Geological Disposal

Environmental Safety Case Strategy

December 2012
Geological Disposal
Environmental Safety Case Strategy

December 2012
Conditions of Publication
This report is made available under the NDA Transparency Policy. In line with this policy, the NDA is seeking to make information on its activities readily available, and to enable interested parties to have access to and influence on its future programmes. The report may be freely used for non-commercial purposes. However, all commercial uses, including copying and re-publication, require permission from the NDA. All copyright, database rights and other intellectual property rights reside with the NDA. Applications for permission to use the report commercially should be made to the NDA Information Manager.

Although great care has been taken to ensure the accuracy and completeness of the information contained in this publication, the NDA cannot assume any responsibility for consequences that may arise from its use by other parties.

© Nuclear Decommissioning Authority 2012. All rights reserved.

Bibliography
If you would like to see other reports available from NDA, a complete listing can be viewed at our website www.nda.gov.uk, or please write to the Library at the address below.

Feedback
Readers are invited to provide feedback to the NDA on the contents, clarity and presentation of this report and on the means of improving the range of NDA reports published. Feedback should be addressed to:

Dr Elizabeth Atherton,
Head of Stakeholder Engagement and Communications,
Nuclear Decommissioning Authority (Radioactive Waste Management Directorate),
Curie Avenue,
Harwell Campus,
Didcot,
Oxon,
OX11 0RH, UK
Preface

This report is part of an ongoing programme of work conducted by the Nuclear Decommissioning Authority (NDA) and its contractors, to support the implementation of geological disposal for radioactive wastes in the UK.

Geological disposal is the UK Government’s policy for higher activity radioactive wastes. The principle of geological disposal is to isolate the waste deep inside a suitable rock formation to ensure that no significant quantities of radioactivity reach the surface environment. To achieve this, the waste will be placed in an engineered underground containment facility – the geological disposal facility. The facility will be designed so that natural and engineered barriers work together to ensure that all disposals of solid radioactive waste to facilities on land are made in a way that protects the health and interests of people and the integrity of the environment at the time of disposal and in the future, inspires public confidence and takes account of costs. In line with accepted international best practice, the NDA plans to use a multi-barrier concept for geological disposal of higher activity radioactive wastes. These wastes include high-level waste (HLW), spent nuclear fuel, intermediate-level (ILW) and certain low-level (LLW) radioactive wastes.

Engineered barriers will be provided by the wasteforms themselves, the containers in which they are packaged, any surrounding backfill or buffer and the mass backfill and seals used to close the facility. Natural barriers will be provided by geological formations that surround the underground facility and that lie between it and the accessible human environment.

At the current stage of the programme the location of a geological disposal facility has yet to be decided. Since the disposal facility designs will be tailored to the geological setting of the disposal facility, this means the disposal designs are also yet to be decided and we are currently working with illustrative, generic design examples.

This document sets out our strategy for understanding, assessing and building confidence in the long-term environmental safety of a geological disposal facility. It describes our strategy for developing a robust Environmental Safety Case (ESC) following a staged approach linked to the geological disposal development programme and associated permits necessary to investigate sites and ultimately to construct and operate a geological disposal facility in the UK.
Executive Summary

Developing an environmental safety case (ESC) is an important and challenging part of the programme to implement geological disposal for higher activity radioactive wastes. An ESC will need to provide confidence that a geological disposal facility (GDF) will remain safe for hundreds of thousands of years after it has been closed and is no longer actively maintained.

Our approach for building confidence in long-term safety is to use multiple barriers to isolate and contain the wastes and to explain our confidence in the performance of these barriers by developing a multi-factor safety case. We will develop a safety case based on varied and different lines of reasoning, including both quantitative aspects and qualitative arguments. We will use a range of safety arguments to support the ESC, drawing on underpinning science and engineering. This will include considering a range of performance indicators and making use of analogues where appropriate.

We have developed a generic ESC (that is not specific to any site or disposal facility design) that considers the long-term safety of illustrative generic disposal facility design examples in stylised geological environments. The generic ESC explains how engineered and natural barriers can work together to isolate and contain the radioactivity in the wastes. The safety arguments in the generic ESC are supported by calculations using a simple model of the engineered barriers and the geological environment. This model is illustrative of a broad range of disposal facility designs and geological environments. The generic ESC provides a benchmark enabling us to undertake disposability assessments for waste packages, without foreclosing potentially suitable GDF locations or designs.

As we progress through the Managing Radioactive Waste Safety (MRWS) site selection process we will start to develop site-specific understanding of potential sites. Progressive development of our “evidence based conceptual understanding” of sites, leading to a site descriptive model and ultimately to a site-specific ESC will provide us with management tools to help us develop work programmes focused on those areas most important to building confidence in the safety of a GDF and those issues raised by the regulators and Community Siting Partnerships. We will also need to submit site-specific ESCs for regulatory approval at key stages in the geological disposal programme. The first stage at which a formal site-specific ESC will be required is to obtain permission to construct a GDF after initial underground operations. This will be the “initial ESC”. A subsequent, more detailed, ESC will be required to obtain permission to place wastes in the GDF.

A site-specific ESC in support of an application for an environmental permit for disposal of radioactive waste at a specific site will be a substantial submission and will need to demonstrate understanding of:

- the geology, hydrogeology, geochemistry, geotechnical characteristics and surface environment of the chosen site and its setting;
- the characteristics of the waste including its radionuclide and materials content, treatment and packaging;
- the design and layout of the disposal facility, including the design of the engineered barriers and how the facility will be constructed, operated and closed;
- the basis for, and output from, computer-based models of the performance of the disposal system and its components; and
- semi-quantitative and qualitative supporting evidence that builds confidence in our claims for environmental safety.

Our approach for developing a site-specific ESC that demonstrates sufficient understanding and confidence in the performance of a proposed GDF can be summarised by a number of Strategic Principles, as follows:
• **Building confidence in the safety cases**: Confidence in the ESC post-closure safety case will be built by applying a multi-barrier concept, the internationally accepted approach to geological disposal.

• **Parallel generic and site-specific safety cases**: We will develop the site-specific ESC(s) as a parallel and separate work-stream to the generic ESC, rather than evolve the generic ESC into a site-specific ESC. This strategy ensures that we have an RWMD-approved benchmark safety case whilst developing the site-specific ESC.

• **Continued maintenance of the generic safety cases**: We will continue to use and maintain the generic ESC as a living suite of documents as we progress through the MRWS site selection process, until such time as we have sufficient confidence in the site-specific ESC and we judge that we no longer require a generic ESC. This strategy enables us to allow for the possibility of additional, alternative sites being put forward for consideration and to continue to undertake disposability assessments that encompass a broad range of potential disposal facility designs until such time as the site-specific GDF construction programme and associated safety case is sufficiently well-established.

• **Iterative development of the site-specific safety cases (closely coupled to needs-driven research, site characterisation, disposal system specification and engineering design programmes)**: As information is gathered from these programmes and analysed in the ESC (and other parallel safety assessments), the ESC will be able to feed understanding back to research, site characterisation, disposal system specification and engineering design activities, guiding them to focus their next steps on those areas where increased understanding will be of most benefit to the evolving safety case.

• **Presentation of complementary environmental safety arguments**: In line with regulatory guidance and the accepted international approach we will demonstrate our confidence in geological disposal making use of multiple lines of reasoning based on a variety of evidence, both qualitative and quantitative. This approach will enable us to present complementary environmental safety arguments.

• **Development and testing of understanding of a GDF system and its evolution over long timescales under a comprehensive range of representative scenarios through computer modelling**: We will follow a rigorous and systematic process to developing and testing our understanding of the long-term performance of a GDF, linked to the needs-driven research, site characterisation and engineering design programmes. We will develop a hierarchy of computer models to represent our understanding and iteratively test and refine these models in the light of the developing understanding from the needs-driven research, site characterisation and engineering design programmes.

• **Demonstration of our understanding of the uncertainties relevant to safety assessment**: Confidence in the ESC will require demonstration that outstanding uncertainties significant to the ESC can be appropriately managed so there is confidence in overall safety. We will adopt an appropriate approach to the treatment of uncertainty at each stage of ESC development activities, noting that:
  - It is neither possible nor necessary to eliminate all uncertainties.
  - The types and extent of uncertainty are expected to change as the geological disposal programme progresses.
  - Where outstanding uncertainties can be quantified they will be explicitly included in ESC calculations (e.g. via appropriate parameter ranges). Where significant uncertainties cannot be quantified, they will be
acknowledged and treated appropriately (e.g. through consideration of potential alternative conceptual models and scenarios).

- Both qualitative and quantitative arguments can be used to address uncertainty.

The first four Strategic Principles are applicable to all our safety case strategies (ESC Strategy, Operational Safety Strategy and Transport Safety Strategy), the last three are specific to the ESC.

In order to achieve confidence in the strategy and the resulting generic and site-specific ESCs, we will undertake the following activities:

- Ensure all data used in the ESC are fit for the purpose for which they are being used and maintain traceability of data by developing and maintaining appropriate databases.
- Follow a systematic approach to identify all relevant features, events and processes that have the potential to affect the initial state of a GDF (i.e. the state of the GDF immediately following backfilling, sealing and closure) or its evolution over long timescales.
- Develop conceptual models which can be tested against site data and verify that these are correctly implemented in software. To achieve this we will develop and maintain intelligent user modelling capability throughout the geological disposal programme, i.e. we will ensure that all staff employed in developing and using models have appropriate qualifications and experience and a firm understanding of the processes being modelled and the expected results of the calculations.
- Test software models against independent data, not used in developing the software models, wherever practicable.
- Apply version control and use only the latest published versions of the ESC (generic and/or site-specific as appropriate) when undertaking any assessments for external release and apply a rigorous change control process prior to accepting any updated components of the ESC.
- Develop clear ESC hierarchical documentation that is suitable for all stakeholders at key stages in the decision-making process.
- Subject ESC-related documents to review throughout their development in accordance with RWMD's procedures and, when appropriate, to a final independent peer review as part of our publication process.
- Maintain consistency with other relevant RWMD strategies, including the RWMD technical strategy, R&D strategy, environmental and sustainability appraisal strategy, procurement strategy and public and stakeholder engagement (PSE) strategy.

This strategy is consistent with regulatory guidance and international practice.

In producing site-specific ESC(s) we will draw on previous experience in the UK and the substantial experience of disposal agencies overseas. The latter have experience in developing safety cases at different stages, from siting strategy, through site evaluation, to the preparation of a detailed safety case to support a GDF licence application. Our focus is on developing and testing our understanding of the components of a GDF, and how they interact and evolve over time. This understanding will be acquired from information from our research, site characterisation activities and design development work, and our analysis of that information using computer models. As our understanding develops, we will be able to develop the methodological aspects of our ESC strategy, including our modelling strategy for the particular GDF site and design.
## List of Contents

**Preface**  
iii  

**Executive Summary**  
v  

1  **Introduction**  
1.1 Background  
1  
1.2 Purpose of this report  
2  
1.3 Scope of this report  
3  
1.4 Overview of subsequent sections  
4  

2  **Context**  
5  
2.1 Purpose of the ESC  
5  
2.2 Permissions schedule  
6  
2.3 Provisional implementation plan for a GDF  
6  
2.4 Environmental safety during the operational period  
7  

3  **Our overall ESC strategy**  
8  
3.1 Approach to building confidence in a long-term safety case  
8  
3.2 Role of generic and site-specific ESCs  
10  
3.3 FEP Analysis and conceptual models  
11  
3.4 Computer modelling in the ESC  
13  
3.5 Underpinning reports  
19  
3.6 Summary of our ESC Strategy  
19  

4  **Development of the generic ESC in the early stages of the MRWS site selection process**  
23  
4.1 Stage 1: Invitation issued and Expression of Interest from communities  
23  
4.2 Stage 2: Consistently applied ‘sub-surface unsuitability’ test  
23  
4.3 Stage 3: Community consideration leading to Decision to Participate  
23  
4.4 Where we are now  
23  
4.5 The generic ESC  
24  
4.6 The generic Post-closure Safety Assessment  
26  

5  **Strategy for the development of the ESC in MRWS Stage 4 and beyond**  
29  
5.1 ESC strategy in Stage 4 of the MRWS site selection process  
29  
5.2 ESC activities in Stage 5.1 of the MRWS site selection process  
31
<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.3</td>
<td>ESC activities in Stage 5.2 of the MRWS site selection process</td>
<td>33</td>
</tr>
<tr>
<td>5.4</td>
<td>ESC Activities in Stage 6 of the MRWS site selection process</td>
<td>36</td>
</tr>
<tr>
<td>6</td>
<td>Links to other GDF development activities</td>
<td>39</td>
</tr>
<tr>
<td>7</td>
<td>Concluding remarks</td>
<td>42</td>
</tr>
</tbody>
</table>
1 Introduction

1.1 Background

As part of its Managing Radioactive Waste Safely (MRWS) programme, the UK Government issued a White Paper in June 2008 setting out a framework for implementing geological disposal of the UK’s higher activity radioactive waste [1]. This White Paper sets out various requirements on the Nuclear Decommissioning Authority (NDA), which is responsible for planning and implementing geological disposal in the UK. (Note, Scotland is excluded from the MRWS site selection process as the Scottish Government has published a separate policy for higher activity waste arising in Scotland [2].) The NDA has set up the Radioactive Waste Management Directorate (RWMD) which it plans to develop into an effective delivery organisation to implement a safe, sustainable and publicly acceptable geological disposal programme. In this document, we use the terms ‘we’ and ‘our’ to refer to RWMD.

Our programme to implement geological disposal is framed by an approach based on voluntarism and partnership as a means of siting a geological disposal facility (GDF). To support this approach we have developed a long-term project for implementing geological disposal [3] with a number of key phases of activities. The phases of activities align to the MRWS site selection process and the schedule of the various decisions and permissions that are required for the geological disposal programme, such as those made by the regulatory bodies (see Figure 1). We are currently in the “preparatory studies” phase of the programme indicated in Figure 1.

We have adopted a staged approach to develop safety cases to support the appropriate stages of the MRWS site selection process. These safety cases will consider transport safety, construction and operational safety, and environmental safety, and together form the Disposal System Safety Case (DSSC).

As part of the preparatory studies phase we have developed a generic DSSC to provide information and confidence in the safety of generic geological disposal systems suitable for a range of UK host geologies for the Baseline Inventory (as set out in the White Paper [1]) for intermediate-level waste (ILW), high-level waste (HLW) and spent fuel (SF) and other nuclear materials that may require disposal. The generic DSSC also provides the basis for disposability assessments of proposals from waste producers for packaging wastes under the Letter of Compliance (LoC) disposability assessment process.

The generic DSSC consists of an overview report describing the safety of a GDF [4] and three key documents, one for each of the three components of the overall safety argument – the generic Transport Safety Case (TSC) [5], the generic Operational Safety Case (OSC) [6] and the generic Environmental Safety Case (ESC) [7]. It is further supported by assessment reports, research status reports, disposal system specification, inventory and design reports.

This document describes our strategy for developing the ESC which will demonstrate our confidence in environmental safety in the period after closure of a GDF. Equivalent strategies have been or are being developed for the other safety cases and related work streams, including our site characterisation strategy, R&D strategy, strategy for sustainability appraisal and environmental impact assessment and communication and stakeholder engagement strategy. Together, these strategies feed into our overall RWMD Technical Strategy [8], to support Government policy.
1.2 Purpose of this report

The purpose of this report is to set out our strategy for developing the ESC as the geological disposal programme progresses. Our current version of the ESC is generic, as is appropriate at this early stage before a site (and hence a GDF design) has been selected. For this generic ESC we chose an approach that represents the hydrogeological setting in a way that would be widely applicable in the UK. The generic ESC is supported by two quantitative assessments: the generic Operational Environmental Safety Assessment (OESA) [9] and the generic Post-closure Safety Assessment (PCSA) [10]. The Operational Environmental Safety Assessment will be developed following standard practice for nuclear plants, and will be updated based on site-specific considerations as the GDF programme is implemented. The key challenge for the development of the ESC resides with the post-closure assessment and therefore this report is limited to consideration of the strategy for developing the post-closure aspects of the ESC. Our strategy for addressing environmental safety during the operational period of the GDF is described within our Operational Safety Strategy¹ and described briefly in section 2.4.

¹ We expect the Operational Safety Strategy to be published in 2013.
The generic ESC has been produced as a platform for use throughout all stages of the MRWS site selection process where a generic approach is required. As we start to obtain understanding about possible sites for a GDF, we will start to develop a site-specific ESC (or ESCs). In MRWS Stages 4 and 5, the site-specific ESC will largely be to inform and develop our own understanding of the site and we expect this understanding to evolve as more information about the site(s) becomes available. There is no regulatory requirement for us to produce an ESC at these Stages. However, to obtain the necessary permit for starting intrusive site investigations, such as drilling bore holes, we will need to submit an acceptable Initial Site Evaluation (ISE) to the environmental regulator. Although the ISE may draw upon understanding from the evolving site-specific ESC, it is important to recognise that the ISE is a separate and specific submission that will need to be developed in accordance with future regulatory guidance to applicants for an environmental permit for intrusive investigation work. Likewise, we will also use the evolving site-specific ESC to inform development of a Preliminary Environmental Safety Evaluation (PESE) that will be required to obtain a permit to start underground operations to confirm a site’s suitability to host a geological disposal facility (MRWS Stage 6).

The site-specific ESC will provide an evolving collation of understanding and safety arguments that will enable us to assess our level of confidence to progress to the next stage of development and will be used to inform decisions, work programmes and regulatory submissions during MRWS Stages 4 and 5. We expect to submit the first site-specific ESC to the environmental regulator during MRWS Stage 6 as part of the environmental permitting process that we will follow in order to construct and operate a GDF. The site-specific ESC will then continue to be developed and updated to support the required regulatory submissions until such time as the GDF permit is surrendered.

This report describes our strategy for developing the site-specific ESC throughout the GDF development programme and for maintaining a generic ESC until such time as it no longer needed.

1.3 Scope of this report

This report describes our strategy for the development of the ESC, and sets out the rationale that underpins it, rather than explaining the detailed processes for producing an ESC. As a strategic document, this report is expected to be relevant for some years into the MRWS process. More detail on the overall methodological aspects of our approach to developing the long-term safety case to demonstrate confidence in geological disposal is available in our generic ESC main report [7] and the underpinning PCSA [10]. As our programme develops, details on the practical implementation of the methodologies, including procedures for data handling, model verification, etc. will be published in our developing ESC Manual.

We anticipate that other documents describing detailed components of ESC development, for example our modelling strategy, will be developed to support the ESC as the geological disposal programme progresses. Such documents will be produced and updated as required. We are also developing our approaches to improving our understanding and representation of specific aspects of the ESC, for example chemotoxic and non-radiological assessments, treatment of the biosphere, including climate change, gas generation and migration, the significance and treatment of colloids in the safety case and the treatment of human intrusion. These and other specific areas are being addressed through tailored research and international collaboration projects. Many of these issues are site-specific and hence will be included in the site-specific ESC at the appropriate stage, but are not discussed further in this report.

Where relevant, we have referenced NDA RWMD documents that provide information on other aspects of the overall strategy to deliver a GDF. However, in order to maintain a
focus in this report on our strategy for developing the ESC, we have not duplicated or reiterated material that is already reported elsewhere.

This strategy document is limited to consideration of the post-closure aspects of the ESC. The strategy for demonstrating environmental safety during the operational period is covered by the companion Operational Safety Strategy.

1.4 Overview of subsequent sections

Section 2 – Context
Section 2 gives some context for the strategy for developing the ESC. We explain the role and purpose of an ESC, discuss the regulatory context, and introduce the regulatory guidance which the ESC is designed to address. We present the ‘Permissions Schedule’ – the steps at which various submissions and permits will be required, and we explain our provisional implementation plan for a GDF and how this links to the MRWS site selection process.

Section 3 – Our overall ESC strategy
This section explains our overall strategy for developing the ESC and the tools that support it. The specific strategic requirements on the ESC at each stage of the MRWS site selection process are then set out in more detail in the following sections.

Section 4 – Strategy for development and role of the generic ESC in the early stages of the MRWS site selection process
This section explains how we reached the current position of developing the generic ESC and discusses the strategy for the ongoing role and development of the generic ESC.

Section 5 – Strategy for stepwise development of the ESC in MRWS Stage 4 and beyond
In this section, we expand on our ESC strategy for each of the forthcoming stages of the MRWS site selection process, Stages 4, 5 and 6. We discuss what is required of the generic and site-specific ESCs at each stage and the strategy for delivering them.

Section 6 – Links to related GDF work programmes
This section summarises how the strategy for the development of the ESC is part of the overall Technical Strategy for a GDF and how the ESC is linked to other GDF development activities. We explain how the site-specific ESC(s) will be iteratively developed as a site characterisation programme progresses, and how the ESC will be used to provide feedback on research needs, data requirements from site characterisation, disposal system specification and design requirements.

Section 7 – Summary
This section summarises the way forward for developing the generic and site-specific ESC.
2 Context

The implementation of a geological disposal facility (GDF) for higher activity radioactive wastes in the UK requires us to demonstrate our confidence that such a facility would be safe, during both the operational period and after the facility has been sealed and closed. The Environmental Safety Case (ESC) is the vehicle we use to demonstrate our understanding of environmental safety.

The environmental regulators have issued guidance on what they require to permit the development of a GDF, known as the Guidance on Requirements for Authorisation (GRA) [11]. The GRA defines ‘environmental safety’ as

“The safety of people and the environment both at the time of disposal and in the future.”

and an ESC as:

“The collection of arguments, provided by the developer or operator of a disposal facility, that seeks to demonstrate that the required standard of environmental safety is achieved.”

An ESC needs to address the principles and requirements set out in the GRA. The guidance provides a set of criteria, both numerical and qualitative, against which the environmental safety of a GDF will be assessed during the operational and post-closure periods.

An ESC needs to consider environmental safety both during the period when an environmental permit is held, and in the long term, after a GDF is closed. As noted earlier, this strategy is focussed on the approach to demonstrating environmental safety for the latter period when the GDF is closed, the ‘post-closure’ period. Our strategic approach for the operational period when an environmental permit is held is briefly summarised in Section 2.4.

The UK regulatory guidance is consistent with international guidance on the preparation and content of a safety case for radioactive waste disposal facilities, including guidance from the International Atomic Energy Agency (IAEA) [12] and the Nuclear Energy Agency (NEA) [13].

2.1 Purpose of the ESC

The ESC will support a range of key activities in the implementation of geological disposal in the UK. For example, it will:

- demonstrate viability, and ultimately safety, of the proposed disposal approach;
- support the environmental permitting process, based on the Environmental Permitting (England and Wales) Regulations 2010 (EPR) [14];
- support dialogue during the MRWS site selection process, including public and stakeholder engagement (PSE);
- integrate and analyse information in a technical assessment that guides research, design and site characterisation programmes during the MRWS site selection process;
- support the Letter of Compliance disposability assessment process enabling production of waste packages which are consistent with the safety case requirements of the engineered barriers (i.e. wasteform and waste container);
- support and inform the specification, development and design of appropriate disposal facility design options for the sites under consideration in an iterative development process, as described in Section 6; and
support implementation of NDA and Government strategy, including optioneering throughout the nuclear fuel cycle.

### 2.2 Permissions schedule

With the objective of ensuring effective coordination of permissioning, we have developed the Permissions Schedule for Geological Disposal of Higher Activity Radioactive Waste (“the Permissions Schedule”). This has been undertaken in consultation with regulators, Government departments, the devolved administrations and representatives of local government in England [15].

The Permissions Schedule sets out what is expected throughout the stages of the MRWS site selection process, in terms of:

- regulatory submissions to be made by NDA’s delivery organisation;
- assessments to be made by regulatory organisations; and
- permissions NDA’s delivery organisation will need to obtain.

The Permissions Schedule covers the regulatory disciplines of:

- environmental protection (including radiological environmental protection and trans-boundary pollution);
- safety (including provision for third-party claims and liability);
- land-use planning (including supporting environmental assessment work);
- transport safety;
- nuclear security; and
- non-proliferation (nuclear safeguards).

Certain non-permissioning activities associated with the site selection process, particularly those involving regulators, are included within the scope of the Permissions Schedule.

It is intended that the Permissions Schedule will remain a ‘live’ document, to be updated periodically as the MRWS site selection process proceeds, to reflect changes to legislation and regulatory requirements, and the permissioning implications of site selection decisions.

The Permissions Schedule is intended to assist in the management of the complexities of the multiple interactions between NDA RWMD, Government, regulators and communities, and to help coordinate the various decision making processes. The Permissions Schedule is not intended to consider in detail the role of local Decision Making Bodies in deciding, at key points within the process, whether to continue participation or exercise a right of withdrawal, as these considerations are separate from regulatory permissioning processes.

As we do not yet have an agreed site for a GDF, our work is being carried out initially on the basis that geological disposal could be implemented in any region of the UK, noting that Scotland is currently not participating in the MRWS site selection process. The Permissions Schedule has therefore been prepared to be applicable throughout the UK. The exception to this is the environment related permission(s) needed for the disposal of radioactive waste where different legislation exists in different parts of the UK, and the Permissions Schedule is aligned with the situation in England and Wales.

### 2.3 Provisional implementation plan for a GDF

A number of uncertainties are inevitably present at this early stage of the planning process, involving the nature and quantities of the wastes for disposal, the geological setting and, related to this, geological facility design. As we are following a volunteer site selection
process in which we are working in partnership with local communities, there is also uncertainty concerning the time required for deliberations to enable key decisions to be made, for example decisions by local communities at key stages of the site selection process or decisions by regulatory bodies variously on land-use planning, health and safety, or environmental protection matters.

In order to be able to plan and to provide certain sorts of information in the light of this level of uncertainty, we have developed a reference case geological disposal programme. This programme provides both a basis for our planning and a framework for formal and transparent control of significant changes to the programme as it evolves. We also use the reference case programme to support the information on implementation of geological disposal that we provide to the UK Government and other interested parties.

The lifecycle of the reference case geological disposal programme can be described for planning purposes as five phases, as shown in the stylised programme in Figure 2. The overlapping construction and underground-based investigation and operation phases will almost certainly represent a high proportion of the overall programme timeline, however the figure is purely illustrative and the relative proportions of time shown for each phase purely reflect our reference planning assumptions about the duration of each phase, based on the assumption of first emplacement of ILW in 2040.

For more information about our provisional programme see sections 6 and 7 of [3].

2.4 Environmental safety during the operational period

GRA requirements R5 and R9 [11] set out requirements for dose constraints that should be applied to individuals (R5) and for assessments of the radiological effects on the accessible environment, during “the period of authorisation” (R9). We interpret this to be equivalent to the operational period when the GDF is subject to an environmental permit issued under the Environmental Permitting Regulations [14].

Our Operational Safety Strategy (OSS) will set out our approach to activities and assessments that address GDF nuclear and non-nuclear hazards across its operational lifetime, including the periods of construction, commissioning, operations and decommissioning/ closure. In addition to on-site hazards, the OSS will also cover the approach to activities and assessments that address off-site hazards due to radiation shine and operational discharges (aerial, liquid and solid) which may impact members of the public or the environment. Activities to address environmental safety issues to meet GRA requirements during the period of authorisation (or using the updated terminology during the period that an environmental permit is held) will be covered by the Operational Safety Strategy. In line with regulatory expectations, the results of our work which address GRA requirements R5 and R9 will be reported to the Environment Agency as part of our environmental permit application.
3 Our overall ESC strategy

In this section we discuss our overall strategy for developing the ESC (hereafter when we refer to the ESC we mean that component that addresses the post-closure phase) and the tools that support it. Specific details on the strategic requirements at each stage of the MRWS site selection process are then given in Sections 4 and 5.

3.1 Approach to building confidence in a long-term safety case

The most challenging aspect of the ESC is building confidence in the long-term (post-closure) safety case. We need a strategy to demonstrate that a GDF will remain safe and will isolate and contain the wastes, with no significant impact on the environment and no requirement for active intervention, over timescales of hundreds of thousands of years, or longer. Over such timescales there will inevitably be uncertainties regarding the evolution of a GDF and its surrounding environment. These uncertainties will be greatest over the longest timescales: however, the process of radioactive decay means that the hazard presented by the wastes decreases as time passes. During the early timescales, when the wastes are the most hazardous, we have the most confidence in the containment properties of a GDF. The ESC needs to explain how uncertainties have been managed and why we can have confidence in the safety case over all timescales.

The intrinsic safety of a GDF is provided by using a multi-barrier concept in which a series of engineered and natural barriers work together to isolate the wastes and contain the radionuclides associated with the wastes. This is the internationally accepted approach to geological disposal [13]. The typical barriers found in a multi-barrier geological disposal concept include:

- the waste form – i.e. the form in which the waste is disposed, including any necessary conditioning of the waste to make it suitable for disposal;
- the waste container – a physical barrier to contain the waste;
- buffer or backfill – material placed immediately around the waste containers in a GDF;
- mass backfill – material filling the excavated access tunnels, shafts or drifts in a GDF;
- sealing systems – complementing the mass backfill, low permeability materials that control the movement of fluids along the previously excavated access tunnels, shafts or drifts;
- the natural geological barrier – comprising the host rock in which the GDF is constructed and the surrounding rocks. The geological barrier provides long-term isolation of the wastes, containment of radionuclides and protection of the engineered barrier system.

These barriers provide complementary safety functions that support the overall safety functions of isolation and containment of the wastes. The ESC needs to demonstrate confidence that these safety functions can be achieved through appropriate design and siting of a GDF, and that the safety functions will be maintained at a sufficient level to satisfy the safety requirements throughout the lifetime of a GDF.

In line with the accepted international approach for demonstrating this confidence, we will present multiple lines of reasoning, including a range of complementary safety arguments, supported by both qualitative and quantitative evidence. Provision of multiple lines of reasoning, supported by both qualitative and quantitative evidence, is a regulatory expectation for an ESC (see paragraph 7.2.7 of [11]).

In line with the accepted international approach for demonstrating this confidence, we will present multiple lines of reasoning, including a range of complementary safety arguments, supported by both qualitative and quantitative evidence. Provision of multiple lines of reasoning, supported by both qualitative and quantitative evidence, is a regulatory expectation for an ESC (see paragraph 7.2.7 of [11]).
This dual approach, of multiple barriers providing complementary safety functions and the use of multiple lines of reasoning to demonstrate our confidence in safety, means that our safety case is not reliant on any single factor (whether that be a particular barrier or aspect of the design or a particular piece of research or set of calculations). We refer to this as a 'multi-factor' safety case. The fact that our claims for the long-term safety of a GDF are supported by multiple factors gives the safety case 'strength in depth'.

Safety arguments will draw upon underpinning science and engineering that provide the evidence for our understanding of the properties of the various components of a GDF and its geological setting. We undertake research and site characterisation activities to provide data which, when processed into information, expand our knowledge base and understanding. It is important that our research is of high quality and trusted by ourselves and our stakeholders. All the work that we commission is specified and carried out following a formalised quality management system, which is certified to the ISO9001 standard. We also require that our suppliers are certified to ISO9001 standard, or can demonstrate that they operate within the framework of an equivalent quality management system, in line with our R&D Strategy [16]. Where appropriate, we commission external experts to provide independent peer review of research delivered by our suppliers, to build confidence in its quality.

It is important that we have access to the widest possible information sources, and in some cases it will be appropriate to use research or literature produced by third parties, not commissioned by ourselves, which may or may not have been produced under an appropriate quality regime. The quality of all such information will be taken into consideration when deciding how the information should be used and presented in the ESC.

As we integrate information from research and site characterisation activities into the developing ESC and improve our understanding of the characteristics and performance of the GDF system\(^2\), we will use the ESC to identify where further information is required to improve our confidence in the long-term safety of a GDF. For example, we will identify where there are still uncertainties in our knowledge and analyse which uncertainties have the greatest impact on our confidence in the ESC. We will then use this to prioritise the next steps in the research and site characterisation work programmes. Likewise, as the design of the engineered barriers is developed, we will represent and test this in the ESC and feed back understanding that will eventually lead to the optimisation of the disposal system specification and design. In this way, the ESC will be developed iteratively, closely coupled to needs-driven research, site characterisation and engineering design programmes. Each iteration is aimed at increasing our understanding of a GDF and its potential evolution and our confidence in that understanding.

We can also obtain evidence to support our confidence in our understanding of the long-term evolution of a GDF by making comparisons of the GDF system, or components of the GDF, with natural analogues. For example, studying uranium-ore deposits can provide information on the role of the natural barrier in isolating and containing uranium for long periods. Additionally, the materials we are considering using in our GDF engineered barriers may be the same as or very similar to materials that people have been using for a long time. This means we can use observations of archaeological artefacts of similar materials to build confidence in our understanding of GDF barrier performance.

Analogues can be helpful in demonstrating understanding of aspects of GDF performance and provide evidence that certain materials can survive for long periods. However, they do

---

\(^2\) In this report, where we refer to the ‘GDF system’ we mean the waste packages, the underground excavations and engineered barriers and the relevant surrounding geological and surface environments.
not provide conclusive proof that these materials will survive for the required periods in the environment of a particular GDF, as the conditions under which the analogue material has survived may not match those expected to occur or evolve in a GDF. Therefore, analogues will be used with caution, and can only ever provide supporting arguments in an ESC. Nevertheless, appropriate analogues can be helpful in providing a long-term practical demonstration to support the theoretical and mathematical safety arguments.

Further details of our approach to building confidence in a long-term safety case are given in the ESC main report [7].

### 3.2 Role of generic and site-specific ESCs

At present, no specific sites for a GDF have yet been identified in the UK. We have therefore developed a generic ESC, which explains in principle why we have confidence in the environmental safety of a GDF, and describes a range of possible geological environments and illustrative generic design examples.

As more information about the nature of a potential disposal site becomes known, we will start to develop an ESC based on site-specific information. However, the generic ESC will continue to have a role whilst a site-specific ESC is developed and will be maintained as a living suite of documents\(^3\). We propose to maintain a schedule of generic safety case documents that will list the current version of each document within the generic DSSC suite. Individual safety case documents will be updated or replaced, as required, and new documents may be added, for example a document explaining any implications of inventory changes. At any given time, the safety case schedule will clearly define what constitutes the current, approved generic ESC. This generic ESC will continue to be used as the basis for disposability assessments of waste packages so that disposability assessments encompass a broad range of potential disposal facility designs. At some future point, when there is sufficient confidence in the site-specific ESC, a decision will be taken that the generic ESC is no longer required.

Our strategy for developing the ESC therefore envisages two parallel and separate work streams for much of the future stages of the MRWS site selection process – the generic ESC and the site-specific ESC. Each work stream would lead to a set of living safety case documents that would be updated as the geological disposal programme progresses to reflect our increasing knowledge base and understanding of the environmental performance of a GDF.

During the site characterisation and construction stages, interim results from both the generic and site-specific ESCs would be fed into the site characterisation, research, disposal system specification and engineering design work programmes so that these are focussed on identified information needs for the requirements for long-term safety.

At appropriate stages, information from the generic and site-specific ESCs would be used to produce the required safety case submissions to support the MRWS site selection process and the regulatory permissions process. More detailed information on the proposed development of both the generic and site-specific ESC during the various stages of the MRWS site selection process is given in Section 5.

---

\(^3\) The Office for Nuclear Regulation uses the term, ‘living document’ in relation to nuclear operational safety cases to mean that the document is subject to review, change and amendment as time proceeds (T/AST/051, Guidance on the Purpose, Scope and Content of Nuclear Safety Cases). Similarly, by a ‘living’ suite of documents, we mean that specific documents within the generic ESC will be updated, as required, to reflect our expanding generic knowledge base and that the generic ESC will be used to undertake disposability assessments and guide our work programmes to expand the knowledge base where appropriate.
3.3  FEP Analysis and conceptual models

As already noted, it is a regulatory requirement that our safety claims for the ESC are supported by both qualitative and quantitative evidence [11]. A quantitative analysis of the long-term performance of a GDF requires extensive use of computer modelling. The greatest challenge in modelling for the ESC is to develop a realistic representation of the GDF system that can be used to give meaningful assessments of how the GDF and its environment may evolve over different potential future scenarios.

The basis of all modelling is the understanding of the system to be modelled. Our conceptual understanding of the GDF system and its behaviour is based on our existing knowledge and experience and information gathered from our research, site characterisation, disposal system specification and engineering design programmes. We use the term 'conceptual model' to express our understanding of this system behaviour. As the geological disposal programme progresses we can undertake further research and site characterisation activities to test that understanding in order to improve our confidence in our conceptual model.

In developing our understanding, we will identify and acknowledge where there are uncertainties that are significant to the ESC. Where it is possible to quantify an uncertainty, that quantification will be explicitly included in our representation of the system. Where such quantification is not possible, the impact of the uncertainty will be assessed, for example by consideration of alternative potential conceptual models or scenarios, as discussed below.

A conceptual model needs to take appropriate account of all the relevant features, events and processes (FEPs) that could affect a GDF and its potential future evolution. We may also need to develop different conceptual models for different evolution scenarios, so that these are appropriately modelled and we need to build confidence that the scenarios we develop encompass the range of possible evolutions of the GDF system.

We have developed a systematic approach to model development [17] in which we:

1. identify all relevant features, events and processes (FEPs) and explore the potential ways in which they could interact;
2. develop scenarios and conceptual models for the GDF system,
3. represent these conceptual models mathematically and then;
4. implement them in software; and
5. build confidence in our models through testing, peer review and stakeholder feedback.

In practice, the fifth stage of building confidence in our models occurs throughout the model development process, as illustrated in Figure 3 below.
Figure 3 Five stage approach to model development

This approach received a favourable review from an independent international expert group [18]. A similar approach has since been adopted by other waste management organisations around the world who are investigating actual sites for geological disposal facilities (for example, see section 5 of [19]). International FEP catalogues have been developed [20] and can be used as a checklist to assist in identifying relevant FEPs for different geological environments and disposal facility designs. One of the encouraging indications of the maturity of this approach is that no significant new FEPs have been identified for a number of years [21].

This systematic approach, in which we seek to identify all relevant FEPs and their potential interactions, was developed by Nirex to provide a comprehensive view of the GDF system, prior to the widespread establishment of international FEP databases. It is consistent with similar approaches, such as the thermal-hydrogeological-mechanical-chemical (THMC) approach developed by the Swedish waste management organisation, SKB; however, the FEP approach is broader in that it is not restricted to consideration of certain types of processes, but also embraces events and all relevant features of the system. The THMC approach is therefore generally complemented by a review of international FEP databases.

Consideration of FEPs is an important starting point for model development, ensuring that all significant factors potentially relevant to the safety of a GDF are included in the models. In the FEP analysis stage particular attention is paid to those FEPs that could have an impact on the safety functions of a GDF (that is those aspects of the site and design that contribute to the isolation and containment of the wastes). The safety case will need to consider scenarios that could potentially lead to the impairment of safety functions and the models will need to have sufficient detail to assess the evolution of the safety functions over time. Therefore analysis of the safety functions can provide a useful framework for considering the safety arguments made in an ESC.

Many FEPs are site-specific, relating to an actual GDF system, that is the geological environment and the engineered barriers of a disposal system. Prior to the identification of potential sites and designs for a GDF it is therefore not possible to develop a full and detailed conceptual model of a GDF system, as we will not know all the relevant FEPs. Instead, at this generic stage, we adopted a stylised approach with the aim of representing the envelope of behaviour of a range of geological settings. (Section 4.6 describes the
approach adopted in our generic Post-closure Safety Assessment, in which the conceptual model was that of radionuclides leaching from the wastes and returning to the surface via dissolution and transport in groundwater. The behaviour of the engineered system and geosphere in this conceptual model was represented by five parameters.

When we start to develop our site-specific ESC, we will review our FEP list and also the international FEP catalogues of relevant overseas programmes to compile an updated FEP list that includes all FEPs relevant to the geological settings and disposal facility designs under consideration.

As noted above, internationally, FEP lists now exist for a range of disposal concepts and geological settings and RWMD is currently contributing to the OECD-NEA review to update the international NEA FEP database. RWMD will use this international database as the starting point for identifying FEPs relevant to any sites under consideration for hosting a GDF. Appropriate experts will consider the sites and relevant disposal concepts to identify whether any additional FEPs need to be included beyond those already identified from the international FEP database. RWMD currently intends that these FEPs will be analysed and structured using the methodology previously developed by Nirex and peer reviewed (as discussed above). The value of this approach to structuring FEPs is that it repeatedly asks ‘what could determine / influence this FEP?’ – a systematic approach that helps to elicit all relevant FEPs. Pair-wise interactions between significant FEPs will be considered systematically using the matrix diagram approach, as developed by Nirex and tested for the ILW / hard rock concept.

RWMD believes that the previously published Nirex FEP methodology is generic and can be applied to any geological environment and disposal concept, although clearly the actual FEPs requiring consideration will be different and a site-specific Master-Directed Diagram (MDD) will need to be developed for each disposal concept. It is envisaged that MDDs will become increasingly site-specific at the lower (more detailed) levels.

This structured FEP analysis will enable us to identify initial conceptual models for the GDF system and its evolution. In the early stages of site-specific work it may be necessary to consider alternative conceptual models that can be tested against the evolving site-specific understanding. Conceptual models are likely to need to be updated, perhaps significantly, as site-specific understanding develops.

We will also identify the safety functions provided by each geological setting and disposal facility concept under consideration. (Our approach to selecting a geological disposal concept is described in our “Concept selection process” [22].) This provides a ‘top-down’ view of the essential roles in containing and isolating radionuclides of the key components of a disposal facility and complements the more fundamental, ‘bottom-up’ consideration of individual FEPs. In practice, consideration of the evolution of the safety functions is used to identify the most significant FEPs and the scenarios and potential release mechanisms for consideration in our computer modelling. As more information is obtained about the geological settings and disposal facility designs under consideration, the safety functions can be defined in greater detail and it may become possible to quantify the performance requirements of some safety function indicators (for example the required thickness of disposal containers, or the chemical conditions in the vaults). The detailed role and use of safety functions is being developed and will be published as part of our underpinning methodology.

### 3.4 Computer modelling in the ESC

The computer model used to represent the GDF system in the generic Post-closure Safety Assessment is directly based on a relatively simple conceptual model of a generic GDF system in which the model parameters representing the behaviour of the engineered
system and geosphere are assigned value ranges to represent a range of GDF designs and geological settings.

When we have more information about the GDF location and design, we will be able to develop a more complex conceptual model of the GDF system and we will need to represent that in more complex computer models. However, complex models can only be justified if there are the data and understanding to support them. We anticipate that the complexity of our models will increase as we gather more data and our understanding develops. However, there is a potential trade-off between increasing model complexity and the uncertainty and reliability of the model results, so models should not be more complex than they need to be. To support and test our understanding, we therefore plan to maintain simple models (for example the generic ESC model) in parallel with the growing complexity of our assessment models, so that the outputs from complex models can continue to be interpreted in relatively simple terms.

A further aspect of our strategy to deal with the complexity of computer models is to develop a hierarchical structure of models, as illustrated in Figure 4.

**Figure 4** Hierarchy of models used in a performance assessment

![Hierarchy of models used in a performance assessment](image)

At the lowest level are ‘process’ models, which represent our understanding of the underlying science of the relevant processes that operate in a GDF. These process models feed into higher level models that represent the evolution of the main GDF components – the engineered barrier system, geosphere and biosphere. In these component models it is important that all relevant interactions between the processes are adequately represented, therefore component models can be quite complex. At the top level of the model hierarchy is a ‘total system model’, which takes information from the component models in order to calculate overall performance measures of the GDF system, such as radiological dose and risk.

The total system model needs to be able to address different scenarios for the long-term evolution of a GDF and take account of the inevitable uncertainties associated with such scenarios. Our strategy for managing uncertainty is discussed in more detail in the generic Post-closure Safety Assessment (PCSA) report [10]. An important part of that strategy is,
where appropriate, to adopt a probabilistic approach for our total system model, in which any uncertainty in a model parameter is represented by a probability density function (PDF). The total system model is then run a large number of times, with different combinations of parameter values being randomly sampled from the PDFs. This means a large number of calculations is performed, capturing the full range of possible parameter combinations, such that the output from the total system model reflects the uncertainty in the model input parameters.

We currently use a commercial software package, called GoldSim [23] for the implementation of our total system model. GoldSim is a probabilistic simulation software package used worldwide to conduct assessments of radioactive waste disposal facilities. It provides functionality for representing contaminant and radionuclide species, transport media, transport routes, contaminant sources and receptors. In particular, its probabilistic nature allows the uncertainties to be explicitly represented.

When we have information about the GDF location and design, we will start to develop specific models of the system components. The understanding gained from these component models needs to be sufficiently represented in the total system model to enable a meaningful calculation of overall system performance.

As understanding develops and we gather site-specific and design-specific data, we expect to make greater use of detailed supporting models (at both the process level and component level) that explicitly consider couplings between, for example, the chemical, mechanical, hydrological, thermal, radiological and biological processes of concern.

Figure 5 indicates, in broad terms, how we envisage developing our models with increasing complexity as we progress through the MRWS site selection process and develop a site-specific ESC. This figure indicates the expected knowledge available at each stage of the MRWS site selection process and explains how that knowledge can be interpreted to give an understanding (conceptual model) of the GDF system and its evolution, which can then be represented in appropriate computer models to give the required performance assessment of the GDF. We have divided MRWS Stage 5 into two distinct phases: Stage 5.1 during which non-intrusive surface-based investigations (such as geophysical surveys) are made at candidate sites and Stage 5.2, during which intrusive surface-based investigations are undertaken (such as borehole drilling).

At the current generic stage, our understanding is illustrative, rather than representative. For the generic ESC we used illustrative designs and generic geological environments, which are incorporated directly in a total system model, using parameters with assigned generic value ranges, in order to produce illustrative risk calculations (as described in Section 4.6).

We expect to follow a similar approach to the generic ESC for our desk-based studies in MRWS Stage 4 except that, with knowledge of the geological environment, we will be able to select illustrative designs appropriate to that environment. From our general scientific understanding of the likely radionuclide release pathways from such a design and geological setting, we will use our total system model understanding with reference to the illustrative design and geological setting to consider the post-closure safety implications (see Section 5.1 for further details). The aim will be to determine the likely ability to make a robust safety case eventually, rather than a quantitative analysis of potential sites.
Figure 5 Model development strategy for the site-specific ESC

Following non-intrusive surface-based investigations in MRWS Stage 5.1 we expect to have a sufficient basic knowledge of the geology of the candidate sites and preliminary disposal concept designs, that we will be able to develop an initial conceptual model of the site and a possible GDF design and consider the potential evolution of the GDF system to identify scenarios for potential radionuclide releases. It may be at this early stage that we will need to consider alternative potential conceptual models that will be tested when more data become available. We expect to be able to construct simple component models of the engineered barrier system (EBS), geosphere and biosphere and to use parameters derived from these component models in a total system model. Modelling at this level of detail is expected to be sufficient to support an Initial Site Evaluation (ISE) to gain permission to start intrusive surface-based investigations (borehole drilling). Further details on the modelling approach for MRWS Stage 5.1 are given in Section 5.2.

During MRWS Stage 5.2 information from boreholes and other research activities will be synthesised and analysed to produce an "evidence-based conceptual understanding" of the site. This will enable us to develop more detailed conceptual models of the site and its evolution. These conceptual models will be tested and successively refined using on-going surface-based investigation data and will assist in disposal concept option selection and...
the optimisation of the GDF design. This will enable increasingly detailed component models to be produced, which in turn will enable development of a more sophisticated total system model, for example directly representing the component models via a ‘response surface’ (in which total system model parameters are directly obtained and interpolated from the component models) – see Section 5.3 for further details.

During MRWS Stage 6 data will be obtained from underground investigations and work will be undertaken to optimise the GDF design. The safety case for licensing of disposal operations produced at the end of MRWS Stage 6 will reflect the detailed knowledge of the site obtained by that stage. The conceptual model will have now evolved into a detailed site descriptive model of the geology, hydrogeology, geochemistry, geotechnical characteristics and surface environment of the site. This site understanding will be represented in detailed component models which have been independently calibrated and the total system model will need to support a demonstration of confidence in the overall system performance – see Section 5.4 for further details.

Whilst we have a general strategy for delivering the models required to support the ESC, the specific details and requirements of those models will only become known as the MRWS site selection process progresses. We therefore expect to set out our modelling approach for each of the main assessment deliverables within the stepwise process at the appropriate time.

The above discussion has demonstrated that computer modelling is an important aspect of the ESC, and the means by which we quantify GDF performance by calculating the radiological risk to individuals who may live on or near the GDF site in the future. It is therefore important that we and our stakeholders can have confidence in the output of computer models. This requires:

- confidence that the modelling software does what it is intended to do, i.e. that the equations have been coded correctly – this is known as verification;
- confidence that the modelling software has been correctly used to create an adequate representation of the actual system; and
- confidence in the quality of the data and its appropriate use in the model (traceability and QA of data sources).

### 3.4.1 Verification

Software verification requires that it has been:

- developed under an appropriate quality management system;
- properly tested; and
- properly documented.

Where software is developed for us by third parties, it is a requirement that it is developed under an appropriate quality assurance regime such as ISO9001 or TickIT4. Our use and development of software in-house is also governed by our own QA procedures which are ISO9001 certified.

### 3.4.2 Confidence building

Building confidence that a software model is a good representation of reality can be hard to achieve in practice. Whilst sometimes it is possible to compare model results with experimental data, this is not always practicable. This is particularly true for models of the environmental implications of radioactive waste disposal which need to consider impacts over hundreds of thousands of years. In such a situation it may still be possible to build

---

4 See [www.TickIT.org](http://www.TickIT.org) for details.
confidence in component parts of the model by comparison against experiment, or by benchmarking against other computer models that take a different approach to solving the problem. For example, simple analytic expressions, such as the ‘insight model’ (see, for example, Volume 3, Section 8 of Nirex 97 [24]) can be compared with the results of a complex model to build confidence that the complex model captures the essential features of the system.

Perhaps the most important aspect of our approach to building confidence in computer models is that we ensure that all staff employed in developing and using such models have appropriate qualifications and experience, i.e. they are ‘intelligent users’. An intelligent user has a firm understanding of all the processes being modelled and the expected results of calculations and does not treat a model as a ‘black box’, believing the results without question. An intelligent user will have been involved with the wider process of conceptual and mathematical model development that underpins the software and hence is well placed to spot any anomalous results from the model (perhaps arising from undiscovered software bugs). It is an important part of our ESC strategy to develop and maintain our intelligent user capability over the lifetime of the GDF project.

3.4.3 Traceability and QA of data sources

Our models use data and information from a variety of different sources including design, research programmes, site characterisation programmes, as well as the output from other models in the hierarchy of models.

RWMD is currently developing an overarching framework for data and information management. When complete, this framework will comprise policy, principles, processes, procedures and tools. It is being designed to provide a management system against which specific data management solutions can be developed, to ensure that data and information of significance for nuclear safety and environmental protection are appropriately managed.

Data and model parameter values need to be fit for purpose and our quality management procedures for data acceptance ensure the purpose of the calculations, the conditions being modelled and the spatial and temporal scope are considered. Acceptance checks for parameter values used in modelling consider the provenance of data on which these values are based and any limitations associated with that provenance. Parameter values used in model calculations are fully recorded (e.g. parameter name and definition; units (SI units are used where possible); model, code and context; available data and references; recommended value and justification; assigned uncertainty or probability density function (PDF); dependence on other parameters (correlations); and applicability).

For the generic ESC, such information is recorded within the GoldSim model, and this can be made available to reviewers. In the future, we expect to develop separate parameter databases in specific areas, for example, those detailing geological, chemical, and/or biosphere parameter values. Such databases will be developed in line with the RWMD data and information management framework described above. These databases will draw on existing national and international databases, and will eventually be tailored to UK wastes and conditions as appropriate. As our programme develops, these databases will contain more site-specific parameter values, and we will have less need to rely on generic values. The parameter databases developed to support assessment models will link to any data management systems developed to support our site characterisation programme and research programme.

It is an important part of our approach to modelling that where there is uncertainty in a parameter we will represent that uncertainty explicitly in our total system model, for example by eliciting an appropriate PDF. For the generic ESC we followed a structured, auditable formal expert elicitation methodology to derive PDFs, involving appropriate experts and drawing upon relevant research [25]. We recognise the importance of recording the rationale behind the advice provided by experts, and the need to propagate
any uncertainties through the calculations in which the parameters are used. We will also maintain a ‘register of uncertainties’ throughout the development of the ESC. In each version of the ESC we will document outstanding uncertainties of significance to the ESC and our plans for addressing them.

3.5 Underpinning reports

An ESC is a substantial set of documents. We established a document hierarchy for the generic ESC and we expect to follow a similar model in developing the site-specific ESC. The generic ESC main report is supported by two safety assessment reports: the Operational Environmental Safety Assessment (OESA) and the Post-closure Safety Assessment (PCSA) (see Section 4.5.1). In turn, these reports are supported by a number of status reports describing the underpinning science, design reports and inventory reports. As we develop the ESC, it will also be necessary to develop the underpinning reports that support the ESC. It is our strategy to treat both the generic and site-specific ESCs as suites of ‘living documents’, and to update each individual report when appropriate; we do not envisage that it will always be necessary to update the full suite of reports simultaneously.

3.6 Summary of our ESC Strategy

The previous subsections have discussed general and specific aspects of our strategy for developing the ESC, including approaches for building confidence in the long-term safety of a GDF, the roles of the parallel generic and site-specific ESCs and our approach to developing conceptual and computer models. Our approach can be summarised by a number of Strategic Principles as follows:

- **Building confidence in the safety case:** Confidence in the ESC post-closure case will be built by applying a multi-barrier concept, the internationally accepted approach to geological disposal.

- **Parallel generic and site-specific safety cases:** We will develop the site-specific ESC(s) as a parallel and separate work-stream to the generic ESC, rather than evolve the generic ESC into a site-specific ESC. This strategy ensures that we have an RWMD-approved benchmark safety case whilst developing the site-specific ESC.

- **Continued maintenance of the generic safety case:** We will continue to use and maintain the generic ESC as a living suite of documents as we progress through the MRWS site selection process, until such time as we have sufficient confidence in the site-specific ESC and we judge that we no longer require a generic ESC. This strategy ensures that we allow for the possibility of additional, alternative sites being put forward for consideration and to continue to undertake disposability assessments that encompass a broad range of potential disposal facility designs until such time as a site-specific ESC is sufficiently well-established.

- **Iterative development of the site-specific safety case (closely coupled to needs-driven research, site characterisation, disposal system specification and engineering design programmes):** As information is gathered from these programmes and analysed in the ESC (and other parallel safety assessments), the ESC will be able to feed understanding back to site characterisation, research, disposal system specification and engineering design activities, guiding them to focus their next steps on those areas where increased understanding will be of most benefit to the evolving safety case.

- **Presentation of complementary environmental safety arguments:** In line with regulatory guidance and the accepted international approach we will demonstrate
our confidence in geological disposal making use of multiple lines of reasoning based on a variety of evidence, both qualitative and quantitative. This approach will enable us to present complementary environmental safety arguments.

- **Development and testing of understanding of the GDF system and its evolution over long timescales under a comprehensive range of representative scenarios through computer modelling:** We will follow a rigorous and systematic process to developing and testing our understanding of the long-term performance of a GDF, linked to the needs-driven research, site characterisation and engineering design programmes. We will develop a hierarchy of computer models to represent our understanding and iteratively test and refine these models in the light of the developing understanding from the needs-driven research, site characterisation and engineering design programmes. This iterative model development process will include:
  - Gathering of relevant information.
  - Interpretation of information by using it to build conceptual models of the GDF components and system and identifying potential evolution scenarios.
  - Development of computer models to represent our understanding of the total system, including any uncertainty in that understanding, at the appropriate level of detail.
  - Testing our understanding of the system and modelling predictions against observations and other relevant information.
  - Identifying where the uncertainty in our understanding has a significant impact on our confidence in the GDF performance.
  - Commissioning appropriate research / site characterisation / engineering analysis to reduce relevant uncertainties and improve our understanding.
  - Updating our models to reflect improved understanding and testing new modelling predictions.
  - Continuing this iterative process of obtaining information, updating and refining models, assessing the significance of outstanding uncertainties until we have sufficient confidence that the ESC will meet regulator and stakeholder expectations.

- **Demonstration of our understanding of the uncertainties relevant to safety assessment:** Confidence in the ESC will require demonstration that outstanding uncertainties significant to the ESC can be appropriately managed so there is still confidence in overall safety. We will adopt an appropriate approach to the treatment of uncertainty at each stage of ESC development activities, noting that:
  - It is neither possible nor necessary to eliminate all uncertainties.
  - The types and extent of uncertainty are expected to change as the geological disposal programme progresses.
  - Where outstanding uncertainties can be quantified they will be explicitly included in ESC calculations (e.g. via appropriate parameter ranges). Where significant uncertainties cannot be quantified, they will be acknowledged and treated appropriately (e.g. through consideration of potential alternative conceptual models and scenarios).
  - Both qualitative and quantitative arguments can be used to address uncertainty.

The first four Strategic Principles are applicable to all our safety strategies (ESC Strategy, Operational Safety Strategy and Transport Safety Strategy), the last three are ESC-specific.
In order to achieve confidence in the strategy and the resulting generic and site-specific ESCs, we will also undertake the following activities:

- Ensure all data used in the ESC are and fit for the purpose for which they are being used and maintain traceability of data by developing and maintaining appropriate databases.
- Follow a systematic approach to identify all relevant features, events and processes that have the potential to affect the initial state of a GDF (i.e. the state of the GDF immediately following backfilling, sealing and closure) or its evolution over long timescales.
- Develop conceptual models which can be tested against site data and verify that these are correctly implemented in software. To achieve this we will develop and maintain intelligent user modelling capability throughout the geological disposal programme.
- Test software models against independent data, not used in developing the software models, wherever practicable.
- Apply version control and use only the latest published versions of the ESC (generic and/or site-specific as appropriate) when undertaking any assessments for external release and apply a rigorous change control process prior to accepting any updated components of the ESC.
- Develop clear ESC hierarchical documentation that is suitable for all stakeholders at key stages in the decision-making process.
- Subject ESC-related documents to review throughout their development in accordance with RWMD’s procedures and, when appropriate, to a final independent peer review as part of our publication process.
- Maintain consistency with other relevant RWMD strategies, including the RWMD technical strategy [8], R&D strategy [16], environmental and sustainability appraisal strategy, procurement strategy and public and stakeholder engagement (PSE).

Figure 6 illustrates our strategy for undertaking both generic and site-specific ESC development activities within separate work streams through the stages of the MRWS site selection process and beyond. This is consistent with our Technical Strategy [8] and the Permissions schedule [15]. The column headed “MRWS site selection Stage” on Figure 6 provides indicative dates for some of the MRWS stages, consistent with the timetable noted by the UK Government. The far right column in Figure 6 indicates the ESC safety case submissions we expect to make throughout the MRWS site selection process. Our ESC strategy for each of the specific stages of the MRWS site selection process is discussed in more detail in Sections 4 and 5.
Figure 6  Our strategy for developing and updating the ESC through and beyond the stages in the MRWS site selection process.
4 Development of the generic ESC in the early stages of the MRWS site selection process

The UK Government’s 2008 MRWS White Paper [1] sets out a series of stages in the selection of a site for a GDF and the development and operation of a GDF, and identifies the decisions to be made and stakeholders involved at each stage. The guidance provided in the GRA [11] on the timing of development of the ESC has been written to be compatible with the MRWS site selection Process (see Figure 1).

This section provides an overview of the early stages in the MRWS site selection process, to provide context to subsequent discussion on our strategy for developing the ESC over stages 4 to 6 and beyond. We also explain how we have reached our current position of developing the generic ESC and discuss its ongoing development and role.

4.1 Stage 1: Invitation issued and Expression of Interest from communities

Stage 1 was launched in June 2008 with publication of the UK Government’s MRWS White Paper. Stage 1 is being led by the UK Government. Communities can express an interest in participating in the MRWS site selection process without commitment to actually hosting a facility, in order to open discussions with the Government.

4.2 Stage 2: Consistently applied ‘sub-surface unsuitability’ test

Once a community has made an Expression of Interest, the British Geological Survey, makes an assessment on behalf of the UK Government of whether sub-surface conditions mean that sub-surface areas covered by the Expression of Interest are obviously unsuitable for development of a GDF. This assessment is against the sub-surface screening criteria listed in the MRWS White Paper. The aim of this stage is to eliminate any obviously unsuitable areas from a geological viewpoint, from further consideration.

4.3 Stage 3: Community consideration leading to Decision to Participate

If the sub-surface screening criteria do not rule out the whole area covered by the Expression of Interest, the community will need to decide whether to participate further in the siting process, still without commitment. Following a Decision to Participate, the UK Government expects that a formal Community Siting Partnership will be set up, such that the host community, decision-making bodies, and those representing wider local interests will work with us and other relevant interested parties for the remaining stages.

4.4 Where we are now

As of June 2012, three communities have expressed an interest in participating in the MRWS site selection process. Sub-surface unsuitability tests have been performed on the areas covered by these communities [26]. These initial screening tests have screened out some areas as unsuitable, but have not ruled out the whole of the areas covered by the communities. Therefore, these communities will need to decide whether to participate further in the MRWS site selection process.

Other communities may come forward and express an interest in the future. If this were to happen, similar screening tests would be carried out and any areas not ruled out would be taken forward in the decision-making process, alongside the existing areas. It is not envisaged that this would affect the development of the site-specific ESC, although there may be an implication for the timing of decisions if additional areas required consideration.
During Stages 1-3 of the MRWS site selection process, we have assembled a generic ESC [7], which will be used by us from Stage 4 onwards. The role of the generic ESC is described below.

4.5 The generic ESC

The generic ESC main report [7] explains why we have confidence that a GDF could be implemented and that it would meet the environmental safety requirements set out in the GRA. The suite of documents making up the generic ESC also provides:

- a basis for us to continue to assess waste packaging proposals;
- a basis for undertaking initial desk-based assessment of candidate sites; and
- a basis for identifying work needed to further develop the ESC through the staged GDF implementation process.

The wastes for disposal in a GDF include high-level waste (HLW), intermediate-level waste (ILW), and low-level waste (LLW) unsuitable for near-surface disposal. The generic ESC considers these wastes and also other nuclear materials that have not been declared as wastes by their owners, but which might be declared as wastes in the future if it were decided they had no further use, namely spent nuclear fuel (SF), separated plutonium (Pu) and uranium (U), including both highly enriched uranium (HEU) and depleted, natural and low-enriched uranium (DNLEU). This inventory is associated with activities primarily related to the generation of nuclear power, defence and R&D activities. The radioactivity and characteristics of these wastes and materials are defined as a "baseline inventory". The generic ESC also considers the implications of disposing of an "upper inventory", defined as wastes and materials that could be generated from an alternative future arisings scenario, including additional wastes that might be generated in the future from a possible programme of new nuclear power stations.

The generic ESC illustrates how geological disposal could be implemented safely in different geological environments for the UK inventory of higher activity radioactive wastes. The generic ESC uses illustrative designs and generic geological environments with assigned generic parameter values to produce illustrative risk calculations. Our confidence that we can develop a GDF for the disposal of higher activity radioactive wastes is built on our understanding of how multiple barriers can work together to provide long-term safety for a wide range of geological environments. We therefore have confidence that once we have a suitable preferred site, we will eventually be able to develop an optimised design that meets all environmental safety requirements.

The generic ESC addresses the environmental safety impacts of discharges from a GDF during the operational period and following sealing and closure – the post-closure period. The generic ESC provides more discussion of the post-closure period because this is where the greatest challenges lie in demonstrating compliance with regulatory guidance and, therefore, where the most work is required. Evaluation of impacts on people and the environment from a GDF during the operational phase is based on similar techniques as those used in assessing such impacts from existing nuclear plant (e.g. waste stores). Clearly there cannot be equivalent experience of a purpose-built underground disposal facility to guide safety assessments over the million-year timescale typically considered for the post-closure period of a GDF – although there is significant experience available from previous work in the UK and from geological disposal programmes in other countries.

Figure 7 illustrates the components of the generic ESC main report. The generic ESC has been structured to reflect the guidance set out in the GRA and also reflects best international practice for structuring such safety cases [13].
The generic ESC will be used as the basis for disposability assessments under the Letter of Compliance process and developed as a living suite of documents until such time as we decide that we have sufficient confidence in the site-specific ESC that we no longer require the generic ESC. The generic ESC will also be used as the basis from which we provide preliminary assessments of the safety aspects of potential candidate sites in MRWS Stage 4.
Our strategy for development of the generic ESC over the next two to three years includes the following components:

- Engagement with stakeholders and regulators to address comments and queries on the generic ESC.
- Further planning for safety assessment activities to be carried out during Stage 4 of the MRWS site selection process.
- Investigation of relevant issues identified through production of the generic ESC and by our issues process [27] and registered in the issues log, which do not require site-specific information.

These activities could identify the need to carry out further specific safety analyses or modelling studies to enhance the generic ESC.

Two assessment reports support the generic ESC, the generic OESA and the generic PCSA. The forward strategy for developing the OESA was discussed in section 2.4. The development of the generic PCSA forms an intrinsic part of the overall development of the ESC and is therefore briefly discussed in the subsection below.

4.6 The generic Post-closure Safety Assessment

In the generic PCSA [10], a radiological assessment of post-closure safety for a generic GDF is presented. The quantitative part of a safety assessment is often referred to as a performance assessment for a disposal facility. At this generic stage there is no information about the geology and hydrogeology at a potential site, and the design of a facility that might be constructed there. In the absence of this information a full performance assessment is not meaningful, so the main purpose of the generic PCSA is to illustrate by example how a post-closure safety assessment would be carried out at a site to be identified in the future. However, there are some quantitative components to the assessment, and these are included for two reasons:

- to illustrate the sensitivity of performance measures to important properties of the site and GDF design in the context of other uncertainties; and
- to provide a quantitative benchmark for continuing to give packaging advice to waste producers through the Letter of Compliance disposability assessment process.

In the generic PCSA, we present a quantitative analysis of the ‘groundwater pathway’, i.e. the route by which radionuclides could give rise to a radiological risk to future populations by dissolution and transport in groundwater. Current knowledge of the potential consequences of gas generated in a GDF is summarised. Two variant scenarios are also considered: inadvertent human intrusion into a GDF and the possibility of an accumulation of fissile material leading to a criticality.

In the absence of a site and GDF design, the quantitative analysis for the groundwater pathway involved calculating risk for sets of values of a limited number of key parameters representing the geology and design. As previously indicated in Figure 5, we used this simplified approach to replace the need for detailed component models of the engineered system, geosphere and biosphere, representing them with five parameters that were used directly in the total system model. These parameters and the way in which they were derived and used are described in detail in the generic PCSA [10]. In broad terms they are as follows:

q – the specific discharge (m yr⁻¹), or Darcy velocity, through the undisturbed host rock at the location of a GDF. This parameter influences the volume flux (m³ yr⁻¹) through the facility which in turn influences the quantity of radionuclides leached out of a GDF as a contaminated groundwater plume.
T – the groundwater travel time (years) from a GDF to the surface. This time influences the amount of dispersion, retardation and decay of radionuclides before they emerge at the surface.

F – the groundwater mixing flux (m$^3$ yr$^{-1}$) in the overlying rocks into which the contaminated groundwater plume leaving a GDF may eventually rise from depth and mix. This mixing flux influences the concentration in the biosphere, and therefore the radiological risks arising from the use of water from wells.

A – the discharge area (m$^2$) into which the contaminant plume is released at the surface. This mixing flux influences the risk from natural discharge into the biosphere.

C – the time (years) taken for failure of the waste container. This represents the period of absolute containment of radionuclides within the waste container.

Figure 8 illustrates the conceptual model on which the parameters q, T, F and A are based, that is a model in which radionuclides from the wastes start to leach out of the engineered system once there is no longer absolute physical containment within the waste container (parameter C) and are carried in groundwater through the geosphere, eventually discharging into the biosphere.

Figure 8 Illustration of parameters q, T, F and A

This is a reasonable conceptual model, in broad terms, for a system in which radiological risk arises from a GDF by the return of radionuclides to the surface via dissolution and transport in groundwater. Other potential mechanisms leading to radiological risk are transport of radionuclides by gas and disruptive scenarios, such as human intrusion (both of which are also considered in the generic PCSA [10]). For different types of geological environment, the so-called ‘groundwater pathway’, may not be the most significant exposure route.
It is recognised that the parameters used to represent the geology and GDF design in the generic PCSA are most appropriate for a higher strength host rock environment. It is possible to make some extrapolation of the methodology to represent lower strength sedimentary host rocks, but an evaporite host rock would require a different treatment. In supporting preliminary assessments of safety during MRWS Stage 4, the generic PCSA methodology will be used, with appropriate modifications to address lower strength sedimentary host rocks and/or evaporite host rocks as required.

The absolute values of calculated peak risks or other quantitative performance measures in the generic PCSA cannot be particularly meaningful at the generic stage, because they depend on those parameters that represent quantities that cannot be known until an actual site and design have been identified. However, we can obtain useful information about the relative contributors to the calculated peak risk. This informs us which of the different components of the waste contribute most to the total risk, and also which radionuclides in the inventory contribute most to the total risk. This helps focus our design and research work on issues that matter; and, similarly, ensures that we address relevant issues when assessing waste packaging proposals.

In the generic PCSA model the values assigned to the generic parameters representing the geosphere and EBS properties reflect the bounds of the values that are likely to be found at a suitable site. In particular, the assumption of zero containment time (parameter ‘C’) for ILW waste packages is clearly conservative – in practice all waste packages will provide some physical containment and many may substantially contain the wastes for thousands of years. The chemical properties of ILW waste packages are important for post-closure performance and are considered in the post-closure disposability assessment process, represented by, for example, solubility and sorption parameters, which are radionuclide-specific and additional to the five ‘qTFAC’ parameters. Thus the overall chemical characteristics of the disposal vaults are represented. Disposability assessments undertaken using the generic PCSA model compare the “detailed” characteristics of individual waste streams with the overall characteristics of the full inventory, largely focusing on inventory and chemistry considerations. As the generic PCSA model covers a broad range of GDF design and geological parameters and does not take credit for any site-specific or engineered features, we can be confident that any waste packaging proposal that satisfies the post-closure safety requirements of the generic PCSA is likely to be acceptable for any suitable site and GDF design.

During MRWS Stage 5 and beyond, site-specific understanding will be represented in a developing site-specific PCSA, produced in parallel to the generic PCSA and following a different modelling approach, as discussed in the following section.
5 Strategy for the development of the ESC in MRWS Stage 4 and beyond

In this section we discuss our strategy for developing the generic and site-specific ESCs in later stages of the MRWS site selection process. For each stage of the MRWS site selection process, we set out:

- A brief overview of the stage in relation to the ESC.
- What we expect to know going into each stage.
- What ESC developments will be required by the end of each stage and why.
- Our strategy to deliver the required ESC developments and inputs into other work areas and/or subsequent MRWS stages.

Our ESC development strategy through the stages of the MRWS site selection process is also illustrated in Figure 6.

During Stage 4, and particularly when moving into Stage 5, we will start to develop site-specific understanding of the candidate sites. This work will continue in parallel with the development of the generic ESC. Although there is no regulatory requirement to produce a site-specific ESC until MRWS Stage 6, we believe it will be helpful to capture our developing site-specific understanding in the context of a developing ESC. This site-specific understanding will be used in Stage 5 to produce an Initial Site Evaluation (ISE) for each of the sites under consideration. The developing ESC may also form a useful basis for ongoing scrutiny by the Environment Agency and for discussions with stakeholders.

During Stage 5 there will be iterative developments of the generic ESC and the developing site-specific ESC. This will provide feedback to the on-going site characterisation work, so that it is directed to meet the needs of the developing site descriptive model and what ultimately will become a site-specific safety case. By the end of Stage 5, our site-specific understanding will need to be sufficient to support the selection of a preferred site to start underground operations; we will then produce a Preliminary Environmental Safety Evaluation (PESE) in the initial part of Stage 6 for that preferred site.

Our strategy for the stepwise development of the ESC throughout the MRWS site selection process is described in the subsections below. As already noted, we have divided Stage 5 into two distinct phases: Stage 5.1, during which non-intrusive surface-based investigations are made at candidate sites (such as geophysical surveys) and Stage 5.2, when intrusive surface-based investigations are undertaken (such as borehole drilling).

5.1 ESC strategy in Stage 4 of the MRWS site selection process

5.1.1 Overview of Stage 4: Desk-based studies in participating areas

Stage 4 will commence once a decision to participate has been made by a potential host community and accepted by the Government. Following a public consultation [28], the Government has produced a document that sets out the Framework for Stage 4 [29]. It divides the process into two steps:

- site identification; and
- site assessment.

A criteria-based approach is proposed for both steps. We will work with the Community Siting Partnership(s) to identify potential host rocks and surface locations that could host a GDF. As potential candidate sites are identified we will undertake a high level assessment and review of the safety and environmental implications and the potential costs of implementing a GDF at the specific sites. This will involve conducting a high level review of the geoscientific information available to identify any early implications for the development of the engineering design and safety case.
During Stage 4 we expect that we will be able to be more specific about relevant disposal facility designs for the geological environments under consideration, depending on the extent and nature of pre-existing information about the geological environment for the potential candidate site(s).

Several of the criteria outlined in the Framework for site identification and site assessment [29] are relevant to the ESC. Consistent with the MRWS White Paper, these proposed criteria include:

- geological setting;
- potential impact on people;
- potential impact on the natural environment and landscape;
- effect on local socio-economic conditions;
- transport and infrastructure provision; and
- cost, timing and ease of implementation.

Each of these covers between two and four detailed sub-criteria (see [29] for a full list of the proposed evaluation criteria). We will work with Community Siting Partnerships during the site identification phase to ensure that local issues are addressed where appropriate. Discussions will also take place on how to ensure that a GDF is acceptable to the potential host community and contributes to its social and economic well-being. The Stage 4 desk-based assessment report will be reviewed by the regulators and also by the UK Government’s advisory body, the Committee on Radioactive Waste Management (CoRWM). The Community Siting Partnerships will make recommendations to their local decision-making bodies, who will then decide whether to proceed to the next stage of the Site Selection Process. On the basis of the assessments, reviews, recommendations and decisions of all parties, the UK Government will then select one or more candidate sites to take forward to Stage 5 of the MRWS site selection process.

Where appropriate to conducting the Stage 4 high level review and site assessments, we will use the understanding presented in the generic ESC to provide arguments regarding our ability to produce a safety case at the potential candidate site(s). Our focus will be on providing sufficient understanding of the properties of the site(s) to identify site-specific safety strategies and disposal facility designs, key safety arguments, and the site-specific evidence that supports them or the type of evidence that is expected to support them. The safety criterion assessments will be based on known geoscientific information, which is expected to be too uncertain to provide meaningful risk calculations: therefore these assessments will be qualitative only and will discuss the relative likelihoods of eventually being able to produce a robust safety case at the potential candidate site(s).

5.1.2 What we will know going into Stage 4

Early in Stage 4, we will know:

- Those areas where siting the underground components of a GDF have not been ruled out as a result of sub-surface unsuitability tests.
- Identified potential sites for a GDF, although these could be fairly large areas rather than defined sites.
- Adapted illustrative disposal facility designs developed for a range of geological environments and approaches for building safety cases in these geological environments, based on a wide variety of international experience (see [22]).
- A range of viable concept options for each candidate site and the key safety issues.
5.1.3 Required environmental safety developments by the end of Stage 4

During Stage 4 we will be required to comment on the viability of making a future environmental safety case at each potential site. We will need to identify qualitatively, where there may be differences between potential sites on safety grounds, based on generic and desk-based information. However, given the likely limited information at this stage, it is anticipated that the extent to which we would be able to discriminate between sites may be limited. We would, however, identify any sites for which it would be unlikely that we would be able to make a safety case based on our generic understanding of long-term safety issues. Work during Stage 4 should enable one or more (notionally two) sites, where safe disposal is considered to be viable, to be taken forward for further investigation.

There are no formal regulatory safety assessment submissions planned in Stage 4, however, the key environmental safety outputs from Stage 4 are:

- Assistance with the identification of potential GDF sites in a volunteer area.
- A high level assessment and review of the ability to make a safety case at these sites, and evaluation of compatibility with national/international siting guidance.
- Qualitative discussion of potential safety-relevant issues at each site.
- Input to site assessment criteria.
- Guidance on the design of site characterisation activities.
- Input to review of the range of GDF designs and rejection of inappropriate designs for each site.
- Input to review to confirm that the adapted illustrative GDF designs remain appropriate, and if not, selection of appropriate alternative illustrative designs.

5.1.4 Our strategy for ESC development during Stage 4

Our ESC development strategy during Stage 4 is to:

- Use understanding from the generic ESC knowledge base to provide the outputs identified above, including input to other RWMD work areas.
- Update elements of the generic ESC as required, including making use of feedback loops to identify needs for additional underpinning science.
- Start to gather site-specific information and start planning the development of a site-specific ESC.
- Work with the Community Siting Partnerships to ensure that local issues are addressed in our assessments.

5.2 ESC activities in Stage 5.1 of the MRWS site selection process

5.2.1 Overview of Stage 5.1: Non-intrusive surface-based investigations on remaining candidates

Site-specific information on the geological setting will be required to develop and build confidence in GDF designs tailored to individual sites. This information is expected to be generated in a staged way, with non-intrusive methods (such as geophysical surveys) being used to determine whether further detailed intrusive investigations (e.g. boreholes) should be carried out.

The GRA [11] sets out the environment agencies’ expectations in terms of regulatory submissions at key points in the lifecycle of the development of a GDF. It is a legal requirement under EPR10 [14] that an environmental permit will be required before proceeding with the Stage 5.2 intrusive investigations (e.g. boreholes), and an “initial site
evaluation" would be expected at this time. We will discuss the timing, nature and content of any application with the relevant environment agencies.

5.2.2 What we will know going into Stage 5.1

Going into Stage 5.1, we will know:

- The candidate sites for a GDF and their basic geology (derived from existing literature and studies).
- Conceptual GDF designs for the candidate sites of viable geological disposal concepts, and approaches to building safety cases at these sites.

5.2.3 Required environmental safety developments by the end of Stage 5.1

By the end of Stage 5.1 we would wish to:

- Provide largely qualitative views on the feasibility of constructing a GDF at the candidate site(s);
- Demonstrate how a GDF at the candidate site(s) could meet the principles and requirements of the GRA;
- Demonstrate a clear understanding of the disposal facility in its geological setting, how the geological disposal system will evolve, and how its various components contribute to meeting the requirement of providing a safe long-term solution for the UK's higher activity radioactive wastes;
- Describe the key environmental safety arguments and the underpinning lines of reasoning and detailed analysis, assessments and supporting evidence;
- Provide guidance for a needs-driven characterisation of the candidate site(s);
- Indicate how we would go about continuing to develop the ESC for a GDF, including setting out a site-specific and design-specific environmental safety strategy, i.e. the top-level description of the fundamental approach to be taken to demonstrate environmental safety of the system;
- Start development of an Initial Site Evaluation (ISE) for each candidate site, such that in the initial part of Stage 5.2 we can obtain the necessary environmental permits to commence intrusive surface-based investigations (e.g. drilling of boreholes).

At this Stage, our analyses will be mainly qualitative, based on available site knowledge and data to support the developments above. An important aim would be to demonstrate that any proposed intrusive surface-based investigations would not compromise the integrity of a candidate site to the unacceptable detriment of the environmental safety of a future GDF.

5.2.4 Our strategy for ESC development during Stage 5.1

Our ESC development strategy during Stage 5.1 is to:

- Continue to maintain and develop general understanding of the disposal system and update the generic ESC where required.
- Continue to use the generic ESC to undertake disposability assessments of waste packages to support the LoC process.
- Develop site-specific understanding based on emerging information from non-intrusive surface investigations.
- Provide assessments of GDF design options tailored to each site.
• Use the developing site-specific understanding to help develop a site characterisation strategy for Stage 5.2 (e.g. identifying appropriate borehole locations).

• Use a combination of generic and site-specific understanding to support the development of the ISE(s).

It is during MRWS Stage 5.1 that a site-specific understanding utilising existing knowledge and data from geophysical surveys and other appropriate non-intrusive investigations that may be undertaken will start to be developed. An important role for this developing site-specific understanding will be to use the limited site-specific data already available to identify where more data would be most beneficial in terms of building confidence in a site-specific ESC. This will be important to support the environmental permit for borehole drilling. We will also need to prepare for the ISE(s).

It is at this Stage that we expect to start to develop conceptual models of the site(s), that is building up an understanding of the relevant features, events and processes (FEPs) that are important at each site and considering how they may interact and evolve. This enables us to build an understanding, in broad terms, of the likely evolution of the site (the ‘base scenario’) and to start to identify possible variant scenarios for its evolution over time. We will start to develop mathematical and software models to represent our conceptual understanding. These models will be used to make predictions that can be tested against future site characterisation activities. As our understanding develops, our models will be successively refined and updated.

However, the eventual outcome of the MRWS site selection process will still be uncertain at this stage, so it would be premature to narrow options for GDF designs. Therefore, we will still need to ensure that waste producers continue to package waste in a way that provides suitable engineered safety barriers (in terms of the wasteform and waste container) for a range of generic disposal facility designs. We will therefore continue to develop the generic ESC, by updating it to reflect advances in our generic knowledge base (e.g. regarding inventory and underpinning sound science and engineering), and use the generic ESC for the LoC disposability assessments.

5.3 ESC activities in Stage 5.2 of the MRWS site selection process

5.3.1 Overview of Stage 5.2: Intrusive surface-based investigations on remaining candidates

During Stage 5.2 the site investigations will focus on the drilling of boreholes to various depths to investigate the local geology in more detail. Environmental permits and planning permission will be required for borehole drilling work at the candidate site(s). The site-specific understanding, as set out in the ISE, will support our initial application to the environmental regulators for an environmental permit. Thereafter, our work will be subject to ongoing formal regulatory control, through the issue of a series of environmental permits, as described in the GRA [11].

Once detailed site-specific data have been obtained, we expect to develop site assessments which will be reviewed by the Community Siting Partnership(s) before they make a recommendation to their local decision-making bodies about whether to proceed to the next stage of the site selection process. The end of Stage 5 is the last opportunity for a Community Siting Partnership to withdraw from the MRWS site selection process. The local decision-making bodies will decide whether they wish to proceed further, and the UK Government will then make an informed decision on a preferred site. Assuming the local decision-making bodies have decided to proceed further, we would make an application to the environmental regulators to revise our environment permit to commence initial underground investigations at the preferred site, and would also need to apply for planning permission for such work. We will continue to work closely with the communities, and they
will be able to participate in the consultations associated with the regulatory and planning processes.

During Stage 5.2, site characterisation activities will proceed in close collaboration with the developing site-specific safety case. Understanding from this developing safety case will be used to guide identification of further borehole locations. Preparatory work will be undertaken for the Preliminary Environmental Safety Evaluation (PESE) that will be produced in the initial part of Stage 6 for the preferred site that is selected to be taken forward for underground operations.

The GRA identifies that, subsequently, the first or “Initial Environmental Safety Case” will be produced during Stage 6, after the first phase of underground investigations. It is only at that time that the environmental regulators would be expecting us to have fully met all the main requirements of the GRA, and hence would be prepared to grant an environmental permit for “disposal in principle” [11].

Although the GRA does not formally require a site-specific ESC prior to Stage 6, there are other reasons for initiating work contributory to its development earlier (even if at such earlier stages the site-specific ESC cannot yet fully address the GRA). In particular, progressive development of the site-specific ESC provides us with a management tool to help us develop work programmes focused on those areas most important to building confidence in the safety of a GDF and those issues raised by the regulators and Community Siting Partnerships. Therefore we expect to start development of the site-specific ESC iteratively during Stage 5.2. We envisage perhaps two or more iterations of the site-specific ESC during MRWS Stage 5.2, as we assimilate the emerging information from the on-going site investigations and provide feedback to the site characterisation programme.

5.3.2 What we will know going into Stage 5.2

Going into Stage 5.2, we will have a completed ISE for each candidate site, based on the geological disposal concept selected at this stage and a reasonable level of site-specific understanding (which may, for example, include preliminary groundwater flow field modelling).

5.3.3 Required environmental safety developments by the end of Stage 5.2

By the end of Stage 5.2, to commence underground operations in Stage 6, an updated site assessment will be required to justify a decision on underground operations at a single site. This is termed the Preliminary Environmental Safety Evaluation (PESE) in the GRA, and is required to be submitted in the initial part of Stage 6. The PESE is likely to include some quantitative assessment based on available site knowledge and data and initial GDF designs. It will also need to demonstrate that underground operations would not compromise the integrity of a candidate site to the unacceptable detriment of the environmental safety of a possible GDF.

At Stage 5.2, the ESC will need to include further information on how we manage safety and how key decisions have been made, including:

- a description of our technical and management system to ensure that a GDF would be constructed, operated and closed as required;
- explanation of how the supporting work programme, including site characterisation and R&D activities, has been prioritised;
- how the disposal facility design has been developed and optimised – for example, how choices between design options for a specific site were made; and
- how uncertainties in our planning assumptions and uncertainties specific to our understanding of candidate site(s) have been and are being managed.
5.3.4 Our strategy for ESC development during Stage 5.2

Our ESC development strategy during Stage 5.2 is to:

- Continue to maintain the generic ESC and use this as the basis of disposability assessments so that we do not narrow options prematurely.

- Test and refine our conceptual understanding of the site(s), by using existing models to make predictions that can be confirmed or rejected based on the outcomes from successive site characterisation activities. This will involve close and iterative interaction with the site characterisation strategy and the developing evidence-based conceptual understanding of the site.

- Use appropriate process-level models that reflect our developing understanding of the site characteristics and use these to develop models of system components (i.e. the engineered barrier system, geosphere and biosphere), which then feed into a top-level system model, i.e. implement a hierarchical modelling approach that represents our understanding on different scales for the site-specific ESC.

- Develop the site-specific ESC to inform decisions on GDF concept designs and take information from site characterisation activities and research to make more detailed safety assessments, in an iterative manner, such that we can give feedback to the ongoing site characterisation and research and engineering programmes and submit a PESE at the start of Stage 6.

It is during Stage 5.2 that we expect to be in a position to have sufficient site-specific understanding to develop a realistic quantitative assessment of post-closure safety for the site(s). At this stage, we would expect such an assessment to include:

- identification and consideration of relevant features, events and processes (FEPs) and an analysis of relevant scenarios;

- substantiation for the choice of a base scenario to represent the expected evolution of the system;

- substantiation for choice of variant scenarios; and

- analysis of all chosen scenarios.

The scope of the analysis for each chosen scenario would be expected to cover (at a level of detail appropriate to the importance of the scenario):

- a detailed description of the scenario, describing relevant FEPs;

- descriptions of conceptual models, numerical model hierarchy and how data will be transferred between models;

- specification of calculation cases;

- model results, including statistical analysis of probabilistic calculations where appropriate;

- comparison of results with simpler analytic models that capture key features of the system; and

- comparison of calculated risks with the regulatory risk guidance level.

During MRWS Stage 5.2 we anticipate that we might produce two iterations of a site(s)-specific ESC, prior to preparing the PESE to take us into Stage 6.
5.4 ESC Activities in Stage 6 of the MRWS site selection process

5.4.1 Overview of Stage 6: Underground operations

During Stage 6 we will undertake underground construction work and investigations at the preferred site. The aims of the initial phase of underground work will be to confirm the site’s suitability to host a GDF that complies with safety and environmental regulatory requirements, and to provide additional information for the final stages of detailed design. We will introduce a set of investigation techniques suitable for use in the underground facilities, although some surface-based work will continue. After gathering sufficient additional information, we will prepare the “Initial ESC”, to feed into a regulatory decision on GDF construction. If regulatory requirements are met, the regulators will permit further underground operations, including construction of waste disposal areas and all required waste handling facilities (at the surface and underground).

We will continue to develop our safety case, in consultation with the regulators and the Community Siting Partnership, throughout Stage 6. If, at any stage in the development process for a GDF, an issue arises that may significantly affect the ESC, we will discuss the means of resolution with regulators and the Community Siting Partnership.

Assuming that the Initial ESC is positively received and that we receive approval for disposal in principle, we expect to begin construction of the disposal areas and complete construction of all necessary waste handling facilities during Stage 6. At a final hold point before waste can be accepted into the GDF, a Pre-operational ESC will be required by the regulators. This update to the ESC would be based on a single characterised site, a finalised design and a specified inventory. The Pre-operational ESC would take account of knowledge and understanding gained during underground investigations and the initial phase of construction, and would demonstrate that the GDF meets the requirements of the GRA. The Pre-operational ESC would provide a basis for an environmental permit to allow waste disposal to start.

Once we commence waste emplacement operations, we expect to produce updates of the ESC at a frequency to be agreed with the environmental regulators (10 yearly is normal practice for periodic safety reviews for operating nuclear plant), to take account of operational experience and to consider the potential impacts of any new proposals for waste packaging or GDF design modifications.

We expect to produce a closure ESC when we have completed disposal operations and a decision has been taken to seal and close the facility. We anticipate a final ESC would be produced after closure of the facility, when we are ready to request that our environmental permit is surrendered.

5.4.2 What we will know going into Stage 6

Going into Stage 6 we will know:

- The preferred site and have a detailed understanding of the geology, based on interpretation of borehole data as well as geophysical survey data – this will include understanding of the groundwater movements in and around the site; and
- The detailed design for a GDF. However, we recognise that the design may evolve as increased knowledge arises during construction so that further optimisation might be possible.

Note that after initial construction of the GDF sufficient to allow disposals to commence, further construction of new disposal areas would proceed in parallel to disposal in existing vaults and tunnels.
5.4.3 Required environmental safety developments by the end of Stage 6

During Stage 6 we will need to:

- Submit a PESE to obtain the necessary environmental permit for underground operations – this will have been largely developed during Stage 5.2 as it is a prerequisite to commence underground operations.
- Develop detailed understanding of the underground site characteristics and hence optimise the GDF design.
- Develop understanding to the degree necessary to inform a regulatory decision on whether an environmental permit for disposal in principle could be granted.
- Develop an “Initial ESC” that supports the necessary environmental and planning applications to construct a GDF.
- Develop a Pre-operational ESC, for the constructed GDF that supports the necessary permits to start GDF operations, including waste emplacement. This would include detailed information of the following types:
  - the geology, hydrogeology, geochemistry, geotechnical characteristics and surface environment of the chosen site and its setting;
  - the characteristics of the waste including its radionuclide and materials content, treatment and packaging;
  - the design and layout of the disposal facility and how it will be constructed, operated and closed;
  - potential events and processes that may influence the evolution of the GDF;
  - the basis for, and output from, computer-based models of the performance of the disposal system and its components; and
  - qualitative and quantitative supporting evidence that builds confidence in our claims for environmental safety.

5.4.4 Our strategy for ESC development during Stage 6

Our ESC development strategy during Stage 6 is to:

- Enhance our understanding of the GDF system iteratively, through a series of research, site characterisation and site-specific assessment studies to build confidence in a detailed understanding of the properties of the site and how they are expected to evolve over both the near-term and long-term.
- Develop the site-specific ESC using the above understanding, in an iterative manner, to inform decisions on the optimisation of the GDF design and the direction of the underground site characterisation and research programmes.
- Ensure all data and models used in the ESC are appropriately verified and tested, giving sufficient confidence for their use to support permit applications. Where possible, model outputs will be tested against independent data, e.g. by using the models to make predictions that can be tested against the next phase of site investigation data. International model comparison exercises may also be appropriate to build confidence in modelling results.
- Prepare an ESC for GDF construction.
- Prepare a Pre-operational ESC to gain permission to commence GDF operations and waste emplacement.
• Cease development of the generic ESC once there is sufficient confidence in the site-specific ESC and it is decided that the risk of basing waste package disposability assessments, and granting LoCs, on the basis of the site-specific ESC is acceptable.
6 Links to other GDF development activities

As one of the three key safety cases for the disposal system, the development of the ESC serves as a significant integrating tool within the geological disposal programme. It brings together our work in topic areas as diverse as disposal system specification, design, R&D, site characterisation, safety assessment, inventory specification, and stakeholder and regulatory dialogue. For each successive update of the DSSC, we need to integrate activities in these topic areas as shown in Figure 9. The central section of Figure 9 illustrates how the key topic areas of assessments, design, disposal system specification and the expansion of our knowledge base (through R&D and site characterisation) are iteratively linked. The development of the ESC is an intrinsic part of this iterative loop and the tool by which much of the developing understanding is captured. One of the outputs from this iterative loop is the production of specific safety cases, including for example, the Initial ESC. As outputs, the safety cases are not seen as part of the iterative loop, although their development and subsequent updating lies at the heart of the iterative working, as indicated by the “Assessments” topic.

Figure 3 Figure 9 Interaction between different topic areas that are addressed and integrated in developing the ESC

The ESC will be developed in a manner that is consistent with other RWMD strategies, including the R&D strategy, procurement strategy, PSE strategy and people strategy. The ESC Strategy forms part of our overall Technical Strategy to implement geological disposal.

Our R&D, design and site characterisation programmes are designed to expand our knowledge base and provide the information we require to identify preferred GDF concept
option designs, and subsequently to optimise the design of a GDF and build the required level of confidence in its performance.

Our R&D strategy [16] identifies six key areas in which we currently plan to carry out work to fill gaps in our knowledge and to build confidence in the implementation of geological disposal at candidate sites:

1. develop and expand our HLW and SF R&D programme;
2. support the development of future management strategies for materials such as separated plutonium and uranium that are considered in the MRWS White Paper, but are not currently declared as wastes;
3. continue R&D into ILW disposal;
4. address GDF implementation issues;
5. prepare for site characterisation; and
6. investigate the social aspects of implementing geological disposal.

Site characterisation is an essential part of the process to develop a GDF and has been undertaken in many countries. Some site characterisations have been undertaken as part of the site selection process. Others have been undertaken to build understanding and to demonstrate disposal systems in a geological environment similar to that planned for the repository, but at another location. For example, in Sweden, an underground hard rock laboratory was constructed at Äspö with the understanding that this would not be a candidate site for a GDF. Later, investigations were conducted at two candidate sites, Forsmark and Laxemar, prior to confirming Forsmark as the preferred site.

In order to optimise site characterisation, all waste management organisations have had to consider the types of information that should be collected and the ways in which this information is to be used to support the safety case. The NEA has undertaken a number of projects to bring together this experience and learning, and to identify trends and important issues. The most recent such NEA project is AMIGO ('Approaches and Methods for Integrating Geological Information into the Safety Case'). It has comprised three workshops (held in 2003, 2005 and 2008) and a summary 'main messages' report issued in September 2010 [30]. This AMIGO 'main lessons' report recognised that geological (or 'geoscientific') information should be used in several ways in the safety case:

- to provide the basis for establishing values (including range and uncertainty) of key parameters in quantitative performance assessment calculations;
- to provide the basis of understanding how the geosphere evolved to its present state and how it will evolve in the future;
- to contribute to setting boundaries and priorities for assessment by identifying and confirming relevant processes and events, aiding in formulation of conceptual models, supporting decisions on acceptable simplifications, etc.
- to provide qualitative and complementary evidence to support statements made regarding the significance of processes affecting the stability of a site, the isolation of the waste, the containment properties of the geosphere, radionuclide release and mobility on the sub-surface and other issues relevant to the safety functions.

Our approach is consistent with this, and is described more fully in our Site Characterisation Status Report [31] and our Site Characterisation Strategy [32]. A clear understanding of the information requirements of the various users of this geoscientific understanding, such as the ESC and the engineering design, is being developed.

Our approach to the selection of GDF design options is described in our optioneering technical note [33]. We are developing a process for selecting geological disposal concept
options and narrowing the range of options at each stage of the geological disposal programme.

Development of the ESC as the MRWS site selection process proceeds will be mirrored by the development of other aspects of RWMD work, e.g. public and stakeholder engagement, R&D, site assessment and characterisation, disposal system specification, transport and surface infrastructure, GDF design options, packaging disposability options, and EIA and SEA.
7 Concluding remarks

This report has explained our general strategy for developing the ESC. The most important aspect of the ESC strategy is to develop our understanding of the GDF system and how it will evolve over long periods. As we gain more information, particularly in the crucial areas of the geological environment, inventory and disposal facility design, we will represent this information in appropriate models and use these models to increase our understanding of the GDF system performance. Whilst we are developing that understanding for a site-specific GDF system, we will continue to develop and maintain our existing generic ESC and use that as the basis for waste package disposability assessments. This strategy prevents us from prematurely narrowing GDF options, until there is sufficient confidence in the site-specific ESC.

In parallel with the generic ESC, we will iteratively develop a site-specific ESC (or ESCs) that reflects our developing site-specific understanding, making use of the available information from the site characterisation, research and disposal system design programmes at each iteration. We will feed understanding from the developing site-specific ESC into the site characterisation, research and disposal system design programmes so that they are appropriately focussed on providing information that supports the on-going development of the ESC.

At key stages we will use integrated information from the generic and site-specific ESCs, as appropriate, to produce tailored assessments to support the MRWS site selection process and safety cases to obtain the necessary environmental permits and regulatory authorisations. We will also use understanding developed from the ESC to inform optioneering studies, including strategic upstream optioneering of the nuclear fuel cycle, thus feeding into the wider NDA Strategy.

At this generic stage, we cannot give precise details about the safety arguments we will make and the models we will need to develop to support them as they will need to reflect the, as yet unknown, geological properties and GDF design. However, we have knowledge of a wide range of international safety assessments, for different geological settings and disposal facility designs. We will initially work with selected designs from this range (as indeed we have already done with the illustrative generic design examples discussed in the generic ESC), refining and optimising as we increase our understanding of the site, until we have a preferred design, tailored to reflect the properties of the geological setting of the selected site and the wastes for disposal. In line with international best practice, we expect to use a multi-barrier approach, in which a series of engineered and natural barriers work together to provide the required long-term environmental safety.

The generic ESC addresses environmental safety both during the operational phase and long-term environmental safety after the GDF has been sealed and closed. The main challenges for the strategy for developing the ESC are post-closure safety issues. Issues to do with operational environmental safety are much less challenging by comparison, and moving forward, the Operational Environmental Safety Assessment will be developed following standard practice for nuclear plants. Our approach to building confidence in long-term safety is to develop a multi-factor safety case, not relying on any single feature of the multi-barrier design or any single line of safety argument, but including different lines of reasoning, which include both quantitative aspects and qualitative arguments. We will use a range of safety arguments to support the ESC, referencing underpinning sound science and engineering, considering alternative performance indicators and use of analogues where appropriate.

Computer modelling is an important component of the ESC. Confidence in such models is built by ensuring that software has been developed under an appropriate quality management system, and has been adequately tested and verified. Of equal or greater
importance is building confidence that the models have been correctly applied by the user. This is achieved by employing suitably qualified and experienced ‘intelligent users’ to develop models and check calculations.

We will continue to maintain and develop the generic ESC, using it to inform assessments of potential candidate sites and support disposability assessments for waste packages, whilst in parallel developing our site-specific understanding and ultimately representing that in an Initial ESC. These parallel activities will continue until such time as there is sufficient confidence in the site-specific ESC that it is decided that the generic ESC is no longer required.

In developing the ESC we can draw on previous experience in the UK and the substantial experience of disposal agencies overseas in developing safety cases at different stages, from siting strategy, through site evaluation, to the preparation of a detailed safety case to support a GDF licence application.

We will review, and if necessary update, our ESC strategy periodically as the geological disposal programme progresses, to take account of emerging developments, stakeholder input and any additional requirements for environmental safety assessment activities.
References


<table>
<thead>
<tr>
<th></th>
<th>Reference</th>
</tr>
</thead>
</table>