 2002a; SEPA 2002). Although there are some differences between the guidance documents from the different regulatory agencies, reflecting the different legislative frameworks, the fundamental principles for conducting an assessment are common and are reflected in the framework described here.

Sources

151. Radioactive waste disposed of at SPB sites is generated by a range of small users, such as hospitals, universities and research establishments, who use radioactive materials for a wide range of purposes. Potentially, therefore, there will be a large number of different radionuclides present in SPB sites. Each radionuclide has different physical and chemical properties, resulting in each radionuclide being responsible for a different potential dose via the different exposure pathways over time.

152. In the past, small users have had authorisations to hold specific amounts of radionuclides and general authorisations to dispose of wastes by different routes. There is insufficient information in the disposal authorisations to give more than a broad indication of the amount of waste disposed to SPB sites. Because users may have inventories below the authorised limits, and because there is no indication of the rate of use of different radionuclides, any estimates of waste amounts based on the authorisations to hold radioactive materials are also highly uncertain. These authorisations do, however, give an indication of the range of radionuclides in use and therefore potentially in the waste (Table 3). SPB disposal may not be the principal disposal route for all of these radionuclides, particularly the gases, but there is a potential for any with half-lives greater than a few days to be present at some level in solid waste.

153. Assessments of potential SPB sites will therefore consider a number of key radionuclides that might be disposed to landfill through SPB, as identified through both a review of current practice and waste production and a consideration of radionuclide properties, such as half-life and sorption characteristics.

154. Disposals of radioactive waste at SPB sites are normally restricted to particular parts of the landfill. Also, the radioactive waste may form only a small proportion of each bag or drum consigned to the site under the disposal authorisation. This concentration of radioactivity in small volumes of waste can be further increased if sealed sources are disposed of within the SPB disposals.

155. The distribution of radionuclides in SPB sites is treated in two different ways in the assessment calculations, depending on the source and pathway concerned. For the pathways involving the transport of radionuclides in liquid, the radioactive source is assumed to be evenly distributed across the disposal cell or landfill (depending how leachate is collected and managed). This is a reasonable assumption, as the liquid (leachate) transporting the radioactivity will mix with the liquid coming from other parts of the landfill, so that receptors will

not be exposed to leachate from only one small part of the site. This approach also applies in the case of pathways involving dust arising from contaminated soil and from fires. In the former case, the soil is contaminated by leachate and so the same assumption about mixing is made. In the latter case, it is assumed that a fire will affect a larger volume of waste than just the radioactive waste, and so, effectively, radioactivity in the dust inhaled by receptors will be diluted.

Table 3: The range of radionuclides used by small users in Glasgow who have authorisations to dispose to SPB sites (note that some of these radionuclides may be disposed of to the atmosphere or to sewers).

Radionuclide	Half-life	Radionuclide	Half-life	Radionuclide	Half-life
In-113m	1.66 h	P-32	14.28 d	Mn-54	312.2 d
F-18	1.83 h	Rb-86	18.65 d	Ru-106	1.02 y
Rb-81	4.57 h	P-33	25.3 d	Th-228	1.913 y
Tc-99m	6.01 h	Cr-51	27.7 d	Na-22	2.605 y
At-211	7.21 h	Xe-127	36.4 d	Fe-55	2.73 y
K-42	12.36 h	Ru-103	39.27 d	Co-60	5.271 y
I-123	13.2 h	Fe-59	44.51 d	Ra-228	5.76 y
Na-24	14.96 h	Hg-203	46.61 d	H-3	12.32 y
Mg-28	20.9 h	Sr-89	50.52 d	Ac-227	21.77 y
K-43	22.3 h	I-125	59.4 d	Pb-210	22.6 y
Sm-153	1.93 d	Sr-85	64.85 d	Sr-90	29.1 y
Y-90	2.67 d	Co-58	70.88 d	Cs-137	30.2 y
Au-198	2.69 d	Ir-192	73.83 d	Ni-63	100 y
Mo-99	2.75 d	Sc-46	83.81 d	Am-241	432.2 y
In-111	2.805 d	S-35	87.2 d	Ra-226	1599 y
Tl-201	3.04 d	Sn-113	115.1 d	C-14	5715 y
Ga-67	3.26 d	Se-75	119.78 d	Pu-239	24110 y
Re-186	3.72 d	Ca-45	162.7 d	Th-230	75400 y
Ca-47	4.536 d	Au-195	186.12 d	Kr-81	210000 y
Xe-133	5.24 d	Gd-153	241.6 d	Tc-99	213000 y
I-131	8.04 d	Zn-65	243.8 d	Cl-36	301000 y
Er-169	9.4 d	Co-57	271.8 d		

156. A different approach is taken for pathways that involve direct irradiation, the handling of waste or inhalation of radioactive gases. These pathways do not involve the diluting effects of mixing leachate or dust from different parts of the site, and it would be unreasonable to assume that the waste was widely dispersed across the whole landfill. In the case of radioactive gases, there will be some mixing with other gases generated within the landfill, but a worker standing

above the waste or a resident living on the closed site will be exposed to gas from a relatively small volume of the overall landfill. For these pathways, therefore, all of the SPB disposals to the landfill are assumed to be concentrated into a small volume (10 m^3) of waste.

157. The appropriateness or otherwise of the assumption that all SPB waste is concentrated into a small volume is related to the issue of waste heterogeneity. If the radioactive waste is in fact distributed throughout the landfill or cell concerned, then this assumption will probably lead to an over-estimation of doses, since these higher concentrations will not be realised in any actual scenario. However, if significant numbers of sealed sources are disposed of within the SPB disposals, the distribution of radioactivity will be heterogeneous, with the inventory concentrated in certain parts of the site. In this case, it is possible that the high concentrations assumed in the calculations could be realised in some actual scenarios.

158. Overall, the assumption of concentrated waste will lead to a maximum for the calculated dose. If risk management measures are implemented through appropriate authorisation conditions (e.g., limiting the activity of sealed sources consigned to SPB sites), then a radiological capacity corresponding to a lower concentration and consequently lower dose could be justified. Radiological capacity and authorisation conditions are discussed in the following Chapter.

Pathways

159. The Assessment Methodology guides the user through defining the exact nature of the exposure pathways associated with the landfill. The potential pathways identified are:

- External irradiation from standing near radioactively-contaminated waste. This pathway will be minimised when the waste is covered, and will then only apply to gamma-emitting wastes.

- Inhalation of contaminated dust. Because SPB waste will be emplaced in sacks and be buried on emplacement, creation of contaminated dust is not considered as an exposure pathway during the normal operation of the landfill[12]. However, deliberate intervention to maintain, remediate or re-engineer the site (including the drilling of boreholes for landfill gas abstraction), or inadvertent excavation during unrelated development of the site after closure, could lead to the creation of contaminated dust.

- Inhalation of aerosols from leachate. Leachate treatment potentially generates aerosols that could be inhaled by workers or members of the public near the site. The spraying of leachate back onto the surface of the landfill is a practice that should be prevented through the PPC permitting process. Aerosols from leachate may, however, be generated during other types of leachate treatment either on or off-site, particularly if this involves aeration. Leachate treatment may continue after closure, but will end at the end of the control period. Use of leachate following the loss of control may also lead to aerosol formation but concentrations are likely to be lower than during leachate treatment.

- Inhalation of dust, particles and gases from fires. Accidental fires in the waste are a potential hazard at landfill sites. A fire at an SPB site could lead to the release of radioactive particles and dust that could be inhaled by workers and members of the

[12] The failure of waste handling procedures is not included because the risks to the potentially exposed workers will be assessed during the establishment of health and safety procedures for handling radioactive materials.

public downwind of the site, and could also lead to some gaseous releases. Waste fires may be associated with the collection and utilisation of landfill gas at sites which accept biodegradable wastes. Gaseous releases of radioactive material from flaring or other use are included in the following pathway.

- Inhalation of radioactive gas, i.e., $^{14}CO_2$, $^{14}CH_4$, ^{3}H, and radon. The first three may be generated through microbial degradation or corrosion of the radioactive waste. Landfill sites which accept biodegradable wastes are required to collect and flare or utilise the gas, and this could disperse radioactive gases that could be inhaled by workers and members of the public downwind of the site. Radon is generated through the decay of Ra-226, which in turn is a decay product of Th-230. Radon could be inhaled by workers, members of the public downwind of the site, and occupants working or living on the site after loss of control.

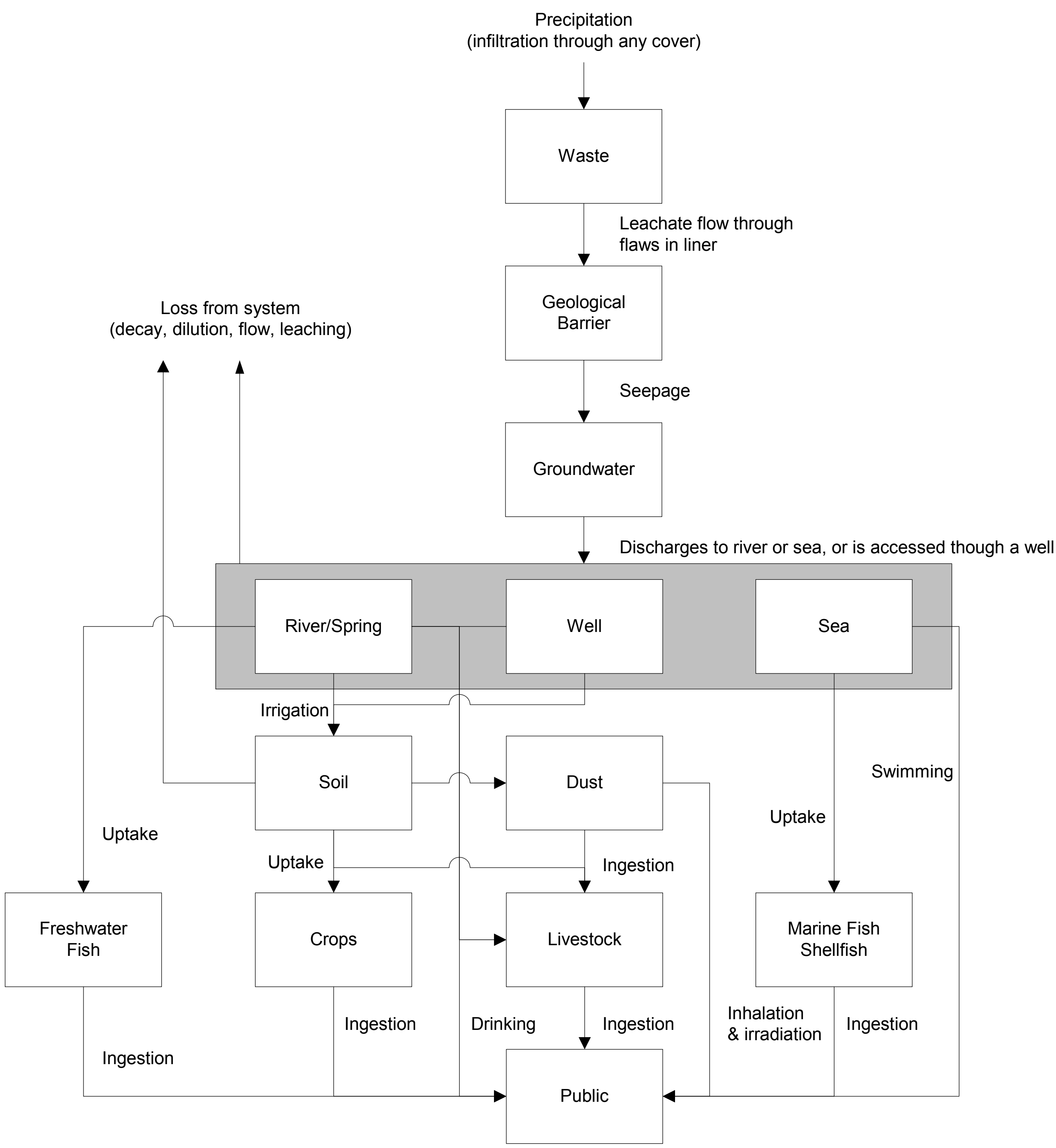
- Ingestion of contaminated water. This pathway arises mainly through the leakage of leachate through the engineering and into groundwater (Figure 5). Once groundwater is contaminated, ingestion can occur through:
  - extraction of contaminated groundwater via a well for drinking; and
  - discharge of contaminated groundwater to surface water used for drinking.

  Surface water may also be contaminated by the unintentional release of contaminated leachate.

- Ingestion of contaminated food. This pathway arises mainly through the leakage of leachate through the engineering and into groundwater. Once in the groundwater, radioactivity can contaminate food supplies through:
  - extraction of groundwater for irrigation, thereby contaminating soil used for farming, or for stock watering;
  - discharge of contaminated groundwater to surface water used for irrigation, thereby contaminating soil used for farming, or for stock watering; and
  - discharge of contaminated groundwater to surface water or marine water that is used for fishing.

  Surface water may also be contaminated by the unintentional release of contaminated leachate, and soil may be contaminated by the lateral discharge of leachate directly from the site after blockage of the drainage system (bathtubbing).

Figure 5: Groundwater exposure pathways for the normal operations and post-closure evolution scenarios in the framework.



- Inhalation of dust from contaminated soil. This pathway arises mainly through the leakage of leachate through the engineering and into groundwater. Once in the groundwater, radioactivity can contaminate soil through:
  - capillary rise of contaminated groundwater into the soil;
  - discharge of contaminated groundwater to surface water and subsequent flooding;
  - extraction of groundwater for irrigation, thereby contaminating soil; and
  - discharge of contaminated groundwater to surface water used for irrigation, thereby contaminating soil.

  Soil may also be contaminated by the lateral discharge of leachate directly from the site after blockage of the drainage system (bathtubbing).

160. In the case of the pathways via contaminated groundwater, the permitted rate of leaking of the leachate and the thickness of the unsaturated zone through which the leachate must pass to reach the groundwater will be different for each landfill, as will the location and use of water resources in the vicinity of the site. The Assessment Methodology will guide the user through identifying and eliminating the relevant pathways.

161. As part of the closure plan, the landfill will be capped. Therefore, creation of aerosols from leachate spraying will cease to be a potential exposure pathway after closure. Conversely, dust inhalation from SPB wastes will not occur during normal operations, but will become a potential pathway if the site is remediated, re-engineered or intruded after closure. The potential for the contamination of groundwater and the subsequent exposure pathways is present throughout the operational and post-closure periods. These may become more significant pathways if the leachate release rate from the landfill increases as the engineering degrades.

Receptors

162. The receptors or critical groups to be considered in the assessments of potential SPB sites are assembled from realistic combinations of the critical habits and average habits of populations living, or likely to be living, in the vicinity of an SPB site. The critical habits are those lifestyles or activities that result in the maximum calculated dose being received from each pathway. The doses from each exposure pathway experienced by an individual are additive. This approach to defining receptors is in accordance with the guidance for dose assessments in Environment Agency et al. (2002).

163. At sites where leachate is treated and discharged off-site, the receptors will be workers and members of the public at or near the treatment plant. However, for the purpose of calculating radiological capacity, the conservative assumption is made that treatment and discharge takes place close to the landfill. This approach allows for the possibility that practices may change in the future and that receptors may be exposed to more than one pathway.

164. For the purposes of assessing potential SPB sites, five groups have been identified, two groups of workers, and three groups comprising members of the public.

- Workers 1. This group comprises workers operating the site during the normal operations phase. The site operators will have the highest occupancy (i.e., period of time spent on the site), and so will receive the highest doses from the exposure pathways associated with the surface of the landfill. For the normal operations scenario, the pathways are external irradiation from the landfill surface, inhalation of aerosols from leachate and potentially inhalation of radioactive gases and dust or particles from fires.

- Workers 2. This group comprises workers engaged in site operations that may lead to the exposure of waste. Pathways include external irradiation from exposed waste and inhalation or ingestion of dust from contaminated material. At sites where there is landfill gas abstraction, this group may be exposed during normal site operations. At all sites exposure may occur during remediation or re-engineering. A group with similar habits may also be involved in inadvertent intrusion of the landfill after closure.

- Public 1. This group comprises members of the public living sufficiently close to the site to be affected directly by site operations. Members of this group may inhale aerosols from leachate treatment and gas from landfill gas utilisation. Spillage of leachate during treatment or handling may contaminate surface water and lead to exposure through ingestion of water or foodstuffs. Fires on the site may lead to exposure of this group through inhalation of dust or particles, ingestion of dust deposited on foodstuffs or irradiation from dust deposited on the ground.

- Public 2. This group comprises members of the public living at the point of groundwater discharge or surface water consumption where they will receive the highest dose associated with contaminated groundwater. Potential exposure pathways include drinking contaminated water, consumption of crops irrigated by contaminated water, consumption of fish and inhalation of dust from soil contaminated by groundwater discharge. The same groundwater pathways and exposed public apply for the normal post-closure scenario and to the failure of barrier and spillage of leachate scenarios.

- Public 3. This group comprises members of the public living on or in close proximity to the site after capping and closure. There are three sets of exposure pathways that could affect this group. The first relates to the continued, normal evolution of the site and comprises inhalation of radioactive gases. The second comprises the ingestion of soil and food contaminated during a bathtubbing incident. These two pathways could potentially occur at any time after closure. The third set of pathways could occur only after loss of control over site use and relates to contamination after an intrusion. It is assumed that the land will be levelled, and that the new soil layer may contain a component of the radioactive waste. Doses are calculated for a member of the public residing on this land and farming it for crops and livestock.

165. For some landfill sites, it is possible that two or more of the public groups may coincide. For example, people residing on the cover of the site after closure (Public 3) may also use groundwater (Public 2).

166. The previous sections have identified the sources, pathways and receptors that have been identified as relevant to the assessment of potential SPB sites. The combinations of these that form the conceptual models for each of the scenarios identified in Section 4.1 are summarised in Table 4.

Table 4: Summary of the different possible source-pathway-receptors considered under the different scenarios in the framework.

Source	Exposure Pathway		Receptor
	Process	Method	
Normal Operations Scenario			
Concentrated waste	Standing in proximity to contaminated waste	External irradiation	Site worker
Concentrated waste	Generation of radioactive gas	Inhalation	Site worker Public near the site
Evenly-distributed waste	Creation of aerosols from leachate management	Inhalation and irradiation	Site worker Public near the site
Evenly-distributed waste	Leakage of contaminated leachate into groundwater	Drinking of contaminated water	Public at the point of groundwater discharge or consumption
Evenly-distributed waste	Contaminated groundwater discharges to surface water	Consumption of water and/or foodstuffs from surface water	Public at the point of groundwater discharge or consumption
Evenly-distributed waste	Contaminated groundwater discharges to sea	Consumption of contaminated seafood	Public at the point of groundwater discharge or consumption
Evenly-distributed waste	Contaminated water used to irrigate soil	Consumption of foodstuffs from contaminated soil	Public at the point of groundwater discharge or consumption
Evenly-distributed waste	Creation of dust from contaminated soil	Inhalation and irradiation	Public at the point of groundwater discharge or consumption

Source	Exposure Pathway		Receptor
	Process	Method	
Normal Operations Scenario – Site with landfill gas abstraction			
Evenly-distributed waste	Creation of dust during site operations	Inhalation	Site worker Public near the site
Evenly-distributed waste	Ingestion of dust and licking fingers during site operations	Ingestion	Site worker
Evenly-distributed waste	Handling and standing next to uncovered waste during site operations	External irradiation	Site worker
Evenly-distributed waste	Dispersed radioactive gases from landfill gas utilisation	Inhalation	Site worker Public near the site
Normal Post-Closure Scenario			
Concentrated waste	Generation of radioactive gas	Inhalation	Public resident and farming contaminated land after intrusion
Evenly-distributed waste	Leakage of contaminated leachate into groundwater	Drinking of contaminated water	Public at the point of groundwater discharge or consumption
Evenly-distributed waste	Contaminated groundwater discharges to surface water	Consumption of water and/or foodstuffs from surface water	Public at the point of groundwater discharge or consumption
Evenly-distributed waste	Contaminated groundwater discharges to sea	Consumption of contaminated seafood	Public at the point of groundwater discharge or consumption
Evenly-distributed waste	Contaminated water used to irrigate soil	Consumption of foodstuffs from contaminated soil	Public at the point of groundwater discharge or consumption

Source	Exposure Pathway		Receptor
	Process	Method	
Evenly-distributed waste	Creation of dust from contaminated soil	Inhalation and irradiation	Public at the point of groundwater discharge or consumption
Failure of Barrier Scenario			
Evenly-distributed waste	Leakage of contaminated leachate into groundwater	Drinking of contaminated water	Public at the point of groundwater discharge or consumption
Evenly-distributed waste	Contaminated groundwater discharges to surface water	Consumption of water and/or foodstuffs from surface water	Public at the point of groundwater discharge or consumption
Evenly-distributed waste	Contaminated groundwater discharges to sea	Consumption of contaminated seafood	Public at the point of groundwater discharge or consumption
Evenly-distributed waste	Contaminated water used to irrigate soil	Consumption of foodstuffs from contaminated land	Public at the point of groundwater discharge or consumption
Evenly-distributed waste	Creation of dust from contaminated soil	Inhalation and irradiation	Public at the point of groundwater discharge or consumption
Spillage of Leachate Scenario			
Evenly-distributed waste	Leachate discharges to surface water	Consumption of water and/or foodstuffs from surface water	Public near the site
Site Remediation / Re-engineering Scenario			
Concentrated waste	Creation of dust from uncovered waste	Inhalation	Site worker Public near the site

Source	Exposure Pathway		Receptor
	Process	Method	
Concentrated waste	Ingestion of dust and licking fingers after contact with the waste	Ingestion	Site worker
Concentrated waste	Handling and standing next to uncovered waste	External irradiation	Site worker
Fire Scenario			
Evenly-distributed waste	Particles in smoke from contaminated waste	Inhalation	Site worker Public near the site
Evenly-distributed waste	Standing in smoke plume	External irradiation	Site worker Public near the site
Evenly-distributed waste	Deposition of particles on land	External irradiation	Public near the site
Evenly-distributed waste	Consumption of foodstuffs from soil contaminated by fire	Ingestion	Public near the site
Bathtubbing Scenario			
Evenly-distributed waste	Leachate rises to surface and contaminates soil	Consumption of foodstuffs from contaminated soil	Public living on and farming contaminated land after intrusion
Evenly-distributed waste	Resident/working on contaminated soil	External irradiation	Public living on and farming contaminated land after intrusion
Evenly-distributed waste	Creation of dust from contaminated soil	Inhalation	Public living on and farming contaminated land after intrusion
Penetration of Waste Scenario			
Concentrated waste	Creation of dust from handled waste	Inhalation	Intruder

Source	Exposure Pathway		Receptor
	Process	Method	
Concentrated waste	Handling and standing next to uncovered waste	External irradiation	Intruder
Concentrated waste	Ingestion of dust and licking fingers after contact with the waste	Ingestion	Intruder
Evenly-distributed waste	Leachate rises to surface and contaminates soil	Consumption of foodstuffs from contaminated soil	Public living on and farming contaminated land after intrusion
Evenly-distributed waste	Resident/working on contaminated soil	External irradiation	Public living on and farming contaminated land after intrusion
Evenly-distributed waste	Creation of dust from contaminated soil	Inhalation	Public living on and farming contaminated land after intrusion

5 Determining Disposal Limits

167. The aim of the framework described in this report is to provide a means for establishing whether particular landfill sites are suitable for the disposal of SPB wastes and for establishing conditions. Each site assessed will have an overall radiological capacity; the amount of radiological material that it can contain and remain within the dose constraint identified as applicable for this type of disposal. This overall radiological capacity is not a unique value, since the mix of radionuclides considered is an important influence on the capacity. The overall radiological capacity is also not necessarily equivalent to the amount of SPB waste that can be disposed of at the site. Calculation of this disposal capacity must also take account of other radiological materials already at the site or that might reach the site in the future.

168. This Chapter describes the theoretical basis of the radiological capacity approach (Section 5.1), sets out the proposed approach for calculating the radiological capacity for potential SPB sites (Section 5.2), and discusses how disposal limits for such sites could be determined (Section 5.3). The types of authorisation conditions that could be considered to enforce and to supplement the disposal limits are discussed in Section 5.4.

5.1 The Radiological Capacity Approach

169. The past few years have seen a debate in the UK over the potential for the use of quantitative methods for establishing operational discharge limits (e.g., McHugh 1997; RWMAC 1998; Environment Agency et al. 2002; DEFRA 2002). During this debate, the nuclear industry has argued in favour of establishing limits based solely on quantitative estimates of environmental impact (e.g., BNFL 1995). Regulatory authorities have, on the other hand, identified the need to consider a wider range of policy and other constraints when establishing discharge limits (e.g., McHugh 1997).

170. In the context of the disposal of radioactive wastes from small users to SPB sites, this wider consideration has led to the adoption of a dose limit analogous to the limit for exemption. By setting appropriate conditions for the emplacement of waste, this means that calculations of radiological capacity can be used to assure the on-going safety of SPB sites without further regulatory control.

171. Determining the radiological capacity from acceptable doses and/or risk limits is termed a back-calculation approach. A recent discussion of this general type of approach in IAEA (2001) describes its possible application to shallow facilities for the disposal of radioactive wastes containing mainly short-lived but also some long-lived radionuclides. The approach described is also designed to apply to both the operational and post closure phases of the disposal facility (IAEA 2001). The theoretical basis is discussed below and its application to potential SPB sites is described in the following section.

172. Briefly, the back-calculation approach involves comparing dose or risk results from safety assessment calculations, conducted in accordance with standard principles and approaches, with appropriate radiological protection criteria. Peak doses (or risks) from a wide range of scenarios are compared with the appropriate dose limit (or risk criterion), and disposal limits are derived in terms of both the total activity (measured in Bq) of each radionuclide that can safely be disposed, and the specific activity (measured in Bq kg^{-1}). This use of specific activities is relevant to specialised disposal facilities, in which the radioactivity is evenly distributed in the waste volume, but is not relevant for SPB disposal where the radioactive waste is only a small proportion of the overall waste volume.

173. To calculate the total activity limit for each radionuclide, IAEA (2001) gives:

$$\text{Total activity limit (Bq)} = \frac{\text{Dose Limit (Sv/y).Waste Activity (Bq)}}{\text{Dose Estimate (Sv/y)}} \qquad (1)$$

with the additional constraint that the total dose from all of the radionuclides must not exceed the relevant dose limit:

$$\sum_z Q_z / Q_{z,l} \leq 1 \qquad (2)$$

where Q_z (Bq) is the actual activity of radionuclide z to be disposed and $Q_{z,l}$ (Bq) is the activity limit for radionuclide z if it were the only radionuclide to be disposed of.

5.2 Calculating Radiological Capacity

Timing of Dose and Grouping of Radionuclides

174. The peak doses and risks from different radionuclides are likely to occur at different times because their properties will cause them to behave differently along the pathways between source and receptor. In the description of the back-calculation approach, IAEA (2001) notes that this difference of timing means that the summation constraint given in equation (2) is likely to be conservative. That is, it will tend to overestimate impacts for a given range of disposed radionuclides or, put another way, tend to yield lower disposal limits than might otherwise be necessary.

175. In order to overcome this drawback, the calculation of radiological capacity for potential SPB sites is undertaken for a number of groups of radionuclides rather than for all radionuclides. These groups are based on the properties of the radionuclides that control when they have most effect on dose. By taking this approach, potentially more activity, composed of dissimilar radionuclides, can be disposed. The following categories have been defined:

- Very short-lived radionuclides (half-lives < 1 year). These radionuclides are only considered in the operational scenarios for exposure through the landfill surface.
- Short-lived radionuclides (half-lives < 3 years) that migrate quickly.
- Short-lived radionuclides (half-lives < 3 years) that migrate slowly. These radionuclides are only considered for exposure through the landfill surface, and are assumed to not enter the groundwater pathway (see below).
- Long-lived radionuclides (half-lives > 3 years) that migrate quickly.
- Long-lived radionuclides (half-lives > 3 years) that migrate slowly.
- Radionuclides with the potential to generate radioactive gases (namely C-14, H-3, Ra-226). These radionuclides are considered for the gaseous pathway, and also for the groundwater and landfill exposure pathways (in one of the above categories according to half-life and retardation).

The Selection of Scenarios

176. The selection of which scenarios to consider in the capacity calculations, i.e., which peak doses to use, is obviously crucial to the results obtained. Certain accident scenarios may have consequences that are too severe for the purpose of setting disposal limits and the IAEA description of the back-calculation approach (IAEA, 2001) suggests, therefore, that disposal limits should be based on the "… limiting case for each radionuclide, i.e., the scenario potentially leading to the highest dose" amongst a limited set of carefully selected scenarios.

177. For determining the overall radiological capacity of potential SPB sites, the results from the normal operation and post-closure evolution scenarios are considered. The scenarios that are not certain to occur are not included. The exposure pathways in some of these scenarios relate only to exposure to a small area of waste and do not reflect the radiological capacity of the entire site. Exposure is also short-lived and the calculation of an annual dose for comparison to the dose limit is meaningless. The results from these scenarios are considered in determining authorisation conditions (Section 5.4).

Non-Linearities

178. The back-calculation approach is based on an assumption that there is a direct linear correlation between the disposed inventory and dose. In other words, it assumes that if the inventory is doubled the dose would also double. However, this assumption does not hold exactly for all the exposure pathways considered.

179. For the groundwater pathway, migration of the majority of radionuclides does not generally occur in a linear fashion. This is due to effects such as kinetics, non-linearity of sorption and colloid processes, co-precipitation and precipitation, and biogeochemical processes. Although these effects mean that the amount of a radionuclide reaching a particular receptor may not have a linear relationship to the source term, the assumption of linearity is likely to lead to an over-estimation of dose.

180. For the gas pathway, peak doses are likely to depend primarily on the rates of gas generation rather than on the amount of radionuclide disposed. Gas generation rates are likely to be controlled by factors such as the supply of water and the biogeochemical conditions prevailing within the disposed waste. Again, however, the assumption of linearity is likely to over-estimate the dose.

181. Overall, therefore, the assumption of linearity is a reasonable one. Where the assumption is not valid, it will lead to an over-estimate of dose for a particular inventory. This in turn will lead to a reduced radiological capacity for a site and hence less material will be authorised for disposal than would otherwise be the case. Adopting the assumption of linearity ensures that a precautionary approach is taken to authorising SPB disposals.

5.3 Determining Disposal Capacity

182. The overall radiological capacity discussed above represents the total amount of radioactivity that a site could contain and remain below the site dose constraint. In the case of a new site, authorisations could be granted for the disposal of SPB wastes up to this capacity. This would depend, however, on there being no other sources of radioactive material going to the site. In the case of existing sites, past disposals must also be taken into account in determining what authorisations could be granted.

183. Apart from authorised SPB disposals, there are two principal sources of radioactive material in landfill sites:

- Exempt wastes. Under RSA 60, a number of waste streams from particular industries and activities were exempt from the requirements for an authorisation. The exemptions continued, with some amendments, under RSA 93, although there are current proposals to consolidate the exemption orders (Thorne and Smith-Briggs 2002). Examples of exempt waste include certain wastes from hospitals, and watches and clocks (in which the tritium, promethium and radium activities are below prescribed levels).

- Very low-level wastes. VLLW with a maximum beta/gamma activity of 400 kBq in each 0.1 m^3 of material (or single items containing less than 40 kBq beta/gamma activity) may be disposed of with ordinary domestic refuse (dustbin disposal). Although these disposals are authorised, and there are general conditions attached on where the waste is consigned, no specific location for disposal is specified.

184. Currently, there is little information about the volumes of these wastes that arise and that need to be considered in assessing the capacity of sites for SPB wastes. There is also little compiled information about the amount of SPB waste that arises or that has already been consigned. In the past, there has been no requirement for small users of radioactive materials to accurately record their arisings, and records from site operators do not accurately record actual disposals. The information that is available relates largely to the authorised limit for disposals. However, few waste producers generate waste up to their authorised limit, and so any estimates based on authorised limits will over-estimate the actual arisings.

185. A review of available information will be undertaken as part of this project. The results of this will be used to determine the extent of the uncertainties involved in estimating inventories and how best to account for these uncertainties in determining capacities and authorisations for SPB wastes. The method adopted will take account of the key principles set out in Chapter 2, including the precautionary principle, but will aim to not be so conservative that future disposals are excluded.

5.4 Setting Authorisation Conditions

186. The disposal of LLW to SPB sites is regulated through authorisations issued to the waste producers, and there is no separate authorisation of the disposal sites. This means that regulatory control must be exercised through authorisation conditions. This section summarises the types of authorisation conditions that could help to minimise the hazard posed by the disposal of LLW in SPB sites, and also help to build confidence in the SPB disposal route. Confidence in the regulatory decisions concerning the use of SPB sites will also be increased if the decisions are fully documented. A summary of the documents generated during the assessment of potential SPB sites is therefore also presented.

Authorisation Conditions

187. A number of standard conditions could be included in each authorisation to ensure that disposals conform with the Agencies' policies for the use of SPB sites. Such conditions should be consistent with conditions in the relevant PPC permit and compatible with practices at the site.

188. Issues to be addressed by authorisation conditions include:

- Rates of radioactive waste disposals to the site should be monitored to avoid enhanced concentrations of radioactive wastes, or "hot-spots", within the landfill, which might result from relatively rapid disposals of radioactive waste at certain times.

- Limits on the activity of single articles may be required to avoid localised concentrations of activity within the landfill.

- Particular waste emplacement campaigns or levels within a site may be deemed to be acceptable, others may not. For example, long-lived radionuclides or sealed sources may require consignment to stabilised waste cells.

- Records of radioactive waste disposals should be available on a regular basis to the regulating agency in order to manage use of the site's radiological capacity.

189. A key uncertainty for the assessment of existing SPB sites is the inventory that has been disposed, both through authorised SPB disposals and through generic authorisations and exemptions. This uncertainty could be reduced for future sites if the regulators or site operators (where they are authorised) maintained records of disposals. This would be most readily achieved through use of a suitable database. Allowance could be made for inputs to a site from several sources and for estimates of the activity associated with historical disposals and non-SPB disposals, and the database used to keep check of the site's remaining capacity.

190. Other issues concerning the design or operation of an SPB disposal site that need to be considered in setting authorisation conditions include:

- The need to authorise disposals to a single disposal site from more than one waste producer.

- The requirements for radiological monitoring activities at and around the site. All potential pathways should be considered in developing a monitoring plan, including gaseous releases where there is utilisation of landfill gas and leachate discharge whether this is treated on-site or off-site[13].

- The need to enforce site practices such as recording emplacement, numbers and responsibilities of staff present during emplacement, the time of day of disposal, weather conditions at the time of disposal, materials covering the waste, waste packages not placed in surface water or leachate, and steps to ensure packages are not inadvertently burst open or damaged by vehicular movement or overburdening.

- To allow for mitigation measures to be considered in setting authorisation conditions, it will be necessary to identify potential measures, their relative costs, and their likely effectiveness in controlling radionuclide releases from a SPB landfill site. Consideration should be given to proposed future end uses of the sites after restoration and whether any restrictions on land use could be included in the set of potential mitigation methods.

Assessment Framework Documentation

191. The output from the framework for assessing the suitability of sites for SPB disposals will be:

[13] Under current RSA authorisation and PPC permitting arrangements, the responsibility for monitoring is likely to lie with the Agencies and the Food Standards Agency through the RIFE (Radioactivity in Food and the Environment) programme rather than with the waste producer or site operator.

- A screening form that presents the basic characteristics of the site in relation to a series of principles for potential suitability for SPB, leading to a decision for further evaluation.

- A summary of the general assessment context that is common to all sites evaluated in the framework.

- Documentation of the site-specific assessment context, including details of the exposure pathways considered, the receptors considered, and the engineering, geological and hydrogeological characteristics of the site.

- Documentation of the site-specific parameter values used to model the exposure pathways.

- The radiological capacity of the site for each individual radionuclide included in the baseline data set, plus any additional radionuclides considered specifically for the site.

- An estimate of any past radionuclide disposals to the site, and an indication of the uncertainty of the estimate.

192. This leaves the combining of the individual radiological capacities and the past disposal estimates to arrive at a decision for future disposals of radioactivity, and the setting of authorisation conditions to ensure that the site conforms to Agency policy regarding SPB and to build confidence in the authorisation process.

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