

Geological Disposal

Generic Disposal System Specification

Part B: Technical Specification

December 2016



Geological Disposal

Generic Disposal System Specification

Part B: Technical Specification

December 2016

Conditions of Publication

This report is made available under the Radioactive Waste Management (RWM) Transparency Policy. In line with this policy, RWM 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. RWM is a wholly owned subsidiary of the Nuclear Decommissioning Authority (NDA), accordingly 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 2016 All rights reserved.

ISBN 978-1-84029-555-9.

Other Publications

If you would like to see other reports available from RWM, a complete listing can be viewed at our website <https://rwm.nda.gov.uk>, or please write to us at the address below.

Feedback

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

RWM Feedback
Radioactive Waste Management Limited
Building 587
Curie Avenue
Harwell Campus
Didcot
OX11 0RH
UK

email: rwmfeedback@nda.gov.uk

Preface

Radioactive Waste Management Limited (RWM) has been established as the delivery organisation responsible for the implementation of a safe, sustainable and publicly acceptable programme for the geological disposal of the higher activity radioactive wastes in the UK. As a pioneer of nuclear technology, the UK has accumulated a legacy of higher activity wastes and material from electricity generation, defence activities and other industrial, medical and research activities. Most of this radioactive waste has already arisen and is being stored on an interim basis at nuclear sites across the UK. More will arise in the future from the continued operation and decommissioning of existing facilities and the operation and subsequent decommissioning of future nuclear power stations.

Geological disposal is the UK Government's policy for higher activity radioactive wastes. The principle of geological disposal is to isolate these wastes deep underground inside a suitable rock formation, to ensure that no harmful quantities of radioactivity will reach the surface environment. To achieve this, the wastes will be placed in an engineered underground facility – a geological disposal facility (GDF). The facility design will be based on a multi-barrier concept where natural and man-made barriers work together to isolate and contain the radioactive wastes.

To identify potentially suitable sites where a GDF could be located, the Government has developed a consent-based approach based on working with interested communities that are willing to participate in the siting process. The siting process is on-going and no site has yet been identified for a GDF.

Prior to site identification, RWM is undertaking preparatory studies which consider a number of generic geological host environments and a range of illustrative disposal concepts. As part of this work, RWM maintains a generic Disposal System Safety Case (DSSC). The generic DSSC is an integrated suite of documents which together give confidence that geological disposal can be implemented safely in the UK.

Executive Summary

Radioactive Waste Management Limited (RWM) a wholly owned subsidiary of the Nuclear Decommissioning Authority, is responsible for implementing UK Government's policy on geological disposal of higher activity waste. RWM will be developed into a Site Licence Company (SLC) responsible for the construction and operation of a geological disposal facility.

RWM has developed a generic Disposal System Specification to describe the requirements on the disposal system and is core to RWM's design and assessments work. The Disposal System Specification comprises two documents:

- The **Disposal System Specification Part A – High Level Requirements**. The purpose of the Part A is to document the high-level external requirements on the disposal system, including the activities required to transport, receive and emplace waste packages in the GDF.
- The **Disposal System Specification Part B – Technical Specification**. The purpose of the Part B is to capture the technical requirements defined by RWM to frame the development of a disposal solution to meet the requirements of Part A.

The primary objective of the DSS is to provide the designers of the disposal system with the requirements that must be satisfied and therefore defines the scope and bounds of the engineering design work. DSS Part A documents the overarching requirements from legislation, regulation, and the inventory for disposal. DSS Part B is written for a technical audience and is published to enable the work programme to develop in line with the functional needs of the GDF.

List of Contents

Conditions of Publication	ii
Preface	iii
Executive Summary	v
1 Introduction	1
1.1 The generic Disposal System Safety Case	1
1.2 Introduction to the Disposal System Specification	2
1.3 Objective	3
1.4 Scope	3
1.5 Document structure	6
2 Disposal System Functions	9
2.1 Generic environmental safety functions for the components of the engineered barrier system	9
2.2 Illustrative disposal concepts	10
3 General Design Requirements	29
3.1 Inventory for geological disposal	29
3.2 Construction safety	49
3.3 Operational safety	53
3.4 Environmental safety	57
3.5 Security and safeguards	59
3.6 Nuclear site licence	61
3.7 Retrievability	61
3.8 Optimisation	61
3.9 Best available technique	62
3.10 Impact of construction on the natural barrier	62
3.11 Impact of operations on the disposal system	63
3.12 Services	66
3.13 Facilities	70
3.14 Geological environment and geographical setting	72
3.15 Monitoring	77
4 Transport	79
4.1 Transport of construction materials, spoil, personnel, materials and goods	79
4.2 Transport of radioactive material and dangerous goods	82

5	Receipt and Surface Handling	89
5.1	Waste package surface handling	89
5.2	Access	90
5.3	Records	90
5.4	Monitoring of waste packages	91
5.5	Decontamination of transport equipment	91
6	Underground Transfer	93
6.1	Waste package transfer	93
6.2	Access routes	94
6.3	Personnel transfer	94
7	Emplace	95
7.1	Waste package emplacement	95
7.2	Selective emplacement	95
7.3	Environmental conditions	96
8	Close	99
8.1	Closure designs	99
8.2	Site restoration	100
8.3	Restoration of host rock natural conditions	100
9	Post-Closure (Contribution from the Geosphere and the Engineered Barrier System)	103
9.1	Maintenance of the engineered barrier system functions	103
9.2	Post- closure safety	105
9.3	Gas generation and migration	105
9.4	Natural events and climate change	106
9.5	Site characterisation	106
9.6	Understanding of long-term evolution	106
9.7	Human intrusion	106
9.8	Passive safety	107
9.9	Multiple safety functions	107
	References	116
	Glossary	125
	Appendix A – Description of the Illustrative Concepts	127

1 Introduction

1.1 The generic Disposal System Safety Case

RWM has been established as the delivery organisation responsible for the implementation of a safe, sustainable and publicly acceptable programme for geological disposal of the UK's higher activity radioactive waste. Information on the approach of the UK Government and devolved administrations of Wales and Northern Ireland¹ to implementing geological disposal, and RWM's role in the process, is included in an overview of the generic Disposal System Safety Case (the Overview) [1].

A geological disposal facility (GDF) will be a highly-engineered facility, located deep underground, where the waste will be isolated within a multi-barrier system of engineered and natural barriers designed to prevent the release of harmful quantities of radioactivity and non-radioactive contaminants to the surface environment. To identify potentially suitable sites where a GDF could be located, the Government is developing a consent-based approach based on working with interested communities that are willing to participate in the siting process [2]. Development of the siting process is ongoing and no site has yet been identified for a GDF.

In order to progress the programme for geological disposal while potential disposal sites are being sought, RWM has developed illustrative disposal concepts for three types of host rock. These host rocks are typical of those being considered in other countries, and have been chosen because they represent the range that may need to be addressed when developing a GDF in the UK. The host rocks considered are:

- higher strength rock, for example, granite
- lower strength sedimentary rock, for example, clay
- evaporite rock, for example, halite

The inventory for disposal in the GDF is defined in the Government White Paper on implementing geological disposal [2]. The inventory includes the higher activity radioactive wastes and nuclear materials that could, potentially, be declared as wastes in the future. For the purposes of developing disposal concepts, these wastes have been grouped as follows:

- High heat generating wastes (HHGW): that is, spent fuel from existing and future power stations and High Level Waste (HLW) from spent fuel reprocessing. High fissile activity wastes, that is, plutonium (Pu) and highly enriched uranium (HEU), are also included in this group. These have similar disposal requirements, even though they don't generate significant amounts of heat.
- Low heat generating wastes (LHGW): that is, Intermediate Level Waste (ILW) arising from the operation and decommissioning of reactors and other nuclear facilities, together with a small amount of Low Level Waste (LLW) unsuitable for near surface disposal, and stocks of depleted, natural and low-enriched uranium (DNLEU).

RWM has developed six illustrative disposal concepts, comprising separate concepts for HHGW and LHGW for each of the three host rock types. Designs and safety assessments for the GDF are based on these illustrative disposal concepts.

¹ Hereafter, references to Government mean the UK Government including the devolved administrations of Wales and Northern Ireland. Scottish Government policy is that the long term management of higher activity radioactive waste should be in near-surface facilities and that these should be located as near as possible to the site where the waste is produced.

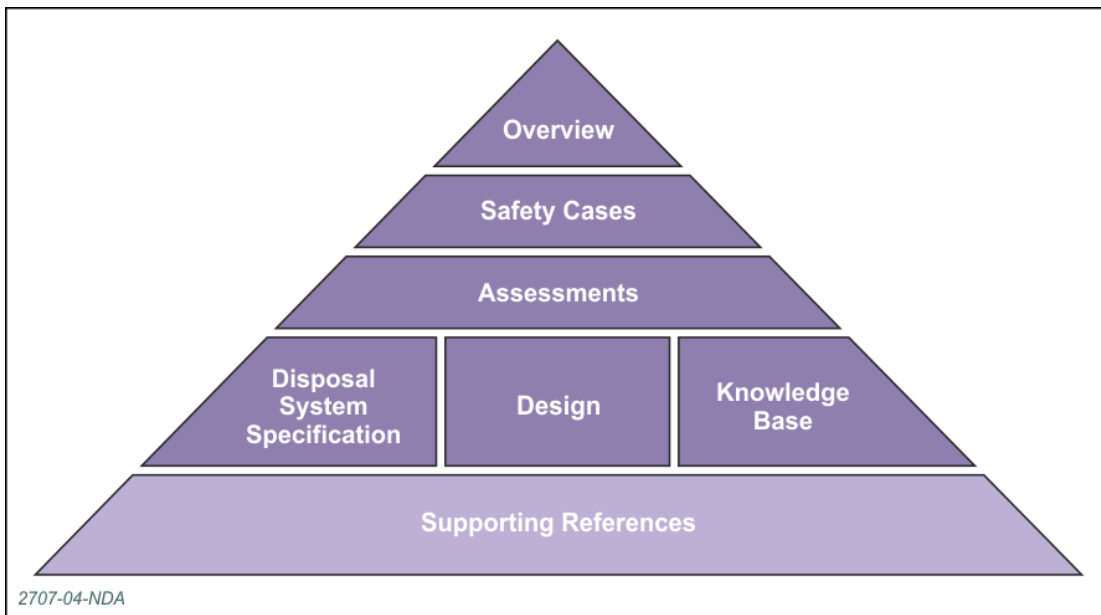
High level information on the inventory for disposal, the illustrative disposal concepts and other aspects of the disposal system is collated in a technical background document (the Technical Background) [3] that supports this generic Disposal System Safety Case.

The generic Disposal System Safety Case (DSSC) plays a key role in the iterative development of a geological disposal system. This iterative development process starts with the identification of the requirements for the disposal system, from which a disposal system specification is developed. Designs, based on the illustrative disposal concepts, are developed to meet these requirements, which are then assessed for safety and environmental impacts. An ongoing programme of research and development informs these activities. Conclusions from the safety and environmental assessments identify where further research is needed, and these advances in understanding feed back into the disposal system specification and facility designs.

The generic DSSC provides a demonstration that geological disposal can be implemented safely. The generic DSSC also forms a benchmark against which RWM provides advice to waste producers on the packaging of wastes for disposal.

Document types that make up the generic DSSC are shown in Figure 1. The Overview provides a point of entry to the suite of DSSC documents and presents an overview of the safety arguments that support geological disposal. The safety cases present the safety arguments for the transportation of radioactive wastes to the GDF, for the operation of the facility, and for long-term safety following facility closure. The assessments support the safety cases and also address non-radiological, health and socio-economic considerations. The disposal system specification, design and knowledge base provide the basis for these assessments. Underpinning these documents is an extensive set of supporting references. A full list of the documents that make up the generic DSSC, together with details of the flow of information between them, is given in the Overview.

Figure 1 Structure of the generic DSSC



1.2 Introduction to the Disposal System Specification

The disposal system fundamentally needs to; *manage the inventory of higher activity waste for disposal to protect people and the environment, both now and in the future, taking into account; safety, security, safeguards, socioeconomic impacts, and value for money.* This is achieved through the definition of requirements on organisational management, site selection and evaluation, design of the GDF and its construction, operation and closure.

To meet this fundamental need, requirements are identified on organisational management, site selection and evaluation, design of the GDF and its construction, operation and closure. These requirements are reported in the DSS using two documents:

- The **Disposal System Specification Part A – High Level Requirements**. The high-level external requirements on the disposal system including the activities required to transport, receive and emplace waste packages in the GDF.
- The **Disposal System Specification Part B – Technical Requirements**. The technical requirements that frame the development of a solution to meet the requirements of Part A.

1.3 Objective

The primary objective of the DSS is to provide the designers of the disposal system with the requirements that must be satisfied and therefore defines the scope and bounds of the engineering design work. DSS Part B is written for a technical audience and is published to enable review and scrutiny of RWM's work programme (for example by regulators and other technical experts). The purpose of this DSS Part B document is to capture the technical requirements, defined at this stage by the current status of knowledge, to frame the development of a solution to meet the technical requirements of DSS Part A. In doing this, the fundamental needs of a geological disposal system are met.

1.4 Scope

1.4.1 Approach to developing the Disposal System Specification

The generic DSS has been developed over many years based on analysis of the developing knowledge base, and analysis of the disposal system. The requirements have been derived from the current state of knowledge and analysis of DSS Part A [4].

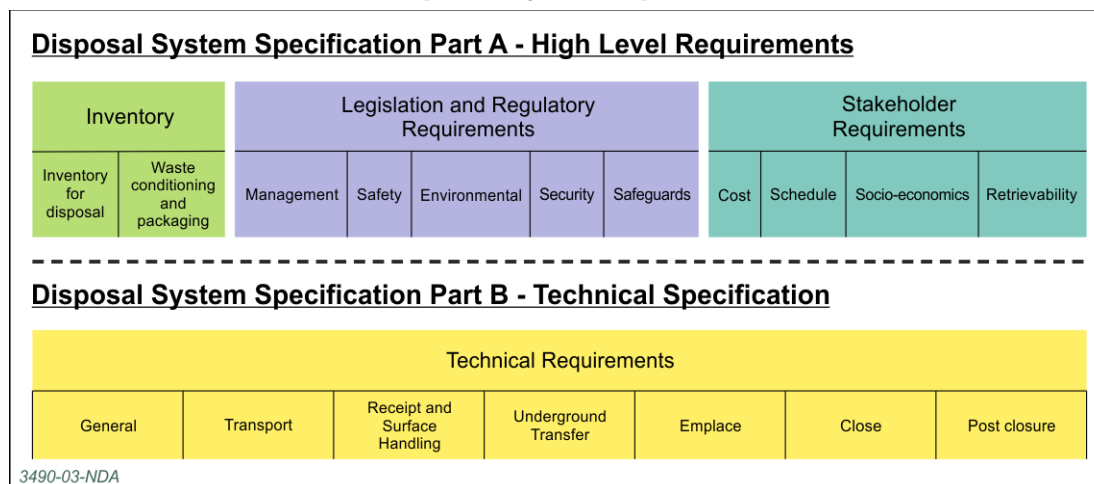
The generic DSS was last published in 2010 [5,6], when it was extended to cover HHGW and high fissile activity wastes in line with Government policy. The DSS has been restructured in order to support better ease of use during generic phase and the definition and capturing of requirements in the site specific phase.

As a first step in the restructuring of the generic DSS Part B for this publication, RWM used the evidence and understanding from the generic Disposal System Safety Case [1] to perform a functional analysis of the disposal system in order to understand the contribution needed from the geological environment and engineered barrier system to satisfy the long-term safety requirements on the disposal system that are defined in DSS Part A. These contributions are described in Section 2 and in more detail in Section 9.

RWM then performed a process analysis by considering the activities required to transport, receive and emplace waste packages in the GDF, and evolution of the disposal system post-closure in order to define all the requirements on the disposal system. This structure (as shown in Figure 2) is designed to be a 'walk-through' of the disposal system activities and is consistent with the Process Flow Diagram which is used as the basis of the generic Operational Safety Case [7].

Hence, the structure of the DSS Part B sets out the requirements on the disposal system for all phases of the disposal system so that these can be defined and checked to be coherent and non-conflicting at the generic and site-specific stage.

Figure 2 Structure of the Disposal System Specification.



1.4.2 Requirements management system

A requirements management approach, consistent with the approaches taken by other international radioactive waste management organisations (for example SKB [8] and Posiva [9]), has been used to develop Parts A and B of the DSS. The aim of a requirements management approach is to provide a rigorous, traceable method of translating high level requirements into technical requirements and subsequently lower level design requirements and component specifications, so enabling an effective review of the compliance of the design with the specified requirements.

The technical requirements include safety requirements and safety functions for the disposal system. Safety requirements specify what the disposal system, or parts of it must do in order to protect humans and the environment against hazards arising from transport and geological disposal of higher activity waste, and therefore meet regulatory and other relevant standards and requirements. A safety function is a property of the disposal system, or part of it, that has the potential to contribute to meeting one or more safety requirements. The safety functions are implemented in the proposed design through a set of design requirements, based on the technical requirements (in DSS Part B) that define the performance of the disposal system.

The high level requirements specified in DSS Part A [4] are not specific to any particular site to be identified via the GDF siting process. DSS Part B will initially describe generic requirements reflecting consideration of a wide range of potentially suitable host geological environments plus a number of assumptions that are made for planning purposes. The DSS Part B describes each of these requirements and assumptions on the disposal system, together with a justification.

The requirements in DSS Part B are presented as a series of 'shall' statements shown in **red italicised bold text**. Where an assumption has been made for planning purposes, the assumption is shown in *purple italicised text*.

At the current stage of the programme RWM is examining a wide range of potentially suitable disposal concepts so that a well-informed assessment of options can be carried out at appropriate decision points in the GDF implementation programme. The range of concepts currently considered by RWM for LHGW and HHGW are reported in [10] and [11] and respectively. Additional detail can also be found in site specific documents, for example [12, 13].

The concepts selected as the illustrative concepts [1, 14] are not necessarily those that will be implemented in a particular geological environment; at this stage no geological

environment has been ruled out. By using the illustrative concepts to develop illustrative designs we are able to develop our understanding of how waste disposal can be carried out in different geological environments and enhance confidence in the way in which long term safety is delivered. The main role of these illustrative disposal concepts is to:

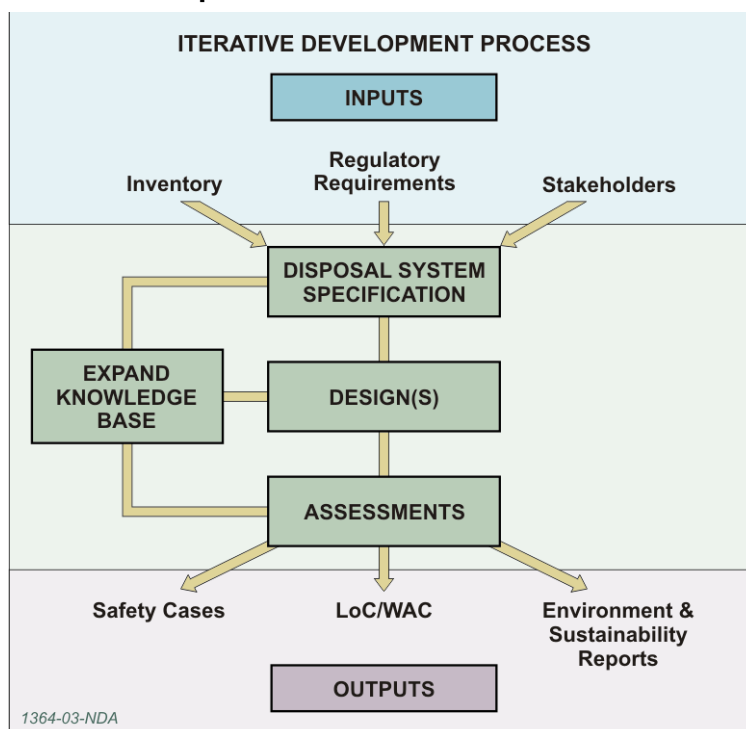
- provide the basis of assessment that underpins the generic Disposal System Safety Case (generic DSSC) and RWM's studies of the environmental, social and economic impacts of the GDF
- support the assessment of the disposability of waste packages proposed by waste packagers

The illustrative disposal concepts also enable RWM to further develop understanding of the safety requirements of the disposal system, develop illustrative generic designs, develop and prioritise its research programme and underpin analyses of the potential cost of geological disposal. A description of the illustrative concepts is given in Appendix A.

The use of illustrative disposal concepts does not restrict RWM from considering other potentially appropriate concepts. When developing concepts, RWM aims to build on existing knowledge available in the UK and overseas and adapt relevant solutions to the UK situation where this knowledge appropriately meets the needs of the UK disposal system and provides an opportunity to improve confidence in the UK programme, reduce programme risk, and provide cost and time savings [15].

Hence, any of the requirements included in DSS Part B that are derived from the illustrative concepts have been clearly highlighted in the generic DSS Part B as assumptions. In the future, as part of GDF siting and development, requirements will be developed to greater levels of detail and assumptions replaced by decisions based on the properties of a specific site, the disposal concept selected and their expected evolution. Therefore, the technical solutions which will arise during the iterative design process may significantly differ from the initial concepts that have been identified. These technical solutions will comply with applicable functions and requirements for the GDF, coupled with a cost-effective approach. Flexibility remains to develop and refine the requirements over time such that the DSS remains fit for purpose at each stage of GDF implementation.

Performance assessment is used to demonstrate in the safety cases, that the disposal system, designed according to the requirements specified in DSS Part B will be compliant with the requirements of DSS Part A. Development of the disposal system can therefore be considered to be a continuous iteration between the DSS, design and assessments as shown in Figure 3, until technical feasibility and safety is demonstrated.

Figure 3 Iterative Development Process

In the generic stage RWM has developed generic designs [16] and safety cases appropriate for the three main host rocks [3]. As site-specific information becomes available, a site-specific DSS Part B will be developed for each site being investigated to support the development of site-specific designs. In parallel with this, a generic DSS Part B will also be maintained until a site is selected in order to provide a basis for generic designs, preliminary safety and environmental assessments and generic Waste Package Specifications, for example [17], that will be used to provide packaging advice in order to ensure options are not prematurely foreclosed.

Detailed site-specific stakeholder requirements (including relevant host community requirements) will be captured in the site-specific DSS Part B document. We will work with community representatives to ensure local issues are addressed appropriately and used to inform the site-specific DSS Part B for each potential site.

As part of a requirements management approach, and in light of experience gained from other international waste management organisations with similar experience of long - duration projects, RWM are developing plans to operate an electronic requirements management system (RMS). The RMS will support the DSS gradual refinements and design development at specific sites. An electronic RMS system will provide a tool for managing the large number of interdependent requirements, particularly at the site-specific stage, and when fully developed, would allow each element of the design to be easily traced back to its driving requirement, for example regulation. Although the decision has not yet been made as to whether the DSS requirements will be added to an electronic RMS, at this generic stage RWM is investigating options and ensuring the DSS is developed to be compatible with an electronic RMS.

1.5 Document structure

Section 2 introduces the post-closure safety requirements that are required from the disposal system and the illustrative concepts for geological disposal that are being used to support the generic phase of the work programme.

The remainder of the document is structured in a way that reflects the activities required to transport, receive and emplace a waste package and other engineered barriers, ultimately leading to closure of the GDF. The requirements of the DSS Part B are organised into the structure illustrated in Figure 4. This structure is then further broken down, presenting requirements in a hierarchical manner as illustrated by the example in Figure 5 for the breakdown of requirements related to services.

Figure 4 Structure of the DSS Part B

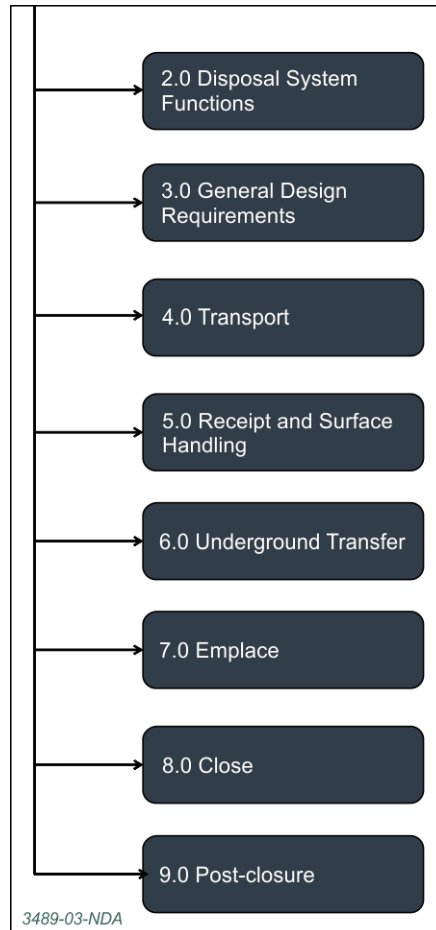
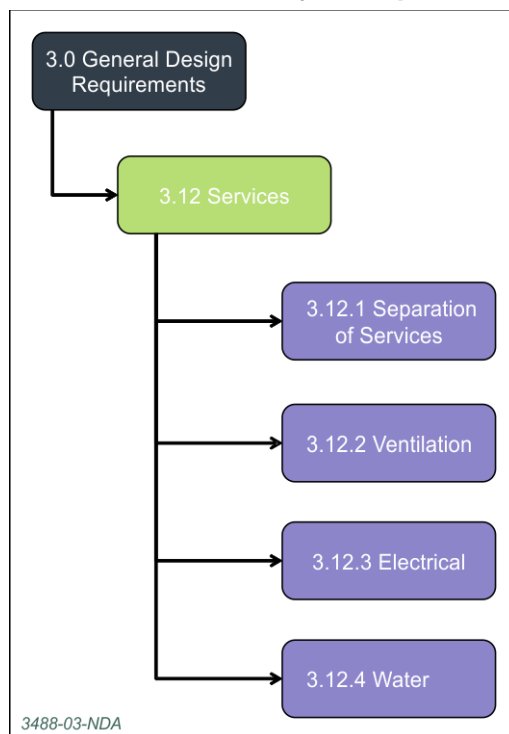


Figure 5 Example of DSS Part B hierarchy of requirements



There are a number of cross-cutting requirements on the disposal system which apply to many of the activities covered in the functional steps. Rather than repeat these requirements in each section to which they apply, RWM has set out general design requirements in Section 3 of DSS Part B which include for example:

- the waste packages that the disposal system should be designed to manage
- requirements relating to safe construction and operation of the GDF
- requirements relating to cost effectiveness and schedule

As explained in DSS Part A [4], aside from the transport of construction materials, spoil, personnel, materials and goods, the responsibility for safe transport of radioactive waste does not lie solely with RWM. RWM has responsibilities as the consignee (receipt of packages) and the waste producers are the consignors (transporting packages to the disposal site). At this stage, the responsible organisation who will act as the carrier is not defined and therefore RWM currently represent the carrier's interest by capturing the related transport requirements. Section 4 therefore sets out the requirements relating to the transport of radioactive materials, construction materials, spoil, personnel, materials and goods.

Section 5 sets out the requirements for receipt of waste packages at the GDF and subsequent surface handling operations before the waste packages are transferred underground. Section 6 sets out the requirements for transferring waste packages between the surface facilities and underground facilities before emplacement. Requirements relating to the emplacement of waste packages underground are specified in Section 7 whilst the requirements for GDF closure are set out in Section 8.

The report concludes with Section 9, the requirements relating to post-closure – the contribution of the geosphere and the engineered barrier system.

2 Disposal System Functions

2.1 Generic environmental safety functions for the components of the engineered barrier system

In its Guidance on Requirements for Authorisation (GRA) [18], the Environment Agency defines environmental safety as ‘The safety of people and the environment both at the time of disposal and in the future’. The GRA further defines environmental safety functions as ‘the various ways in which components of the disposal system may contribute towards environmental safety, e.g. the host rock may provide a physical barrier function and may also have chemical properties that help to retard the migration of radionuclides’.

The key long term safety functions required for a GDF are isolation and containment. By isolation we mean the removal of the wastes from people and the surface environment. By containment we mean retaining the radioactivity from the wastes within various parts of the disposal facility for as long as required to achieve safety.

Long term safety is achieved through the mutually complementary interactions of the components of the engineered barrier system and the host rock (natural barrier). The functions of the individual components of the engineered and natural barrier to achieve isolation and containment of the waste will depend on the waste type and the geological environment selected [19].

At the generic stage, RWM has defined a range of geological environments encompassing typical potentially suitable UK geologies and selected an illustrative disposal concept for low heat generating waste (LHGW) and high heat generating waste (HHGW) in each geological environment. An overview of the illustrative concept and the contributing safety functions is given in Sections 2.2.1 to 2.2.6. These environmental safety functions are site-specific, developed for the safety cases of the sites that have been chosen as RWM’s illustrative concepts. Therefore, these safety functions are not necessarily the only safety functions for a disposal system in these host rocks, but form a platform for a generic safety case. The safety functions will differ between concepts largely due to the varying nature of the contribution of the geological environment.

2.1.1 Post-closure safety

A functional analysis of the national and international standards and guidance captured in DSS Part A and evidence and understanding from our generic Disposal System Safety Case [1] was performed in order to identify the contribution needed from the geological environment and engineered barrier system to satisfy the long-term safety requirements on the disposal system.

The long-term safety requirements are listed below:

- The disposal system shall be sited in an environment in which the functions of the engineered barrier system will be maintained for a period that will prevent release of radionuclides and toxic materials reaching the surface in quantities that could cause harm.
- The disposal system shall ensure that harmful quantities of radionuclides or toxic substances entering groundwater will not compromise safety.
- The disposal system shall ensure that any gas generated in the facility will not compromise safety.
- The disposal system shall be sited in an environment in which natural events and climate changes will not compromise safety.

- The disposal system shall be sited in an environment in which the site can be characterised sufficiently to demonstrate safety.
- The disposal system shall be sited in an environment in which the effect of long-term evolution on safety can be understood.
- The disposal system shall be developed such that the consequences of human intrusion can be assessed and any practical measures implemented to reduce the likelihood.
- Within the disposal system design, safety shall be ensured by passive means to the fullest extent possible.
- The engineered barriers shall be designed to provide safety by means of multiple safety functions such that the overall performance of the disposal system shall not be dependent on a single safety function.

These long-term safety requirements (all except the last 2 that specifically relate to the design of the disposal system) have been used to support the development of National Screening Guidance [20] that has been developed to support the process of siting a geological disposal facility in the UK.

The long-term safety requirements are defined in more detail in Section 9 of this report alongside the requirements for other phases of the disposal system.

2.2 Illustrative disposal concepts

Taking into account the long-term safety requirements in Section 2.1.1, and through evaluation of international approaches to disposal system development, the illustrative disposal system concepts have been identified and are described with their safety functions and contributing components in Sections 2.2.1 to 2.2.6.

2.2.1 Illustrative disposal concept for high heat generating waste in higher strength rock

The illustrative concept for the disposal of high heat generating waste in higher strength rock is the KBS-3V concept developed by SKB in Sweden. Note that the KBS-3V concept has been developed jointly by SKB (Sweden) and Posiva (Finland) for two separate sites – only minor differences occur between the two conceptual designs. Figure 6 gives a graphical representation of the concept whilst Table 1 provides the environmental safety functions that would be delivered by the individual components of the engineered barrier system.

Containment of radionuclides would be achieved through the container integrity which is provided by the corrosion resistance of the container material and the mechanical strength of the container insert. Copper is identified for the container material due to its excellent corrosion resistance and high ductility. Corrosion resistance would be maximised through incorporation of a clay buffer, which restricts the water flow around the container and limits microbial activity that could otherwise accelerate corrosion. The material in the insert is nodular cast iron, selected for its strength. The insert would be cast to fill the void space between channels, reducing the chance of a criticality occurring [21].

Figure 6 Illustrative concept for the disposal of high heat generating waste in higher strength rock.

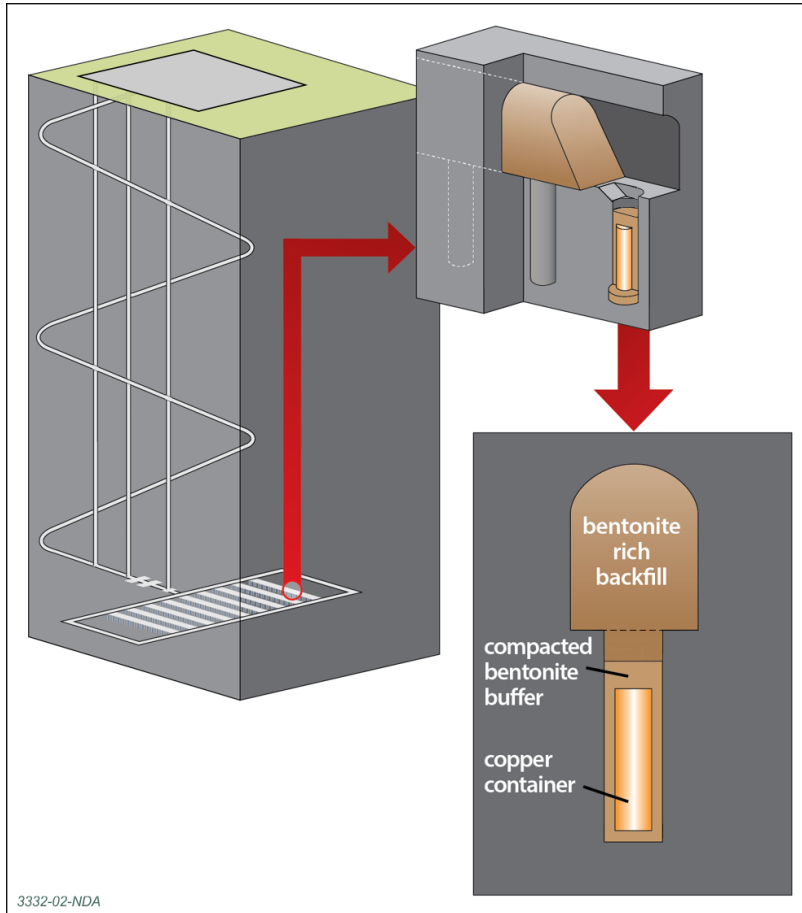


Table 1 Environmental safety functions of the principal components of the engineered barrier system for the illustrative disposal concept for high heat generating waste in higher strength rock.

Barrier	Environmental Safety Function
Wasteform	<ul style="list-style-type: none"> • <i>limits the release of radionuclides by providing a stable, low solubility matrix</i> • <i>expected to be sub-critical after disposal, even after breach of the container and ingress of groundwater</i>
Container	<ul style="list-style-type: none"> • <i>limits the release of radionuclides by:</i> <ul style="list-style-type: none"> ○ <i>providing containment of the waste for the period of interest</i> ○ <i>withstanding loads associated with shear displacements in the rock associated with earthquakes</i> ○ <i>withstanding loads from bentonite swelling which may be heterogeneous and which could otherwise cause crushing of the container</i> • <i>mechanical strength of the container prevents failure through over-pressurisation</i> • <i>criticality control by:</i> <ul style="list-style-type: none"> ○ <i>the exclusion of water by the container (apart from the residual water content of the spent fuel waste packages) minimising neutron moderation</i> ○ <i>spent fuel assemblies will be placed in fuel channels in the cast iron insert, which will provide criticality control by limiting neutron interactions by assemblies</i>
Local buffer or backfill	<ul style="list-style-type: none"> • <i>during the period of containment, protects the container against corrosion attack and minor rock movements by:</i> <ul style="list-style-type: none"> ○ <i>limiting the presence of water and aggressive species at the disposal container surface</i> ○ <i>limiting microbial activity that could otherwise accelerate corrosion of the disposal container</i> ○ <i>providing a minor buffering effect on pH and the redox potential of the engineered barrier system and</i> ○ <i>conditioning porewater that contacts the disposal container such that corrosion is limited</i> • <i>after container failure, limits the release of radionuclides by providing a low permeability barrier which limits fluid flow and ensures solute transport is by diffusion only</i>
Mass backfill	<ul style="list-style-type: none"> • <i>stabilises the structure and geometry of the engineered barriers by:</i> <ul style="list-style-type: none"> ○ <i>restoring mechanical stability to the rock and engineered region of the GDF so that the other engineered barriers are not physically disrupted.</i> ○ <i>restoring the hydrological conditions in the area</i> • <i>limits the release of radionuclides by limiting groundwater ingress and egress to the disposal areas</i>

Barrier	Environmental Safety Function
Seals	<ul style="list-style-type: none"> • <i>isolation of the waste by preventing access of people into a closed GDF</i> • <i>prevents the release of radionuclides by cutting off potential groundwater flow pathways within a backfilled GDF</i> • <i>provides mechanical support to the backfill material in a disposal module</i>
Geological environment	<ul style="list-style-type: none"> • <i>isolation of the waste by:</i> <ul style="list-style-type: none"> ○ <i>providing a substantial radiation shield</i> ○ <i>Sufficiently thick cover to be robust to erosion from natural processes</i> ○ <i>sufficiently deep to not be intercepted by near-surface resource exploration and recovery activities</i> • <i>protection of the engineered barriers by:</i> <ul style="list-style-type: none"> ○ <i>having stable, reducing, alkaline, and low to moderate salinity groundwater conditions which will lead to low rates of metal corrosion in the EBS</i> ○ <i>conducting heat energy away from disposal facility</i> ○ <i>allow dispersion of gases along interconnecting fractures</i> • <i>limitation of contaminant transport to the surface environment</i>

2.2.2 Illustrative disposal concept for low heat generating waste in higher strength rock

The illustrative concept for the disposal of low heat generating waste in higher strength rock is the UK ILW/LLW concept developed by the RWM/the NDA, UK. Figure 7 gives a graphical representation of the concept whilst Table 2 provides the environmental safety functions that would be delivered by the individual components of the engineered barrier system.

In this concept, the wastefrom may be cement encapsulated or unencapsulated. The principal environmental safety functions would be the slow rate of container corrosion which is maintained through the alkaline conditions of the cementitious backfill, as well as its ability to suppress microbial activity and allow the migration of gas away from the waste packages preventing over-pressurisation.

Figure 7 Illustrative concept for the disposal of low heat generating waste in higher strength rock

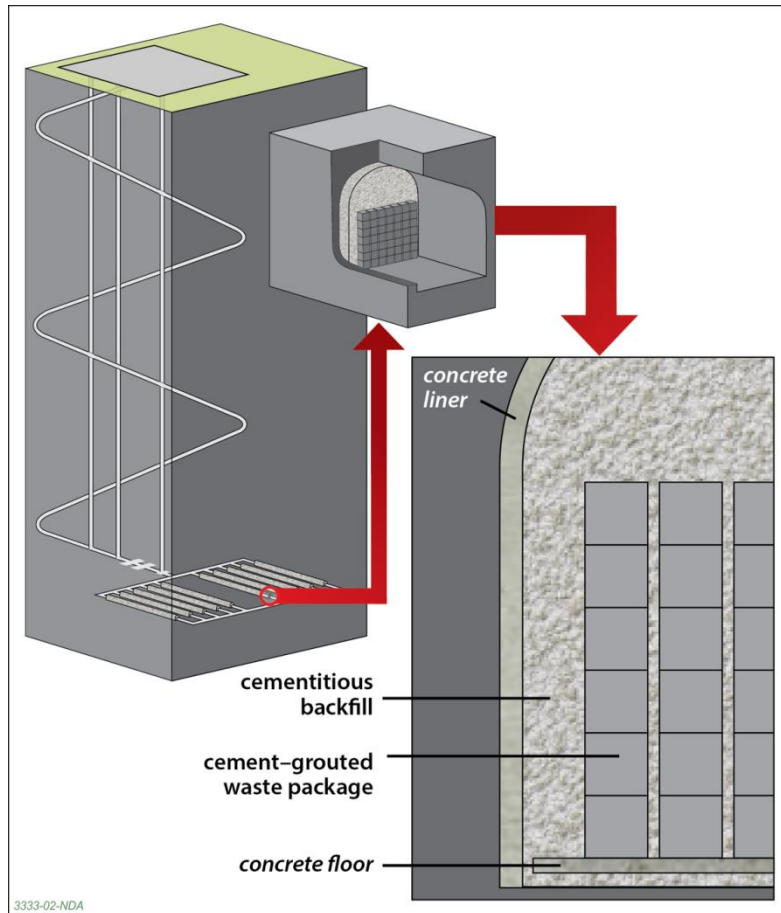


Table 2 Environmental safety functions of the principal components of the engineered barrier system for the illustrative disposal concept for low heat generating waste in higher strength rock

Barrier	Environmental Safety Function
Wasteform	<ul style="list-style-type: none"> • <i>limits the release of radionuclides by providing a stable, low solubility matrix</i> • <i>fissile material limits and other controls, such as ensuring that the fissile material is distributed uniformly in a waste package, will prevent criticality</i>
Container	<ul style="list-style-type: none"> • <i>stabilises the structure and geometry of the EBS by providing a degree of mechanical strength</i> • <i>limits the release of radionuclides by corroding slowly in a way that maintains chemically reducing conditions</i> • <i>prevents over-pressurisation of waste packages via the use of vents</i> • <i>criticality control by:</i> <ul style="list-style-type: none"> ○ <i>container walls will shield and separate fissile wastefoms from each other in a vault</i> ○ <i>exclusion of water will limit neutron moderation and fissile material relocation</i>
Local buffer or backfill	<ul style="list-style-type: none"> • <i>protects the container by:</i> <ul style="list-style-type: none"> ○ <i>creating uniform alkaline conditions to reduce metallic corrosion rates</i> • <i>limits the release of radionuclides by:</i> <ul style="list-style-type: none"> ○ <i>controlling the solubility of radionuclides</i> ○ <i>supressing microbial activity</i> ○ <i>inhibiting the migration of radionuclides away from the engineered barrier system</i> ○ <i>providing a high active surface for the sorption of radionuclides</i> • <i>limits over-pressurisation by allowing the migration of gas away from waste packages</i>
Mass backfill	<ul style="list-style-type: none"> • <i>limits release of radionuclides by:</i> <ul style="list-style-type: none"> ○ <i>preventing access tunnels from acting as preferential flow pathways for groundwater.</i> ○ <i>controlling the solubility of radionuclides</i> ○ <i>providing a high active surface area for the sorption of radionuclides</i>
Seals	<ul style="list-style-type: none"> • <i>prevent access of people into a closed GDF</i> • <i>prevents the release of radionuclides by cutting off potential groundwater flow pathways within a backfilled GDF</i> • <i>provides mechanical support to the backfill material in a disposal module</i> • <i>prevents over-pressurisation by allowing the passage of gas</i>

Barrier	Environmental Safety Function
Geological environment	<ul style="list-style-type: none"> • <i>isolation of the waste by:</i> <ul style="list-style-type: none"> ○ <i>providing a substantial radiation shield</i> ○ <i>sufficiently thick cover to be robust to erosion from natural processes</i> ○ <i>sufficiently deep to not be intercepted by near-surface resource exploration and recovery activities</i> • <i>protection of the engineered barriers by:</i> <ul style="list-style-type: none"> ○ <i>having stable, reducing, alkaline, and low to moderate salinity groundwater conditions which will lead to low rates of metal corrosion in the EBS</i> ○ <i>conducting heat energy away from disposal facility</i> ○ <i>allow dispersion of gases along interconnecting fractures</i> • <i>limitation of contaminant transport to the surface environment</i>

2.2.3 Illustrative disposal concept for high heat generating waste in lower strength sedimentary rock

The illustrative concept for the disposal of high heat generating waste in lower strength sedimentary rock is the Opalinus Clay Concept developed by Nagra, Switzerland. Although the Swiss concepts are used as the basis of the illustrative disposal concepts, information is also drawn from the French programme and from the Belgian HLW/spent fuel supercontainer concept based on disposal of HHGW in Boom Clay. For simplicity, the illustrative disposal adopted in 2010 has been maintained.

Figure 8 gives a graphical representation of the concept whilst Table 3 provides the environmental safety functions delivered by the individual components of the engineered barrier system.

In this concept, the spent fuel would be packaged in thick walled steel containers that provide containment for several thousand years. The bentonite buffer would restrict the water flow around the container and limits microbial activity that could otherwise accelerate corrosion. Radionuclide mobility would be limited by the reducing conditions in the disposal module and the sorption of radionuclides to the container corrosion products. Additionally, the bentonite buffer would attenuate the release of radionuclides as transport is by diffusion only, and the plasticity of the bentonite would allow self-sealing following physical disturbance in the host rock [13].

Figure 8 Illustrative concept for the disposal of high heat generating waste in lower strength sedimentary rock.

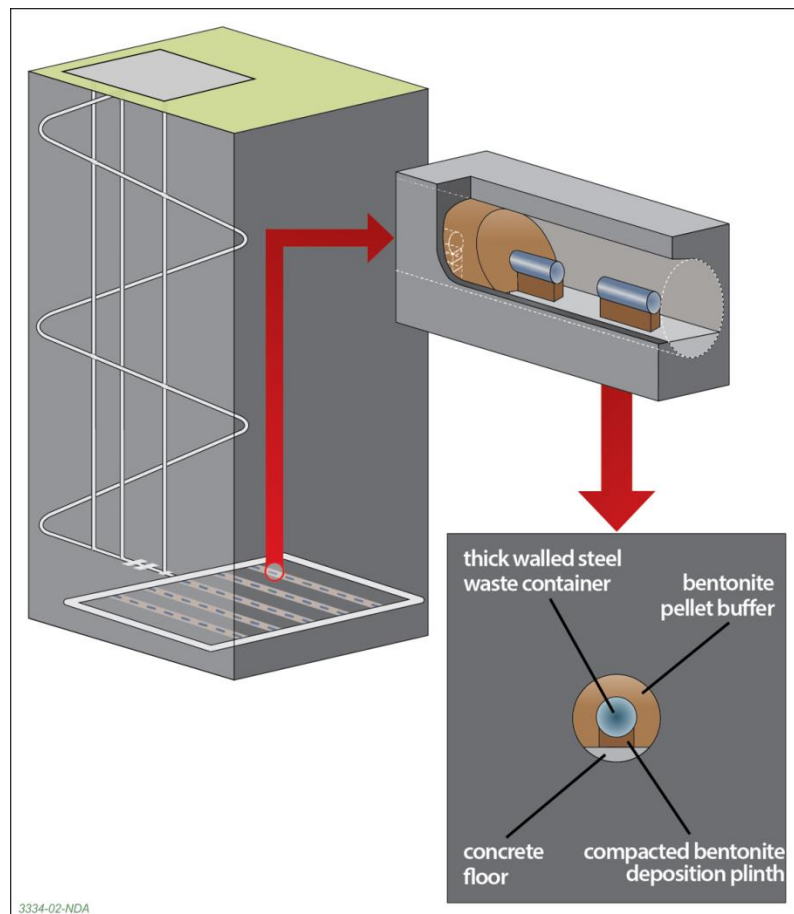


Table 3 Environmental safety functions of the principal components of the engineered barrier system for the illustrative disposal concept for high heat generating waste in lower strength sedimentary rock

Barrier	Environmental Safety Function
Wasteform	<ul style="list-style-type: none"> • <i>limits the release of radionuclides by providing a stable, low solubility matrix</i> • <i>expected to be sub-critical after disposal, even after breach of the container and ingress of groundwater</i>
Container	<ul style="list-style-type: none"> • <i>limits the release of radionuclides by:</i> <ul style="list-style-type: none"> ○ <i>providing complete containment of waste for the period of time where the wastes generate heat (the thermal period)</i> ○ <i>providing redox buffering in the engineered barrier system through corrosion of the container which limits the solubility of some radionuclides whilst the corrosion products provide a surface for radionuclide sorption</i> • <i>criticality control by:</i> <ul style="list-style-type: none"> ○ <i>placing spent fuel assemblies in channels in the carbon steel containers which will provide criticality control by limiting neutron interaction between assemblies</i> ○ <i>exclusion of water by the container (apart from residual water content of the spent fuel waste packages) will minimise neutron moderation</i> ○ <i>the longevity of the container will ensure that substantial decay of Pu-239 to U-235 will have occurred in the waste packages prior to container breach</i>
Local buffer or backfill	<ul style="list-style-type: none"> • <i>limits the release of radionuclides by:</i> <ul style="list-style-type: none"> ○ <i>providing confinement of the waste due to long resaturation times</i> ○ <i>providing attenuation of radionuclides due to low solute transport rates and ensuring solute transport is by diffusion only</i> ○ <i>providing a cation exchange capability for sorption of radionuclides</i> ○ <i>providing filtration of radionuclide containing colloids so that their migration is limited</i>
Mass backfill	<ul style="list-style-type: none"> • <i>stabilises the structure and geometry of the engineered barriers since the access tunnels would be backfilled to fill void spaces</i>
Seals	<ul style="list-style-type: none"> • <i>seals in access tunnels and shafts will isolate the waste by providing a barrier to access of people into the GDF</i> • <i>limits the release of radionuclides by cutting off potential groundwater flow pathways within a backfilled GDF</i> • <i>stabilised the structure and geometry of the engineered barriers by providing mechanical support to the backfill material in a disposal module</i> • <i>limits over-pressurisation by allowing the passage of gas</i>

Barrier	Environmental Safety Function
Geological environment	<ul style="list-style-type: none"> • <i>isolation of the waste by:</i> <ul style="list-style-type: none"> ○ <i>providing a substantial radiation shield</i> ○ <i>sufficiently thick cover to be robust to erosion from natural processes</i> ○ <i>sufficiently deep to not be intercepted by near-surface resource exploration and recovery activities</i> • <i>protection of the engineered barriers by:</i> <ul style="list-style-type: none"> ○ <i>limiting the supply of water needed to drive degradation of the EBS</i> ○ <i>water present will be stable, reducing, alkaline, and low to moderate salinity groundwater conditions which will lead to low rates of metal corrosion in the EBS</i> ○ <i>conducting heat energy away from disposal facility</i> ○ <i>allow dispersion of gases along interconnecting fractures</i> • <i>limitation of contaminant transport to the surface environment</i>

2.2.4 Illustrative disposal concept for low heat generating waste in lower strength sedimentary rock

The illustrative concept for the disposal of low heat generating waste in lower strength sedimentary rock is the Opalinus Clay concept developed by Nagra, Switzerland. However, it should be noted that there is similarly extensive information available for a concept that has been developed for implementation in Callovo Oxfordian Clay by Andra (France), and which has also been accorded strong endorsement from international peer review. We will also draw on information from the andra programme to support development of a GDF in this host rock.

Figure 9 gives a graphical representation of the concept whilst Table 4 provides the environmental safety functions delivered by the individual components of the engineered barrier system.

In this concept, the wasteform may be cement encapsulated or unencapsulated. The principal environmental safety function would be the slow rate of container corrosion. The cementitious backfill in the emplacement tunnels would maintain conditions that would limit the corrosion rate by ensuring an alkaline pH, suppress microbial activity and allow the migration of gas away from the waste packages. The backfill would also reduce the radionuclide transport once containers are breached by creating alkaline conditions and limiting water flux.

Figure 9 Illustrative concept for the disposal of low heat generating waste in lower strength sedimentary rock.

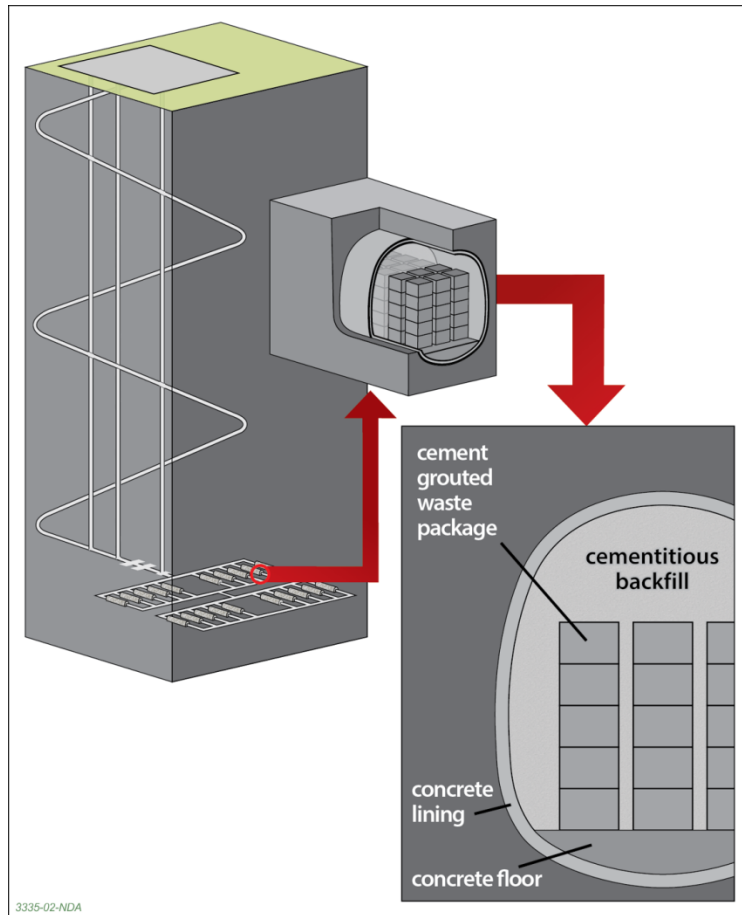


Table 4 Environmental safety functions of the principal components of the engineered barrier system for the illustrative disposal concept for low heat generating waste in lower strength sedimentary rock

Barrier	Environmental Safety Function
Wasteform	<ul style="list-style-type: none"> • <i>limits the release of radionuclides by providing a stable, low solubility matrix</i> • <i>fissile material limits and other controls, such as ensuring that the fissile material is distributed uniformly in a waste package, will prevent criticality</i>
Container	<ul style="list-style-type: none"> • <i>limits the release of radionuclides by: <ul style="list-style-type: none"> ○ <i>buffering groundwater and porewater to high pH</i> ○ <i>limiting the rate at which water contacts the waste to ensure radionuclide transport is diffusion dominated</i> </i> • <i>prevents failure of the waste container through over-pressurisation by allowing the passage of gas</i> • <i>prevent criticality by shielding and separating fissile wasteforms from each other in a vault (limiting neutron transport between packages)</i>
Local buffer or backfill	<ul style="list-style-type: none"> • <i>stabilises the structure and geometry of the engineered barriers by filling voids around the waste containers</i> • <i>limits the release of radionuclides by: <ul style="list-style-type: none"> ○ <i>Limiting the rate at which water comes into contact with the container and ensuring that radionuclide transport is diffusion dominated</i> ○ <i>Buffering groundwater and porewater to high pH.</i> ○ <i>Providing a cation exchange capability for the sorption of radionuclides</i> </i> • <i>prevents failure through over-pressurisation by having sufficiently high porosity to accommodate gas generated in the engineered barrier system.</i>
Mass backfill	<ul style="list-style-type: none"> • <i>limits the release of radionuclides by: <ul style="list-style-type: none"> ○ <i>preventing access ways from becoming preferential radionuclide transport pathways</i> ○ <i>providing a physical barrier to human intrusion</i> </i> • <i>stabilises the structure and geometry of the engineered barriers to prevent voids from collapsing as the host rock creeps</i>
Seals	<ul style="list-style-type: none"> • <i>prevents the release of radionuclides by providing a physical barrier to human intrusion into a closed GDF</i> • <i>limits the release of radionuclides by cutting off potential groundwater flow pathways within a backfilled GDF</i> • <i>limits over-pressurisation by allowing the passage of gas</i>

Barrier	Environmental Safety Function
Geological environment	<ul style="list-style-type: none"> • <i>isolation of the waste by:</i> <ul style="list-style-type: none"> ○ <i>providing a substantial radiation shield</i> ○ <i>low permeability sedimentary cover rocks will be present and will protect the evaporite from dissolution from near-surface hydrological systems</i> ○ <i>sufficiently deep to not be intercepted by near-surface resource exploration and recovery activities</i> • <i>protection of the engineered barriers by containing no mobile groundwater:</i> <ul style="list-style-type: none"> ○ <i>reduced degradation of the EBS</i> ○ <i>little response to events such as glaciation</i> ○ <i>significant gas generation is not expected due to the low levels of metal corrosion</i> ○ <i>reduced chance of nuclear criticality due to less corrosion of packages, less water moderation, less mass transfer processes, and neutron absorbance by chlorine</i> • <i>limitation of contaminant transport to the surface environment as fractures close through rock creep</i>

2.2.5 Illustrative disposal concept for high heat generating waste in evaporite rock

The illustrative concept for the disposal of high heat generating waste in evaporite rock is the Gorleben Salt Dome Concept developed by DBE-Technology, Germany. Figure 10 gives a graphical representation of the concept whilst Table 5 provides the environmental safety functions that would be delivered by the individual components of the engineered barrier system.

In this concept, the waste would be packaged in thick walled carbon steel containers and emplaced inside tunnels that would be backfilled with crushed evaporite host rock. Due to the low permeability of evaporites, the host rock would not contain any mobile groundwater, and any groundwater they do contain would be in isolated pores. Therefore, there would be little water available to facilitate radionuclide migration in the evaporite and rock creep would be expected to encapsulate the wastes after disposal, closing any fractures and voidage that could act as radionuclide transport pathways (see geosphere status report [22]). Low permeability sedimentary rock cover would continue to protect the evaporite host rock from near-surface hydrological systems and any dissolution

Figure 10 Illustrative concept for the disposal of high heat generating waste in evaporite rock

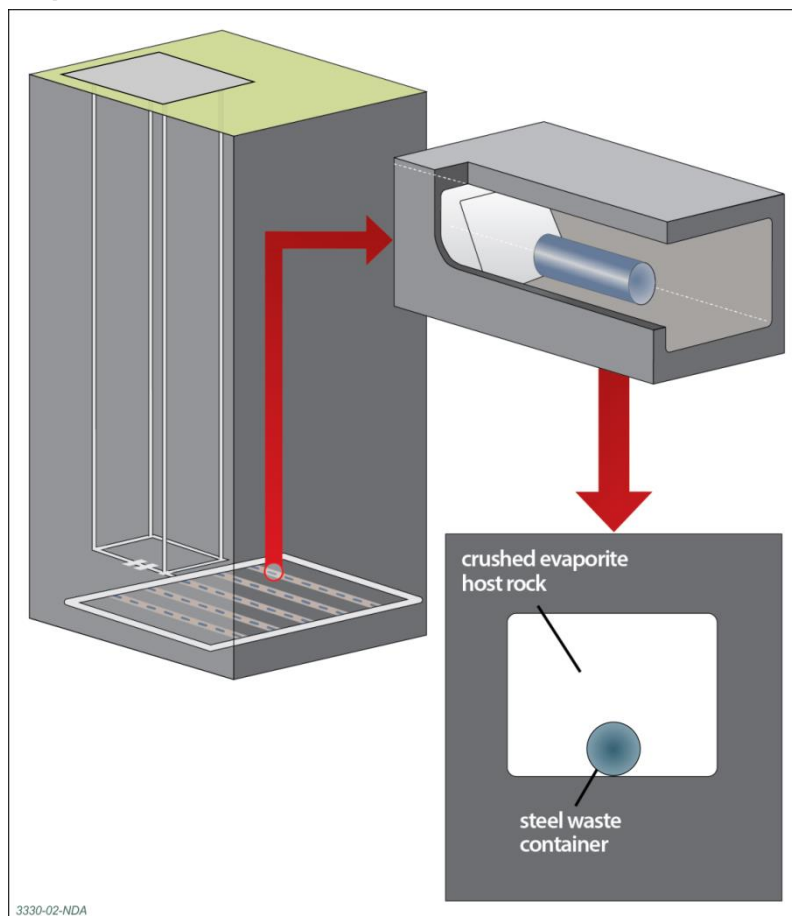


Table 5 Environmental safety functions of the principal components of the engineered barrier system for the illustrative disposal concept for high heat generating waste in evaporite rock

Barrier	Environmental Safety Function
Wasteform	<ul style="list-style-type: none"> • <i>limits the release of radionuclides by providing a stable, low solubility matrix</i> • <i>expected to be sub-critical after disposal, even after breach of the container and ingress of groundwater</i>
Container	<ul style="list-style-type: none"> • <i>limits the release of radionuclides by isolating and completely containing the waste during emplacement operations</i> • <i>criticality control by:</i> <ul style="list-style-type: none"> ○ <i>placing spent fuel assemblies in channels in the carbon steel containers which will provide criticality control by limiting neutron interaction between assemblies</i> ○ <i>exclusion of water by the container (apart from residual water content of the spent fuel waste packages) will minimise neutron moderation</i>
Local buffer or backfill	<ul style="list-style-type: none"> • <i>contributes to protecting the container by initially isolates the container from the rock</i> • <i>stabilises the structure and geometry of the engineered barriers by:</i> <ul style="list-style-type: none"> ○ <i>creeping under the influence of overburden pressure and temperature to eventually become solid with almost identical properties to the surrounding undisturbed rock</i> • <i>prevents access of water from surrounding formations so long as the salt remains stable</i>
Mass backfill	<ul style="list-style-type: none"> • <i>stabilises the structure and geometry of the engineered barriers by:</i> <ul style="list-style-type: none"> ○ <i>creeping under the influence of overburden pressure and temperature to eventually become solid with almost identical properties to the surrounding undisturbed rock</i> • <i>prevents access of water from surrounding formations so long as the salt dome remains stable</i>
Seals	<ul style="list-style-type: none"> • <i>prevents the release of radionuclides by:</i> <ul style="list-style-type: none"> ○ <i>keeping the disposal system as dry as possible to prevent these regions from acting as preferential radionuclide transport pathways</i> ○ <i>isolating the GDF until rock creep has compacted and consolidated the crushed salt components of the seal</i> ○ <i>providing a physical barrier to human intrusion into a closed GDF</i>

Barrier	Environmental Safety Function
Geological environment	<ul style="list-style-type: none"> • <i>isolation of the waste by:</i> <ul style="list-style-type: none"> ○ <i>providing a substantial radiation shield</i> ○ <i>low permeability sedimentary cover rocks will be present and will protect the evaporite from dissolution from near-surface hydrological systems</i> ○ <i>sufficiently deep to not be intercepted by near-surface resource exploration and recovery activities</i> • <i>protection of the engineered barriers by containing no mobile groundwater:</i> <ul style="list-style-type: none"> ○ <i>reduced degradation of the EBS</i> ○ <i>little response to events such as glaciation</i> ○ <i>significant gas generation is not expected due to the low levels of metal corrosion</i> ○ <i>reduced chance of nuclear criticality due to less corrosion of packages, less water moderation, less mass transfer processes, and neutron absorbance by chlorine</i> • <i>limitation of contaminant transport to the surface environment as fractures close through rock creep</i>

2.2.6 Illustrative disposal concept for low heat generating waste in evaporite rock

The illustrative concept for the disposal of low heat generating waste in evaporite rock is the WIPP Bedded Salt Concept developed by US Department of Energy, USA. Figure 11 gives a graphical representation of the concept whilst Table 6 provides the environmental safety functions that would be delivered by the individual components of the engineered barrier system.

In this concept, waste would be packaged in stainless steel containers (500 litre drums) and robust shielded containers. Sacks of magnesium oxide would be placed on top of each waste stack to absorb carbon dioxide and water and buffer pH, reducing corrosion rates and the solubility of key radionuclides. As the magnesium oxide hydrates and swells, the porosity and permeability of the engineered barrier system would be reduced and a cation exchange capability would be provided for the sorption of radionuclides.

Due to the low permeability of evaporite rock, the host rock will not contain any mobile groundwater, and any groundwater they do contain will be in isolated pores. Therefore, there would be little water available to facilitate radionuclide migration in the evaporite and rock creep would be expected to encapsulate the wastes after disposal, closing any fractures and voidage that could act as radionuclide transport pathways (see geosphere status report [22]).

It is assumed that a low permeability sedimentary rock cover would continue to protect the evaporite host rock from near-surface hydrological systems and any dissolution. Transport would be limited to diffusion through any brine that might be present.

Figure 11 Illustrative concept for the disposal of low heat generating waste in evaporite rock.

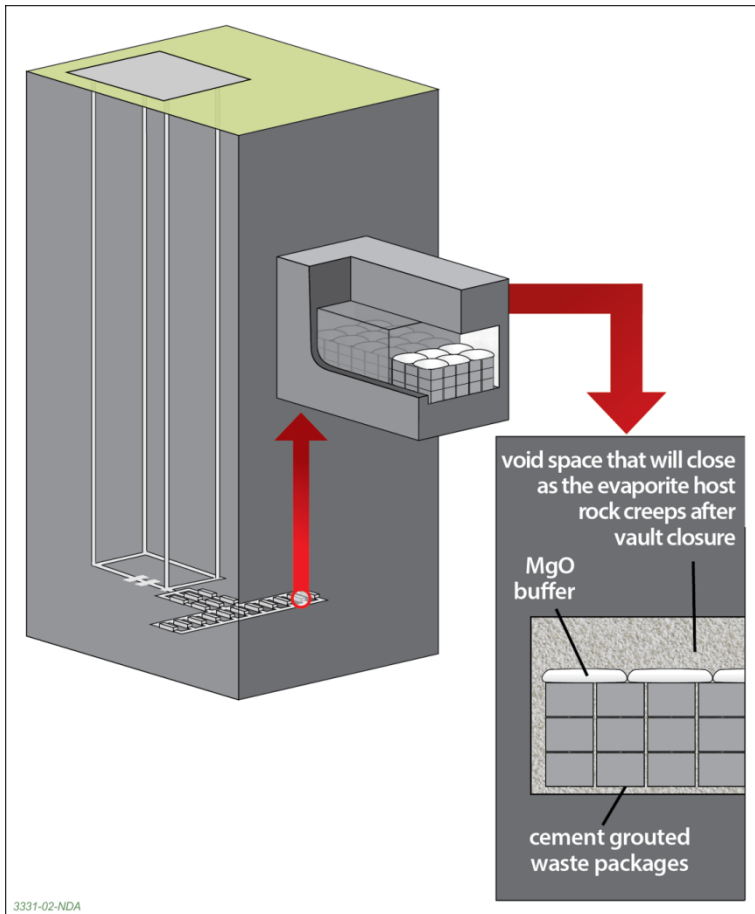


Table 6 Environmental safety functions of the principal components of the engineered barrier system for the illustrative disposal concept for low heat generating waste in evaporite rock

Barrier	Environmental Safety Function
Wasteform	<ul style="list-style-type: none"> • <i>the wastes are not required to be immobilised and do not have a specified safety function</i> • <i>fissile material limits and other controls, such as ensuring that the fissile material is distributed uniformly in a waste package, will prevent criticality</i>
Container	<ul style="list-style-type: none"> • <i>limits the release of radionuclides by:</i> <ul style="list-style-type: none"> ○ <i>limiting water from contacting the waste</i> ○ <i>corroding slowly in a way that maintains chemically reducing conditions</i> • <i>prevents over pressurisation of waste packages</i> • <i>prevent criticality by shielding and separating fissile wasteforms</i>
Local buffer or backfill	<ul style="list-style-type: none"> • <i>protects the waste containers by:</i> <ul style="list-style-type: none"> ○ <i>absorbing water which helps delay the onset of water contacting the waste packages thus reducing corrosion</i> • <i>limits the release of radionuclides by:</i> <ul style="list-style-type: none"> ○ <i>providing a measure of physical containment as the magnesium oxide hydrates and swells, reducing porosity and permeability of the engineered barrier system</i> ○ <i>buffering the pH to alkaline conditions which reduces solubility of key radionuclides</i> ○ <i>providing a cation exchange capability for the sorption of radionuclides</i> • <i>limits over-pressurisation by:</i> <ul style="list-style-type: none"> ○ <i>absorbing carbon dioxide and therefore helping to mitigate the effects of gas generation</i>
Mass backfill	<ul style="list-style-type: none"> • <i>stabilises the structure and geometry of the engineered barriers</i> • <i>limits the release of radionuclides by preventing water circulation in the disposal region</i>
Seals	<ul style="list-style-type: none"> • <i>limits the release of radionuclides by:</i> <ul style="list-style-type: none"> ○ <i>keeping the disposal system as dry as possible to provide a barrier and prevent these regions from acting as preferential radionuclide transport pathways</i> ○ <i>isolating the GDF until rock creep has compacted and consolidated the crushed salt components of the seal</i>

Barrier	Environmental Safety Function
Geological environment	<ul style="list-style-type: none"> • <i>isolation of the waste by:</i> <ul style="list-style-type: none"> ○ <i>providing a substantial radiation shield</i> ○ <i>low permeability sedimentary cover rocks will be present and will protect the evaporite from dissolution from near-surface hydrological systems</i> ○ <i>sufficiently deep to not be intercepted by near-surface resource exploration and recovery activities</i> • <i>protection of the engineered barriers by containing no mobile groundwater:</i> <ul style="list-style-type: none"> ○ <i>reduced degradation of the EBS</i> ○ <i>little response to events such as glaciation</i> ○ <i>significant gas generation is not expected due to the low levels of metal corrosion</i> ○ <i>reduced chance of nuclear criticality due to less corrosion of packages, less water moderation, less mass transfer processes, and neutron absorbance by chlorine</i> • <i>limitation of contaminant transport to the surface environment as fractures close through rock creep</i>

3 General Design Requirements

3.1 Inventory for geological disposal

RWM's quantified inventory for disposal in the GDF shall be used as the source of waste package information for the disposal system design and assessments.

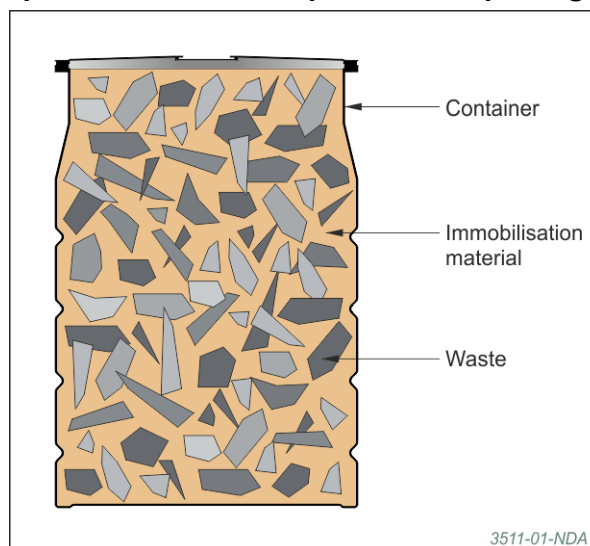
The inventory for geological disposal is produced by RWM, and quantifies the packaged waste inventory for disposal that is defined in the implementing geological disposal White Paper. The UK Radioactive Waste Inventory (RWI), produced periodically by the Department for Business, Energy and Industrial Strategy (BEIS), takes account of all radioactive waste that has arisen (or will arise) from existing facilities, and is used as the basis of the inventory for geological disposal. The UK RWI is updated periodically (currently every three years) and the inventory for geological disposal is updated based on this, as well as the Government policy at the time (for example, plans for re-use of plutonium), and industry plans (for example, for new build).

The term 'waste packages' refers to the unit that will be disposed of in the GDF. This includes the waste, encapsulation or immobilisation material, and the disposal container, see Figure 12 below. In many cases, the waste may be transported to the GDF inside a re-useable transport container, which does not form part of the waste package for disposal.

The waste package can be considered to comprise of two distinct components, each of which can act as a barrier (see Section 3.1.5) in its own right [17]:

- the waste container, which provides a physical barrier and also enables the waste package to be handled safely
- the wasteform, which may provide a significant degree of physical and/or chemical containment of the radionuclides in the waste

Figure 12 The components that make up the 'waste package'



3.1.1 Inventory – managing uncertainty

RWM's designs and assessments shall be developed to take into account inventory scenarios in order to understand the impacts of inventory uncertainties.

The inventory for geological disposal presents information that is based on the best available data and assumptions. The uncertainty in the inventory for disposal is driven by:

- uncertainties in the data provided by the waste producers for the UK RWI (for example, the uncertainties in radionuclide activities specified by the waste producers in the UK RWI)
- possible changes to the assumptions that are made by RWM and waste producers (for example, the timing and size of a new build programme)

As part of the 2013 inventory for geological disposal, previously referred to as the Derived Inventory, RWM considered a number of alternative inventory scenarios to explore the sensitivity of the inventory to these uncertainties and possible changes [23]. The alternative scenarios are considered in isolation in order to allow the impact of each to be more clearly understood.

3.1.2 Waste Acceptance Criteria (WAC)

A geological disposal facility shall only accept waste packages that comply with the WAC.

It is currently assumed that wastes are packaged for disposal prior to transport to the GDF.

Since the nature of the waste and its manner of packaging are important factors in the design of a waste disposal system, minimum standards and levels of performance should be defined by the implementer of the GDF. The basis for such definition comes from the WAC, which will specify the characteristics that waste packages will have to satisfy before being accepted for disposal. Such WAC are produced and issued by the facility operator following appropriate regulatory scrutiny.

WAC will be based on the specific design of the GDF including the disposal concept and the geological environment in which it is implemented. The WAC will be determined by the safety standards to be achieved by the GDF, including requirements specified in the authorisation/permit for disposal and conditions attached to the nuclear site licence, and also take account of standardisation, design constraints, legal, operational and economic factors.

The WAC will state the requirements that waste packages should fulfil in relation to their management at the GDF. However, since it is assumed that waste packages will have to be transported on the existing transport network, constraints on their conditioning and packaging in addition to the WAC may be necessary to ensure compliance with regulatory requirements for such transport. The waste package requirements in Section 3.1.5 and the contents of the generic Waste Package Specifications [17] are defined so that they would be bounding for the likely constraints imposed by geological disposal. As such, the generic requirements act as preliminary WAC. Although the WAC for a UK GDF has not yet been defined, the WAC will be influenced by the fact that when the GDF is available to accept waste, much of the UK RWI will have been packaged.

The issue of a Letter of Compliance (LoC) gives the waste producer confidence that the waste package has been assessed by an independent waste management organisation in accordance with procedures that are scrutinised by the regulators, and has been found to be compliant with the concept for geological disposal as presently understood. It does not remove the need for assessment of the waste package against future WAC, but the provision of a Final stage LoC is an essential component of the package record that will be required at that time.

3.1.3 Waste Packaging and Conditioning

Disposal system development shall be designed to accept waste packages that comply with the Generic Waste Package Specification.

The disposal system development shall take into account of Letters of Compliance already issued.

It is essential that the developer/operator of a GDF has confidence that all waste packages destined for disposal there are compatible with their established packaging standards and specifications [17]. This is because a GDF will be required to accommodate some 200,000 individual waste packages, many of which already exist or will exist prior to the definition of the WAC for the facility. Prior to the identification of a specific site and disposal concept for a GDF the information necessary to define the WAC is not available. In the meantime, and as a precursor to WAC, RWM produces generic packaging specifications, the primary purpose of which is to enable the holders of radioactive wastes to condition that waste into a form that will be compatible with the anticipated needs of transport to, handling, and disposal in a GDF.

Waste producers have the responsibility for packaging waste in compliance with the appropriate Generic Waste Package Specification or WAC. Waste producers are responsible for the safe management of the waste they hold up to the point at which it is accepted for transport from their site. This includes responsibility for ensuring that the waste is conditioned in a manner that will result in transportable and disposable waste packages and for ensuring that waste packages remain in this condition until transport to a GDF takes place.

Prior to the definition of the WAC, the disposability of waste packages is judged by their compliance with the various criteria defined by the appropriate packaging specification. RWM carry out the assessments of such compliance by way of the Disposability Assessment process [24]. In undertaking disposability assessments, RWM determines whether waste packages will have characteristics compliant with the requirements defined by the relevant packaging specification, and ultimately whether the wastes could be accommodated within the operational and environmental safety case of a GDF. The main output of a disposability assessment is an Assessment Report, which may be accompanied by the issue of a LoC endorsing the packaging proposal. In line with the regulatory guidance, such endorsement is now seen by the regulators as an important component of the operator's Radioactive Waste Management Case, an ONR requirement showing how operations are integrated with the lifetime plans for the waste and the site as a whole.

Periodic review of LoCs are carried out, typically every 10 years or if triggered by significant changes in the disposal system and/or safety case, to ensure that the properties of endorsed waste packages remain consistent with developing plans for geological disposal, and the associated safety assessments for their transport and geological disposal [25].

Following the endorsement of a proposal to package waste it is the waste producers' responsibility to ensure that the actual packaging of the waste takes place in accordance with the processes endorsed by the LoC. Following manufacture, waste packages must be stored in such a manner to ensure that they do not deteriorate to such an extent that they will no longer be disposable. At some point prior to sending waste to a GDF, WAC will be produced and will be used as a means of judging the acceptability of individual waste packages for disposal.

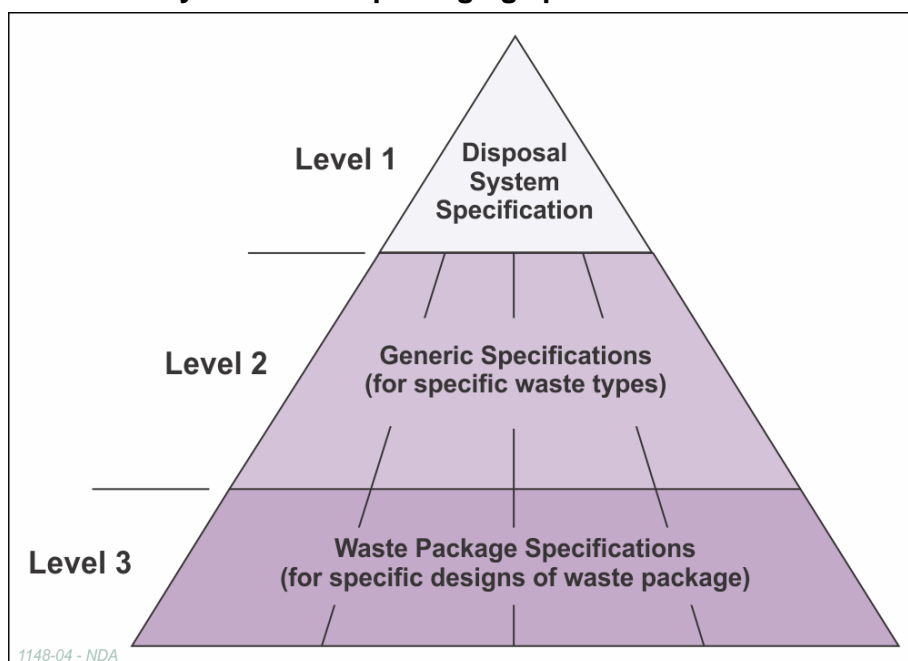
Immediately prior to transport, it will be the waste producer's responsibility to carry out checks of compliance of each waste package with both the WAC and the requirements for transport. Such checking will be assumed to be carried out by a combination of physical checks of the waste packages and using information contained in records created during the manufacture and storage of the waste package.

RWM has defined generic waste package requirements which are derived from full consideration of all future phases of waste management. The requirements are defined so that they would be bounding of the eventual Waste Acceptance Criteria (WAC) for an operational GDF and as such the generic requirement for waste packages act as preliminary WAC.

The generic requirements defined here are for waste packages containing any type of radioactive waste which could be subject to geological disposal. These are the highest level requirements in a hierarchy of packaging specifications as illustrated in Figure 13.

The hierarchy comprises three 'levels' of packaging specification in which each successive level represents an increasing degree of specificity, both to the nature of the waste and the design of the waste package. The DSS Part B contains all Level 1 requirements whilst Level 2 Generic Specifications and Level 3 Waste Package Specifications are developed for specific waste types and specific designs of waste packages respectively.

Figure 13 Hierarchy of the RWM packaging specifications.



The waste package requirements have been developed in line with the principle of isolate and contain, as stated in the International Atomic Energy Agency (IAEA) Specific Safety Guide for geological disposal facilities [19]: *“The objective of geological disposal of radioactive waste is to provide containment and isolation of the radionuclides in the waste from the biosphere.”*

The most immediate barriers that provide containment of radionuclides in the GDF are those provided by the waste package, provided by the physical barrier of the waste container and the immobilisation of waste form.

A key aspect in the packaging of waste for geological disposal is the achievement of passive safety by waste packages. Requirement 5 of the IAEA Specific Safety Requirements [26] (as referenced in DSS Part A [4]) states that: *“The operator shall evaluate the site and shall design, construct, operate and close the disposal facility in such a way that safety is ensured by passive means to the fullest extent possible...”*

As a potential key component in the safety of a disposal facility, this requirement encompasses the waste packages that are disposed there and their design should include features that ensure that they will be passively safe for an appropriate period.

The joint regulatory guidance on waste conditioning and the disposability of packaged waste [27] states that: *“Waste conditioning should yield waste packages that are:*

- *passively safe and suitably robust physically, so as to ensure containment and safe handling...*

- *suitable for safe transport ... and*
- *disposable, such that the nature and properties of the conditioned waste product are compatible with the anticipated standards for eventual disposal for example, WAC of an appropriate disposal facility”*

With regard to the definition of WAC, for which the packaging specifications are intended to be forerunners, Requirement 13 the UK regulators’ Guidance on Requirements for Authorisation for geological disposal facilities (GRA) [18] (as referenced in DSS Part A [4]) includes a requirement for the developer/operator of such a facility to: “...*establish waste acceptance criteria consistent with the assumptions made in the environmental safety case and with the requirements for transport and handling, and demonstrate that these can be applied during operations at the facility.*”

In this context the ‘requirements for transport’ are those implemented into UK law as referenced in DSS Part A, notably the IAEA Regulations for the Safe Transport of Radioactive Material [28].

3.1.4 Waste package safety functions

Waste packages shall be compatible with safe transport to, handling, and disposal in the GDF.

To provide a basis for the identification of the full range of safety functions that are required of waste packages RWM define a high-level safety function for all waste packages which encompasses both aspects of their long-term management following export from interim storage (that is transport and disposal).

The various components of a multiple barrier geological disposal system each contribute to the achievement of safety in different ways over different timescales. This approach is intended to provide a means of setting out what each barrier should achieve to ensure the overall safety of the disposal system.

3.1.4.1 Waste package safety functions that apply to transport and GDF operations

The waste packages are required to be able to provide the following five operational safety functions:

- ***provide containment of radionuclides and other hazardous materials during normal operations and under accident conditions***
- ***limit radiation dose² to workers and members of the public***
- ***preclude criticality***
- ***provide the means of safe handling***
- ***withstand internal and external loads***

The barriers provided by the waste package will play key roles in achieving the required degree of safety during transport and will continue to do so during the operational period³ of the GDF. The exact period for which these safety functions will be required to persist will depend on the disposal concept selected for each specific type of waste and specifically on the timescale defined for the operational period (it being assumed that, by comparison, the

² In this context radiation dose is that which could result from exposure to direct radiation from the surface of the waste package.

³ The operational period is assumed to extend until the time when the GDF is backfilled and closed.

transport operation will be relatively short-term). Their persistence for such a time will also give confidence that the waste packages will enter the post-closure period in an appropriate condition.

The actual timescale for which the operational safety functions may need to be maintained will also depend on the period during which retrieval of the waste package is required. The 2014 White Paper states that waste that has been placed in the GDF could be retrieved during the operational period of the GDF if there was a compelling reason to do so [2]. Retrieving placed waste would tend to become more difficult with time, particularly after the end of the operational period (that is, once the GDF has been closed permanently).

3.1.4.2 Waste package safety functions that apply to the post-closure period

The waste packages are required to be able to provide the following four post-closure safety functions:

- *provide containment of radionuclides and other hazardous materials*
- *contribute to the overall performance of the EBS*
- *contribute to ensuring that, following GDF closure, a criticality event is not a significant concern*
- *withstand internal and external loads*

The durations of the periods for which each of these safety functions will be required to persist will, as was the case for the operational safety functions, depend on the disposal concept selected for each specific type of waste. It will also depend to a significant degree on the nature of the contents of waste packages, notably the type and quantities of radionuclides and their half-lives. For many radionuclides, the waste package can provide total containment until they and their daughters decay to insignificant levels. However, the barriers provided by the waste package will degrade progressively over time and will eventually gradually lose their ability to provide containment of longer-lived radionuclides. The period of containment provided by the waste package will, in the case of HSR and LSSR concepts, be extended by the presence of the buffer surrounding the container which will limit the supply of aggressive sulphide ions to the canister surface and subsequently inhibit the rate of corrosion.

During the GDF post-closure period the role the waste packages play in the multiple barrier disposal system will change. It is assumed in the post-closure safety case that waste packages will enter that period possessing properties that will enable them to continue to provide a barrier to the release of radionuclides. It is also acknowledged that over time, evolution of waste packages in the disposal environment will result in the eventual loss of those properties, following which the containment provided by the other barriers will act to maintain the overall safety of the geological disposal system.

Further containment of radionuclides will however be provided by the other components of the EBS, and the geological barrier, which will act to delay the movement of any remaining quantities of these longer-lived radionuclides as they are released from the waste package. The isolation provided by the geological disposal system will also contribute to containment in that locating the GDF in a suitably deep and stable environment protects the engineered barriers, helping them to preserve their containment functions for longer periods.

The waste packages could have a potential impact on the effectiveness of the other barriers that make up the geological disposal system, notably the other components of the EBS. For example, the chemical barrier provided by the backfill in some disposal concepts could be subject to challenges derived from waste packages, including exposure to heat,

ionising radiation and/or the chemical products of waste package evolution⁴. Each of these has the capability to cause localised chemical changes in the surrounding engineered or natural materials, which could result in it no longer fulfilling its intended purpose.

3.1.4.3 The identification of packaging criteria

Following identification of the waste package safety functions, the requirements for waste packages are now defined in the form of a series of packaging criteria which can be used to show that all of the necessary waste package safety functions can be achieved in practice.

To aid in the identification of these packaging criteria RWM has used IAEA guidance on the properties of waste containers [29]⁵ and of waste packages and their contents [30], which have significance for their transport and disposal. Also of relevance in this process is IAEA guidance of the development of specifications for packaged waste [31], studies of the potential form of WAC for a UK GDF [32], and a consideration of the WAC produced for disposal facilities worldwide [33].

For waste containers the following criteria are identified [34]:

- handling: shape, dimensions, lifting arrangements, gross package weight, stackability, impact resistance and gas build-up/venting systems
- radiological protection: surface contamination and surface dose rate
- container durability: container material, container closure and degradation of the material
- waste package identification

Similarly the following criteria are identified for waste packages and wasteforms [35]:

- properties related to radioactivity: total activity, radionuclide composition, criticality safety, heat output, radiation stability, homogeneity, surface dose rate
- chemical properties: chemical stability, composition, pyrophoricity, ignitability, reactivity, corrosivity, explosiveness, chemical compatibility, gas generation, toxicity, decomposition of organics
- physical properties: permeability, porosity, homogeneity, density, voidage
- mechanical properties: load resistance, dimensional stability, impact resistance
- thermal properties: fire resistance, thermal conductivity, freeze/thaw stability
- biological properties: biological degradation, decomposition of organic wastes

3.1.5 Waste packaging requirements

The requirements defined below apply to the complete waste package as prepared for transport to, handling, and disposal in the GDF. They do not apply to any devices that may be used as part of either of those stages of geological disposal, such as overpacking containers that could be used to provide additional protection during transport, or ancillary equipment used to assist in the handling or stacking of waste packages. The

⁴ These could include chemicals resulting from corrosion of the waste container and/or those released from the waste package (that is from the waste and/or conditioning materials).

⁵ Whilst this guidance is primarily aimed at containers for use with ILW the general principles it contains are also generally applicable to waste containers that could be used for the packaging of all categories of higher activity waste.

consequences of the use of such devices will be included, where relevant, in the definition of packaging requirements in the generic specifications and the WPS.

It should be noted that whilst packaging requirements are, in general, defined for the complete waste package, in practice the manner in which they are achieved will depend on a number of factors including:

- the nature of the waste container
- the physical, chemical and radiological properties of the waste
- the means by which the waste is conditioned for disposal

The requirements defined below are separated into those which are most directly related to the waste container, the wasteform, or to the waste package as a whole. In addition, a number of generic requirements are defined to be applied during the manufacture and storage of waste packages. This approach and justification for each requirement is further developed for the different specific types of waste in the generic specifications.

In a number of the requirements defined below reference is made to waste packages meeting 'regulatory limits' during transport and/or the operational period of the GDF. Such limits are defined in accordance with all of the relevant UK and international regulations and are applied to specific designs of waste package in the relevant waste package specification.

It should be noted that, where the words 'shall' and 'should' are used in the packaging requirements, they have the following meaning:

- 'shall' denotes a limit which is derived from consideration of a regulatory requirement and/or from a fundamental assumption regarding the current designs of the transport or disposal facility systems
- 'should' denotes a target, and from which relaxations may be possible if they can be shown not to result in any significant reduction in the overall safety of the geological disposal system

3.1.5.1 Requirements for waste containers

General properties

The properties of the waste container shall be such that, in conjunction with those of the wasteform, it satisfies all of the requirements for the waste package.

The compatibility of the wasteform and waste container is assessed against the waste package requirements using the Disposability Assessment process, outlined in Radioactive Wastes and Assessment of the Disposability of Waste Packages [24].

External dimensions

The external dimensions of the waste package shall be compatible with the transport and GDF handling systems.

This requirement applies to waste containers and any overpack that is used for transport and disposal.

Handling feature

The waste package shall enable safe handling by way of the transport and GDF handling systems.

This requirement maintains that waste containers contain a handling feature, or are transported and disposed of with an overpack that has compatible features to allow handling.

Stackability

Where required by the transport or disposal system, the waste package shall enable safe stacking.

Identification

The waste package shall enable unique identification until the end of the GDF operational period.

Durability of the integrity of the waste container

The waste package shall enable safe handling by way of its handling feature until the end of the GDF operational period.

The waste container shall maintain containment for as long as is required by the GDF safety case.

3.1.5.2 Requirements for wasteforms

The properties of the wasteform shall be such that, in conjunction with those of the waste container, it satisfies all of the requirements for the waste package.

The properties of the wasteform shall comply with the requirements for containment within the geological disposal concept, as defined by the GDF safety case.

3.1.5.3 Requirements for waste packages**Activity content**

The activity content of the waste package shall be controlled to comply with the radionuclide related assumptions that underpin the safety cases for transport and the GDF operational period.

Gross mass

The gross mass of the waste package shall be compatible with the transport and GDF handling systems and with the requirement for the waste package to be safely stacked.

External dose rate

The external dose rate from the waste package shall enable safe handling of the waste package during transport and the GDF operational period, and shall comply with regulatory limits for transport.

Heat output

The heat generated by the waste package shall be controlled to ensure that:

- *thermal effects result in no significant deterioration in the performance of the waste package, or of the disposal system as a whole*
- *regulatory limits on the surface temperature of transport packages are not exceeded*

Surface contamination

The non-fixed surface contamination of the waste package shall be as low as reasonably practicable and shall comply with regulatory limits for transport.

Gas generation

The generation of bulk, radioactive and toxic gases by the waste package shall comply with the requirements for safe transport and disposal.

The release of radionuclides in gaseous form from the waste package shall comply with the assumptions that underpin the safety cases for transport and the GDF operational period.

Criticality safety

The presence of fissile material, neutron moderators and reflectors in the waste package shall be controlled to ensure that:

- *criticality during transport is prevented*
- *the risk of criticality during the GDF operational period is tolerable and as low as reasonably practicable*
- *in the GDF post-closure period both the likelihood and the consequences of criticality are low*

Accident performance

The high level requirements for waste packages are outlined in the Generic Waste Package Specification [35] and include the following:

- *under all credible accident scenarios the release of radionuclides and other hazardous materials from the waste package shall be low and predictable*
- *the waste package should exhibit progressive release behaviour within the range of all credible accident scenarios*

The impact and fire accident performance of the waste package shall comply with the assumptions that underpin the safety cases for transport and the GDF operational period.

The accident performance of the waste package shall ensure that, in the event of any credible accident during the GDF operational period, the on- and off-site doses resulting from the release of radionuclides from the waste package shall be as low as reasonably practicable and should be consistent with meeting the relevant Basic Safety Levels.

The response of waste packages to the full range of such challenges should be 'progressive' in that there should be no significant 'cliff-edge' effects where a small increase in the magnitude of the challenge would produce a large deterioration in waste package performance.

3.1.5.4 Requirements for the manufacture and storage of waste packages

Adequate controls shall be established and applied to ensure that manufactured waste packages have the properties and performance required of them.

Adequate controls shall be applied during any period of interim storage to ensure that waste packages retain their required properties and performance for the duration of such a period.

Quality management

Adequate management arrangements shall be applied to all aspects of the packaging of radioactive waste, and the storage of waste packages, that affect product quality. These arrangements shall be agreed with RWM prior to the start of the activities to which they relate.

Data and information recording

Information shall be recorded for each waste package covering all relevant details of its manufacture and interim storage. This information shall be sufficient to enable

assessment of the characteristics and performance of the waste package against the requirements of all stages of long-term management.

3.1.5.5 Requirements for waste packages containing nuclear materials

The management of waste packages containing nuclear material shall comply with all relevant international safeguards obligations and security requirements for their transport and disposal.

3.1.6 Waste containers

Design of the disposal system shall assume the need to handle waste packages manufactured using the following containers, some of which include specific variants⁶:

- **500 litre drum**
- **3 cubic metre box**
- **6 cubic metre concrete box**
- **3 cubic metre drum**
- **4 metre box**
- **2 metre box**
- **500 litre concrete drum**
- **1 cubic metre concrete drum and**
- **Miscellaneous Beta Gamma Waste Store (MBGWS) box (currently used to store MBGW at the Sellafield site and which is expected to be suitable for disposal but has not yet been endorsed)**
- **Robust Shielded Containers (for example, cubical (Type 6) and cylindrical (Type 2) ductile cast iron containers (DCICs))**
- **DNLEU Transport and Disposal container**
- **Disposal Containers for High Level Waste (HLW) and Spent Fuel (SF)**

The Generic Waste Package Specification and the Specification for Waste Packages for Vitrified HLW and SF are subject to change. Iterations of the design shall incorporate changes as required.

For planning purposes, it is assumed that:

- *500 litre drum waste packages would be handled, transported and disposed of using four-drum disposal stillages. The stillage is used to hold the drums in place and allow stacking. The containment is provided by the drums.*
- *Pressurised Water Reactor (PWR) spent fuel would be disposed of intact within a high integrity container.*
- *Advanced Gas-cooled Reactor (AGR) spent fuel would be 'consolidated' (that is by the removal of graphite sleeves) and disposed of within a high integrity container.*
- *HLW Waste Vitrification Plant (WVP) canisters would be overpacked using a high integrity container.*

⁶ Only containers that have been approved through RWM's Change Management procedure and for which RWM has developed a Level 3 waste package specification are considered in the GDF design.

- *Plutonium and Highly Enriched Uranium (HEU) would be packaged in high integrity containers prior to disposal.*
- *Depleted, Natural and Low Enriched Uranium (DNLEU) would be packaged in (i) cemented 500 litre drums or (ii) in DV-70's, 200 litre drums and 210 litre drums which are overpacked in a transport and disposal container.*

The list above represents the range of containers available for use by waste producers. Alternative approaches to the packaging of waste may be proposed by waste producers in the future and would be evaluated for inclusion in the GDF design through the change management procedure.

Generic Waste Package Specifications are defined mainly in terms of standardised external dimensions and lifting/stacking arrangements to ensure that their transport to the GDF and, on receipt, their subsequent handling and emplacement can be carried out in a safe and efficient manner. Standardisation of waste container design is internationally recognised as good practice in that it simplifies handling arrangements and, therefore, reduces opportunities for error, whilst also permitting safe and efficient operation of disposal systems. In addition it increases flexibility to integrate operations when disposing of different types of waste.

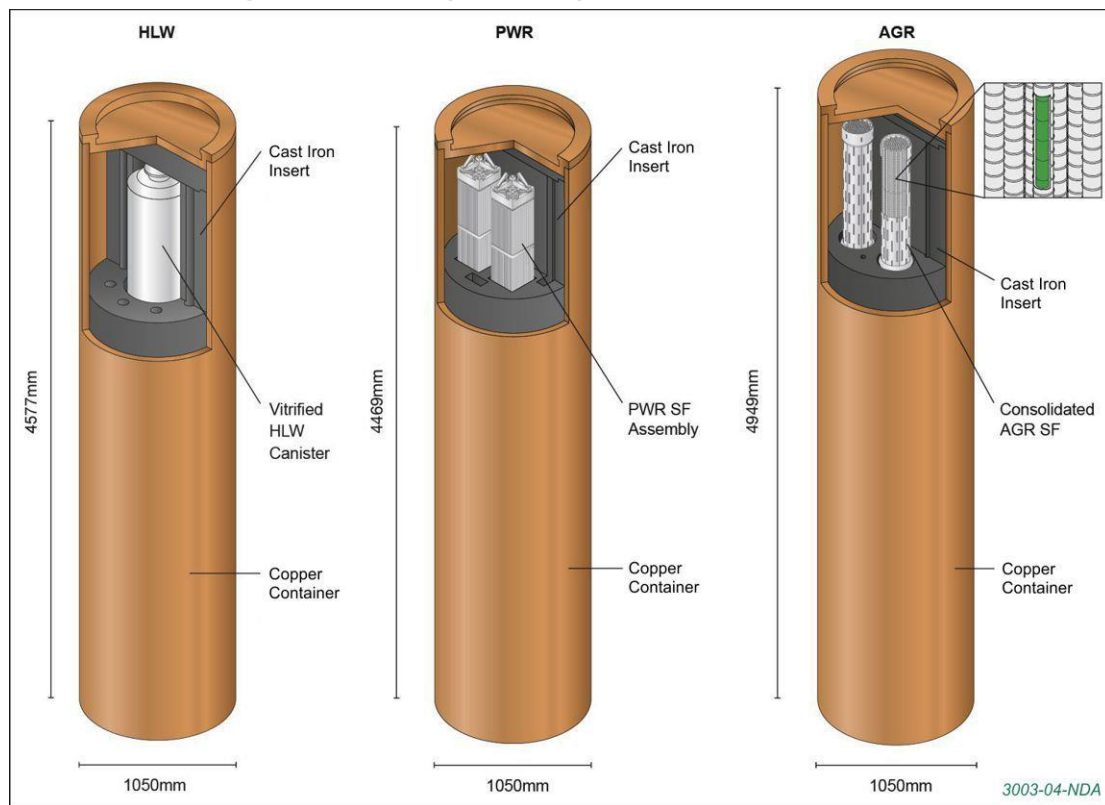
It is anticipated that RWM or Site Licence Companies (SLCs) may develop new approaches to the packaging of certain wastes in the future, and that these could prove more optimal than current approaches using the existing range of waste containers. As a result, the range of containers and assumed wasteforms that need to be considered in the disposal system design could be extended in the future, for example, work is identified in the Science and Technology Plan [36] to understand the evolution of different wasteforms for DNLEU to support strategic decision making, disposability assessments and the concept development for these wasteforms.

In general, a high integrity container for HLW and SF is required as a minimum to contain the wastes during the thermal period, that is the period where heat energy produced by the waste could adversely affect the performance of the disposal system, typically a thousand years [for example 37, 38, 39, 40]. As the geological environment for which RWM need to design a geological disposal concept is not yet known, no decision has yet been made on the engineered barrier system for HLW and SF; this includes the waste container material for high integrity containers which will need to be assessed against the conditions at a site. As set out above, it is currently assumed for planning purposes that HLW and SF will be packaged for disposal in a high integrity container although the use of disposal containers does not represent the full extent of RWM's consideration of options for management of heat generating waste. Advantages have been identified of using standardised disposal containers for packaging HLW and SF, that is standard disposal container external dimension including, handling features, etc. The containment provided by the material will ensure that the release of contaminants is limited. The two disposal container conceptual designs that have been developed are [41]:

- Variant 1 – a copper-based container with a cast iron insert
- Variant 2 – a carbon steel based container

In relatively benign conditions, the required corrosion allowance of the container may be small enough to be practically negligible relative to the material thickness required for structural or manufacturing purposes. This is the case for the Variant 1 container design recently developed in the UK based on the Swedish/Finnish KBS-3 design (50 mm thick).

Figure 14 Conceptual design of HLW and spent fuel disposal container developed in the UK (Variant 1) [41].



3.1.6.1 Waste containers for ILW and LLW

As set out in Section 3.1.6, RWM has worked in collaboration with SLCs to define a range of waste containers that are considered suitable for packaging the majority of the Intermediate Level Waste (ILW) and Low Level Waste (LLW)⁷ expected to require geological disposal, and these constitute an appropriate set of waste containers to assume for the design of the disposal system. The waste containers currently considered suitable for disposal are listed in Section 3.1.6.

The dimensions of these waste containers is given in Table 7 whilst Table 8 provides the assumptions that the designers should use related to maximum stack heights and stacking characteristics.

Table 7 Dimensions of waste containers for ILW/LLW

Waste container	Does this container serve as a transport package?	Level 3 Waste Package Specification	External dimensions of package (m)	Handling features (m)	Maximum waste package mass ⁸ (te)
500 litre drum	No	WPS/300	0.800 dia. x 1.200 high	Drum flange, 0.800 dia. x 0.020 wide	2

⁷ It should be noted that some UILW and SILW packages can also contain quantities of waste that would otherwise be classified as LLW.

⁸ Referring to the disposal package and not including any container or overpack required for transport.

Waste container	Does this container serve as a transport package?	Level 3 Waste Package Specification	External dimensions of package (m)	Handling features (m)	Maximum waste package mass ⁸ (te)
3 cubic metre box Side-lifting variant	No	WPS/310	1.720 × 1.720 plan, 1.245 high (max.)	4 mid-side twistlock apertures, 1.5465 centres	12
3 cubic metre box Corner-lifting variant	No	WPS/315	1.720 × 1.720 plan, 1.245 high (max.)	4 corner twistlock apertures, 1.5170 centres	12
3 cubic metre drum	No	WPS/320	1.720 dia. × 1.225 high	4 twistlock apertures, 1.5465 PCD	8
MBGWS box	No	WPS/340	1.850 × 1.850 plan, 1.370 high	4 corner twistlock apertures, 1.650 centres	12
4 metre box	Yes	WPS/330	4.013 × 2.438 plan, 2.200 high	4 corner twistlock apertures, 3.809 × 2.259 plan	65
2 metre box	Yes	WPS/350	1.969 × 2.438 plan, 2.200 high	4 corner twistlock apertures, 1.765 × 2.259 plan	40
Cylindrical (Type 2) robust shielded container (DCI2)	Yes ⁹	WPS/380	1.060 dia × 1.500 high	Integral circumferential feature on base	10
Cylindrical (Type 2) robust shielded container (DCI2)	No ¹⁰	WPS/381	1.060 dia × 1.500 high	Integral circumferential feature on base	10

⁹ Transported as Type IP transport package in own right

¹⁰ Transported with additional protection as Type B transport package

Waste container	Does this container serve as a transport package?	Level 3 Waste Package Specification	External dimensions of package (m)	Handling features (m)	Maximum waste package mass ⁸ (te)
Cubical (Type 6) robust shielded container (DCI6)	Yes	WPS/382	2.000 x 1.600 plan, 1.700 high	4 corner twistlock apertures 1.822 x 1.397 plan	25
1 cubic metre concrete drum (CC1)	Yes	WPS/362	1.402 dia x 1.302 high	Integral circumferential feature 0.188 from upper surface	8
500 litre concrete drum (CC4)	Yes	WPS/361	1.102 dia x 1.302 high	Integral circumferential feature 0.188 from upper surface	6
6 cubic metre concrete box	Yes	WPS/360	2.21 x 2.438 plan, 2.2 high	4 corner twistlock apertures, 2.108 x 1.96 plan	50

Table 8 Assumptions that the designers should use related to maximum stack heights and stacking characteristics

Container type	Stacking characteristics
500 litre drum (All variants)	<i>For emplacement in disposal modules it is assumed that these packages are handled and stacked using 4-drum stillages. All variants of stillages are assumed to be capable of withstanding the stacking load resulting from a seven high stack with each stillage containing four 500 litre drum waste packages, each with a mass of 2,000 kg.</i>
3 cubic metre box (Both variants)	<i>All 3 cubic metre box waste packages are assumed to be capable of withstanding the stacking load resulting from a seven-high stack of such waste packages, each with a mass of 12,000 kg.</i>
3 cubic metre drum ⁽¹⁾	<i>All 3 cubic metre drum waste packages are assumed to be capable of withstanding the stacking load resulting from a seven-high stack of such waste packages, each with a mass of 8,000 kg.</i>
MBGWS box	<i>It is assumed that the MBGWS box will be stacked six high in the GDF. It is therefore assumed to be capable of withstanding the stacking loads that would result from this height of stack with boxes with a gross mass of 11,000 kg.</i>
4 metre box ⁽²⁾	<i>All 4 metre box waste packages is assumed be capable of withstanding the stacking load resulting from a five-high stack of such waste packages, each with a mass of 65,000 kg.</i>
2 metre box ⁽²⁾	<i>All 2 metre box waste packages is assumed be capable of withstanding the stacking load resulting from a five-high stack of such waste packages, each with a mass of 40,000 kg.</i>
6 cubic metre concrete box ⁽²⁾	<i>The 6 cubic metre concrete box is designed for stacking up to six high. The stacking features of the box are not compatible with RWM's standard shielded packages⁽³⁾.</i>
500 litre concrete drum	<i>500 litre concrete drums are assumed to be capable of withstanding the stacking load resulting from a stack height of up to 11 m.</i>
1 cubic metre concrete drum	<i>1 cubic metre concrete drums are assumed to be capable of withstanding the stacking load resulting from a stack height of up to 11 m.</i>
Robust Shielded Containers	<i>Cylindrical robust shielded containers (Type 2) are assumed to be capable of withstanding the stacking load resulting from a 3 high stack of containers with a gross mass of 10,000 kg</i>
	<i>Cubical robust shielded containers (Type 6) are assumed to be capable of withstanding the stacking load resulting from a 3 high stack of containers with a gross mass of 25,000 kg</i>

Notes:

- There will be up to fifty 3 cubic metre drum waste packages manufactured at Trawsfynydd which will be capable of being stacked six-high with a gross mass of 12,000 kg.

- Waste packages that are also transport packages will have to be capable of withstanding a compressive load equivalent to a six-high stack of such waste packages, each with the same mass as the waste package.
- Due to the different stacking feature, can only be stacked with other 6 cubic metre boxes.

The 500 litre drum ILW packages can be handled either individually, or in groups of four by use of a stillage. Previous work has shown that there would be operational benefits from the use of a stillage for handling and stacking drums in disposal modules. RWM have developed a stillage design that is suitable for storage, transport and disposal. A prototype has been manufactured and tested to demonstrate the feasibility of the stillage design, and requirements have been captured in the Waste Packaging Specification [42]. Sellafield Limited have various stillage designs, currently used in stores that they intend to use for transport and disposal, on the basis that they are designed to have sufficient performance for a period of prolonged storage and continue to provide stacking performance for a time after closure of the GDF. Specifically the dimensions of the stillage should be such as to allow:

- simple and efficient loading and unloading of up to four 500 litre drum waste packages of 0.8 m diameter and 1.2 m high with a 2 t individual drum gross weight
- simple and efficient loading and unloading of the fully loaded stillage into the cavity of a transport container
- safe and effective stacking of the stillage with other similarly specified stillages

The majority of 500 litre drum waste packages to be emplaced at the GDF will originate from the Sellafield site.

3.1.6.2 Waste containers for spent fuel

For the disposal of PWR spent fuel in a UK geological disposal facility it is assumed that the whole of the fuel assembly between the top and bottom nozzles would be packaged within a high integrity waste container.

In the case of AGR spent fuel, it is assumed that fuel assemblies would be 'consolidated' to reduce their volume by the removal of the outer graphite sleeve and the fuel pins from the mounting assembly. The fuel pins would then be placed in stainless steel baskets to form consolidated fuel bundles, which would be packaged within a high integrity waste container prior to receipt at a geological disposal facility.

For planning purposes it is also assumed that new build and MOX spent fuel is packaged in high integrity waste containers prior to receipt at a geological disposal facility and therefore the high integrity waste containers must be compatible with the transport regulations and constraints.

The disposal of spent fuel typically involves the overpacking of complete fuel assemblies with the minimum of dismantling [11, 37]. This is on the basis that any such dismantling would result in unnecessary dose to workers and the generation of secondary wastes, which themselves would require long-term management. The purpose of the high integrity container is to address the need to provide containment during a sustained period of high temperatures from these HHGW.

Table 9 Disposal container dimensions and masses assumed for planning and design¹¹

Waste type	Container length (m)	Container diameter (m)	Mass of Container and contents (t)
Vitrified HLW	4.577	1.05	25.79
PWR spent fuel	4.469	1.05	24.46
AGR spent fuel	4.949	1.05	27.73
Plutonium	3.765	1.05	21.21
HEU	3.765	1.05	21.21
New build spent fuel ⁽¹⁾	5.2	1.05	30.45
MOX SF	5.2	1.05	32.35
Sellafield misc.	4.8	1.05	23.17
Prototype Fast Reactor (PFR)	3.2	1.05	16.67

Notes:

- AP1000 reactor and European Pressurised Reactor (EPR) fuel assemblies.

3.1.6.3 Waste containers for HLW

It is anticipated that all UK HLW will be rendered passively safe through vitrification in the WVP at the Sellafield site. It is currently assumed that these WVP products would be packaged for disposal within a high integrity waste container prior to receipt at a geological disposal facility.

The products of the WVP are sealed stainless steel canisters containing HLW in vitrified form. In some cases, operational and decommissioning waste arising in WVP and its associated plants may arise in sealed stainless steel canisters, or in some other suitably conditioned form.

3.1.6.4 Waste containers for plutonium and uranium

It is assumed for planning purposes that HEU and separated stocks of plutonium (not re-used as MOX fuel) will be packaged for disposal within high integrity waste containers prior to receipt at a geological disposal facility.

¹¹ The disposal container dimensions presented have been assumed for planning and generic design purposes and they are subject to change. The disposal container design has not been optimised. The examples given relate to a copper container with a cast iron insert; alternative concepts are also being evaluated.

Depleted, Natural and Low Enriched Uranium (DNLEU) will be packaged in either (i) cemented 500 litre drums, or (ii) DV-70's, 200 litre drums and 210 litre drums which are overpacked in a transport and disposal container.

The 2014 White Paper [2] specifies the need for RWM to consider disposal of plutonium and uranium in the GDF. Disposal concepts for these waste types are still under development, including specification of suitable wasteforms. Therefore, disposal containers have not yet been defined. However, the current planning assumption for HEU and separated stocks of plutonium is that disposal will be facilitated through packaging in high integrity containers that meet the requirements of transport and handling, and provide the necessary safety functions that is containment for a prolonged thermal period and shielding, during the transport and the operational and post-closure phases of GDF development.

The current planning assumption for DNLEU arising as enrichment plant tails and magnox depleted uranium is for uranium oxide powder that is stored in DV-70's, 200 litre drums and 210 litre drums would be overpacked in a transport and disposal container. The dimensions and stacking assumptions for the transport and disposal containers for DNLEU are shown below in Table 10 and Table 11.

It is noted that the reprocessing of enriched uranium fuels from AGR stations can result in a uranium product with uranium-235 enrichments of up to ~1.6%. It is currently assumed that this material and relatively small quantities of miscellaneous DNLEU arising from a variety of fuel manufacturing processes, would be mixed with cementitious grout and packaged in 500 litre drums.

These current waste packaging assumptions are consistent with the 2014 White Paper but it is recognised that the position is subject to change.

Table 10 Dimensions of waste containers for DNLEU

Waste container	Does this container serve as a transport package?	Level 3 Waste Package Specification	External dimensions of package (m)	Handling features (m)	Maximum waste mass (te)
500 litre drum	No	WPS/300	0.800 dia. x 1.200 high	Drum flange, 0.800 dia. x 0.020 wide	2
Transport and Disposal Container (TDC)	Yes	WPS/230	Containing DV70 = 6.05 x 2 plan, 2.3 high Containing 210-l drums = 6.05 x 2 plan, 2.1 high Containing 200-l drums = 6.05 x 2 plan, 2.4 high	4 corner twistlock apertures, 3.809 x 2.259 plan	Containing grouted 200-l drums = 29.5 Containing grouted 210-l drums = 44.1 Containing grouted DV-70's = 52.9

Table 11 Assumptions that the designers should use related to maximum stack heights and stacking characteristics.

Container type	Stacking characteristics
500 litre drum (All variants)	<i>For emplacement in disposal modules it is assumed that these packages are handled and stacked using 4-drum stillages. All variants of stillages are assumed to be capable of withstanding the stacking load resulting from a seven high stack with each stillage containing four 500 litre drum waste packages, each with a mass of 2,000 kg.</i>
Transport and Disposal Container (TDC)	<i>It is assumed the TDC's can withstand a stacking load resulting from a stack height of up to 11 m.</i>

3.1.7 Integrated waste strategy

The design shall be developed taking into account:

- ***on-site management of both radioactive and non-radioactive waste***
- ***discharges to air, water (including groundwater) and land***

Operators of nuclear facilities are required to have strategies for the management of radioactive wastes by UK Government policy [43], including production of a Site Waste Management Plan. RWM will address this through the production of an Integrated Waste Strategy (IWS) [44], which will describe:

- how the site will optimise its approach to waste management in an integrated way
- the wastes and discharges expected from facility operations
- the actions required to improve the approach to waste management

An IWS considers holistically how all wastes, both radioactive and non-radioactive, and materials that may become waste in the future, will be managed over their lifecycle to protect the environment. The production of an IWS is intended to provide a framework to optimise the approach to waste management. It includes the requirement to consider foreseeable waste management strategies and the application of the waste hierarchy, so enabling an effective balance of priorities including value for money, affordability, technical maturity, the views of stakeholders and the protection of health, safety, security and the environment.

3.1.8 Schedule

The design and development of the disposal system shall take into account the GDF schedule.

The GDF waste receipt schedule will be defined by a range of factors and is subject to change over time. These factors include the inventory for disposal, the capacity of the emplacement facilities and equipment, and the rate at which wastes become available for disposal. The current schedule has been produced to take account of waste producer's site licence plans.

3.1.9 Operating capacity

Targets shall be established for the operating capacity and availability of the facility for disposal operations which take into account:

- ***safety***

- **operational timescales**
- **the quantity of waste to be disposed**
- **the complexity of emplacement operations**

The following operational throughput rates are currently assumed¹²:

- the drift or shaft throughput capacity in all geological environments is assumed to be 3,900 packages per year
- the unshielded Intermediate Level Waste (UILW) Inlet Cell capacity is 2,500 packages per year in all geological environments
- the HLW / spent fuel / plutonium and HEU throughput is assumed to be 200 packages per year in all geological environments¹³

The operational timescale of the GDF will be determined in conjunction with the waste producers so as to ensure cost-effective use of the disposal system and other facilities. The operational period includes maintenance of the disposal areas to enable retrievability after wastes have been emplaced.

Assumptions regarding the period of ILW and LLW disposal are based on several considerations:

- the time required to emplace the volume of the inventory for disposal
- the need for waste owners to clear their stores once emplacement begins, before the buildings and facilities require significant refurbishment
- a reasonable design lifetime for plant and equipment

Assumptions regarding the period of HLW and spent fuel disposal are based on lifetime plans developed by SLCs and assume emplacement at a constant rate for a nominal period.

Targets for operating capacity and facility availability are required to constrain the range of emplacement solutions considered and discussions with SLCs on the operational timescale.

The emplacement rate of waste packages will be affected by the method of emplacement selected, and therefore, an estimate of this rate is required to inform decisions regarding the operational timescale and is an important consideration in developing the delivery schedule of waste packages to the GDF. The drift or shaft throughput capacity is determined by the time taken for the emplacement locomotive to travel the length of the drift, unload and travel back. In the illustrative design for an evaporite rock, there is no drift but a fourth shaft for waste emplacement. The UILW inlet cell capacity is similarly determined by the time taken for emplacement. The rate of emplacement for canisters containing HLW, spent fuel, plutonium, and HEU is based on the Swedish KBS3-V emplacement times using the deposition machine.

3.2 Construction safety

Construction of the above-ground and below-ground facilities shall be undertaken in a manner that does not compromise unduly the long-term safety of a geological disposal facility and protects:

¹² ILW/LLW emplacement – a ramp up period is assumed with 500 packages per year prior to first waste emplacement to complete active commissioning with an additional 500 packages per year up to the maximum throughput capacity.

¹³ HLW / spent fuel / plutonium and HEU emplacement rate – a ramp up period is assumed with 50 packages emplaced per year from 2073 to full capacity in 2076.

- **workers**
- **members of the public**
- **the environment**

The requirement to develop procedures to provide protection to workers and members of the public to achieve the required quality of construction, and as far as reasonably practicable, to minimise effects on the environment, are discussed in detail in Sections 3.2.1, 3.2.4 and 3.4.1.

3.2.1 Approach to construction

Construction of the underground parts of a geological disposal facility shall generally be based on established techniques and methods, adapted to suit the particular geological environment.

Well established techniques shall be used for below-ground construction, where available.

Construction of the below-ground facilities shall be undertaken in a manner that enables concurrent underground-based investigations if required.

The Mines Regulations [45], and associated guidance [46, 47] require that the design should be capable of being implemented without undue risk to any person. The design will, in addition to containing basic design details, need to include sufficient information about risks associated with implementing the design to secure safe working.

The design should include as appropriate:

- the limits of extraction
- excavation dimensions
- pillar sizes
- the support and/or reinforcement density
- the specification(s) of any material or equipment forming part of any ground control system
- the proposed method of work
- procedures for dealing with abnormalities
- information on other risks such as known zones of weakness or proximity to other workings

The likely ground stresses and movements over the life of the excavation, ventilation requirements and clearances for people and equipment are factors which also need to be taken into account in developing the design.

As explained in DSS Part A, although the GDF is not subject to the same health and safety legislation that applies to mines, as good practice, tunnelling and underground excavation will be undertaken after consideration of The Mines Regulations 2014 [45] and associated guidance published by the Health and Safety Executive (HSE).

Safety during construction will generally be provided by adopting relevant good practice, by working to a well-defined safety management system, and by establishing a strong safety culture. Where novel technology is used it will be supported by trials. Safety management systems should be based on good practice from the mining and tunnelling industry.

As also explained in DSS Part A, the disposal system will be developed in accordance with the Construction (Design and Management) Regulations (CDM Regulations) [48], and guidance [49, 50] which apply to all construction work. The definition of construction

is wide-ranging and includes building, civil engineering, and engineering construction operations. Construction work can include repairs, alterations, cleaning, preparation, site clearance and exploration, as well as new-build construction; and applies to any 'structure' – the definition of which includes all the facilities and associated works forming part of the GDF.

The application of CDM would include the consideration of appropriate scheduling and co-ordination to take account of concurrent operations being undertaken in close proximity to the construction activities.

Under the CDM Regulations, every designer has to avoid foreseeable risks to the health and safety of any person by:

- eliminating hazards from construction, cleaning, maintenance, use of structures designed as a workplace, and demolition of a structure
- reducing risks from any remaining hazards
- giving collective risk reduction measures priority over individual measures

Designers must also:

- take account of the Workplace (Health, Safety and Welfare) Regulations 1992 [51, 52] when designing a workplace structure
- provide information with the design to assist clients, other designers and contractors
- inform others of significant or unusual / 'not obvious' residual risks

Under Regulation 12 of the CDM Regulations, it is a requirement that the principal contractor develop a construction phase plan, to an acceptable level, prior to being permitted to commence work on site. The plan provides a focus for managing and co-ordinating health and safety on the site. The amount of detail in the safety plan should depend on the nature and extent of the project and on the contract arrangements for the construction work.

In addition, to comply with legislation, applicable safety standards should be met, as set out in the engineering principles [53]. Examples of such safety standards can be found in the application of appropriate sections from UK mining legislation and HSE published guidance. In particular, safety management systems should be based on the principles of the British Standard 18001 Occupational Health and Safety Assessment Specification (OHSAS) [54] or the HSE guide to 'Successful health and safety management' [55].

The generic GDF design [16] recognises the different packaging and disposal processes for different types of waste with LLW, ILW and DNLEU disposal in a LHGW disposal area. The disposal of HHGW and LHGW in separate areas of the same facility is referred to as co-location. Within the two areas, the wastes are further partitioned: in the HHGW area, spent fuels are grouped together, separate from HEU¹⁴ and plutonium; in the LHGW area, DNLEU, DCICs, shielded wastes (excluding DCICs) and unshielded wastes are disposed of in separate vaults.

3.2.2 Worker safety

Provision shall be made for a personnel exit to the surface from all underground areas.

Provision shall be made for emergency vehicle access throughout the surface site.

Provision shall be made for mine rescue access to underground areas.

¹⁴ It is noted that HEU does not generate significant heat, it is included in the HHGW area as its disposal concept is very similar to that of HHGW.

In order to demonstrate that the GDF will be operated safely and that the environment will be protected, it is necessary to define procedures by which this safety and protection will be ensured.

Additionally, there are specific health and safety regulations for certain activities that are related to worker safety and should be taken into account, as well as their supporting guidance, for example:

- Lifting Operations and Lifting Equipment Regulations (LOLER) 1998 [56], supported by [57, 58].
- Provision and Use of Work Equipment Regulations (PUWER) 1998 [59], supported by [60, 61].
- Manual Handling Operations Regulations 1992 (as amended) (MHOR) [62], supported by [63, 64].
- Work at Height Regulations (WAHR) 2005 [65], supported by [66].
- Control of Vibration at Work Regulations 2005 [67], supported by [68, 69, 70].
- Control of Noise at Work Regulations 2005 [71], supported by [72, 73].
- Confined Spaces Regulations 1997 [74] – Approved Code of Practice, Regulations and Guidance (L101), Third Edition, 2014 [75].
- Personal Protective Equipment Regulations (PPER) 2002 [76], supported by [77, 78].
- Pressure Equipment Directive (Directive 97/23/EC) [79] and Pressure Equipment Regulations [80].
- Control of Substances Hazardous to Health Regulations 2002 [81], supported by [82, 83].

Provision for emergency vehicle access throughout the surface site is good practice for addressing emergencies on any major industrial site. For the purposes of escape and rescue, the underground construction and nuclear areas should be considered as one facility covered by one integral plan.

Due to the confined conditions in some areas of the GDF, and the similarities in operations with the mining industry, similar emergency provisions should be made.

3.2.3 Emergency response

All necessary emergency arrangements and equipment shall be in place and available during construction.

As a planning assumption, provision is made for at least two independent personnel exits to the surface from all underground areas, as far as is practicable.

For the purposes of escape and rescue, the underground areas will be considered as one facility covered by one integrated plan. An emergency plan that covers all potential incidents will be developed. This would include the construction of both surface and underground facilities. It is assumed that provision will be made for at least two independent personnel exits to the surface from all underground areas, as far as is practicable. In the event of an accident or failure of equipment affecting one of the exit routes, a second route will then be available for personnel to be evacuated from the underground or to effect recovery. The requirement for at least two personnel exits originated from The Mines (Safety of Exit) Regulations 1988 [84] which have since been superseded by the Mines Regulations 2014 and are less prescriptive in this respect than

the previous regulations. However, this is considered to be an appropriate assumption to use in accordance with long-standing mine safety practice.

3.2.4 Impact of construction on the environment

All effluents from construction shall be managed so as to provide environmental protection and comply with appropriate regulations.

Environmental conditions in and around the GDF shall be monitored to ensure compliance with regulatory conditions.

As the programme progresses, cost effective mitigation measures for reducing the environmental impacts of construction shall be identified and applied.

Pre-construction monitoring will establish a baseline from which changes can be identified. As explained in DSS Part A, the disposal system must meet the requirements of the Environmental Permitting Regulations (EPR10) [85] and as such will apply for and work within the conditions of an environmental permit. This includes water discharge activities during GDF construction. Discharges from construction will be made in accordance with conditions of the environmental permit and it is envisaged that monitoring activities will be required by the relevant environment agencies as part of demonstration of compliance.

3.2.5 Support for underground openings

The design, excavation and maintenance of underground openings shall ensure that openings are effectively supported and monitored.

To allow development of the generic designs and cost estimates, it is currently assumed that the following rock supports are required

- *in higher strength rock environments: rock bolts, mesh and shotcrete*
- *in lower strength sedimentary rock environments, rock bolts and mesh will be required as a minimum for the HLW / spent fuel / plutonium and HEU disposal areas and rock bolts and shotcrete for the ILW/LLW disposal areas*
- *in evaporite rock environments, systematic¹⁵ rock bolts and mesh*

In order to ensure the safe operation of the GDF and the performance of natural and engineered barriers, the design must ensure that appropriate support structures are provided in underground openings. The provision of excavation and support monitoring will assist in validating the integrity of the excavations/support and provide early evidence of any deterioration in support integrity, thereby helping to ensure the protection of personnel, machinery and waste packages from rock-fall or collapse.

3.3 Operational safety

A geological disposal facility shall be operated in a manner that provides protection to:

- ***workers***
- ***members of the public***

¹⁵ Systematic rock bolting is common practice in underground excavations and means that rock bolts are installed in a regular pattern at regular intervals, which will be based on the properties of the host rock including the number, nature and orientation of joints. The purpose of systematic rock bolting is to transfer the load from the rock around the immediate excavation (which may have been damaged during excavation and/or a fairly weak material) to an interior, stronger part of the rock mass.

- ***the environment***
- ***waste packages***

Engineered barriers shall be designed to provide safety during the operational period.

A geological disposal facility shall be operated in a manner that does not unduly compromise the long-term safety of a geological disposal facility.

Safety during operations will be provided by following the general principles of good engineering and operational safety, adopting good practice developed in other areas of underground operation, such as mining, working to a well-defined safety management system and establishing a strong safety culture.

The Nuclear Installations Act 1965 (NIA 65) [86] requires anyone, other than the Crown, to have a licence granted by the Office for Nuclear Regulation (ONR) before constructing or operating a nuclear installation. ONR assigns conditions to a site licence to ensure the safe operation of the installation.

The ONR Safety Assessment Principles (SAPs) [87] represent guidance to ONR inspectors and provide principles of good practice regarding the design and safety justification of new nuclear facilities, and requirements for compliance with the conditions of nuclear site licences, particularly those relating to the production of nuclear safety cases.

Demonstrating good practice in engineering, operation and safety management is a fundamental requirement for safety cases. The establishment of a strong safety culture will ensure that protection and safety issues receive the attention warranted by their significance.

Site Licence Conditions may include the requirement that adequate arrangements are made for all operations that affect safety, which can be achieved through implementation of appropriate safety policies, systems and procedures. The development of safety procedures based on risk assessment (as required by the Managing Health and Safety at Work Regulations (MHSWR) [88, 55]) provides a basis for compliance with the relevant Health and Safety legislation.

An Operational Safety Case (OSC) will be prepared prior to any waste emplacement and updated as emplacement proceeds. This will consider the GDF functionally, and assess potential faults that are identified.

3.3.1 Radiation monitoring

Essential services related to radiological protection and radiological compliance monitoring shall be assessed and included as required.

The Ionising Radiation Regulations (IRR 99) require that an approved dosimetry service is obtained from an organisation approved by the ONR, and that specified forms of personnel monitoring are carried out [89].

Radiological compliance monitoring (for example continuous air samplers, criticality detection and associated alarm systems) is required to support the operational safety case, as specified in the ONR SAPs [87].

3.3.2 Fire protection

Fire prevention and fire-fighting facilities shall be provided that are adequate for a geological disposal facility.

Geological disposal facility fire protection facilities shall be designed, built and operated to the best standards appropriate for the specific application, in conformity with statute and related British, European and International standards.

The specification of fire prevention measures is well established in statute, and related British, European and other international standards. The requirements on underground fire prevention and the associated escape and rescue provision needs are derived based on consideration of both the Mines Regulations 2014 and the ONR SAPs, and the relevant fire safety legislation in England and Wales [90] or Northern Ireland [91], since the GDF combines both nuclear plant and conditions similar to that of a mine. The GDF is somewhat different from normal mineral extraction workings, in that it may have larger openings, more permanent installed equipment, and nuclear material. However, the appropriate mining legislation and standards are the current good practice for underground work and therefore have been used to form the basis or provide guidance for the escape, rescue and fire safety specifications for the GDF.

The operations in the GDF shall be assessed to prevent ignition of a fire. Fire protection systems should be capable of rapidly detecting and extinguishing fires, prevent fire growth and spreading, and containing the fire so that the facility's safety function can be reliably performed irrespective of the effects of the fire. This would therefore require the containment of the nuclear material to prevent releases to the environment. Waste packages are assessed against a 1000°C fire for a 30 minute duration as part of the Disposability Assessment process. The escape routes from the underground areas of the GDF will be via a drift or a shaft, both of which require power. There is the potential that a major incident could interrupt power supplies, temporarily making escape via either route impossible. In such a scenario, the provision of safe havens appears to be essential to protect personnel. It is for the detailed safety assessments to examine whether such emergency scenarios are realistic and to determine from that whether the provision of safe havens in the design can be justified. Where shaft access is employed, provision should be made for emergency winding facilities, in line with good mining practice.

Detection of fires will play an important role in the early identification and fire suppression required to prevent major incidents. It is envisaged that a number of systems will be used to suit the location and to trigger the automatic or manual application of suppressants.

A fully equipped surface Fire and Rescue Station is justified on the grounds that any fire scenario, either underground or at the surface, is likely to require a combination of expertise not normally associated with a normal civilian fire station. Trained personnel will be available so that prompt action can be taken. Supplementary assistance would be sought from the local fire services and National Mines Rescue in the event of a large-scale emergency.

The Dangerous Substances and Explosive Atmospheres Regulations (DSEAR) 2002 [92, 93] are also in place for protection against the risks from fire and explosion associated with dangerous substances (i.e. substances with properties that have the potential to give rise to a fire, explosion or other similar events) and explosive atmospheres, supported by HSE guidance [94, 95]. These substances include flammable or explosive gases such as hydrogen and methane, petrol, liquid petroleum gases, paints, varnishes, solvents and dusts. DSEAR require that any workplace where explosive atmospheres may occur are classified into hazardous zones based on the risk of an explosion occurring, and protected from sources of ignition by selecting equipment and protective systems on the basis of the categories set out in the Equipment and Protective Systems for Use in Potentially Explosive Atmospheres Regulations (EPS) [96, 97].

Further requirements and information on gas generation can be found in the following Section 3.3.3 and in Section 3.11.1.

3.3.3 Gas generation and migration

Design of a geological disposal facility shall ensure that there cannot be an accumulation of gas during the operational phase that could impact worker health.

A variety of mechanisms may generate gases in the GDF including corrosion of waste materials, microbial action, radiolysis of water, and ingrowth of gaseous radionuclides.

The bulk of the gas generated in the GDF will be hydrogen, which is regulated under the relevant Dangerous Substances and Explosive Atmospheres Regulations (DSEAR) (see Section 3.3.2). There is potential for sealed waste packages to become pressurised as a result of gas generation. Waste packages that have, or are liable to attain a pressure greater than 0.5 bar above atmospheric pressure will be subject to the Pressure Systems Safety Regulations (PSSR) [98], supported by [99, 100]. These Regulations apply to operational safety and the potential pressure within a waste package in post-closure is considered in the disposability assessments.

Gaseous radionuclides may be generated from waste and accumulation should be prevented to reduce the exposure of workers to dose.

3.3.4 Criticality

Design of a geological disposal facility shall ensure that the risk of criticality during the operational period is tolerable and consistent with the ALARP principle.

Design of the GDF will be such that the risk of criticality is tolerable and consistent with the 'as low as reasonably practicable' (ALARP) principle during operations. A criticality event during operations could present unacceptable risks to workers and the public. In the absence of specific requirements for radioactive waste disposal facilities RWM has adopted this requirement as currently applied to surface storage facilities on nuclear licensed sites. It is based on principle ECR.1 of the ONR SAPs which states that "*Wherever a significant amount of fissile material may be present, there should be safety measures to protect against unplanned criticality*".

3.3.5 Recovery operations

Mitigation measures shall be implemented to recover from the effects of accidents.

It is currently assumed that a geological disposal facility will not contain sufficient quantities of toxic hazardous material to qualify as a storage facility for inclusion under the Control of Major Accident Hazard Regulations.

It is important that recovery from operational accidents such as fire or waste package impact is possible, and that any effect of accidents on waste package properties can afterwards be mitigated. This may require waste to be repackaged, for example small items of debris being placed in drums and grouted, or overpacked in the case of a damaged box or drum. These measures will address the management of damaged packages and spilled material.

The Control of Major Accident Hazard Regulations (COMAH Regulations) [101], which implement European Union (EU) Council Directive (2012/18/EU) on the control of major-accident hazards [102] (also known as the Seveso III Directive), include the requirement to consider the non-radiological hazards of materials with regard to major accident potential, and are supported by HSE guidance [103]. A scoping assessment will be undertaken at an appropriate time to confirm whether or not the GDF will contain sufficient quantities of toxic hazardous material to qualify as a storage facility for inclusion under COMAH.

In planning how to discharge the duties imposed on us by the CDM Regulations [48], RWM will take into consideration the requirements imposed on Mine Operators under The Mines Regulations 2014 [45].

3.4 Environmental safety

It shall be demonstrated that the location and design of a geological disposal facility ensures environmental safety during the period of authorisation and subsequently.

In accordance with the groundwater protection provisions of the Environmental Permitting (England and Wales) Regulations 2010, it shall be demonstrated that all necessary technical precautions will be taken to:

- ***limit the input of hazardous substances to groundwater***
- ***limit the input of non-hazardous pollutants to groundwater so as to ensure that such inputs do not cause pollution of groundwater***

An Environmental Safety Case (ESC) will be produced to demonstrate that the relevant requirements in the GRA [18] (as set out in DSS Part A [4]) have been met through presentation of a set of supported claims concerning the environmental safety of disposals of solid radioactive waste, substantiated by a structured collection of arguments and evidence. It should demonstrate that the health of members of the public and the integrity of the environment are adequately protected, and demonstrate consistency with the principles set out in the guidance, and show that the management, radiological and technical requirements in the guidance are met. The GRA explains how to prepare and what to include in an ESC, based on a fundamental protection objective and principles that the developer/operator of a disposal facility and the environment agencies should follow.

The GRA also sets out the maximum permissible doses to individuals which may result from any source or from a single site. The dose constraints place upper bounds on optimisation of the facility that apply during the period of authorisation, which includes the period of time while disposals are taking place and any period afterwards while the site is under active institutional control.

The GRA requires that facility design and development is optimised continuously through to the end of the period of authorisation, such that radiological risks to members of the public are 'as low as reasonably achievable' (ALARA) during the period of authorisation and afterwards. This is achieved through an iterative development process, where growth in knowledge and assessments of safety feedback into GDF design development. Radiological risk during the period of authorisation is reduced by reducing exposure to radiation, which, in turn, may be reduced by reducing radioactive discharges [28].

The GRA provides guidance on the requirements for demonstrating operational and post-closure environmental safety for radiological and non-radiological hazards, including an expectation for a multiple-function environmental safety approach, based on a disposal system consisting of multiple components or barriers.

The GRA provides guidance on how the Fundamental Protection Objective and Principles can be met through a structured set of claims including both quantitative and complementary arguments. The GRA notes that compliance with numerical criteria is not a sufficient demonstration of safety and that additional safety arguments are required in the ESC to provide confidence in the long-term safety of the GDF.

A supplementary guidance note to the GRA [104] provides guidance on compliance with the groundwater protection provisions of EPR 10 in the context of geological disposal. The groundwater protection provisions in question give effect to certain provisions of the EU Groundwater Daughter Directive [105] in England and Wales.

The supplementary guidance requires the developer or operator to substantiate, through its ESC, that all necessary technical precautions have been, or are being, taken to prevent or limit, as appropriate, the input of any pollutants into groundwater. In relation to inputs of radioactive substances, this will involve a demonstration that proper consideration has been given to the input of radioactive substances to groundwater in optimising the design

of the facility in relation to its geological environment, so that radiation doses to people are kept as low as reasonably achievable, subject to economic and societal factors. The developer or operator must also show that the radiation dose to members of the public through the groundwater pathway during the period of authorisation is consistent with, or lower than, a dose guidance level of 20 μSv per year; and that the radiological risk to members of the public through the groundwater pathway after the period of authorisation is consistent with or lower than a risk guidance level of 10^{-6} per year. Similarly, any venting of gases to the atmosphere that may occur should consider the implications on people and the environment, and therefore the same dose and risk guidance levels will be applied to gaseous discharges. These are assessed as part of the ESC [106].

In relation to non-radiological hazards associated with radioactive waste, the supplementary guidance requires these to be managed so that the EPR 10 provisions for groundwater activities can be met.

3.4.1 Environmental and socio-economic considerations

For a given location, the disposal system shall be developed with consideration of alternative concept designs for a geological disposal facility and alternative options for its associated transport system.

The disposal system shall be developed with consideration of climate change issues and disaster risk.

The disposal system shall be developed with consideration of the RWM sustainable design objectives.

To support the siting process, generic proposals for the design, construction, operation and closure of the GDF will take into account potential environmental and socio-economic effects.

As explained in DSS Part A, to comply with legislative requirements and national guidance relating to the development consent process, proposals for the design, construction, operation and closure of the GDF at a specific site must be subject to Environmental Impact Assessment (EIA) [107] and Habitats Regulations Assessment (HRA) [108].

It is a requirement under the EIA Directive to consider 'reasonable alternatives'. The disposal system will be developed with consideration of alternative concept designs for implementing geological disposal and alternative options for the transport of radioactive waste to the GDF [109].

An EIA must include consideration of potential effects on, but not necessarily limited to the following:

- population and human health
- biodiversity
- land
- soil
- water
- climate (for example greenhouse gas emissions, effects relevant to adaptation)
- material assets
- cultural heritage
- landscape
- disaster risk

The assessment of socio-economic effects, while not an explicit legislative requirement, will be included within the scope of generic and community-specific assessments, and within the scope of EIA. Socio-economic assessment will include consideration of the following issues:

- employment
- property values
- economic development
- tourism
- the agricultural economy
- social services and infrastructure
- social stability and community cohesion
- housing and accommodation

The Habitats Regulations require '*competent authorities*' to be satisfied that the integrity of designated '*European Sites*' and their conservation objectives will not be adversely affected by a proposed plan or project, before development consent is granted. If significant effects are judged likely, then alternative solutions must be considered. If no satisfactory alternatives can be found, or effective mitigation measures applied, then the proposal may only go ahead on the basis of '*imperative reasons of overriding public interest*'.

Where assessment work identifies significant adverse environmental or socio-economic effects, measures to avoid, reduce or remedy those effects will be developed and implemented. Similarly, opportunities to enhance positive effects will be explored and, where appropriate, will be incorporated into disposal system development.

The environmental and socio-economic assessment work will not necessarily capture and address all of the environmental and sustainability issues associated with design development – particularly at a detailed level and during the implementation phase. To take account of this, Sustainable Design Objectives have been defined to proactively guide design development [110]. These objectives will be addressed at appropriate points in the design process.

3.5 Security and safeguards

The design shall take into account security and safeguards factors that influence construction, operations and post-closure.

Security measures are required for the safety of the public and staff, protection of plant and equipment and the safeguarding of nuclear materials. Regulatory requirements relating to security and safeguards are explained in DSS Part A. Some of the wastes destined for geological disposal will contain nuclear materials. However, most wastes are unlikely to constitute a significant proliferation threat. In consultation with the Government and the safeguards authorities, RWM will develop an approach to meeting safeguards requirements based on the disposal system design, operational constraints and nuclear material type, quantity and form. The safeguards approach will therefore be commensurate with the perceived proliferation risk at each stage of the waste lifecycle.

3.5.1 Layout of disposal areas

Within the disposal horizons, the overall layout of the disposal areas and other facilities shall take into account security and safeguards requirements.

It is assumed that the GDF will be designed and constructed to accommodate the appropriate space to provide sufficient physical security to operate as a Category I facility, as defined in the conceptual security arrangements, from the outset.

The current illustrative designs assume that the GDF should be designed and constructed to accommodate the appropriate space to provide sufficient physical security to operate as a Category I facility from the outset. However, it would operate initially as a Category III facility from the first receipt of ILW/LLW, in advance of any Category I quantities of plutonium and HEU arriving on site (See NORMS, Part One, Chapter 1, Annex B [111, Table 1]). It should be noted that the NORMS document also contains information on the categorisation of ILW and LLW waste containing nuclear material (NM) (See NORMS, Part One, Chapter 1, Annex B [111, Table 2]). It is also assumed that the GDF will be re-categorised from a Category III to Category I civil licensed nuclear site, for physical protection purposes.

3.5.2 Reporting requirements

The reporting requirements of Commission Regulation (Euratom) 302/2005 shall be met in accord with the safeguards approach.

Information on the design and operation of a geological disposal facility shall be provided to the European Commission at least 200 days before construction commences and updated periodically.

The safeguards approach shall be kept under review and may be amended in the light of changes.

The safeguards approach for a geological facility will change over time. Important considerations when developing the safeguards strategy include the ability to verify the nuclear material content and to maintain a continuity of knowledge following these verification measurements up to the point of committal for emplacement (prior to backfilling), irrespective of the point in the process at which this verification is performed. Therefore, an approach used during the construction of the facility and disposal of the waste may not be applicable during the post-closure phase. For example, the focus may shift from obtaining assurance about individual waste items to assurance about the integrity of the entire facility. However, it is IAEA policy that safeguards will not be terminated after disposal, but that the approach will be altered to reflect the 'operational status' and increased isolation of the nuclear materials.

The requirement for information on the design and operation of the GDF to be provided to the European Commission (EC) at least 200 days before construction commences is derived from Article 4 of Euratom 302/2005 [112].

3.5.3 Role of Safeguards Office

RWM shall work with UK Safeguards Office (UKSO) to ensure that the disposal system complies with international safeguards obligations.

Appropriate arrangements shall be made for inspections of a geological disposal facility and its records by the International Atomic Energy Agency and European Commission verification inspectors.

The safeguards approach at the GDF will be overseen by the UK Safeguards Office. Wastes containing isotopes of uranium, plutonium or thorium derived from the UK civil nuclear programme are likely to be subject to international safeguards and as such, reported to the UK Safeguards Office.

The IAEA has been developing safety requirements for geological disposal to ensure that people and the environment are protected from the effects of exposure to ionising radiation both now and in the future. The technical measures required to meet IAEA safeguards

requirements at the GDF and their potential impact on the operation and safety of the facilities are provided in [113].

3.6 Nuclear site licence

No waste shall be emplaced in the disposal areas until appropriate site licence and authorisation conditions for the operational phase have been met.

The requirement for an authorisation to dispose of radioactive waste is defined in the Environmental Permitting Regulations 2010 [85]. The requirement that no waste will be emplaced in the disposal areas until appropriate site licence and authorisation conditions for the operational phase have been met is consistent with Licence Conditions 32 and 33 of the Nuclear Licence Site Conditions [114].

3.6.1 Commissioning

A geological disposal facility shall be commissioned by means of functional tests on all facilities.

Licence Condition 21 of the Nuclear Site Licence Conditions [114] and principle ECM.1 of the ONR SAPs describe the requirements for commission testing before operating any facility or process that may affect safety [87]. Note that appropriate site license and authorisation conditions would include those required for active commissioning.

3.7 Retrievability

The planning, design and construction of a geological disposal facility shall be such that a geological disposal facility can be closed and institutional control withdrawn without violating safety requirements however; this shall not exclude the option of retrievability prior to closure.

The UK Government, the Committee on Radioactive Waste Management (CoRWM) and regulators agree that the purpose of the GDF is to dispose of waste, not store it. The 2014 White Paper notes that permanently closing the GDF at the earliest opportunity once operations have ceased provides for greater safety, greater security, and minimises the burden on future generations [2].

During the operation phase of the GDF, waste that has been emplaced within the GDF can be retrieved if there was a compelling reason to do so. Retrieval of waste will become increasingly more difficult with time particularly after cessation of the operation phase and closure and sealing of the GDF. Backfilling and closure assumptions for the GDF are discussed further in Sections 8.3.1 and 8.3.2.

3.8 Optimisation

The design of a geological disposal facility shall ensure that the radiological impacts of the disposal system are as low as reasonably achievable (ALARA), taking into account economic and societal factors.

The iterative design process should ensure that the optimum way forward is selected at each stage when there are different considerations to be balanced, such as potential radiological and non-radiological consequences, and economic and societal factors.

The environmental regulators have defined their expectations regarding optimisation of the GDF in the GRA. Expectations are defined in Principle 2 and Requirement R8, both of which relate optimisation to demonstrating that radiological risks will be ALARA, taking into account economic and societal factors. The supporting text for both Principle 2 and Requirement R8 indicates that:

- optimisation is about finding the best way forward, and radiological risks should not be given a weight out of proportion to other considerations
- optimisation requires good communication
- optimisation studies should be undertaken where there are choices to be made among significantly different alternatives
- guidance on Best Practicable Environmental Option (BPEO) and Best Practicable Means (BPM) is relevant to optimisation of the GDF but does not apply directly
- optimisation should be considered at each decision-making stage

Therefore, although the environment agencies expect optimisation to be demonstrated through application of the ALARA principle, the developer should be able to explain why a particular option has been selected over any other in a way that assesses the advantages and disadvantages of the preferred option over other potential options and provide a robust justification.

The ONR places the optimisation requirements of ALARP and SFAIRP (so far as is reasonably practicable) on the organisations it regulates [87]. The practical meaning of these concepts is akin to the environment agencies' expectations in the GRA. ALARP will govern design decisions that influence operational safety of the GDF.

3.9 Best available technique

The use of Best Available Techniques (BAT)¹⁶ shall be demonstrated as appropriate.

As explained in DSS Part A, the use of BAT is specified in the Environment Agency's Radioactive Substances Regulation Environmental Principles (REPs) [115]. The REPs explain that the best available techniques should be used to ensure that production of radioactive waste is prevented and where that is not practicable minimised with regard to activity and quantity. Further, the processes of handling, treating or storing radioactive substances should be chosen and optimised to prevent the production of secondary effluents. Considerations should also include reuse and recycling of materials and wastes, in accordance with the waste hierarchy.

3.10 Impact of construction on the natural barrier

Excavation of a geological disposal facility shall be undertaken in such a way that the quality of the natural barrier and the safety functions provided by the host environment are preserved as far as reasonably practicable.

The geological barrier needs to provide a stable host environment for the engineered barriers. As explained in DSS Part A, it is important to preserve the safety functions of the host geological environment and thus construction of the GDF should not physically, hydrogeologically or geochemically reduce the performance of the geological barrier.

3.10.1 Construction methods

Construction design shall recognise the potential for groundwater ingress, particularly in the development of surface access to the disposal horizon.

It is currently assumed that the strata from surface to 300 m depth will be water bearing and therefore requires measures to limit groundwater ingress.

Where groundwater ingress is likely to impact the performance of the facility, pre-treatment is assumed to be carried out employing grouting or other groundwater control techniques,

¹⁶ Note: BAT/BPM only apply to waste management not to operational or construction safety.

followed, as necessary, by the provision of a hydrostatic pressure resistant lining and seal to preclude or minimise groundwater ingress into facility access ways.

It is currently assumed that:

- *in higher strength rock environments, a concrete hydrostatic lining would be utilised with shotcrete and bolting to the host rock*
- *in lower strength sedimentary rock environments, a concrete hydrostatic lining would be utilised with shotcrete and bolting to the host rock*
- *in evaporite rock environments a steel composite hydrostatic lining and rock bolting would be utilised*

As explained above, it is important to preserve the safety functions of the host geological environment. Excavation and construction of the facility should avoid unnecessary disturbance of the host geological environment and thus minimise the extent of an excavation disturbed zone and the introduction of hydrogeological and geochemical transients. Applying high quality excavation techniques will also aid the stability of excavations and the safety of construction.

Controlling groundwater ingress by grouting and sealing at source will lead to low groundwater inflows, avoiding issues associated with environmental discharges (pumping) and with risk of contamination of groundwater if it comes into contact with the externals of waste packages during the operational period.

3.11 Impact of operations on the disposal system

The GDF shall be operated in such a manner as to preserve the safety functions that are important to safety after closure.

All effluents from GDF operations shall be managed so as to provide environmental protection and comply with appropriate regulations.

Environmental conditions in and around the GDF shall be monitored to ensure compliance with regulatory conditions.

The disposal system shall be designed to allow concurrent underground construction and operation activities through a combination of best radiation protection, industrial, mining and civil engineering safety practices at the time of the relevant activity.

Designers shall refer to requirements specified in RWM's Radiological Protection Criteria Manual [116].

As discussed in DSS Part A and IAEA international guidance [19] safety after closure of the GDF is achieved by developing a disposal system in which the various components work together to provide and ensure the required level of safety [117]. It is important to consider the potential impacts of GDF operations on the performance of the disposal system after closure since the operations to emplace the waste and engineered barriers deliver the 'initial state'. The 'initial state' is the state in which a given component has been emplaced according to its design and will thus deliver the required safety functions as the disposal system evolves post-closure.

The chemical and physical content of any liquid discharges will be specified in authorisations granted by the environmental regulators, and analysis will be required to confirm that liquid discharges meet the requirements of these authorisations. The need for limits on discharges to the environment is stated in RWM's Radiological Protection Criteria Manual [116], and such limits are standard conditions for permitting under EPR 10. Monitoring of all radioactive liquid effluents and demonstration of ALARP will be required to satisfy the environmental regulators.

3.11.1 Gas generation

The airborne discharge shall conform to the relevant regulatory requirements.

Any discharge stack shall be sited at a suitable distance from any underground ventilation intake so as to not affect underground air quality.

A variety of mechanisms may generate gases in the GDF including corrosion of waste materials, microbial action, radiolysis of water, and ingrowth of gaseous radionuclides.

The bulk of the gas generated in the GDF will be hydrogen, and the accumulation should be prevented in the post-closure phase to reduce the risk of explosion and damage to the engineered barriers and host rock, so preventing the development of additional pathways for the transport of dissolved radionuclides. There is potential for sealed waste packages to become pressurised as a result of gas generation and thus build-up of explosive mixtures. Waste packages that have, or are likely to attain a pressure of 0.5 bar greater than atmospheric pressure will be subject to the PSSR [98].

Filtration of the aerial discharge arisings from the underground parts of the GDF may be required in order to demonstrate that the discharges are within the limits imposed by the environmental regulators. Even if, before filtration, the discharges are within the limits imposed by the regulatory bodies, some filtration may be necessary in order to demonstrate that the discharges comply with the ALARP principle, and to provide protection against accidents.

The requirement that any discharge stack will be sited at a reasonable distance from any ventilation intake is included to ensure that designers check that airborne effluent discharges do not affect the underground air quality.

3.11.2 Effluents

Surface drainage shall be designed to prevent underground flooding as well as effluents and rainwater run-off from entering the underground part of a geological disposal facility.

The design shall seek to minimise the amount of contaminated effluents produced by disposal facility operations.

Effluent handling and treatment processes shall minimise the generation of further effluents and solid waste arisings.

The availability of appropriate disposal routes for secondary effluents and solid waste arisings developed in construction and operation shall be demonstrated.

Wherever the opportunity exists, liquid effluent streams of potentially higher-activity content shall be segregated from streams of potentially lower-activity content. Each effluent stream shall be provided with separate collection and sampling facilities.

No effluent streams shall be mixed until after they have been sampled and shown to meet specified requirements.

Provision shall be made for analysis of all effluents, covering:

- ***radioactivity characterisation and measurement***
- ***particulate determination***
- ***physical and chemical property determinations (for example, temperature, pH, alkalinity)***
- ***non-radioactive measurements for anions and cations***

Treatment facilities shall be provided as necessary to ensure that concentrations of contaminants (radioactive and non-radioactive) conform to the authorisation, before the effluent is discharged.

Design of the treatment plant shall ensure that treatment facilities are available for the operational period of the disposal system.

After backfilling, any excess liquids draining from the backfill, if present shall be prevented from migrating to accessible areas of a geological disposal facility.

Provision shall be made for the management of contaminated water arising from decontamination activities.

Water from decontamination operations shall be kept separate from the surface drainage until sampled and analysed.

The effluent treatment should be conducted in line with the waste management hierarchy, therefore minimising the generation of further waste. It is not anticipated that significant amounts of secondary waste will be generated from disposal operations and GDF management generally, as the waste packages could be sealed and prepared to comply with the WAC.

It is a basic principle of effluent management that each stream will be kept separate until monitoring of each stream and assessment of the consequences has shown justification for streams to be combined. This is to prevent:

- dilution of more concentrated waste streams that may be treatable
- contamination of large-volume, more dilute waste streams
- undesirable chemical reactions when incompatible streams are combined

Where disposal includes backfilling, the backfill will saturate, and, therefore, measures may be required to ensure that any drainage (which could be active) does not migrate into of the GDF where workers may be present. If such measures involve removal of the liquid as an effluent stream from each disposal module, those streams should be segregated and managed according to the general effluent management requirements.

The design of surface drainage facilities must take account of the overall risk to safety from flooding during GDF construction, operation and closure. In addition to providing protection from underground flooding from the surface, prevention of surface runoff is in accordance with the effluent segregation principles listed above.

Contaminated water arising from routine decontamination activities needs to be managed separately from other liquid effluent streams in accordance with the effluent segregation principles listed above. Routine decontamination operations could include the cleaning of the waste transport containers, rail wagons, road vehicles and the drift locomotive (if used).

The need for treatment facilities for liquid effluents is related to the need to use BAT to reduce discharges (see Section 3.9).

Liquid effluent treatment facilities must remain available throughout the operational lifetime of a disposal facility, including any care and maintenance period, because the operational availability of the GDF relies on the ability to treat and dispose of liquid effluents as they arise. This applies even during planned maintenance shutdowns because extra effluents may be generated by the maintenance work.

The requirement for a discharge monitoring strategy is based on the need to demonstrate compliance with regulatory authorisations.

3.12 Services

Within the disposal horizons, the overall layout of the disposal areas and other facilities shall take into account the provision of services.

Services are resources necessary to maintain the various components of the GDF in an operational state at all times. Services may include for example electricity, gas, water and fuel. Some services could be performed completely off-site, and others may be purchased off-site but delivered on-site. For example, the operator might purchase a number of services from external suppliers, for example, dosimetry and medical services, some of which would need to be delivered on site.

3.12.1 Separation of services

Services supplied to the areas of a disposal facility that are under construction, shall be separated physically from those supplied to the active areas, as far as reasonably practicable, to reduce the potential for disruption in one area affecting the other.

The separation of services between construction and active areas will help to prevent cross contamination between the two areas, and will reduce the potential for disruption in one area affecting the other. These are important considerations where construction and operation activities are being undertaken in parallel.

3.12.2 Ventilation

Within the disposal horizons, the overall layout of the disposal areas and other facilities shall take into account ventilation requirements.

The ventilation system for a disposal facility shall provide adequate ventilation underground, and to other manned areas, at all times during construction and operations.

Working conditions shall comply with appropriate regulations, standards or good practice in terms of the temperature, humidity, radon, and levels of dust.

The ventilation system shall prevent the accumulation of toxic, asphyxiating, radioactive, flammable or explosive gases within the facility.

The ventilation systems shall reinforce physical containment by providing appropriate pressure gradients between areas.

Where the physical containment of the radioactive area is breached by openings, the ventilation system shall provide appropriate means to maintain the containment during normal operation, unplanned events or accidents.

The response of the ventilation system to abnormal events shall be based on a detailed hazard assessment that considers safety in underground areas under construction and where operations are taking place.

Monitoring shall be undertaken to confirm whether the overall performance of the ventilation system remains satisfactory and that quantities of dust, aerial contaminants, gases and radionuclides are below regulatory guidelines.

The ventilation systems ensure that air is moved into and out of the facility, however not adversely affecting operations, for example accumulation of radioactive flammable or explosive gases.

The ONR SAPs state that “Containment and ventilation systems should confine the radioactive material within the facility and prevent its leakage or escape to the environment in normal operation and fault conditions, except in accordance with authorised discharge conditions, or as part of a planned transfer to another facility.” [87, paragraph 519].

The Atomic Energy Code of Practice No. 1054 (AECP 1054) [118] which was for many years, the industry code of practice has been replaced by the Nuclear Ventilation Forum document NVF/DG001 [119] which has been developed under the auspices of the Safety Director's Forum and represents best design and operational practice. As stated above, requirements are also included in the ONR SAPs, which require that the plant design should incorporate a ventilation system which will, under normal operating and fault conditions, segregate and isolate hazards and prevent the mixing of ventilation streams of different hazard potentials, for example explosive, toxic and radioactive, until they have been neutralised. The construction area of the facility should for example be maintained at a higher pressure so that movement of air at any controlled area barrier is always towards the active area. As necessary, the primary disposal module extract filters shall be as close as possible to the extract points from a disposal module.

A hazard assessment considering failure of the ventilation system is required as part of the operational safety case. The emergency plans relating to ventilation will form part of the overall GDF Site Emergency Plan.

Monitoring of the ventilation system is required to confirm that it remains fit for purpose and to meet regulatory requirements for monitoring of dust, aerial contaminants, gases and radionuclides.

HEPA filters in the ventilation system will be managed in accordance with radioactive waste management best practice at the time.

3.12.3 Electrical

The detailed design of the electrical supplies to the underground facilities shall take account of The Electricity at Work Regulations, Code of Practice, The Use of Electricity in Mines and the ONR SAPs.

Electrical power supplies shall be maintained to ensure the continuing safety of a disposal facility and of personnel under all circumstances.

Secure electricity supply shall be provided when electrical plant is an essential part of hazard control.

It is currently assumed that there shall be two separate supply feeds ('firm supplies') to a disposal facility from the regional electricity supply infrastructure, each of which shall be capable of providing 100% of the facility load.

It is assumed that the two separate supplies of electricity to the underground areas shall be routed separately.

The requirement for provision and maintenance of adequate electrical power supplies is derived from the ONR SAPs [87, paragraph 436], the Mines Regulations, HSE guidance on electrical safety in mines and prudent design practice. Two separate supplies of electricity are assumed so that an alternative supply source is available to supply essential plant should there be a primary supply fail.

The Electricity at Work Regulations (EAWR) 1989 [120], Electricity Safety, Quality and Continuity Regulations (ESGCR) 2002 [121] and British Standards for requirements for electrical installations [122], introduce a control framework for incorporating fundamental principles of electrical safety, applying to a wide range of plant, system and work activities. They apply to all places of work and electrical systems of all voltages, and are supported by HSE guidance [123, 124, 125, 126].

3.12.4 Water

A supply of process water shall be available for:

- ***wash down***

- **fire systems (including firefighting)**
- **backfill mixing**
- **other uses as identified**

The water provided for each activity shall be of a volume and quality that is fit for the purpose and of lowest obtainable cost.

Wherever possible within the above constraints, water shall be recycled.

Security of the water storage and distribution system for fire-fighting is required by the ONR SAPs. It is expected that for most process applications, a supply of clean and filtered but otherwise untreated water will be adequate; and because it is untreated it is likely to be the cheapest source.

Water recycling will reduce the cost of the water demands of the GDF, and the environmental impact on water resources; recycling will also reduce the costs and environmental impacts of liquid effluent streams from the GDF.

3.12.5 Communications

Adequate voice, visual and computer communications facilities shall be provided throughout a disposal facility, and shall be available at all times.

For communications between the surface and underground, it is assumed that a minimum of two types of equipment with independent power supplies are provided.

It is assumed that computer interfaces are provided and used to track waste package movements.

Adequate communications systems are required to enable information and instructions to be transmitted between locations and to provide external communication with auxiliary services and such other organisations as may be required.

A systematic failure analysis may be required to ensure that provisions can be made for communication systems in all circumstances.

3.12.6 Materials handling

Within the disposal horizons, the overall layout of the disposal areas and other facilities shall take into account materials handling requirements.

Methods will be developed for the transfer of buffer and backfill materials to disposal modules that ensure that the condition on emplacement of the materials meets their design specification (for example, see Section 9.9.1).

The layout of the facility will need to include routes for the delivery of buffer and backfill material. If the condition of the materials were affected during transport, unacceptable material performance could result. For example, should a bentonite buffer be used, premature wetting of the buffer could cause swelling prior to emplacement and reduction in final emplacement density.

3.12.7 Operational control

A main Operational Control Room (OCR) on the surface shall be provided from which all operations can be managed, and the 'real-time' safety, environmental and operational status of all areas of a disposal facility continually monitored.

A second control room shall be established underground, from which all underground operations can be managed.

Readings from local instrumentation underground shall also be relayed to the surface OCR.

For planning purposes, it is assumed that the main OCR also carries out the functions of an Emergency Control Room (ECR).

The ONR SAPs specify the requirement for a central control room with sufficient instrumentation and controls to enable adequate monitoring of the state of the plant (GDF in this instance), to provide warning of changes in state, and to allow initiation and confirmation of remedial actions. In addition, such controls should be available at appropriate locations elsewhere on the plant.

Complex operations such as those within the inlet cells would be likely at times to require local operation, with direct operator viewing through windows to identify and rectify problems. Co-ordination of these underground operations would take place from an underground control room. It is essential that both control rooms (above and below ground) have access to the same GDF status and environmental information.

Consensus in the UK nuclear industry is that it is undesirable to separate the functions of an ECR from those of the everyday OCR. The experience has been that a dedicated ECR is generally only used during emergency exercises; but if the OCR is used for emergencies as well, staff are already familiar with the layout and facilities, and the equipment is regularly checked because it is in constant use.

If the GDF already has two control rooms with duplicated equipment and readouts, there may be little justification in adding a separate ECR whose maintenance in full working order at all times would be resource intensive.

3.12.8 Personnel movement

Within the disposal horizons, the overall layout of the disposal areas and other facilities shall take into account the requirements for personnel movement. The layout shall:

- ***ensure that sufficient access and lighting are available to be able to carry out all necessary operational, maintenance, inspection and testing activities***
- ***ensure that radiation doses to workers carrying out operational, maintenance, inspection and testing activities are ALARP***
- ***provide an alternative means of access to facilities and control functions essential to safety that may require local manual intervention***
- ***ensure a safe means of escape, with normal and emergency lighting, from buildings or plant areas that may be affected by an incident***
- ***have alternative access to rescue equipment in all normally manned areas***

The layout is important to safety in that it can affect ease of access for normal operational needs. Facility layout may have an influence upon the ability to meet the duty to reduce radiation doses to ALARP and can be a factor in providing means of preventing unauthorised access. Layout can also affect the consequences of incidents, particularly internal and external hazards, and the access conditions following an incident.

3.12.9 Maintenance operations

Within the disposal horizons, the overall layout of the disposal areas and other facilities shall take into account maintenance operations and closure.

The level of installed equipment within a disposal module shall be minimised as far as practicable and consider the need for remote access into disposal areas.

Using the minimum of installed equipment reduces initial costs, avoids unnecessary maintenance problems, and avoids the need to remove equipment prior to closure.

The design will consider provision of facilities to undertake maintenance tasks, recovery, repackaging and overpacking based on an analysis of design basis faults. A suitable location where such operations could take place will be identified in GDF layouts. Remote systems might be required to recover waste packages. Provision of space for emplacement of overpacked waste is required to allow for simple management of waste packages affected by accidents.

3.13 Facilities

A geological disposal facility shall consist of surface works, underground excavations and connections between the two.

For planning purposes it is assumed that specific facilities and equipment are provided on the surface or underground as appropriate for activities including, but not necessarily limited to:

- *receipt of waste at the site separate receipt and transfer facilities for LHGW and for HHGW)*
- *temporary storage of transport vehicles (including railway sidings if appropriate) and transport vehicle maintenance*
- *inspection, quality control and monitoring of waste packages*
- *management of out-of-specification waste packages*
- *transfer of waste to underground transport vehicle*
- *transfer of waste to underground receipt facility*
- *removal of waste packages from re-usable transport containers*
- *inspection and maintenance of re-usable transport containers*
- *transport of empty re-useable transport containers to surface and off-site*
- *excavation and maintenance of disposal areas (vaults, tunnels, shafts or boreholes as appropriate) and associated access routes*
- *handling and storage of construction materials*
- *management of excavated material – a proportion of the excavated material will require storage*
- *emplacement of waste packages in the final disposal location*
- *construction, installation and maintenance of engineered barriers*
- *emplacement of backfill and site closure*
- *transport of personnel, equipment and materials to and from the underground facility*
- *protection of personnel and the environment from radiological and non-radiological hazards*
- *maintenance of appropriate environmental conditions for workers, equipment and waste packages*
- *provision of active services (including laundry and decontamination)*
- *monitoring of environmental conditions in and around a geological disposal facility*
- *management of all effluents from a geological disposal facility*

- *management of GDF decommissioning waste*
- *provision of security and essential services*
- *provision of infrastructure (including any facilities required following closure)*
- *provision of administrative services, information recording and data management*
- *responding to accidents and emergencies*
- *maintenance of facilities, structures and equipment*
- *provision of a visitors centre*
- *provision of new buildings and processing facilities associated with the GDF which shall be designed with the intent to decommission*

The requirement for surface and underground facilities is necessary for the appropriate functioning of the GDF.

The design philosophy adopted for the disposal system is that waste is stored at a nuclear site, generally the site of origin or site of packaging, until just before it is to be disposed of to the GDF. Storage facilities for ILW have been established at nuclear reactor sites and fuel cycle facilities. HLW is stored at Sellafield where it is generated. Spent fuel assemblies may be stored at the power station of origin, or consolidated and managed through facilities at the Sellafield site. Therefore, the disposal system design does not require significant interim waste storage facilities at the GDF site. There is a need for the transport system design to incorporate contingencies that allow for changes to the availability of the GDF (see Sections 4.2.3). This design assumption may minimise the storage and land requirements at the GDF, while allowing for operational flexibility within the overall system.

It may be appropriate for some wastes to be conditioned and packaged at the GDF where this would reduce the number of specialist packaging plants developed. For example, a spent fuel packaging plant could be developed at the GDF site. However, the present design assumption is that any spent fuel requiring disposal will be packaged at the site where it arises (or at Sellafield if the fuel has already been sent there). This assumption is included in the Lifetime Plans of Sellafield, Sizewell B and Dounreay.

As stated in Section 3.1.2, it is currently assumed that wastes are packaged for disposal prior to transport to the GDF. If it is decided to locate facilities for packaging of particular waste types at the GDF, it should be assumed that the waste will arrive at the GDF in an appropriate condition for packaging and disposal.

LHGW and HHGW will be received at different receipt buildings at the GDF due to the different handling and shielding required.

3.13.1 Surface facilities

In determining which operations will be conducted in surface facilities, differences between the environmental impacts of conducting operations at the surface and those of conducting operations underground shall be considered and weighed against other factors including, but not limited to:

- ***safety***
- ***security***
- ***cost***

It is currently assumed that surface facilities are required for waste receipt, materials handling, including excavated material which may be stored for later use, and access to the underground facility.

It is currently assumed that the surface facilities are located directly above the underground disposal facility, however it is recognised that the surface facilities could be in a different location to the underground site and linked by access drifts.

The construction and commissioning of a geological disposal facility will require some operations to be carried out at the surface, and there are other operations that could take place either at the surface or underground. There are potential benefits from conducting operations above ground and potential benefits from conducting operations below ground. Conducting operations above ground could be more cost-effective and could allow recovery from accidents more readily than recovery from accidents underground. However, conducting operations underground could reduce the environmental impact from operations (for example, visual impacts, noise and dust), enhance security, reduce the off-site risks from accidents, and add consistency with the techniques developed internationally. Therefore, decisions regarding the location of operations (above ground or below ground) will require appropriate consideration of the benefits and disadvantages of available options.

The nature of operations at the GDF will require worker radiological protection and welfare facilities (such as toilets, showers and changing rooms) on the surface; this will therefore necessitate the construction of support structures and buildings to be utilised by personnel working at and visiting the GDF.

Access drifts will provide at least one of the emergency access ways as described in the 'Emergency response' Section 3.2.3.

3.14 Geological environment and geographical setting

The design of a geological disposal facility, both above and below ground, shall take account of the geographical setting of the site.

The design shall take into account geographical and geological factors that influence construction, operations and post-closure.

- *These factors, and potentially others, will be investigated to provide site-specific information that informs GDF development: location and structural characteristics*
 - *location, (that is inland or coastal setting)*
 - *potential impact of tectonic and climatic evolution (stability)*
 - *geological structure including folds, faults, bedding planes, joints, and fractures*
 - *lithology (host rocks, surrounding and overlying rocks and soils)*
 - *depth of proposed host rock(s)*
 - *gas generation characteristics (for example, radon)*
 - *rock stress*
 - *complexity*
- *hydrogeological characteristics*
 - *hydraulic properties (for example, transmissivity, hydraulic conductivity and porosity)*
 - *the nature of flow through the various formations (for example, contribution from matrix, role of fractures and joints)*
 - *the nature of the driving forces (for example, magnitude and orientation of hydraulic gradients and their variation with depth)*
- *geochemical characteristics of each groundwater regime encountered*

- *groundwater chemistry and age*
- *groundwater density*
- *potential for groundwater – engineered barrier – rock interactions*
- *mechanical characteristics of host rocks*
 - *rock strength*
 - *creep properties*
- *thermal characteristics*
 - *geothermal gradient*
 - *thermal conductivity*
 - *ambient rock temperature*
- *solute transport characteristics*
- *gas migration characteristics of all rock types to surface*
- *mineral, hydrocarbon, groundwater, geothermal resources*

It is currently envisaged that work on the design, operational safety and post-closure safety will examine ranges of values for the factors (or parameters) listed above in order to establish broadly acceptable values for each of these as the geological disposal concept design develops.

As recognised in the ONR SAPs [87, paragraph 116], the following aspects of the geographical setting could also impact safety and, hence, design of the GDF:

- meteorological conditions will affect the dispersion of radioactive and non-radioactive gases during operations
- the local topography, hydrology, soil, geology and hydrogeology will affect the migration of any accidental discharge of radionuclides during operations, and the migration of releases from the closed facility in the long-term (recognising that significant changes to the surface environment will almost certainly have occurred over this timescale)
- the potential for natural hazards (for example, flooding and landslides) to affect safe operation of the disposal system

These factors along with the size and spatial constraints of a specific site could also place constraints on GDF operations.

A more detailed description of the parameters and their influence on GDF design, construction, operational safety and post-closure safety is provided in a previous generic DSS for ILW/LLW [127]. Some qualitative observations on the nature of those parameters are also included.

At this stage of the geological disposal implementation programme the DSS Part B is a generic specification and a living document. It will be subject to review and revision in order to develop from a generic specification to a site-specific specification, taking in to account site-specific information when it becomes available. This includes more detailed and specific requirements regarding the geological factors that need to be taken into account in the design for a specific site. The proposed strategy for geoscientific aspects of site characterisation will be steered to provide the information required to allow GDF development.

The term geological environment encompasses the geological, geotechnical, hydrogeological and geochemical characteristics of the volume of rock that is under

consideration. A host rock is a unit or formation within which disposal modules are developed. A geological environment may contain more than one potential host rock. The geological environment that needs to be considered extends beyond the host rock and contributes to GDF performance. The evolution of the geological environment over significant timescales also needs to be considered.

The nature of the geological environment is fundamental in determining the most appropriate disposal concept to be used for each waste type. The geosphere must provide a sufficient barrier to the transport of radionuclides for each combination of waste type and disposal concept. It must be possible to construct and operate sufficiently large openings to allow handling and disposal of waste packages.

The overall characteristics of the geological environment determine the appropriate disposal concept and hence the detailed requirements of site investigation and supporting research and development programmes. The content of these programmes will differ for different geological environments.

The geological environment's role in post-closure safety varies with waste type, disposal concept and geological environment. In all cases, the geological environment must protect the engineered barrier system both by providing physical protection and geochemical conditions that will assure the performance of the engineered barriers.

The geological environment provides a physical barrier that isolates the wastes from the surface environment. As a result, perturbations arising from events occurring at the surface will either not be transmitted to disposal depths or their impact will be significantly attenuated. The depth of a disposal facility defines the thickness of this physical barrier but the performance of the physical barrier would also be influenced by a number of factors including geological structures, permeability and geochemical buffering.

The geological environment, and the host rock in particular, must be sufficiently stable (taking into account, for example, tectonic activity and geomechanical factors) to allow development of the underground infrastructure using conventional engineering practices. The degree of engineering support required by the excavations will depend on factors such as intrinsic rock strength, the degree and orientation of fracturing, the stress state and the size of openings. The disposal concept and duration of the operational period must also be considered, as any support measures that are installed will need to be maintained until facility closure. These considerations may have a significant bearing on what is considered to be 'sufficiently stable' in terms of combinations of rock properties and excavation design.

Demonstrating long-term stability, both in the past and against changes in external conditions, is an important element of the ESC and will form a component of site investigation and research programmes. It may be necessary to demonstrate a wide range of different types of stability: geological, seismic, geotechnical, hydrogeological and geochemical. Stability, in this sense, does not imply that steady-state conditions exist; the geosphere is constantly evolving and such evolution may not impact on acceptability for safe geological disposal.

3.14.1 Layout of disposal horizons

Within the disposal horizons, the overall layout of the disposal areas and other facilities shall take into account factors including:

- ***physical characteristics of the host rock***
- ***number and nature of waste packages (for example, heat)***
- ***disposal concept***
- ***provision of services, such as ventilation, materials handling, personnel movement, maintenance operations and closure***

- **performance of engineered and natural barriers**
- **security and safeguards**
- **simplicity and flexibility of layout**

It is currently assumed that the disposal horizons of the GDF are accommodated within a single level; however, the option of a multi-level facility has not been excluded.

The nature and quality of the host rock must be taken into account when selecting a site and a disposal concept, and will be one of the major constraints on underground layout. Rock quality is essentially a summation of the geotechnical or engineering geological characteristics of the rock mass. It will influence and constrain such factors as the size and spacing of the underground openings, the nature of ground support requirements, operational safety within the openings, and the long-term stability of the openings. The layout will also take into consideration the waste handling and emplacement operations including the potential benefits gained from modular design. Modular design would enable waste handling and emplacement to begin in some disposal modules when construction of other disposal modules is underway.

Factors that are likely to have an influence on disposal module excavation and support design include:

- depth of disposal module excavations
- in situ stress properties of the host rock
- long-term creep properties of rocks
- effects of surface degradation on stability of underground excavations and rock support
- development of disturbed zones around underground openings that may impact stability or provide flow pathways during the post-closure period
- requirements for maintenance of rock support systems
- stability during ground vibration (natural and man-made)
- composition of the groundwater and water/rock interactions

In a previous study, reported in 1997, the quality of the rock, coupled with an assumed disposal module depth, was used to define, on the basis of precedent practice, the maximum size of the disposal areas (expressed in terms of span of excavations) [128]. The precedent practice study determined the maximum excavation spans for an ILW/LLW concept design developed for the Longlands Farm site, near Sellafield. At an appropriate stage in the programme, these will be reviewed and revised to take account of developments in mining engineering techniques and the concept design selected for implementation.

The layout of the GDF will also need to consider the movement, underground transfer and emplacement of the waste packages, and develop designs for the facilities that will be used to achieve this.

Licensing of the GDF will require the preparation of several safety cases and management plans. A key to regulatory approval of these safety cases will be the ability to demonstrate that the arguments presented are well founded and viable in practice. Simplicity and flexibility in the design will support such demonstration and this will be influenced by the disposal concept selected and its operating regime. In addition, simplicity and flexibility in the design will be useful to accommodate variability or change in operations.

3.14.2 Depth of disposal horizons

The depth of the disposal horizons shall be determined on the basis of results from geological and hydrogeological investigations at the site of a geological disposal facility and development of the safety case.

Within geologically suitable formations, the location of the disposal areas shall take into account the potential advantages and disadvantages of increased depth.

It is currently assumed that the facility is most likely to be constructed between 200 m and 1000 m below the ground surface.

For planning purposes:

- *in a higher strength rock environment, the depth of the disposal horizon is assumed to be 650 m below ground level*
- *in a lower strength sedimentary rock environment, the depth of the disposal horizon is assumed to be 500 m below ground level*
- *in an evaporite rock environment, the depth of the disposal horizon is assumed to be 650 m below ground level*

The depth of the disposal horizons in conjunction with the properties of the geological environment will be important in determining the extent to which the geosphere provides isolation and containment of the radioactivity in the waste, and in determining the constructability, excavation characteristics, support requirements and longevity of any underground structures. Important effects of increasing depth on engineering characteristics include increased in situ stress and temperature. The depth of disposal horizons for lower strength sedimentary rock is lower than the other geological environments due to the capability of the rock to support excavations below this depth.

For planning purposes, a minimum depth of 200 m is specified to provide a depth of cover greater than the likely maximum extent of surface change in the very long term while the wastes are still hazardous. Existing studies [128] indicate that the average depth of erosion that occurred in the UK during the Quaternary (the last 1.6 million years) was 130-160 m. Local erosion in ice stream valleys could have been in excess of 1000 m. In contrast, general erosion in glaciated upland areas is unlikely to have exceeded 100 m. Beneath the level of any such future erosion there is likely to be a zone of rock affected by stress relief and weathering. The maximum depth for disposal is likely to be defined by practical and economic considerations. In situ rock stresses increase with depth [129] such that the stability of underground excavations (for a given set of rock mass properties) tends to decrease with increasing depth and increasing stress. In addition, the deeper a disposal module, the greater the cost, from a simple consideration of the costs associated with the provision of access to that disposal module.

The increasing difficulties and costs of construction tend to impose a practical limit to the depth of disposal of approximately 1000 m below ground surface. However, it may be possible to construct the GDF at a greater depth if required.

3.14.3 Size of openings

The design development shall consider the qualities and properties of the host rock and the duty for which the excavation is being made, in determining the size of excavations.

The size and extent of the excavations will be determined by several factors including:

- the engineering properties of the rocks (rock strength, rock stress, degree and orientation of fracturing, creep properties and the physical extent (horizontal and vertical) of the rock mass)

- the disposal concept and related safety functions to be implemented for each disposal module
- the size and shape of the waste packages to be emplaced and the underground operations that must be carried out to remove them from their transport overpacks and emplace them
- maintenance requirements for any rock support that would need to be installed
- service networks (for example power supply and ventilation)

3.15 Monitoring

The design shall ensure that appropriate monitoring can be conducted during:

- ***construction***
- ***operation***
- ***closure***
- ***potentially, into the post-closure phase as defined in a site-specific monitoring programme***

Monitoring activities during operations shall verify that safety goals are being met.

Monitoring is defined as, “Continuous or periodic observations and measurements of engineering, environmental, radiological or other parameters and indicators/characteristics, to help evaluate the behaviour of components of the repository system, or the impacts of the repository and its operation on the environment, and to help in making decisions on the implementation of successive phases of the disposal concept” [130]. The GRA Requirement R14 [18] states that, “In support of the environmental safety case, the developer/operator of a disposal facility for solid radioactive waste should carry out a programme to monitor for changes caused by construction, operation and closure of the facility”.

The process leading to commissioning of the GDF is lengthy and involves a number of decision points. Once licensed to operate, the GDF is expected to remain in operation for many decades before its eventual closure and decommissioning. Monitoring information will be an important support to decision-making at all stages of the GDF development programme.

The long-term safety of the GDF will not rely on institutional controls as described in Section 3.4 (Environmental safety), including monitoring. However, continuing monitoring could be a societal demand for some time after disposal facility closure. Such monitoring, besides demonstrating that the process of decommissioning surface facilities has been successfully completed, could strengthen confidence, in some sectors of society, that the evolution of the GDF is in accordance with expectations.

Baseline information will be required for comparison with data acquired through the monitoring programme in order to understand both the impacts and performance of the GDF. Acquisition of the baseline information will need to commence during the early stages of site characterisation to avoid, as much as is practicable, collecting information that is affected by transients introduced by site characterisation. The IAEA documents the starting point of the baseline monitoring that would be required for a site [131]: “Pre-operational studies should be performed for practices to establish ‘baseline’ environmental radiation levels and activity concentrations for the purpose of subsequently determining the impacts of the source.”

4 Transport

The transport system design can be divided into two main areas – the transport of construction materials, spoil and personnel associated with building the GDF and the more specialised transport of radioactive waste to the GDF.

The transport system design associated with constructing the GDF will utilise methods that are common to the construction industry.

The transport system for the transport of radioactive waste includes all of the processes, equipment and management arrangements required for the movement of waste packages from a waste producing site to the GDF; including, for example, loading of transport packages onto vehicles, monitoring of transport packages and vehicles, overnight stops and changes in transport mode.

There are regulations governing transport safety in the UK, for example [132, 133]. Additionally, there is legislation governing the transport of radioactive waste in the UK, specifically the Carriage of Dangerous Goods and Use of Transportable Pressure Equipment Regulations 2009 (CDG) regulations [134], as amended in 2011 [135], and IAEA SSR-6 [136], establishing standards of safety which are required for transport of radioactive materials.

4.1 Transport of construction materials, spoil, personnel, materials and goods

4.1.1 Modes of transport

The transport system design shall take into account transport of construction materials, spoil, personnel, materials and goods by:

- ***inland waterway***
- ***sea***
- ***rail***
- ***road***

The transport system is required to take account of and comply with, national and local policy for the transport of personnel, excavated material and construction materials.

The use of inland waterway, sea, rail, and/or road modes of transport can be optimised by the provision of transport interchanges, depending on the transport infrastructure available at any given location, and the need to take account of the economic, social and environmental factors applicable at that time.

4.1.1.1 Developments to the transport infrastructure

The transport system design shall consider the need for developments to the transport infrastructure, including both new infrastructure and improvements to existing infrastructure.

It is appropriate to consider the transport of significant quantities of GDF construction material to the GDF and the export of excavated material by inland waterway, sea and rail via interchange facilities. However, it is recognised that many of the smaller deliveries of construction materials and the deliveries of other goods may have to be by road.

The existing transport infrastructure may need development to enable the transport of personnel, excavated material, construction materials and other goods. Developments to

the transport infrastructure may include new or improved access roads, links to the national road network, links to the national rail network and/or harbour improvements.

Transport policies and requirements may change over time. Also, the facilities and resources needed for inland waterway, sea, rail and road transport will vary with both time and location of the GDF.

The GDF will need to be linked to the transport network by access roads to facilitate the transport of personnel, construction materials, excavated spoil and other goods. The option of onwards road transport for all construction materials, excavated spoil and other goods is retained to ensure long-term robustness and flexibility of the transport strategy; however, use of this option would require justification within environmental and transport assessments. This is most relevant in the case of excavated spoil where the potential benefits of other management options including use of the material, will be considered. Improvements to the national road network may be needed in the vicinity of the GDF, depending on the existing infrastructure and the proportion of waste and other materials and the weight of packages that are to be transported by road.

4.1.1.2 Planning

Planning for changes to the transport infrastructure shall be undertaken on a timescale that allows changes to be implemented prior to any need for significant movement of materials from or to the site of a geological disposal facility.

Due consideration will be given to the necessary design development, planning applications, site licensing requirements and timescales for physical alterations needed to implement the required transport infrastructure. This may include developments to access roads, the national road and rail networks, and the provision of railheads, ports and other transport interchange facilities.

Specific components of the transport infrastructure will need to be in place before the start of construction of the GDF to enable the transport of construction materials to the site and the removal of excavated spoil, if required. The transport system may have to be justified by a construction phase plan.

4.1.1.3 Safety

Safety requirements defined by the competent authority and all other applicable regulations shall be taken into account in the transport of:

- ***construction materials***
- ***excavated spoil***
- ***personnel***
- ***materials and goods***

Conventional transport assessments will be undertaken as part of the EIA described in Section 3.4.1. Compliance throughout the characterisation, construction and operational period of the GDF with applicable regulations, the developer/operator's health, safety, security and environmental (HSSE) and radiological protection policies, and the Carriage of Dangerous Goods and Use of Transportable Pressure Equipment Regulations 2009 (CDG 2009 Regulations) [134] ensures that safety is inherent within the transport system.

4.1.2 Schedule

The transport system shall be designed to ensure timely delivery and despatch of personnel, materials and goods in line with the GDF schedule.

The personnel transport system is likely to include an appropriate and sustainable combination of public and private transport networks including pedestrian, cycle, car, bus, rail, road and air transport to provide robustness and flexibility. It may be appropriate to consider the provision of interchange facilities and to prepare a workplace travel plan to introduce choice, flexibility and sustainability for personnel during both the construction and operational period of the GDF.

The requirements on personnel transport will be considered as part of the construction phase plan and operations management plans.

As with all other aspects of transport, the needs for personnel transport will vary with time.

4.1.2.1 Scheduling of delivery of construction materials, removal of spoil and personnel transport

The requirements for the transport of all personnel at each phase of activity at a geological disposal facility shall be identified and considered within the design.

The transport system shall be designed to ensure timely delivery and despatch of personnel, materials and goods.

Personnel transport scheduling, in conjunction with the construction schedule and operational requirements, are assumed to ensure that personnel are available at a geological disposal facility when they are needed, and prevent the interruption of operations by reasonably foreseeable short-term events related to the availability of personnel due to transport difficulties.

In higher strength and lower strength sedimentary rock, excavated spoil is assumed to be kept on site as landscape bunds with excess material transported offsite. Some is assumed to be used as backfill material.

In evaporite rock environments, excavated spoil is assumed to be transported offsite and material is assumed to be imported onsite for construction of the landscape bunds. Some excavated spoil is assumed to be used as backfill material.

Planning will ensure that the transport system is sufficiently flexible to respond to variations in demand in a sustainable and cost-effective manner, and that appropriate resources for transport will be allocated as required during construction, operation and closure of a geological disposal facility.

The volume of materials to be transported and the number of personnel required will vary during the construction, operation and closure of the GDF and in relation to the design and implementation. Initial planning for the transport system in support of underground investigation and subsequent construction of the GDF may be based on a construction phase plan that incorporates a material and personnel resource programme. This will be used to forecast the quantities of construction materials and other goods required on site, the quantities of excavated spoil, and the timing of deliveries and spoil arisings resulting from the construction schedule.

The timely delivery and despatch of materials and goods is required to ensure that the storage of construction materials, other goods, and excavated spoil on the GDF site before use or removal is as planned, and that interruptions to excavation, construction, operation and closure activities by reasonably foreseeable short-term events are avoided.

Excavated spoil may be used for radiation shielding and/or visual screening or landscaping of the area around the GDF, rather than being transported away from the site. The optimum strategy for the use of spoil will depend on above ground and below ground conditions at any specific disposal site and the GDF design and implementation.

4.2 Transport of radioactive material and dangerous goods

4.2.1 Modes of transport

The transport system design shall take into account transport of radioactive waste and dangerous goods by:

- ***inland waterway***
- ***sea***
- ***rail***
- ***road***

It is currently assumed that radioactive waste does not require transport to a geological disposal facility by air. However, in future air transport may need to be considered for shipments of small quantities of radioactive material in order to ensure their physical security.

The transport system is required to take account of and comply with, national and local policy for the transport of radioactive waste and dangerous goods.

The use of inland waterway, sea, rail, and/or road modes of transport can be optimised by the provision of transport interchanges, depending on the transport infrastructure available at any given location, and the need to take account of the economic, social and environmental factors applicable at that time. It is currently expected that the majority of waste will arrive at the GDF by rail due to constraints on other transport modes such as weight limits. However, consideration of transport of suitable waste by road allows for greater flexibility in the transport system design.

4.2.1.1 Use of compliant facilities

Any facilities used for waste transfer between modes of transport shall comply with appropriate requirements regarding:

- ***security***
- ***monitoring***
- ***temporary storage***

An appropriate Quality Assurance programme shall be applied to transshipment activities, including any temporary storage, for all modes of transport.

It must be demonstrated that facilities used for waste transfer between modes of transport such as harbours or railheads (transshipment) are compliant with the relevant regulatory requirements (as set out in DSS Part A [4]) such as the IAEA Transport Regulations [28].

4.2.1.2 Developments to the transport infrastructure

The transport system design shall consider the need for developments to the transport infrastructure, including both new infrastructure and improvements to existing infrastructure.

The transport system is required to be capable of delivering radioactive waste packages to the GDF by a range of safe, sustainable and practical combinations of inland waterway, sea, rail and road.

The existing transport infrastructure may need development to enable the transport of the volumes of radioactive waste and other materials specified in the inventory for geological disposal (see Section 3.1) to the GDF. Developments to the transport infrastructure may include new or improved access roads, links to the national road network, links to the

national rail network and/or harbour improvements. An integrated transport strategy aimed at achieving a co-ordinated, cost-effective transport system for radioactive waste, personnel, excavated material and construction materials will be developed that is acceptable to stakeholders at the waste-producing sites, at the GDF and along the transport routes. Development of the transport infrastructure might need to be undertaken in consultation with the waste producers because improvements may be needed to the infrastructure at their sites.

Transport policies and requirements may change over time. Also, the facilities and resources needed for inland waterway, sea, rail and road transport will vary with both time and location of the GDF.

The GDF will need to be linked to the transport network by access roads to facilitate the transport of radioactive waste. Improvements to the national road network may be needed in the vicinity of the GDF, depending on the existing infrastructure and the proportion of waste and other materials and the weight of packages that are to be transported by road.

Rail transport should be considered for the transport of waste from sites with existing railheads to the GDF. For waste-producing sites that do not have an on-site railhead, it is appropriate that transport system planning considers the use of off-site railheads serving one or more waste-producing sites. Some nuclear power stations have local off-site railheads to which spent fuel flasks are currently transported by a short road journey. The development of new railheads may also be considered to minimise the requirement for road transport between waste-producing sites and the GDF, subject to requirements and local conditions.

Similarly, for port facilities and interchange provision to seaborne transport modes, it is appropriate that transport system planning makes appropriate use of off-site port or harbour facilities serving one or more waste-producing sites. It may also be appropriate to consider the development of new port or harbour facilities to minimise road and rail transport requirements. The use of a limited number of ports would be preferred to avoid having to establish specialist facilities at a large number of locations. As with railheads, due consideration would need to be given to site licensing requirements and timescales.

The transport of spent fuel by sea to the UK has demonstrated a good safety and security record for several decades. Most of the waste-producing sites have coastal locations, but waste packages would nonetheless require overland transport to one or more ports for onward sea transport to a port near the GDF.

The provision of transport interchange facilities will need to be considered to enable an optimum combination of inland waterway, sea, rail and/or road modes of transport to be used, particularly for the transport of waste packages from the waste-producing sites to the GDF. This will take in to consideration the treatment of 'trans-shipment' within the IAEA Transport Regulations [28] and their supporting documentation, and to the modal regulations relating to dangerous goods Class 7 (Radioactive Material).

4.2.1.3 Planning

Planning for changes to the transport infrastructure shall be undertaken on a timescale that allows changes to be implemented prior to any need for significant movement of materials from or to the site of a geological disposal facility.

Due consideration would need to be given to the necessary design development, planning applications, site licensing requirements and timescales for physical alterations needed to implement the required transport infrastructure. This may include developments to access roads, the national road and rail networks, and the provision of railheads, ports and other transport interchange facilities.

4.2.2 Safety

Radioactive materials and dangerous goods shall be transported in accordance with the safety requirements defined by the competent authority and all other applicable regulations.

Conventional transport assessments will be undertaken as part of the EIA described in Section 3.4.1. For the transport of radioactive waste, demonstrating compliance with the safety requirements defined by UK legislation will involve preparation of a transport safety assessment, covering the safety of the transport system during the characterisation, construction and operation of the GDF. Compliance throughout the characterisation, construction and operational period of the GDF with applicable regulations, the developer/operator's HSSE and radiological protection policies, and the CDG 2009 Regulations [134] ensures that safety is inherent within the transport system.

4.2.2.1 Transport package safety

Transport of radioactive material shall use transport package designs that comply with the packaging requirements and test procedures specified in the International Atomic Energy Agency's Regulations for the Safe Transport of Radioactive Material.

The high degree of safety associated with the transport of radioactive material is inherent in the transport package design itself. That is the philosophy of the IAEA Transport Regulations [28], which are embedded in, and implemented, through CDG 2009 [134], as outlined in [137]. Transport packages are designed to provide shielding, containment and criticality safety for the radioactive contents, under both normal and severe accident conditions of transport. The detailed requirements that transport packages for different categories of radioactive waste must meet are set down in the IAEA Transport Regulations.

The competent authority requires that the safety of transport packages is demonstrated in Package Design Safety Reports (PDSRs) [138]. Approval of PDSRs is signified by the issue of a transport approval certificate applicable to a particular transport package design. The consignor must then demonstrate that each transport package (which includes the contents) is compliant with the requirements of the PDSR before the wastes can be transported. In this way, the consignor demonstrates that the transport package is compliant with the IAEA Transport Regulations and the implementing UK legislation, as described in DSS Part A.

A Radiation Protection Programme will be established for the transport system to provide for consideration of radiation protection measures in transport and to ensure that the system of radiological protection is adequately applied.

4.2.2.2 Package design safety reports

Transport package designs shall be demonstrated to meet the requirements of the applicable regulations and consequently the IAEA's Regulations for the Safe Transport of Radioactive Material.

As part of the design process for the Transport Packages and Industrial Packages that will be employed for transport of waste to the GDF, PDSRs [138] will be produced to demonstrate compliance with the CDG Regulations 2009. The competent authority in the UK for package designs is the ONR's Radioactive Materials Transport (RMT) Programme. The competent authority is responsible for programmes of compliance assurance to ensure the application of quality assurance through audits of the procedures in place to govern the production of PDSRs within organisations responsible for transporting waste packages.

Safety within the transport system will be inherent through compliance with all relevant regulations, and with the developer's HSSE and radiological protection policies [116], which include numerical acceptance criteria and an overall ALARP (as low as reasonably

practicable) requirement. A Radiation Protection Programme will be established for the transport system to provide for consideration of radiation protection measures in transport and to ensure that the system of radiological protection is adequately applied.

4.2.2.3 Accidents and emergencies

The transport system shall include arrangements to deal effectively with any accidents or emergencies during transport.

It must be demonstrated that industrial transport packages can withstand normal transport operations and that their contents are in a form which presents no significant risk to workers or the public under accident conditions. Type B transport packages are required to withstand not only conditions of normal transport, but also transport accident conditions, including severe impacts, fires and water immersion, while sustaining no significant loss of either shielding or containment. Where the waste package contains fissile materials, sub-criticality must also be maintained during normal and accident conditions. Therefore, it is not expected that accidents will lead to any significant radiological impacts.

Non-radiological impacts cannot be discounted during transport operations and it is important that transport operations are supported by an appropriate emergency response plan covering both radiological and non-radiological impacts (for example for radiological monitoring of any accident site; to facilitate recovery of any packages/vehicles involved in a transport accident). Different types of waste package will present different risks, and, therefore, the emergency arrangements need to be appropriate to the waste being transported.

When evaluating the emergency response requirements of radioactive material shipments from the waste producer, consideration must be given to the existing RADSAFE organisation¹⁷ and the infrastructure incorporated in to the National Arrangements for Incidents involving Radioactivity (NAIR) [139].

4.2.2.4 Criticality

Design of the transport system shall ensure that criticality during transport is prevented.

In line with the transport regulations explained in DSS Part A and in more detail in the IAEA Transport Regulations, the transport system design, including associated transport packaging as required, will enable the transport of fissile material in such a way so as to ensure sub criticality during routine, normal and accident conditions.

4.2.2.5 Reusable transport containers

Except when waste packages are certified as transport packages, all radioactive waste shall be transported to a geological disposal facility in reusable transport containers¹⁸.

All reusable transport containers and their contents shall be capable of being transported by inland waterway, sea, rail or road, or by a combination of these modes and including facilities to transfer between modes.

¹⁷ RADSAFE is a private company limited by guarantee that offers mutual assistance in the event of a transport accident involving radioactive materials belonging to a RADSAFE member.

¹⁸ Exceptions may be allowable where re-use of transport containers is not cost-effective or not feasible for operational reasons.

The use of reusable transport containers in some disposal concepts has the potential to reduce the volume of waste requiring management in the GDF relative to the use of transport containers that also serve as disposal containers.

Different logistical and regulatory constraints can apply to the transport of radioactive materials using different modes of transport. The reusable transport containers are specifically designed against these constraints to ensure viability of the transport of waste packages by inland waterway, sea, rail or road, or by a combination of these modes (for example, [140]).

4.2.2.6 Equipment contamination checks

Equipment used regularly for the transport of radioactive material shall be periodically checked to determine the level of contamination.

To enable the timely and cost-effective return of the reusable containers to the waste-producing sites, facilities will be needed for the maintenance and preparation for transport of empty containers, and other items required for the transport of radioactive waste (see Section 5.5).

For consistency with the transport strategy and requirements for the transport of full reusable transport containers, it will likely be appropriate that empty reusable transport containers are returned by the same means of transport as was used for delivery to the GDF. The strategy for the return of reusable transport containers will be to quantify the potential contents that cannot be cost effectively removed by decontamination and to ship the container as a package containing those quantified contents.

4.2.3 Transport Schedule

The transport system shall be designed to take into account scheduling of consignments of radioactive waste to a geological disposal facility including:

- ***the ability of sites to consign the waste***
- ***the ability of a geological disposal facility to accept waste packages***

The schedule for transport of radioactive waste to the GDF will be defined by a range of factors and is subject to change. The transport schedule is referred to in Section 3.1.8 . A key benefit of a 'just in time' waste package delivery strategy (that is delivery of waste packages immediately prior to their disposal) would be the potential elimination of the need to duplicate the storage facilities that already exist at the waste-producing sites. This could potentially reduce the number of package handling operations (and any associated dose), and minimise land use at the GDF site. However, development of the disposal schedule is a matter for optimisation, and balance of the needs of interim storage sites and operation of the GDF.

Transport schedules will need to be planned and managed by the operator in sufficient detail to ensure that the schedules are feasible and that appropriate transport resources will be allocated throughout the lifetime of the GDF. Transport planning needs to consider:

- the supply of new reusable transport containers and transport stillages and the return of empty ones, to meet the changing requirements of each waste-producing site
- the supply of transport vehicles
- the timing of any required upgrades along transport routes, including any special provisions such as interchanges, marshalling yards, overnight stops for road vehicles
- the available capacity of temporary storage and maintenance facilities at the GDF

The current scheduling of consignments assumed for planning purposes has been developed through engagement with sites, so aligning with the expected availability of waste packages for disposal.

4.2.3.1 Flexibility and robustness of the waste transport system

The transport system design shall incorporate contingencies to provide flexibility and the capability of responding to variations in waste delivery rates.

Flexibility has already been discussed to a degree in the scheduling described in Section 4.2.3 in the context of 'just in time' delivery. Beyond that, however, the transport system will need to be able to respond to the following issues over short, medium and long periods throughout the operation of the GDF:

- the requirements of the GDF or of individual waste-producing sites, which may change
- the transport system, which relies on the national transport infrastructure, but the availability of which is not under the control of RWM, the NDA or the SLCs

Flexibility and robustness of the waste transport system can be ensured by:

- considering a combination of transport modes (inland waterway, sea, rail and/or road), noting that the optimum combination may depend on changes in national transport policy, infrastructure provision, transport costs and site-specific factors
- designing a transport system that can respond flexibly to these changes in a safe, cost-effective, environmentally sound and sustainable manner
- ensuring that no reasonably conceivable change can prevent transport objectives from being achieved
- anticipating and incorporating contingencies into plans during the development of the transport system, and assessing such contingencies within the transport safety case

4.2.3.2 Contingencies for interruptions to geological disposal facility waste emplacement operations

The transport system design shall incorporate contingencies that allow for changes to the availability of a geological disposal facility including:

- ***interruptions to operations at a geological disposal facility***
- ***disruptions to parts of the transport network (it should be possible to re-route waste packages, use alternative means of transport, or change the scheduling of waste consignments from different sites if part of the transport network is disrupted)***
- ***interruptions to the conditioning and packaging of wastes at waste-producing sites (it should be possible to change the scheduling of waste consignments from different sites)***

It is currently assumed that temporary storage provisions at the GDF site shall be made to accommodate 1 week's consignments.

If waste emplacement activities were halted for any reason, it may be necessary to halt the despatch of waste packages from the waste-producing sites. There may also be a need for sufficient temporary storage at the GDF to enable the receipt of waste packages that were already in transit (see Section 5.1.1). If short-term storage was accomplished by leaving the waste packages on their transport conveyances, adequate, secure and safe siding and/or road parking space would be needed at the GDF.

4.2.3.3 Contingencies for interruptions to the transport system or to the production of waste packages

The transport system design shall ensure that disruptions to parts of the transport network, and interruptions or delays to the planned conditioning and packaging of wastes at any one site can be accommodated.

It is assumed that in the event that the primary route between the site of the waste arisings and a geological disposal facility becomes unavailable, the scheduling of waste consignments from different sites may need to be altered, or alternative routes or modes of transport may need to be provided.

The transport system needs to provide contingency plans to manage unforeseen interruptions to the transport system between the waste-producing sites and the GDF that are not under the direct control of RWM, the NDA or the SLCs.

The appropriate national and local bodies will be consulted on the establishment of alternative routes or modes of transport in the event of unforeseen interruptions to the transport system.

In addition, if there is a delay to the conditioning and packaging of waste at one site, the transport system should be sufficiently flexible to allow the same waste type from another site to be transported to the GDF.

5 Receipt and Surface Handling

5.1 Waste package surface handling

The GDF shall be designed to safely handle waste packages in the inventory for disposal from receipt to underground transfer in line with the GDF schedule.

5.1.1 Waste package receipt

Facilities shall be provided to ensure that short term variations in the rate of waste receipt and waste disposal can be accommodated.

The design of the facility should seek to minimise the need to hold waste packages in temporary storage.

Facilities shall be available to manage:

- ***non-compliant transport containers***
- ***waste packages***

It is assumed that, should the non-compliant package be unfit for transport on the existing transport network, the remedial action would have to be carried out at the site of a geological disposal facility, and, therefore, arrangements for the management of non-compliant packages are required.

Quality checks and monitoring at the GDF will normally comprise visual inspection for deformation or damage, and confirmation of package identification number. Other measurements, such as package weight and radioactivity, may be recorded for operational reasons. Where such measurements are made they could also be used to provide further confirmation of identity, but need not necessarily form part of the quality checking system. The provision of good control at the site of arising and of transport systems considerably reduces the potential need for packages to be opened or taken offline at the GDF, with overall benefits of reducing potential for contamination and operator dose.

There is a potential for non-compliant waste packages and transport containers to arrive at the GDF and assessment of non-compliant packages could result in identification of the need for remedial action. The need to keep records of radioactive wastes accumulated on nuclear licensed sites is specified in Licence Condition 32 of the Nuclear Site Licence Conditions and the ONR SAPs [87, paragraph 824].

Technology may have advanced by the time the GDF becomes operational and, therefore, the flexibility to install new instrumentation should be retained.

Should packages be scheduled for delivery at a rate that allows timely emplacement the need to duplicate storage facilities that already exist at waste producing sites would be minimised. This would reduce the potential number of package handling operations (and any associated dose) and minimise land use at the GDF site. Scheduling of waste package delivery is discussed in Section 3.1.8 and 4.2.3.

There may be advantages in providing a small amount of temporary storage for waste that has been unloaded from its transport conveyance. This is partly to allow some flexibility in the emplacement of individual packages according to their contents; and partly to allow packages arriving in very small numbers to be held until emplacement can take place in short, efficient campaigns. In both cases, the objective would be to prevent unduly detailed constraints on the timing of delivery of individual packages via the transport system from the waste packaging sites.

In addition, if emplacement activities were halted for any reason, waste packages would have to be placed in temporary storage and/or the transport of waste packages to the GDF would also be halted. There must be facilities to accommodate temporary storage of any waste packages that arrive at the GDF but which cannot be emplaced in a disposal module. As stated in Section 4.2.3 a current planning assumption is that the GDF design should include temporary storage to accommodate one week's consignments. This is an assumption that is believed to be reasonable for accommodating the packages awaiting emplacement and those en route to the GDF. If problems with emplacement were incurred, transport of waste packages to the GDF would be halted through communications with the relevant sites.

Temporary storage could include facilities for the storage of waste on the surface or underground.

5.2 Access

The geological disposal facility design shall ensure that provision of access to a geological disposal facility is compliant with relevant safety and security requirements.

Security requirements are specified in the Nuclear Industry Security Regulations 2003 [141]. These requirements are described in more detail in DSS Part A. The arrival of specific waste consignments at the GDF may impose additional security requirements. RWM will produce a security plan which will be assessed and approval sought through the ONR's Civil Nuclear Security (CNS) programme.

5.3 Records

The geological disposal facility design shall include facilities for:

- ***monitoring and record checks at package receipt***
- ***management and storage of waste package records***

Arrangements shall be made for the preservation of details of a geological disposal facility and records of the type and location of wastes.

The operating period of the GDF is expected to be decades. Records of the nature and quantity of wastes and the location of packages within the facility will be an important basis for future generations to make decisions regarding the development of the facility in the future. Records will also be kept on the construction design of the GDF.

The need to keep records of radioactive wastes accumulated on nuclear licensed sites is specified in Licence Condition 32 of the Nuclear Site Licence Conditions and the ONR SAPs [87, paragraph 824].

5.3.1 Assessment of non-compliant waste packages

Non-compliant packages shall be assessed with the aim of determining any necessary actions.

A waste packaging process, in common with any manufacturing process, has the potential to produce products that are outside the appropriate specifications or that exhibit defects that could be unacceptable to the customer. Site-specific information could influence the development of WAC and this could lead to packaged waste now falling outside of the specifications in the future. However, the intent is for Generic Waste Package Specifications to be conservative to reduce the potential for such circumstances to arise. A number of terms may be used to describe such variations, for example defective, non-compliant, nonconforming or out-of-specification, but the term non-compliant is used in this document to reflect the need for the significance of the variation to be separately assessed.

Notwithstanding the terminology adopted, to maintain confidence in the quality of packaged wastes, it is important that any unacceptable variations are identified at an early stage and strategies devised for their remediation. The WAC will specify the quality and nature of records that are required for packages and these will enable non-conformance to be more easily managed. Within an approved quality management system (QMS), such variations will be governed by a formal procedure for dealing with non-compliance. Typically such a procedure would instigate a review of the consequence(s) of the variation(s) and, if necessary, result in the definition of what remedial or investigative action is required. These processes would also be under the control of the waste producer's QMS which should be consistent or compatible with the QMS of RWM as the GDF operator.

5.4 Monitoring of waste packages

Facilities shall be developed in which surface contamination checks and other monitoring of waste packages and re-usable transport containers can be performed.

The process of unloading re-usable transport containers has the potential to cause surface contamination of the exterior of the container, which would need to be removed. Acceptable external contamination levels are specified in the IAEA Transport Regulations.

The frequency of monitoring required will depend on operational experience; initially, all containers may need to be monitored to establish a statistical baseline, but this frequency may be reduced as confidence in the control arrangements is gained.

5.4.1 Waste package contamination checks

Facilities for waste package monitoring shall provide the necessary shielding, containment and access provisions.

Measurement of surface contamination levels on waste packages may form part of the quality assurance arrangements for package receipt, depending on the compliance monitoring strategy adopted at the GDF. It is therefore prudent to make provision for such measurements in GDF design.

5.5 Decontamination of transport equipment

Facilities shall be available to decontaminate any equipment used for the transport of radioactive material before further use.

Facilities shall be provided to decontaminate the external and internal surfaces of transport containers if necessary, in such a way that normal operations of the disposal system are not impeded.

The need for decontamination will be determined by monitoring (as defined in Section 5.4). Post-decontamination monitoring may also show that the process needs to be repeated. These uncertainties mean that decontamination is better done offline from the main emplacement process. This will minimise any requirement for decontamination on the management of other containers that are being processed at the GDF. Consideration should also be given to moving the monitoring part of this activity offline, again in order to obtain an improvement in the efficiency of container handling at the GDF.

Internal contamination monitoring of reusable transport containers will be used to support and audit the arrangements for contamination control of transport containers. Acceptable internal contamination levels need to be agreed between the GDF operator and the waste package consignors (with the consent of the regulators).

6 Underground Transfer

6.1 Waste package transfer

The GDF shall be designed to safely transfer the waste packages in the inventory for geological disposal underground in line with the GDF schedule.

Facilities shall be provided for the transfer underground of all waste packages such that doses to operators shall be ALARP.

Remote-handling facilities shall be provided where appropriate.

All package handling routes for non-heat generating waste (that is ILW, LLW and uranium) shall have adequate clearance to allow oversized items such as an overpacked drum or box to be transferred and emplaced.

It is recognised that, at this generic stage, the waste packages or disposal containers assumed for planning purposes for HLW, spent fuel, DNLEU, HEU or plutonium are subject to change. However, as explained in Section 3.1.6, two disposal container conceptual design variants have been developed for spent fuel and HLW.

Shielded Intermediate Level Waste (SILW) packages should have dose rates low enough to allow conventional handling (for example, forklift truck). The requirement that doses to workers are ALARP is derived from the ONR SAPs [87, paragraph 12].

Unloading of reusable transport containers could be undertaken above or below ground. Remote handling facilities will need to be provided for handling of UILW, HLW, spent fuel and plutonium packages as dose rates would otherwise exceed regulatory limits.

Standardisation of waste packages is internationally recognised as good practice. It simplifies handling arrangements and, therefore, reduces opportunities for error, whilst also permitting safe and efficient operation of GDF systems. The key criteria specified are those considered to be essential for container standardisation, namely dimensions, shape, maximum gross mass and lifting features, although this is an area of ongoing research.

Mass limits for waste packages will ultimately be set by the mass rating of the GDF handling equipment therefore the waste package will be compatible with GDF provisions for handling and emplacement.

The physical configuration of some waste package contents (in particular PWR fuel assemblies) is such that it may lead to an uneven mass distribution within the waste package. This may have consequences for the stability of the waste package during handling, and for the design and operation of the emplacement equipment. Excessive unevenness of mass distribution within waste packages should be avoided where practicable.

The integrity of the waste package and its lifting feature(s) will be such that it will be retrievable for the duration of the operational phase of the facility (see Section 3.1.5.1).

Integrity is defined as the ability of the waste package to maintain the containment of its contents, as well as the surety of physical-handling features (ie lifting locations). The basic integrity requirements need to encompass the operational period of the GDF so that the waste package enters the post-closure period in good condition. For HHGW, a high integrity container is required to ensure the waste package maintains its condition for a longer period of time. It is assumed that maintenance of the integrity of lifting features is required to meet current commitments for the design of the facility to not exclude retrievability. Waste package integrity requirements will take into account operational aspects including emplacement procedures and potential accident scenarios.

- Meeting a specified integrity requirement will require consideration of:

- the waste package material
- the wall thickness
- methods of fabrication and final closure
- corrosion mechanisms, including internal and external surface finish and the availability of reactants
- the nature of the buffer / backfill material

Ensuring containment of HLW, spent fuel, enriched uranium and plutonium for the thermal period will simplify the post-closure safety assessment and this is discussed in Section 9.9.5 where engineered barrier performance aspects of waste packages are described.

6.2 Access routes

The design of the access routes shall take account of the geological and hydrogeological conditions.

Potential geological environments exist in which a disposal module could be excavated in low permeability rocks, but where access to them would need to be gained by passing through higher permeability cover rocks. In these circumstances, measures must be taken to control water inflow into the accesses (shafts and/or drifts), for example by provision of a hydrostatic lining to control water inflow. These solutions are described in more detail in Section 3.10.1 (Construction methods).

6.3 Personnel transfer

The GDF shall be designed to ensure safe and timely transfer of personnel (for construction and operations), construction materials, excavated spoil and engineered barrier system materials.

The number of access routes will be determined by:

- the need to provide separate access routes for personnel and waste
- the need to segregate the construction and waste emplacement operations within the facility
- the provision of services such as power and ventilation
- current good practice in terms of emergency response (as described in Section 3.2.3)

7 Emplace

7.1 Waste package emplacement

The disposal system shall be designed to safely emplace the waste packages in the inventory for geological disposal in line with the GDF schedule.

Facilities shall be provided for the emplacement of all waste packages such that doses to operators shall be ALARP.

Remote-handling facilities shall be provided where appropriate.

It is recognised that, at this generic stage, the waste packages or disposal containers assumed for planning purposes for ILW, HLW, spent fuel, DNLEU, HEU or plutonium are subject to change. However, as explained in Section 3.1.6, two disposal container conceptual design variants have been developed for spent fuel and HLW.

The nature of the waste will influence the development of the waste emplacement systems within the design and the need for remote handling such that doses remain within regulatory limits and are consistent with the ALARP principle. The requirement that doses to workers are ALARP is derived from the ONR SAPs [87, paragraph 12].

7.2 Selective emplacement

The design and operation of a geological disposal facility shall allow waste packages to be selectively emplaced if required in order to take account of package and inventory:

- *waste type*
- *package type and stacking properties*
- *fissile content of wastes*
- *heat output*
- *gas generation*
- *physico-chemical conditions and their expected evolution*

The design and operation of a geological disposal facility shall take into account the requirements of waste packages listed in the Special Emplacement Register¹⁹.

Certain packages may need to be placed at particular locations with respect to other packages, the overall facility layout or the rock wall. This may be because the form of the package means that special handling arrangements are required, or because the content of the package requires that they be positioned in a particular location.

There are several potential reasons for this:

- some packages may have non-standard handling features and therefore need specialist equipment to handle
- it may be desirable to position higher heat output waste packages in cooler areas of the GDF, in order to keep waste package temperatures and humidity as low as reasonably practicable in both the operational and the post-closure period

¹⁹ A list of waste packages that are currently assumed to have special emplacement requirements are kept within a register as an appendix to the generic GDF Design Report [16].

- it may be desirable to position packages containing reactive metals away from packages with a higher heat output to reduce gas generation rates for these packages
- some wastes may need to be segregated from particular constituents of other packages (for example, organics) to avoid increased radionuclide mobility
- criticality considerations may lead to a requirement to separate packages containing fissile material
- 'random' emplacement (in other words, the absence of any specific waste emplacement strategy) does not guarantee a uniform distribution of waste within a disposal module.

An emplacement strategy for all wastes may not be necessary; nevertheless, such a strategy may be advantageous for certain waste streams, so the ability to emplace certain packages at particular locations is an important reserve option.

7.3 Environmental conditions

Environmental conditions within the GDF shall be maintained suitable for:

- ***equipment***
- ***waste packages and***
- ***personnel***

The GDF will be operated to protect people and the environment according to the conditions of a nuclear site licence and other regulatory requirements as explained in DSS Part A. Environmental conditions such as temperature and air humidity within the disposal areas will depend on the requirements for worker access to specific areas, requirements for the safe operation of equipment and the need to provide conditions under which the safety functions of the engineered barriers assumed post-closure are maintained.

7.3.1 Operational temperature limits

During the operational period, the temperature of air within an ILW disposal vault shall not exceed 50°C.

During personnel access to a disposal module containing shielded waste, disposal module temperature shall be in line with that specified for other occupied areas.

Measures shall be taken in the design and operation of a geological disposal facility to minimise rates of metallic corrosion by:

- ***minimising ILW, LLW and uranium waste package temperatures during operation as far as reasonably practicable***
- ***limiting the duration of short-term increases in temperature that may occur during operations***

The upper temperature limit for the air within the disposal module environment during the operational period is set at 50°C to provide satisfactory conditions for in-disposal module electrical equipment. The temperature limit would also provide a margin to ensure effective operation of HEPA filters, if they are included in the disposal system design to filter the air extracted from a disposal module. Within the disposal module, the ILW vaults, mechanical handling equipment such as overhead cranes are vital items of plant whose reliability needs special consideration.

Standard cranes are designed to operate at an ambient temperature of 40°C but cranes suitable for a tropical environment and continuous use at 50°C are readily obtainable at

minimal extra cost. Hence 50°C has been adopted as the target for the vault air temperature. In a period where SILW/LLW vaults may have personnel access, the vault temperature must be in line with those specified for other occupied areas.

As discussed in Section 9.9.6, minimisation of ILW, LLW and similar wastes package temperature would also help to ensure that the waste packages enter the post-closure period in the best condition practicable. In particular, maintaining lower temperatures in the waste stacks during the operational period would result in:

- lower rates of metallic corrosion, which would enhance the longevity of the waste container walls, and would also reduce the swelling of metallic wasteforms
- reduced gas generation (due to reduced metallic corrosion rates), which affects wasteform physical integrity and releases of flammable, radioactive or toxic gases

This temperature management will be determined by the designers of the GDF, and may be possible through engineered features (for example, a cooling system).

7.3.2 Relative humidity

The design shall ensure that the relative humidity of disposal module environment prior to backfilling can be managed to limit:

- ***waste package corrosion damage***
- ***potential for wasteform corrosion***
- ***potential for liquid effluent generation on the surface of waste packages***

The design shall ensure that the relative humidity of the air in disposal modules during emplacement of any buffer or backfill materials used can be managed taking account of the nature of the materials employed, to ensure that the humidity does not adversely impact the performance of these materials.

It is assumed that the relative humidity of air at the inlet to any extract filters installed in disposal modules does not exceed 90%.

The main factor influencing the relative humidity limit before backfilling is the corrosion of waste containers. The objective is to ensure that the waste packages enter the post-closure period in the best condition practicable, to avoid any operational problems due to package corrosion and to maintain the ability for packages to be retrieved during the operational period if required. It is important that the GDF is operated in such a way as to preserve the safety functions of the disposal system that are assumed in the safety case and that are important for safety post-closure. Control of the relative humidity to prevent condensation would also avoid the potential for effluent arising within disposal modules which would require management as outlined in Section 3.11.2 (Effluents).

As explained in Section 9.9.5 the previous DSS for ILW/LLW [6] was more prescriptive on relative humidity before backfilling. For example, it specified that before backfilling, air in an LHGW disposal module should have a relative humidity below 60%, it may be necessary to specify a minimum relative humidity to control atmospheric stress corrosion cracking of waste containers, which could be accelerated at low levels of relative humidity. However, at this stage DSS Part B recognises that specific requirements and environmental control strategies will be dependent on the nature of the geological environment present at a particular site. Further work will therefore be needed to specify the appropriate relative humidity for the different disposal modules of the geological disposal concept that is adopted at this stage.

The relative humidity of the air in disposal modules during emplacement of buffer and backfill materials could impact the performance of the materials. For example, should a cementitious backfill be used in disposal modules used for ILW, the relative humidity of the

air would affect the extent of surface drying and plastic shrinkage crack development. In the case of emplacement of a bentonite buffer, the relative humidity could impact the swelling and density of the bentonite, and a low-humidity emplacement environment would be preferred.

The limit on relative humidity of air at the inlet to any extract filters installed in a disposal module is based on consultation with filter manufacturers, who have stated that although filters can operate at a relative humidity approaching 100%, a limit of 90% should be set to provide a suitable working margin [142].

7.3.3 Groundwater inflows

The design shall take into account the potential effects of expected groundwater inflow such that there is no detrimental impact on the engineered barrier system, including waste packages.

Contact of groundwater with waste packages during the operational period could result in:

- enhanced corrosion of the waste packages
- displacement of porewater by groundwater after backfilling
- generation of active liquid effluents

Measures must therefore be taken to determine acceptable groundwater inflow rates and criteria for positioning waste packages in order to direct groundwater, particularly saline groundwater, away from waste packages during the operational phase.

In concepts where bentonite buffer²⁰ is used in the disposal modules, it is important for the inflow of groundwater to be limited during the initial emplacement and deposition of the waste package. The reason is that bentonite is susceptible to swelling, which could adversely affect handling of bentonite and the positioning of the waste package. Excessive groundwater inflow could also lead to piping and erosion of the bentonite.

Water flow into the deposition areas will contribute to the wetting of the emplaced buffer. However, if the flow is localised by fractures that carry more water than the swelling buffer can absorb, there will be a water pressure in the fracture acting on the buffer. For some buffer materials and disposal concepts, sufficient groundwater inflows may be required along the entire length of the emplacement areas to enable relatively even swelling of the emplaced buffer.

²⁰ Bentonite is available in a range of forms including loose, pelletised and compacted, pre-fabricated components and this has an impact on its management and handling.

8 Close

8.1 Closure designs

The disposal system shall be designed to be safely closed in line with the GDF schedule.

Feasible designs for closure of a geological disposal facility shall be included in the overall design developed for authorisation to construct a geological disposal facility.

The initial designs for closure shall be further developed, taking account of information acquired during construction and operation of a geological disposal facility.

Final designs for each phase shall be assessed prior to their respective implementation.

These requirements on the development of closure designs are derived from the ONR SAPs [87, paragraphs 825–827], which cover the decommissioning of nuclear facilities, and the GRA [18, paragraph 6.4.23], which requires that, “*At the design stage and periodically during the lifetime of the facility, the developer/operator should demonstrate that it is able satisfactorily to close the disposal facility and, where relevant, seal the access tunnels, shafts and drifts, boreholes and any other potential preferential pathways for radionuclide transport that will or may be introduced as a result of the siting, construction and operation of the disposal facility*”.

The key phases to be considered in the closure design are:

- backfilling and sealing of disposal areas
- backfilling and sealing of access tunnels, shafts and boreholes
- removal of surface buildings and installations and site restoration
- transfer or removal of institutional control

8.1.1 Institutional control

The GDF shall be designed, constructed, operated and closed in such a way that safety is ensured by passive means to the fullest extent possible and the need for actions to be taken after closure is minimised.

It is currently assumed that responsibility for any period of institutional control after closure of a geological disposal facility and site restoration have been completed will rest with an appropriate authority other than RWM.

What happens to the site following closure will be a matter for future generations – subject to the appropriate transfer of liabilities, the site could be farmed, forested, allowed to return to nature, or used for construction or other purposes, with the waste itself isolated within the multi-barrier system in the geological formations hundreds of metres below the ground. Records of the location and general contents of the facility would be held by local records offices and a national archive.

The site could also be retained under active control for some period of monitoring if desired by future generations living in or near the host community.

Assuming that there would be no period of institutional control allows for the greatest flexibility in returning the site to an alternative use determined by future generations at the earliest possible opportunity.

8.2 Site restoration

The design shall provide for site restoration during the closure phase.

It is assumed that decommissioning of the surface facilities will require dismantling of buildings and surface infrastructure.

Activities during site restoration could include:

- dismantling of all surface buildings and associated features
- dismantling and removal of all surface infrastructure, including roads, drainage and services, apart from those required for any active institutional control

Licence Condition 35 of the Nuclear Site Licence Conditions [114] requires licensees to make adequate arrangements for decommissioning facilities on a nuclear licensed site. Proposals for the closure and decommissioning of the site will be developed in consultation with the host community and regulators. An EIA will be undertaken which looks at the potential social, economic, health and environmental impacts of closure and decommissioning. This will be used in any planning permission process that is required. The EIA will also consider mitigation measures to eliminate or reduce negative impacts of site restoration. Any radioactive waste generated from site restoration is envisaged to be managed as LLW.

The management of wastes that would arise are subject to the Waste (England and Wales) Regulations 2014 [143], which ensures that a duty of care through requirements, for example that waste is stored correctly, only collected by registered waste carriers, covered by a valid transfer note and records of transfers of waste are kept for at least two years.

8.2.1 Environmental impacts of closure operations

Mitigation measures for reducing the environmental impacts of closure shall be identified and applied.

Reducing the environmental impacts of closure is consistent with the ONR SAPs [87] and will be assessed as part of the EIA for closure and decommissioning.

8.3 Restoration of host rock natural conditions

Closure of the GDF shall, so far as practicable, restore the natural conditions of the host rock.

Closure of the GDF involves activities such as backfilling and sealing the underground openings of the disposal facility. As explained in DSS Part A it is a requirement to close the GDF in such a way as to preserve the safety functions that are assumed in the safety case. One key aspect of this, as explained in IAEA guidance [26] is to restore, as far as practicable, the natural conditions of the host rock and the geological environment that may have been affected before excavation started. However, it should be noted that in a cementitious repository concept, for example low heat generating waste concept in the HSR concept, groundwater that has reacted with cement within the repository will react with the surrounding rock, forming an alkaline disturbed zone. This may lead to dissolution of some minerals and precipitation of others, leading to a change in hydrogeological and chemical properties that are different from the surrounding unaltered rock [144].

8.3.1 Backfilling and sealing disposal areas

Where appropriate, backfilling equipment shall be segregated from the waste disposal areas of the facility and the number of operational interfaces between disposal areas and backfill equipment shall be minimised.

After backfilling of the disposal areas, each disposal module shall be sealed through installation of a sealing plug.

For planning purposes the following assumptions are made with regards to backfilling of low-heat-generating waste (LHGW) disposal areas:

- *in higher strength rock (HSR), it is assumed that vaults remain open once filled with waste packages. All vaults are assumed to be backfilled with Nirex Reference Vault Backfill (NRVB)²¹ on closure of the GDF*
- *in lower strength sedimentary rock (LSSR), individual vaults are assumed to be backfilled with cement grout and sealed once filled with waste packages*
- *in evaporite rock (EVR), it is assumed that no backfill is required as the host rock is assumed to creep. Bags of magnesium oxide are assumed to be utilised for chemical conditioning of the environment. Individual vaults are assumed to be sealed once filled with waste packages*

It is assumed that there will be 1 backfill gallery for every 2 vaults in HSR environments. No backfill galleries are required for LSSR or EVR environments.

For planning purposes the following assumptions are made with regards to backfilling of high-heat-generating waste (HHGW) disposal areas:

- *in HSR, individual disposal tunnels are assumed to be backfilled with bentonite blocks and sealed once all deposition holes within a tunnel are filled with disposal containers*
- *in LSSR, individual disposal tunnels are assumed to be backfilled with pelleted bentonite and tunnels sealed once filled with disposal containers*
- *in EVR, individual disposal tunnels are assumed to be backfilled with crushed rock and sealed once filled with disposal containers*

A key phase to be considered in the closure design is backfilling and sealing of disposal areas. Backfilling and sealing of disposal areas is required to ensure that the multi-barrier system is emplaced as envisaged. As much equipment as is practicable must be removed from the disposal areas to avoid any negative impacts on post-closure performance.

Segregation of backfilling activities simplifies the handling of raw materials, construction effluent and waste, and simplifies access for maintenance and recovery, reducing the potential for accidents and costs.

Limiting groundwater flow from a disposal module to the access ways will ensure that there are no unwanted groundwater interactions between the different disposal modules.

The number and extent of plugs required will depend on the disposal module design and layout and should take into account the probability of high-pressure gradients occurring within different parts of the GDF. The design assumptions regarding the extent of desaturation during the operational period and any extended storage period should be confirmed by monitoring. In addition, the positioning of plugs will be influenced by the condition of the host rock at the desired locations. Plugs should preferably be placed in regions of good quality rock, away from fractures.

Sealing plugs should be constructed from low permeability, high strength materials. The resaturation of areas is expected to be sensitive to the local rock permeability, which will vary, so sealed sections are expected to resaturate at a range of rates and times. Plug

²¹ NRVB is a cementitious material that was developed by United Kingdom Nirex Limited for the backfilling of ILW/LLW vaults.

specifications for different locations will depend on the predicted timescale for resaturation and the magnitude of the predicted pressure difference across the plug.

The length and strength of the plugs and other aspects of their design will depend on the performance requirements during resaturation and longer term. An important role of plugs is to protect sealed sections of the GDF that are in less permeable sequences from hydrostatic pressure gradients that may develop rapidly during resaturation. However, it may be necessary for the sealing plug to allow gas to migrate from a disposal module at the same time as restricting water flow. In some geological environments where gas cannot easily migrate through the host rock, the migration of gas from the disposal areas into the access ways and other underground spaces is an important process for limiting gas pressures within a disposal module.

8.3.2 Backfilling and sealing access tunnels, shafts and boreholes

The sealing system shall comprise a combination of low permeability seals and mass backfill to meet the requirements for closure and long-term safety.

Mass backfill shall be used to fill voids remaining after the backfilling and sealing of disposal modules and shall be placed in the spaces between low permeability seals.

It is assumed that the number, location and characteristics of low permeability seals takes into account engineering and long-term safety requirements. The permeability of the low permeability seals is assumed to be equivalent to the effective permeability of the host rock, or, if this is not achievable, is assumed to be as low as reasonably practicable.

The total volume of the excavations that provide access routes to the disposal modules may be large. It would be impracticable and uneconomical to seal all access ways and other underground spaces with low-permeability material. The use of a combination of sealing plugs and mass backfill, with different performance requirements, is routinely considered in GDF designs and is therefore judged to represent good practice for closure of the access tunnels and shafts.

Installation of low permeability seals would limit the flow of groundwater and gas, and the transport of radionuclides along backfilled access ways connecting disposal modules to the biosphere. A related function is to isolate sections of access ways that intersect major fracture zones. A further function is to divide the GDF into several sections, so that if geological containment is breached, the breach would be limited to one section and would not affect the entire facility. Limiting the flow of groundwater and gas would require the low permeability seals to have an effective permeability equivalent to the host rock, or as low as practicable.

Potential locations for emplacement of low permeability seals include the entrances to drifts and/or shafts, and boreholes. The RWM strategy for the geoscientific aspects of site characterisation [145] states an objective of site investigations is to “*implement site characterisation in a manner which avoids unnecessary impacts on the safety case for the long-term protection of people and the environment*” hence the detailed requirements for the sealing of site characterisation boreholes will be defined at the site-specific stage. Work is ongoing in the generic stage as described in the RWM Science and Technology Plan [36] to provide scientific evidence and technological demonstration that site investigation boreholes will be sealable to appropriate criteria in a UK context.

Installation of mass backfill will limit the presence of underground voids (for example, access ways) and will isolate the waste from the biosphere. Work is ongoing in the RWM Science and Technology Plan to develop and consider post-closure safety arguments in relation to voidage, to inform RWM decision making related to concept development and waste package guidance.

9 Post-Closure (Contribution from the Geosphere and the Engineered Barrier System)

For each disposal concept, the engineered and natural barrier system components would provide their environmental safety functions, as set out in Sections 2.2.1 to 2.2.6, in combination and at different times after disposal. In this section, the contribution to post-closure safety from the geosphere and engineered barrier system is described.

9.1 Maintenance of the engineered barrier system functions

The disposal system shall be sited in an environment in which the functions of the engineered barrier system will be maintained for a period that will prevent release of radionuclides and toxic materials reaching the surface in quantities that could cause harm.

As explained in the DSS Part A [4], it is a requirement that the engineered barriers will be designed and the host environment selected so as to provide features that contribute to containment of the waste. In a multiple safety function approach, the disposal system should provide a combination of natural and engineered characteristics to support efficient containment such that safety is not unduly dependent on a single safety function and the evolution of the engineered barriers complements the performance of the natural barrier.

9.1.1 Disposal system layout

The disposal system shall take into account potential thermal, mechanical, hydrogeological and chemical interactions and the potential for migration of GDF derived gas to ensure engineered and natural barrier performance.

The design will accommodate the overall volume of wastes as described in the inventory for disposal. Design of the facility assumes that separate disposal modules will be developed for certain categories of waste for reasons of handling and shielding, and post-closure interactions where this will improve the safety or environmental protection afforded by the facility or the reliability and/or cost-effectiveness of achieving this. Such separated disposal areas may well employ different engineered barrier systems and/or different waste emplacement methods.

9.1.2 Layout of engineered and natural barriers

Within the disposal horizons, the overall layout of the disposal areas and other facilities shall take into account engineered and natural barrier performance.

The disposal system design shall have flexibility to adapt layout and engineered barriers so as to take advantage of the natural characteristics of the site and barrier potential of the host geological environment.

Design of a geological disposal facility shall ensure that interactions between one disposal module and another will not compromise the performance of the disposal system.

Potential thermal, mechanical, hydrogeological and chemical interactions and the potential for migration of geological disposal facility-derived gas shall be taken into account when determining the separation distance between disposal modules for different waste categories.

For planning purposes, design of the facility shall assume a minimum horizontal separation distance of 500 m between disposal horizons for ILW/LLW and disposal horizons for HLW/SF, plutonium and HEU.

As explained above, different disposal modules may adopt different engineered barrier materials. There is potential for interactions between disposal modules that could have an impact on disposal system performance [146, 147, 148]. For example, alkaline fluids from a cementitious disposal module could potentially impact the performance of bentonite in an adjacent disposal module. The assumed separation distance of 500 m between disposal modules for ILW/LLW and HLW/SF, plutonium and HEU is based on earlier work undertaken by the European Commission and is supported by a further co-location study completed by Nirex [149]. Recent modelling also supports that this value is an appropriately conservative assumption, suggesting that the temperature interaction between HLW/SF and ILW/LLW disposal modules is the most limiting in terms of defining the minimum disposal area separation distance. Whilst this assumed distance is appropriate for planning purposes, these interactions are site and disposal-concept specific and will need to be taken into account in the design process [148].

9.1.3 Influence of waste characteristics on disposal system layout

The design of the disposal system shall be tailored to the characteristics of the waste.

Optioneering shall be undertaken to identify opportunities to tailor the disposal system, taking into account the nature of the site and the waste.

For planning purposes it is currently assumed that:

- UILW is assumed to be disposed of separately from SILW due to the different handling requirements associated with unshielded and shielded package types*
- disposal of HLW, SF, plutonium and HEU is assumed to be undertaken in an area of a geological disposal facility separate from the disposal of ILW*
- vitrified ILW is assumed to be disposed of in a separate vault to other ILW to ensure that all disposal modules function as intended without interactions occurring between different systems that could unacceptably affect their performance*
- DCIC containers are assumed to be disposed of in a separate vault due to their different handling requirements compared to other ILW waste packages*
- C1 and C4 concrete casks are assumed to be disposed of in a separate vault due to their different handling requirements compared to other ILW waste packages*

The radionuclides in ILW/LLW are dispersed through a relatively high volume of packaged waste compared with the higher concentrations of radionuclides in HLW/SF/Pu/HEU wasteforms. The materials contained in various ILW/LLW waste streams are physically and chemically heterogeneous in nature and in many cases will be chemically reactive when contacted by groundwater. For a number of ILW/LLW waste streams significant quantities of gas will be produced from reactions of the waste materials and/or steel waste containers with water.

By contrast, vitrified HLW and SF/Pu/HEU, when in the form of metal oxides, represent in each case relatively homogeneous wasteforms that are chemically stable in the presence of water where the main reaction will be slow dissolution. Because of the high concentration of radionuclides, HLW and SF in particular will generate significant amounts of heat for many years.

In view of these very different characteristics, different disposal concepts may be envisaged for the safe disposal of the different types of waste. For example, in the case of ILW/LLW a suitable disposal concept will ensure that unacceptable gas over-pressures are avoided. In the case of HLW/SF/Pu/HEU an important feature of a suitable disposal concept will be physical containment, achieved by a high integrity container [41] which will remain intact for a long period of time under the conditions of the engineered system.

Therefore the design must accommodate different disposal concepts employing different engineered barrier systems, ensuring that each can be installed and will function as intended without interactions occurring between the different systems that could affect their performance unacceptably.

Work is currently planned within the RWM Science and Technology Plan to develop a mechanistic understanding of vitrified ILW to support the development of disposal concepts for this type of wasteform and underpin the assessment of packaging proposals for thermally treated ILW.

Account will also be taken of the different physical properties or engineered features of waste packages which make it more reliable and/or cost-effective to dedicate separate disposal areas to specific package types. For example, this could apply to SILW where the relatively low external radiation dose does not require remote handling of the packages as is the case for UILW.

9.2 Post- closure safety

The disposal system shall ensure that the quantities of radionuclides or toxic substances entering groundwater will not compromise safety.

In order to meet the regulatory requirements specified in DSS Part A [4], RWM will be required to demonstrate that the disposal system will protect people and the environment both now and in the future. Safety after closure is achieved by developing a disposal system in which the various components work together to provide and to ensure the required level of safety [27].

9.2.1 Geosphere

Criteria shall be developed to determine the required separation between waste disposed of and features that may act as preferential radionuclide transport pathways.

Preferential pathways for fluid flow could affect the long-term safety of a GDF through detrimental effects of localised groundwater flow on the engineered barrier system. Placing the waste at a suitable distance from any areas where groundwater could have a significant detrimental impact on the EBS will ensure that it is suitably protected by the geosphere. Correspondingly, any radionuclides migrating away from the EBS have to travel through a suitably extensive section of the host rock before encountering a potential preferential pathway.

9.3 Gas generation and migration

The disposal system shall ensure that any gas generated in the facility will not compromise safety.

Design of a geological disposal facility shall ensure that gas pressures cannot develop within a disposal module that result in:

- ***significant damage to the engineered structures or host rock***
- ***development of additional pathways for the transport of dissolved radionuclides***

The principal gas, by volume, that is expected to be generated during the post-closure period is hydrogen. This will be produced by the anaerobic corrosion of steels (waste packages and infrastructure as well as metallic wastes). The gas that is generated will partly dissolve in the porewater of the engineered barrier system and diffuse out to the mobile groundwater or be advected out of the engineered barrier system if flow rates are sufficiently large. If this escape rate is less than the gas production rate, the gas pressure will build up to become larger than the water pressure in the surrounding rock. Gas generation is linked to water availability and therefore to groundwater flow, which is required for gas generation mechanisms to operate.

Gas migration is a site-specific process. For the gas to escape from a disposal module, the pressure must also be able to overcome the capillary entry pressure in the host rock. If the gas pressure in a disposal module exceeds the rock strength, new fracture pathways may develop, which may compromise the ability of the host rock to function as a barrier to

radionuclide release in groundwater. Thus, it is important that the GDF facility design includes measures to prevent the build-up of potentially damaging gas pressures.

The formation of gas may influence water saturations and flows. It is also possible that particulate radionuclides could be transported with the gas phase, as particulates tend to accumulate at the gas-water interface.

9.4 Natural events and climate change

The disposal system shall be sited in an environment in which natural events and climate changes will not compromise safety.

As explained in the DSS Part A, siting and designing the GDF should be done in such a way as to provide features aimed at isolation of the waste from people and the environment. In this respect, consideration is given both to understanding the expected natural evolution of the disposal system and events that could cause a disturbance. Locating the facility in a stable geological formation provides protection from the effects of geomorphological processes such as coastal erosion, glacial cycling and tectonic movements.

9.5 Site characterisation

The disposal system shall be sited in an environment in which the site can be characterised sufficiently to demonstrate safety.

As explained above, it is a regulatory requirement that a site for the GDF is characterised at a sufficient level of detail to support an understanding of the site and how it will evolve (see DSS Part A). Site characterisation is an activity undertaken in order to understand the natural features, events and processes at a site and to describe their spatial and temporal extent and variability. As explained in IAEA guidance [26] the focus is on understanding the features, events and processes that could have an impact on safety and that thus need to be considered in the safety assessment. Knowledge of the site characteristics will evolve through the site investigation and the facility development phases as more data are accumulated and scientific understanding of a particular site is developed.

As explained in Section 1.3, RWM has adopted an iterative approach to disposal system development where the disposal system requirements and subsequently the design and safety cases are refined based on results obtained from research and site characterisation activities. This will in turn help to guide what further site characterisation activities are needed.

9.6 Understanding of long-term evolution

The disposal system shall be sited in an environment in which the effect of long-term evolution on safety can be understood.

As explained in DSS Part A, it is a regulatory requirement that RWM demonstrates that the geological environment is characterised, understood and can be analysed to the extent necessary to support the environmental safety case. This is required to provide a high level of confidence that the host geological environment can be relied upon to contribute to the necessary containment and isolation over the required timescales.

9.7 Human intrusion

The disposal system shall be developed such that the consequences of human intrusion can be assessed and any practical measures implemented to reduce the likelihood.

Human intrusion into the disposal facility may be regarded as highly unlikely, but not impossible, because of the facility's deep location, expected to be well beyond the reach of many types of intrusive activity.

It is a regulatory requirement of the GRA (as explained in DSS Part A) that RWM shall assess the potential consequences of human intrusion after the period of authorisation and to implement any practical measures that might reduce the likelihood of human intrusion. Consideration for example will be given to the location of the facility relative to significant known valuable resources to reduce the risk of inadvertent human intrusion into the facility and a potential conflict of use of the area surrounding the facility in the future. It is recognised that it is important that any measures intended to reduce the likelihood of human intrusion do not compromise the environmental safety performance of the disposal system if human intrusion does not occur. Implementation of any measures intended to reduce the likelihood of human intrusion is subject to agreement from the regulator.

9.8 Passive safety

Within the disposal system design, safety shall be ensured by passive means to the fullest extent possible.

Principle 4 of the GRA states [18]:

‘Solid radioactive waste shall be disposed of in such a way that unreasonable reliance on human action to protect the public and the environment against radiological and any non-radiological hazards is avoided both at the time of disposal and in the future.’

During the operational period, protection of people and the environment is provided both through passive measures, that is measures that do not depend on human intervention, and through active measures that do rely on people. It is recognised both in the GRA and IAEA requirements [150] as good engineering practice for protection to be provided during this period as far as reasonably practicable through passive measures as this will help to reduce the risks during the operational period.

Towards the end of the operational period and as closure operations progress, there will be a shift from active measures and monitoring towards reliance on passive measures. It is a requirement that post-closure safety is demonstrated through passive means only (as defined in the GRA). This means reliance on a combination of engineered measures that can contribute to passive safety (recognising the lifetime for which such features can be expected to remain effective) and natural features and processes within the host environment.

9.8.1 Compatibility with the host geological environment

The disposal system shall be designed to be physically and chemically compatible with the host geological environment.

As explained in Section 2, long-term safety is achieved through the mutually complementary interactions of the components of the engineered barrier system and the host rock (natural barrier). The functions of the individual components of the engineered and natural barrier to achieve isolation and containment of the waste will depend on the waste type and the geological environment selected.

The methods and materials that make up the engineered barrier system for the various waste types at a specific site will be selected to be compatible with the waste and the host rock such that undesirable impacts on the safety functions of any element of the disposal system are limited.

9.9 Multiple safety functions

The engineered barriers shall be designed to provide safety by means of multiple safety functions such that the overall performance of the disposal system shall not be dependent on a single safety function.

As explained in the DSS Part A, it is a requirement that the host environment is selected, the engineered barriers designed and the facility operated and closed such that safety is

provided by means of multiple safety functions and that undue reliance is not placed on any single function. Sections 2.2.1 to 2.2.6 explain the generic environmental safety functions that have been defined by RWM and applied to the illustrative concepts for LHGW and HHGW.

9.9.1 Buffer and backfill

The nature and quantity of buffer, backfill and seal materials shall be determined by the safety functions they are designed to perform, which are dependent on the characteristics of the waste and the geological environment, and the disposal concept adopted.

The functions that the buffer and backfill will be required to perform within the disposal concept are dependent on the waste type and the geological environment. Whilst the engineered barrier system has not been selected since the design and materials will be dependent on the above, some example materials for the engineered barrier system are discussed in Section 9.9.2.

Buffer and backfill for low-heat-generating waste

The generic illustrative disposal concepts for ILW in higher strength rock and lower strength sedimentary rock are assumed to use a cementitious backfill material²² to fulfil the required safety functions²³ as set out in Sections 2.2.2 and 2.2.4.

In the illustrative disposal concepts that incorporate cementitious backfill:

- *the quantity of backfill is determined to provide appropriate engineered barrier system chemistry during the post-closure period, and considers the quantity and chemical nature of the waste, and the flow rate and chemical nature of the groundwater*
- *the volume of backfill required in comparison to the volume of the ILW packages (the backfill ratio) is assumed to be 1:1 for planning purposes*
- *the volume of backfill to be associated with each stack of waste packages is assumed to be emplaced so as to directly surround those packages, with a uniform thickness around the packages as far as is practicable*
- *the cementitious backfill is assumed to be maintained in a 'saturated' condition, currently it is assumed that prior to closure, at least 75% of the volume of capillary pores is occupied by unbound water*

The generic illustrative disposal concept for ILW in evaporite rock assumes use of a magnesium oxide backfill material²² to fulfil the required safety functions as set out in Section 2.2.6²³.

In the illustrative disposal concepts that incorporate magnesium oxide backfill, the quantity of backfill is assumed to provide appropriate engineered barrier system chemistry during the post-closure period.

Cementitious materials have been extensively investigated as backfill materials in ILW and LLW geological disposal concepts.

The requirement for a backfill ratio of 1:1 has been applied in generic GDF studies to date [151, 152], and is the volume of backfill required in comparison to the volume of the ILW packages. This ratio is assumed to be a reasonable assumption for a backfill ratio that would maintain a high pH in the engineered barrier system environment during the post-closure period.

²² This does not and should not preclude the consideration of alternative backfill materials

²³ There is no technical reason why suitably formulated cementitious backfills should not be used.

The pH conditioning behaviour and sorption performance of cementitious materials is dependent on the mineralogy of the material. The following reactions may influence the mineralogy of cementitious materials and, therefore, need to be considered during the design process when specifying quantities and exact compositions of cementitious materials:

- reaction with acidic compounds derived from the decomposition of organic wastes
- carbonation through reaction with carbonate in the groundwater or air during the operational period
- formation of ettringite through the reaction of cement minerals with aluminium derived from the waste, and sulphate ions derived from the groundwater
- alteration of the calcium/silicon ratio of the backfill cement and waste immobilisation grouts (the pozzolanic reaction)

These various reactions may not take place uniformly throughout a disposal module, and, therefore, heterogeneity should be taken into account during the design process. Particular attention should be paid to the likelihood of increased extents of reaction around the periphery of a disposal module and/or adjacent to flowing features. Ensuring a uniform thickness of backfill will mitigate against further heterogeneities affecting the chemical conditioning of the engineered barrier.

Saturation of cementitious backfill prior to closure is required because it may provide several potential benefits:

- it promotes anaerobic conditions within the waste stack, thereby preventing localised corrosion (particularly pitting of stainless steel containers)
- the thermal conductivity of saturated backfill is higher than that of dry backfill, reducing the maximum temperature achieved within the waste stack
- it will prevent or reduce the extent to which the backfill is subject to shrinkage and cracking
- it could help to prevent/reduce ingress of saline-containing groundwater into the waste stack, thereby reducing the extent of chloride-induced corrosion of the waste containers

Magnesium oxide is a naturally occurring solid mineral which provides the safety functions of the backfill in the illustrative concept for low heat generating waste in an evaporite rock as set out in Section 2.2.6 by:

- absorbing carbon dioxide and therefore helping to mitigate the effects of gas generation
- absorbing water which helps to delay gas generation and wasteform dissolution
- as it hydrates, magnesium oxide swells which reduces porosity of the engineered barrier system and provides a measure of physical containment and
- provides chemical conditioning of the engineered barrier system to around pH 9–10. This reduces the corrosion rates of waste containers and the solubility of radionuclides and hence, limits radionuclide release through the engineered barrier system [153]

Buffer and backfill for high-heat-generating waste

The generic illustrative disposal concepts for HLW, spent fuel, HEU and plutonium in higher strength rock and lower strength sedimentary rock are assumed to use bentonite clay as a buffer material to fulfil the required safety functions as set out in Sections 2.2.1 and 2.2.3 respectively.

The generic illustrative disposal concept for HLW, spent fuel, HEU and plutonium in evaporite rock assume the use of crushed salt as a backfill material to fulfil the required safety functions as set out in Section 2.2.5.

The justification for the list of requirements that should be considered should a bentonite buffer be included in HLW, spent fuel, HEU and plutonium GDF designs (HSR and LSSR concepts) is as follows:

- the disposal canister would need to be surrounded by a sufficient thickness of buffer, and this would require that the buffer was dense enough to support the canister
- preventing direct contact of the disposal canister with the host rock reduces the risk of mechanical effects on disposal canister integrity ensuring that radionuclides are not released
- low permeability would limit mass transport to a diffusion dominated process
- the buffer would be expected to retard any radionuclides released from the wastefrom through sorption and restricting groundwater flow
- limiting the transport of dissolved corroding agents to the canister will limit the potential for corrosion of the canister
- colloid-facilitated transport provides a possible mechanism for rapid solute transport; limiting the transport of colloids away from the disposal canister would restrict such transport
- microbes could provide a method for enhancing corrosion of the disposal canister, but their activity can be minimised by providing a dense buffer

Work is ongoing within the RWM Science and Technology Plan [36] to support the safety case by developing understanding of the evolution of bentonite based buffers and the achievement of the required safety functions (as set out in Sections 2.2.1 and 2.2.3) through modelling of the thermal, hydraulic, mechanical and chemical processes during water re-saturation in buffer, backfill and the engineered barrier system (in higher strength rock).

In the case of the illustrative disposal concept for HLW, spent fuel, HEU and plutonium in evaporite rock the crushed salt backfill compacts and creeps under the influence of the overburden pressure as the tunnel walls converge due to the plasticity of salt. Eventually, the crushed salt backfill would become continuous with almost identical properties to that of the surrounding host rock [11].

9.9.2 Engineered barrier system materials

The materials used in the engineered barrier system shall fulfil the required safety functions and be compatible with:

- ***the wastes***
- ***the geological environment***

Additives shall not be used in engineered barrier materials in quantities capable of forming chemical complexes with radionuclides that are significant for the safety of a geological disposal facility.

The EBS is made up of the wastefrom, container, local buffer or backfill, mass backfill, and plugs and seals. The safety functions of these components are presented below for the different illustrative concepts.

A wide range of engineering materials might potentially be used in the engineered barrier system [38]. Examples include:

- copper, titanium, nickel-based alloys, carbon steel, cast iron, stainless steel, lead and concrete – which could be used for the manufacture of waste containers
- concrete, Nirex Reference Vault Backfill (NRVB), bentonite, magnesium oxide and crushed rock – which could be used to manufacture buffers, backfills and seals
- concrete and steel – which could be used as construction materials

These various materials would perform to different degrees in different environments, and therefore are specific to the containment performance and safety function required for specific waste in a specific environment.

The engineering materials will interact with the waste and the host rock, and these interactions need to be researched in order to understand their impact on the long term performance of a disposal facility. The materials could be excluded should these impacts jeopardise safety.

For example, if additives such as organic superplasticisers or retarders are used in the mix formulations for concrete, there is a potential for them to form complexes with radionuclides [154]. Complexation may lead to increased solubility and decreased sorption for many key radionuclides under conditions expected within the engineered barrier system and hence the benefits of the use of such materials need to be compared with the effects of any potential degradation in the performance of the engineered barrier system. Consideration will be given to other interactions including those involving gas, colloids and microbes. To support safety assessments and provision of packaging advice, work is ongoing in the RWM Science and Technology Plan to determine the impact of superplasticiser contained within concrete on disposal system performance and to determine the suitability of these materials for use in cementitious materials for waste packaging.

9.9.3 Construction materials

Any concrete used for engineered structures within a disposal module shall be chosen to have properties that are appropriate for the geological environment, waste characteristics and disposal concept.

The design shall minimise the potential for both the structural concrete and any shotcrete used in a disposal module to provide a source of aggressive ions.

The construction materials used in a disposal module, in particular concrete (for example, floors and structural linings), are capable of modifying the performance of the engineered barrier system and the geosphere. Concrete can be formulated to give a range of engineered properties (for example, permeability and pH). The low permeability, good mechanical stability, and long-term durability of concrete are all highly valued in the construction of barriers for the containment of radioactive, toxic and hazardous wastes. Concrete mixes based on ordinary or sulphate-resisting Portland cement blended with pulverised fuel ash, granulated blast furnace slag or micro silica could be used. Low-pH cements may also be considered.

Compatibility with the geological environment and waste form is required to ensure that these properties are not removed by corrosion or alteration of the materials, and that these processes do not lead to significant gas generation, subject to the requirements in Section 9.3.

9.9.4 Adventitious materials

Quantities of materials that do not form part of the engineered barrier system and that would remain in a geological disposal facility following closure shall be minimised.

The potential long-term impact of these materials on the disposal system shall be considered.

A range of materials will be used in the GDF during its construction, operation and closure. Some of these materials could remain in the facility following closure inadvertently if procedures were not adopted to ensure their recovery. Other materials, for example materials used in the emplacement process that cannot be recovered or materials used to stabilise excavations, may be deliberately left in the facility. These adventitious materials could have a detrimental impact on the performance of the facility and need to be considered in the ESC. Evaluation will be necessary to consider the impact of leaving adventitious material in the GDF and compare this with the impact of any operations to remove adventitious materials or mitigate their effects.

9.9.5 Waste packages as an engineered barrier system

The disposal module environment shall be maintained so that the long-term performance of waste packages is not compromised.

A geological disposal facility and conduct of operations shall be designed to ensure that the waste packages enter the post-closure period intact and in good condition.

Conditions shall be such that corrosion of the waste packages shall be kept to the minimum practicable during the operational phase of a geological disposal facility.

Formulations for materials used in the engineered barrier system shall not provide a significant source of aggressive ions.

It is currently assumed that disposal containers for high-heat-generating waste provide physical containment for at least the period that waste is still producing heat energy in amounts that could adversely affect the performance of the disposal system (ie at least 1,000 years post-closure).

Designing the GDF and conducting operations so that the waste packages enter the post-closure period intact and in good condition will ensure containment of short-lived radionuclides (for example, Cs-134, Cs-137 and Sr-90) following waste emplacement and so minimise releases to the environment. The provision of a significant period of physical containment by the waste package can lead to the retention of short-lived radionuclides within the waste package for periods in excess of several half-lives, thereby reducing the source term for these radionuclides considerably. The physical barrier provided by the waste packaging can also spread the source term for longer-lived radionuclides over a longer period avoiding a peak in releases to the engineered barrier system, for example by creating a range of containment times for the radionuclides located within different waste packages. As described in Section 3.1.6, the requirement for waste package integrity during the 'thermal period', of at least 1,000 years post-closure, to allow sufficient time for short lived radionuclides to decay, has been defined previously by Nirex for waste packages containing high heat generating waste [37]. Further work is required to specify fully these waste package requirements. The duration of the thermal period is also defined as 1,000 years by a number of other nations that are developing geological disposal concepts [40].

Furthermore, ensuring that the waste packages enter the post-closure period intact would provide confidence in the condition of the waste at closure, and thereby provide support to the development of safety cases.

The current generic DSS Part B identifies a number of generic requirements regarding the disposal module environment that relate to minimising waste package corrosion during the operational phase of the GDF (that is those described in Sections 7.3.1 to 7.3.3 that relate to operational temperature limits, relative humidity and groundwater inflows). The previous DSS for ILW/LLW [6] was more prescriptive in some of these areas. For example, it

specified that before backfilling, air in the LHGW disposal module should have a relative humidity below 60%, it may be necessary to specify a minimum relative humidity to control atmospheric stress corrosion cracking of waste containers, which could be accelerated at low levels of relative humidity.

However, at this stage the DSS Part B recognises that specific requirements and environmental control strategies will be dependent on the nature of the geological environment present at a particular site. For example, controlling the relative humidity and minimising chloride contamination on waste packages is likely to be different in a higher strength host rock that may be granitic in composition (humid, but relatively poor in chlorides) than in a saline evaporite rock (very dry, but rich in chlorides) [155]. Further work at the site-specific stage is therefore needed to specify fully the required environment for the different disposal modules of the geological disposal concept that is adopted in order to keep waste package corrosion to the minimum practicable during the operational phase of the GDF.

Depending on the geological environment, the disposal module environment should be such as to avoid waste packages that utilise stainless steel containers from becoming contaminated with chloride. The avoidance of chloride contamination on steel containers will enhance the corrosion performance of waste packages [155]. The packages could become contaminated with chloride as a result of direct contact with inflowing groundwater, deposition of airborne droplets, and condensation (although it is unlikely that the condensate would contain significant levels of chloride).

For a period following closure, aerobic corrosion of iron and steel will occur until available sources of oxygen are used up. Under aerobic conditions, localised corrosion of carbon and stainless steels is the dominant process and is promoted by elevated temperatures and the presence of aggressive ions such as chloride and thiosulphate. It is likely that any groundwater that enters a disposal module would be saline, so chloride could enter in the groundwater as a disposal module resaturates. However, it may only reach the waste container surfaces after aerobic corrosion has already ceased due to lack of oxygen. However, the presence of chloride or thiosulphate in sealing materials could provide a source of aggressive ions that would be available during the aerobic corrosion period and this should be avoided.

9.9.6 Temperature

Measures shall be taken in the design and operation of a geological disposal facility to keep temperatures within a disposal module as low as practicable, and to limit the duration of unavoidable short-term increases in temperature that may occur during operations in order to maintain the integrity of waste packages and the disposal system as a whole.

Disposal modules shall be designed to comply with a long-term maximum temperature target that shall depend on the waste characteristics and the nature of the geological environment. Waste package assessment shall take into account factors that could potentially cause high-temperature excursions for example, Wigner energy release from irradiated graphite or chemical incompatibility resulting in exothermic reactions.

For planning purposes, the following temperature limits have been used in the design of the disposal modules, taken from the illustrative concepts:

A guidance value of less than 50°C for all LLW and ILW waste packages following closure is assumed. The consequences of any period when this target is exceeded (for example, in response to backfill curing should a cementitious backfill be used) shall be considered. In ILW disposal designs that incorporate a cementitious backfill, waste package temperatures of up to 80°C is assumed to be acceptable for a period of 5 years.

The design of the HLW and spent fuel disposal modules in higher strength rock is based on a temperature limit of 100°C on the surface of the bentonite at any time following emplacement.

The design of the HLW and spent fuel disposal modules in lower strength sedimentary rock is based on a temperature limit of 125°C at the outer half of the bentonite.

The design of the HLW and spent fuel disposal modules in evaporite rock is based on a temperature limit of 200°C on the backfill at any time following emplacement.

Minimising temperatures within a disposal module would provide the following benefits to engineered barrier performance:

- lower rates of metallic corrosion, which would enhance the longevity of the waste package walls, and would also reduce the swelling of metallic wastefoms and
- reduced gas generation, which affects wastefom physical integrity and releases of flammable, radioactive or toxic gases

The performance of some components of the GDF is sensitive to temperature, including the host rock. Therefore, conservative targets have been specified, which bound several processes that are dependent on temperature. The overall objective is to limit the progress of the undesired reactions by limiting the temperatures (because chemical reaction rates increase exponentially with temperature) and also by limiting the duration of temperature excursions (note operational temperature limits are discussed in Section 7.3.1).

It is not possible to specify a simple maximum temperature for short term temperature excursions; duration has to be taken into account as well. For example, for disposal concepts that include backfilling in situ using cementitious backfill, some increases in temperature are inevitable, owing to the exothermic hydration (curing) reaction that occurs when cement sets. There is likely to be a thermal transient associated with the curing of cement used in closure operations, for example emplacement of seals. The need to accommodate temperature increases due to cement curing for ILW disposal modules is the reason for the 80°C maximum for temperature excursions of five years or less [156].

After any temperature excursion associated with cement curing, if carried out in situ, it becomes feasible to specify the waste temperature in terms of a simple long-term maximum target of less than 50°C. This is considered to be a realistic long-term temperature target for design purposes. It will be necessary to consider the potential for temperature excursions > 50°C when assessing the waste packages in the Disposability Assessment process.

An upper limit of 100°C has currently been assumed on the surface of the bentonite buffer in HLW/SF disposal concepts in higher strength rock to prevent thermal processes from affecting the buffer's ability to fulfil its safety functions [157]. In the case of lower strength sedimentary rock, a temperature limit of 125°C is placed on the outer half of the bentonite so as to retain maximum swelling capacity in at least the outer half of the bentonite to ensure a good quality hydraulic seal around each canister [158]. In the case of the illustrative concept for high heat generating waste in evaporite rock, a temperature limit of 200°C has been set because, due to its relatively high emplacement porosity, the crushed salt exhibits low heat conductivity which leads to high temperatures at the waste container/backfill interface. As the backfill becomes more compact with time (elevated temperatures have been shown to increase the rate of compaction and rock creep) porosity decreases and heat conductivity increases, thereby reducing the temperature at the waste container/backfill interface [159].

The temperature limit on the buffer would depend on the requirements for the engineered barrier system selected and in some cases may not be required. Higher thermal limits could also be specified on the basis of the design selected; for example, the inclusion of a sacrificial layer of bentonite that was not required to remain unaffected by thermal

alteration. In the case of bentonite buffers emplaced in the GDF, high temperatures can lead to alterations to the mineralogy of the bentonite. There is some evidence that the performance of bentonite buffers is affected by temperatures as low as 100°C [160]. It should be noted however that there is uncertainty over the impact of thermal processes on the engineered barriers, for example the temperature at which potentially detrimental mineral transformations occur in bentonite is subject to uncertainty and there is evidence that the transition may occur at temperatures higher than 100°C [161, 162]. Thus it may be possible to justify a higher thermal limit if required.

Work is currently ongoing as defined within the RWM Science and Technology Plan to understand the effect of elevated temperatures on backfill performance in terms of its ability to provide the safety functions defined in Section 3.1.4 and as part of concept development for a cement based disposal concept for high heat generating waste.

9.9.7 Criticality

Design of a geological disposal facility shall ensure that in the post-closure period both the likelihood and the consequences of criticality are low.

The requirement that both the likelihood and consequences of a criticality are low during the post-closure phase is derived from Paragraph 6.4.27 of the GRA, which states: “*The developer/operator will also need to demonstrate that the possibility of a local accumulation of fissile material, such as to produce a neutron chain reaction, is not a significant concern. This demonstration might be achieved by showing that the chance of such an event occurring would be very remote and/or that even if it were to occur the subsequent performance of the disposal system would still be acceptable.*”

9.9.8 Underground access

Design of the geological disposal facility access routes shall take into account the desire to minimise the number of openings that will eventually have to be sealed against the inflow of groundwater and migration of radionuclides out of a geological disposal facility.

The location of access routes shall take into account potential impact on post-closure performance.

Based on the illustrative concepts currently used by RWM, it is currently assumed that:

- *in higher strength rock environments, underground access is via 3 shafts and 1 drift*
- *in lower strength sedimentary rock environments, underground access is via 3 shaft and 1 drift*
- *in evaporite rock environments, underground access is via 4 shafts*

The location of access routes is a site-specific issue that should take into account the predicted evolution of the hydraulic environment in the long-term. For example, to avoid the potential for access routes to act as radionuclide transport pathways post-closure, consideration could be given to locating them ‘upstream’ of disposal modules in terms of the groundwater flow at the disposal horizon. It will be necessary to take into account the expected evolution of the groundwater flow field when designing access routes and their spatial relationship to disposal modules. Further, the location of the surface facilities relative to the disposal horizons will also need to be taken into account, for instance if the underground facilities are located some distance from the surface facilities, then access may only be possible via a drift.

References

- 1 Radioactive Waste Management, *Geological Disposal: Overview of the Generic Disposal System Safety Case*, DSSC/101/01, December 2016.
- 2 Department of Energy and Climate Change, *Implementing Geological Disposal - A framework for the long term management of higher activity waste*, URN 14D/235, July 2014.
- 3 Radioactive Waste Management, *Geological Disposal: Technical Background to the generic Disposal System Safety Case*, DSSC/421/01, December 2016.
- 4 Radioactive Waste Management, *Geological Disposal: Disposal System Specification Part A – High Level Requirements*, DSSC/401/01, December 2016.
- 5 Radioactive Waste Management, *Geological Disposal: Generic Disposal System Functional Specification*, NDA/RWMD/043, December 2010.
- 6 Radioactive Waste Management, *Geological Disposal: Generic Disposal System Technical Specification*, NDA/RWMD/044, December 2010.
- 7 Radioactive Waste Management, *Geological Disposal: Generic Operational Safety Case Main Report*, DSSC/202/01, December 2016.
- 8 Svensk Kärnbränslehantering AB, *Design and production of the KBS-3 repository*, TR-10-12, December 2010.
- 9 Posiva Oy, *Safety Case for the Disposal of Spent Nuclear Fuel at Olkiluoto – Design Basis 2012*, POSIVA 2012-03, December 2012.
- 10 T. W. Hicks, T. D. Baldwin, P. J. Hooker, P. J. Richardson, N. A. Chapman, I. G. McKinley, and F. B. Neall, *Concepts for Geological Disposal of Intermediate-level Radioactive Waste*, Report to NDA RWMD, April 2008.
- 11 T. D. Baldwin, N. A. Chapman and F. B. Neall, *Geological Disposal Options for High-level Waste and Spent Fuel*, Report to NDA RWMD, January 2008.
- 12 Svensk Kärnbränslehantering AB, *Long-term safety for the final repository for spent nuclear fuel at Forsmark*, Main report of the SR-Site project, Volume 1, March 2011.
- 13 Nagra, *Project Opalinus Clay, Safety Report, Demonstration of disposal feasibility for spent fuel, vitrified high-level waste and long lived intermediate-level waste*, TR02-05, 2002.
- 14 NDA RWMD, *Geological Disposal: Steps towards implementation*, NDA/RWMD/013, March 2010.
- 15 Radioactive Waste Management, *Geological Disposal: Approach to developing a strategy for technology transfer* NDA Report NDA/RWMD/099, 2013
- 16 Radioactive Waste Management, *Geological Disposal: Generic Disposal Facility Designs*, DSSC/412/01, December 2016.
- 17 NDA RWMD, *Geological Disposal: Generic Specification for waste packages containing low heat generating waste*, NDA/RWMD/068, August 2012.

- 18 Environment Agency and Northern Ireland Environment Agency, *Geological Disposal Facilities on Land for Solid Radioactive Wastes: Guidance on Requirements for Authorisation*, 2009.
- 19 International Atomic Energy Agency, *Geological Disposal Facilities for Radioactive Waste*, Specific Safety Guide No. SSG-14, 2011.
- 20 Radioactive Waste Management, *National Geological Screening Guidance*, 2016.
- 21 SKB, *Design analysis report for the canister*, TR-10-28, April 2010.
- 22 Radioactive Waste Management, *Geological Disposal: Geosphere Status Report*, DSSC/453/01, 2016.
- 23 NDA, *Geological Disposal: The 2013 Derived Inventory: Alternative Scenarios*, NDA/RWM/125, December 2016.
- 24 Radioactive Waste Management, *Geological Disposal: Waste packages and the assessment of their disposability*, DSSC/441/01, December 2016.
- 25 NDA RWMD, *Waste Package Specification and Guidance Documentation WPS/909: Guidance on the Scope of Periodic Review of Final Stage Letters of Compliance*, Doc Ref: 9699135, January 2009.
- 26 International Atomic Energy Agency, *Geological Disposal Facilities for Radioactive Waste*, Specific Safety Guide No. SSG-14, 2011.
- 27 Office for Nuclear Regulation, Environment Agency, Scottish Environmental Protection Agency and Natural Resources Wales, *The management of higher activity radioactive waste on nuclear licensed sites. Joint guidance from the Office of Nuclear Regulation, the Environment Agency, the Scottish Environment Protection Agency and Natural Resources Wales to nuclear licensees*, Revision 2, 2015.
- 28 International Atomic Energy Agency, *Regulations for the Safe Transport of Radioactive Material, Specific Safety Requirements*, No.SSR-6, 2012.
- 29 International Atomic Energy Agency, *Containers for Packaging of Solid Low and Intermediate Level Radioactive Wastes*, IAEA Technical Report Series No. 355, 1993.
- 30 International Atomic Energy Agency, *Characterisation of Radioactive Waste Forms and Packages*, IAEA Technical Report Series No.383, 1997.
- 31 International Atomic Energy Agency, *Development of Specifications for Radioactive Waste Packages*, IAEA TECDOC-1515, 2006.
- 32 Nirex, *Initial Consideration of Waste Acceptance Criteria for the Long-term Management of Certain UK Radioactive Wastes and Potential Wastes*, Nirex Report No. N/118, 2004.
- 33 RM Consultants, *Comparison of the Nirex Waste Package Specification with Waste Acceptance Criteria for Storage and Disposal Facilities in Other Countries*, RMC225, R02-229(S), 2002.
- 34 NDA RWMD, *Radioactive Wastes and Assessment of the Disposability of Waste Packages*, NDA/RWMD/039, 2010.
- 35 NDA RWMD, *Geological Disposal: Generic Waste Package Specification*, NDA/RWMD/067, March 2012.

- 36 Radioactive Waste Management, *Geological Disposal: Science and Technology Plan*, NDA/RWM/121, 2016.
- 37 Nirex, *Specification for Waste Packages Containing Vitrified High Level Waste and Spent Nuclear Fuel*, Nirex Report N/124, December 2005.
- 38 M. White, T. Baldwin, T. Hicks, P. Hooker, *Engineered Barrier Materials for Geological Disposal Facilities*, Report to NDA RWMD, 14 November 2008.
- 39 Svensk Kärnbränslehantering AB, *Long-term safety for the final repository for spent nuclear fuel at Forsmark. Main report of the SR-Site project*, TR-11-01, Vol. 2, March 2011.
- 40 P.J. Richardson, M.J. White, *Requirements on Canister Containment during the Thermal Period*, Galson Sciences Ltd Report, 1151b5-1 Version 1, 28 June 2013.
- 41 Arup, *Disposal Container for HLW and Spent Fuel, Conceptual Design Report*, Report to RWM, Issue 4, September 2014.
- 42 Radioactive Waste Management, *Geological Disposal: Specification for stillage for the transport and disposal of 500 litre drum waste packages*, WPS/605/01, July 2015.
- 43 Defra, *Non-statutory Guidance for Site Waste Management Plans*, April 2008.
- 44 NDA, *Specification and Guidance on the Content and Format of an Integrated Waste Strategy*, Doc No ENG01 (Rev 3), 2012.
- 45 The Stationery Office, *The Mines Regulations*, 2014, SI 2014 No. 3248.
- 46 HSE, *First aid at mines, Health and Safety (First-Aid) Regulations 1981, Approved Code of Practice L43*, ISBN 9780717606177, 1993.
- 47 HSE, *Electrical safety in mines*, HSG278, First edition, 2015.
- 48 The Stationery Office, *The Construction (Design and Management) Regulations 2015*, SI 2015 No. 51.
- 49 HSE, *Managing health and safety in construction, Construction (Design and Management) Regulations 2015, Guidance on Regulations*, L153, ISBN 9780717666263, 2015.
- 50 HSE, *Health and safety in construction*, HSG150, third edition, 2006, ISBN 9780717661822.
- 51 The Stationery Office, *The Workplace (Health, Safety and Welfare) Regulations, 1992*, SI 1992 No. 3004.
- 52 HSE, *Workplace health, safety and welfare, Workplace (Health, Safety and Welfare) Regulations 1992, Approved Code of Practice and guidance*, Second edition, ISBN 9780717665839, 2013.
- 53 Nirex, *The Engineering Foundations of the Phased Disposal Concept*, Nirex Report N/019, 2001.
- 54 BSI, *Occupational health and safety management systems requirements*, BS OHSAS 18001:2007, July 2007.
- 55 HSE, *Managing for health and safety*, ISBN 9780717664566, 2013.
- 56 The Stationery Office, *The Lifting Operations and Lifting Equipment Regulations 1998*, SI 1998, No. 2307.

- 57 HSE, *Safe use of lifting equipment, Lifting Operations and Lifting Equipment Regulations 1998*, Approved Code of Practice and guidance, Second edition, ISBN 9780717665839, 2013.
- 58 HSE, *Lifting Equipment at Work*, A brief guide, revision 1, 2013.
- 59 The Stationery Office, *Provision and Use of Work Equipment Regulations (PUWER) 1998*, SI 1998 No. 2306.
- 60 HSE, *Safe use of work equipment, Provision and Use of Work Equipment Regulations 1998*, Approved Code of Practice and guidance, Fourth edition, ISBN 9780717666195, 2014.
- 61 HSE, *Providing and using work equipment safely*, A brief guide, INDG291, Revision 1, 2013.
- 62 The Stationery Office, *The Manual Handling Operations Regulations 1992*, SI 1992 No. 2793.
- 63 HSE, *Manual Handling, Manual Handling Operations Regulations 1992*, Guidance on Regulations, Fourth edition, ISBN 9780717666539, 2016.
- 64 HSE, *Manual handling at work*, A brief guide, INDG143, Revision 3, 2012.
- 65 The Stationery Office, *The Work at Height Regulations 2005*, SI 2005, No.735.
- 66 HSE, *Working at Height*, A brief guide, INDG401, Revision 2, 2014.
- 67 The Stationery Office, *The Control of Vibration at Work Regulations 2005*, SI 2005 No. 1093.
- 68 HSE, *Hand-arm vibration, The control of Vibration at Work Regulations 2005*, Guidance on Regulations, L140, ISBN 9780717661251, 2005.
- 69 HSE, *Hand-arm vibration at work*, A brief guide, INDG175, Revision 3, 2012.
- 70 HSE, *Control back-pain risks from whole-body vibration*, Advice for employers on the Control of Vibration at Work Regulations 2005, INDG242, Revision 2, ISBN: 0717661199, 2005.
- 71 The Stationery Office, *Control of Noise at Work Regulations 2005*, SI 2005 No. 1643.
- 72 HSE, *Controlling noise at work*, The Control of Noise at Work Regulations 2005, Guidance on Regulations, L108, Second edition, ISBN: 9780717661644, 2005.
- 73 HSE, *Noise at work*, A brief guide to controlling the risks, INDG362, Revision 2, 2012.
- 74 The Stationery Office, *The Confined Spaces Regulations 1997*, SI 1997 No. 1713.
- 75 HSE, *Safe work in confined spaces*, Confined Spaces Regulations 1997, Approved Code of Practice and guidance, L101, Third edition, 2014.
- 76 The Stationery Office, *The Personal Protective Equipment Regulations 2002*, SI 2002, No. 1144.
- 77 HSE, *Personal protective equipment at work*, Personal Protective Equipment at Work Regulations 1992, Guidance on Regulations, L25, Third edition, 2015.
- 78 HSE, *Personal protective equipment (PPE) at work*, A brief guide, INDG174, Revision 2, 2013.

- 79 European Union, Directive 97/23/EC of the European Parliament and of the Council of 29 May 1997 on the approximation of the laws of the Member States concerning pressure equipment.
- 80 The Stationery Office, *The Pressure Equipment Regulations 1999*, SI 1999 No. 2001.
- 81 The Stationery Office, *The Control of Substances Hazardous to Health Regulations 2002*, SI 2002, No. 2677.
- 82 HSE, *Control of substances hazardous to health, The Control of Substances Hazardous to Health Regulations 2002 (as amended), Approved Code of Practice and guidance*, L5, Sixth edition, 2013.
- 83 HSE, *Working with substances hazardous to health, A brief guide to COSHH*, INDG136, Revision 5, 2012.
- 84 The Stationery Office, *The Mines (Safety of Exit) Regulations 1988*, SI 1988 No. 1729.
- 85 The Stationery Office, *Environmental Permitting (England and Wales) Regulations 2010*, SI 2010 No. 675.
- 86 The Stationery Office, *Nuclear Installations Act 1965*, 1965 c57.
- 87 Office for Nuclear Regulations, *Safety Assessment Principles for Nuclear Facilities*, 2014 Edition, November 2014.
- 88 The Stationery Office, *Management of Health and Safety at Work Regulations 1999*, SI 1999 No. 3242.
- 89 The Stationery Office, *The Ionising Radiations Regulations 1999*, SI 1999 No. 3232.
- 90 The Stationery Office, *The Regulatory Reform (Fire Safety) Order 2005*, SI 2005, No. 1541.
- 91 *The Fire and Rescue Services (Northern Ireland) Order 2006*, SI 2006 No. 1254 (N.I.9) and *The Fire Safety Regulations (Northern Ireland) 2010*, SRNI 2010 No. 325.
- 92 The Stationery Office, *The Dangerous Substances and Explosive Atmospheres Regulations 2002*, No. 2776, 2002.
- 93 The Stationery Office, *Dangerous Substances and Explosive Atmospheres Regulations (Northern Ireland) 2003*, No. 152, 2003.
- 94 HSE, *Dangerous substances and explosive atmospheres, Dangerous Substances and Explosive Atmospheres Regulations 2002, Approved Code of Practice and guidance*, L138, 2013.
- 95 HSE, *Controlling fire and explosion risks in the workplace, A brief guide to the Dangerous Substances and Explosive Atmospheres Regulations*, INDG370, Revision 1, 2013.
- 96 The Stationery Office, *The Equipment and Protective Systems Intended for Use in Potentially Explosive Atmospheres Regulations 2016*, SI 2016 No. 1107, 1996.
- 97 *The Equipment and Protective Systems Intended for Use in Potentially Explosive Atmospheres Regulations (Northern Ireland) 1996*, S.R. 1996 No. 247
- 98 The Stationery Office, *The Pressure Systems Safety Regulations*, No. 128, 2000.

- 99 HSE, Safety of pressure systems, Pressure Systems Safety Regulations 2000, Approved Code of Practice and guidance, L122, 2014.
- 100 HSE, Pressure Systems, A brief guide to safety, INDG261, 2012.
- 101 The Stationery Office, *The Control of Major Accident Hazards Regulations (COMAH) 2015*, SI 2015 No. 483.
- 102 European Union, *Directive 2012/18/EU of the European parliament and of the council on the control of major – accident hazards involving dangerous substances, amending and subsequently repealing Council Directive 96/82/EC*, 2012.
- 103 HSE, *The Control of Major Accident Hazards Regulations 2015*, Guidance on Regulations, L111, Third edition, 2015.
- 104 Environment Agency, *Guidance Note for Developers and Operators of Radioactive Waste Disposal Facilities in England and Wales – Geological Disposal Facilities on Land for Solid Radioactive Wastes: Guidance on Requirements for Authorisation – Supplementary guidance related to implementation of the Groundwater Directive*, Version 1.0, July 2012.
- 105 European Union, *Directive 2006/118/EC of the European Parliament and of the Council of 12 December 2006 on the protection of groundwater against pollution and deterioration*, December 2006.
- 106 Radioactive Waste Management, *Geological Disposal: Generic Environmental Safety Case*, DSSC 203/01, December 2016.
- 107 European Union, *Council Directive 2014/52/EU of 16 April 2014 amending Directive 2011/92/EU on the assessment of the effects of certain public and private projects on the environment*, 2014.
- 108 The Stationery Office, *Conservation of Habitats and Species Regulations 2010*, SI 2010, No.490.
- 109 NDA RWMD, *Geological Disposal: A Strategy for Sustainability Appraisal and Environmental Assessment*, NDA Report No. NDA/RWMD/014. July 2009.
- 110 NDA RWMD, *Geological Disposal: Sustainable design objectives for a geological disposal facility*, NDA RWMD Technical Note 13835210, March 2010.
- 111 Office for Nuclear Regulation, *National Objectives, Requirements and Model Standards (NORMS) for the Protective Security of Civil Licensed Nuclear Sites, Other Nuclear Premises and Nuclear Material in Transit*, 451urity, Issue 1, October 2012.
- 112 Euratom, *Commission Regulation (Euratom) No 302/2005*, February 2005.
- 113 International Atomic Energy Agency, *Technological Implication of International Safeguards for Geological Disposal of Spent Fuel and Radioactive Waste*, NW-T-1.21, 2010.
- 114 Office for Nuclear Regulation, *Licence Condition Handbook*, January 2016
- 115 Environment Agency, *Regulatory Guidance Series, No RSR 1, Radioactive Substances Regulation, Environmental Principles*, April 2010.

- 116 Radioactive Waste Management, *Radiological Protection Criteria Manual*, RWM02, 2015.
- 117 International Atomic Energy Agency, *Disposal of Radioactive Waste*, Specific Safety Requirements SSR-5, 2011.
- 118 Atomic Energy Authority, *Atomic Energy Code of Practice, Ventilation of Radioactive Areas*, AECF 1054, March 1993.
- 119 Nuclear Ventilation Forum, *An aid to the Design of Ventilation of Radioactive Areas*, NVF/DG001, Issue 1, January 2009.
- 120 The Stationery Office, *The Electricity at Work Regulations 1989*, SI 1989, No. 635.
- 121 The Stationery Office, *The Electricity Safety, Quality and Continuity Regulations 2002*, SI 2002, No. 2665.
- 122 BSI, *Requirements for Electrical Installations, IET Wiring Regulations*, BS 7671:2008+A3:2015.
- 123 HSE, *The Electricity at Work Regulations 1989*, Guidance on Regulations, HSR25, 2015.
- 124 HSE, *Electricity at work, Safe working practices*, HSG85, Third edition, 2013.
- 125 HSE, *Electrical safety and you, A brief guide*, INDG231, revision 1, 2012.
- 126 HSE, *Electrical safety in mines*, HSG278, 2015.
- 127 United Kingdom Nirex Limited, *Generic Repository Studies, Generic Disposal System Specification*, Volumes 1 & 2, Nirex Report N/075, July 2003.
- 128 United Kingdom Nirex Limited, *Large Underground Caverns – Precedent Experience Study, Phases I and II*, Nirex Report SA/97/019, 1997.
- 129 United Kingdom Nirex Limited, *Assessment of the In-situ Stress Field at Sellafield*, Nirex Report S/97/003, 1997.
- 130 European Commission, *Thematic network on the role of monitoring in a phased approach to geological disposal of radioactive waste*, EUR21025 EN, 2004.
- 131 International Atomic Energy Agency, *Environmental and Source Monitoring for Purposes of Radiation Protection*, IAEA Safety Guide No. RS-G-1.8, 2005.
- 132 The Stationery Office, *The Railways and Other Guided Transport Systems (Safety) Regulations 2006*, SI 2006, No. 599.
- 133 Office for Rail Regulation, *Common Safety Method for risk evaluation and assessment*, Guidance on the application of Commission Regulation (EU) 402/2013, March 2015.
- 134 The Stationery Office, *The Carriage of Dangerous Goods and Use of Transportable Pressure Equipment Regulations 2009*, SI 2009, No 1348 (as amended).
- 135 The Stationery Office, *The Carriage of Dangerous Goods and Use of Transportable Pressure Equipment Regulations (Amendment)*, Statutory Instruments No. 1885, 2011.
- 136 International Atomic Energy Agency, *Regulations for the Safe Transport of Radioactive Material, Specific Safety Requirements*, No.SSR-6, 2012.

- 137 Office for Nuclear Regulation, *Guidance for Applications for UK Competent Authority Approval*, TRA-PER-GD-014, Revision 1, July 2016.
- 138 International Atomic Energy Agency, *European PDSR Guide, Package Design Safety Reports for the Transport of Radioactive Material*, Issue 2, September 2012.
- 139 N. P. McColl and P. Kruse, *NAIR Technical Handbook 2002 Edition: Technical Handbook on the National Arrangements for Incidents Involving Radioactivity*, NRPB-W7, May 2002.
- 140 Radioactive Waste Management, *Geological Disposal: Generic Transport System Design*, DSSC/411/01, December 2016.
- 141 The Stationery Office, *Nuclear Industry Security Regulations 2003*, SI 2003 No. 403.
- 142 N.R. Smart, A.M. Pritchard, A. Turnbull, *Review of environmental conditions for storage of ILW radioactive waste containers*, SERCO/TAS/E.2098/P3443, 2010.
- 143 The Stationery Office, *Environmental Protection, England and Wales*, SI 2014, No. 656.
- 144 Nirex, *Research on the Alkaline Disturbed Zone resulting from Cement-Water-Rock Reactions around a Cementitious Repository*, Nirex Report N/054, 2002.
- 145 NDA RWMD, *Geological Disposal: Proposed strategy for the geoscientific aspects of site characterisation*, NDA/RWMD/017, 2011.
- 146 S. Watson, T. Hicks, G. Towler, D. Reedha, A. Paulley, T. Baldwin and A. Bond, *Post-closure Performance Assessment: Consideration of a Co-located Geological Disposal Facility in the Safety Case*, Quintessa Report QRS-1378P-R1, Version 2.1, May 2009.
- 147 B. Winpenny, T. Hicks, S. Watson, M. White, *Separation of Co-located Geological Disposal Facility Emplacement Modules: Thermal, Hydrogeological, Mechanical, Chemical and Gas Interactions*, 1151b1-1, Version 1, 2012.
- 148 T. Hicks, S. Watson, *A potential methodology for determining a tolerable separation distance between disposal areas containing different types of waste*, Assist Report 1151b1-3, Version 2, December 2015.
- 149 S. King, *Feasibility of Co-Disposal. Nirex Technical Note*, Document Number 336843, Version 8, UK Nirex Ltd 2003.
- 150 International Atomic Energy Agency, *Disposal of Radioactive Waste, Specific Safety Requirements SSR-5*, 2011.
- 151 Nirex, *Why a Cementitious Repository?*, Nirex Report N/034, 2001.
- 152 Radioactive Waste Management, *Geological Disposal: Engineered Barrier System Status Report*, DSSC/452/01, December 2016.
- 153 S. J. King, and M. Poole, *Issues Associated with the Co-disposal of ILW/LLW and HLW/SF in the UK*, WM'02 Conference, February 24-28, 2002, Tuscon, AZ, February 2002.
- 154 Radioactive Waste Management, *Geological Disposal: Behaviour of Radionuclides and Non-radiological Species in Groundwater*, DSSC/456/01, December 2016.
- 155 Radioactive Waste Management, *Geological Disposal: Waste Package Evolution Status Report*, DSSC/451/01, December 2016.

- 156 D. Charles, A. Fenton, A. Harris, A. Haworth, T. Heath, N. Pilkington, N. Smart, *Specification and justification of waste package temperature criteria*, AEAT-1031 Issue 2, 1997.
- 157 Svensk Kärnbränslehantering AB, *Buffer, backfill and closure process report for the safety assessment SR-Site*, TR-10-47, 2010.
- 158 Nagra, *Project Opalinus Clay, Safety Report, Demonstration of disposal feasibility for spent fuel, vitrified high-level waste and long lived intermediate-level waste*, TR02-05, 2002.
- 159 GRS, *Endlagerkonzepte: Bericht zum Arbeitspaket 5, Vorläufige Sicherheitsanalyse für den Standort Gorleben*, GRS 272, 2011 (In German).
- 160 T. Hicks, M. White, P. Hooker, *Role of bentonite in determination of thermal limits on geological disposal facility design*, Report to NDA RWMD, 2009.
- 161 P. Wersin, L. Johnson and I. McKinley, *Performance of the bentonite barrier at temperatures beyond 100°C: A critical Review*. *Physics and Chemistry of the Earth, Parts A/B/C*, 32, 8–14 pp 780–788, 2007.
- 162 Radioactive Waste Management, *Geological Disposal: High-heat-generating Wastes Project: Final Report*, TN18325, ISBN 978-1-84029-527-6, 2016.

Glossary

A glossary of terms specific to the generic DSSC can be found in the Technical Background.

Appendix A – Description of the Illustrative Concepts

A1 Illustrative Concept for High Heat Generating Waste in Higher Strength Rock

Attribute	Generic
Source example	KBS-3V Concept – SKB, Sweden
Waste to which concept applies	Suitable for a wide range of HHGW, although the very long container lifetime provided by copper container may not be optimal for some wastes (for example, HLW) which do not need to be contained for such a long period. Alternatives to copper will be considered.
Geological environment on which illustrative concept is based	Higher strength host rock overlain by sedimentary sequence that provides significant (tens of thousands of years) groundwater travel time.
Components	<p>1.5 m diameter borehole approximately 8-10 m deep drilled vertically from the floor of horseshoe shaped deposition tunnel. Borehole designed to take single waste package and buffer. Copper container with cast iron insert to provide mechanical strength.</p> <p>Compacted bentonite buffer.</p> <p>Bentonite-dominated deposition tunnel backfill.</p> <p>Crushed rock mass backfill in access tunnels.</p> <p>Low permeability sealing system.</p>
Waste handling and emplacement	<p>Waste package transported underground in re-useable transport container and then emplaced remotely.</p> <p>Robust sealed waste package prevents releases during operations.</p>
Post-closure safety concept	A very long container lifetime ensuring no release for hundreds of thousands of years. Combination of protection provided by the buffer and choice of container material ensures extremely long container lifetime.
Monitoring (of waste packages) and retrievability	Tunnel backfill must be emplaced as soon as possible after buffer emplacement so potential for monitoring and retrievability limited.
Technical maturity	The Swedish KBS-3V concept is an example of this concept. A site-specific safety case has been submitted for regulatory review but certain aspects of the concept are still subject to development for a UK geological environment.
References	[11, 12]

A2 Illustrative Concept for Low Heat Generating Waste in Higher Strength Rock

Attribute	Generic
Source example	UK ILW/LLW Concept – the NDA, UK
Waste to which concept applies	Suitable for LHGW in the UK inventory.
Geological environment on which illustrative concept is based	Higher strength host rock overlain by sedimentary sequence that provides significant (tens of thousands of years) groundwater travel time.
Components	<p>Large horseshoe-shaped vaults (for example, 16 m × 16 m × 300 m) A lining may be installed to prevent rockfall and water ingress. Stack support as is required will be provided by rock bolting, mesh and shotcrete.</p> <p>Cement grouted waste in standardised vented stainless steel containers.</p> <p>High pH, high porosity and permeability cementitious backfill (Nirex Reference Vault Backfill – NRVB) surrounding waste packages. Emplaced as part of closure engineering.</p> <p>Crushed host rock mass backfill.</p> <p>Low permeability seals/plugs.</p>
Waste handling and emplacement	<p>Unshielded packages transported underground within transport container.</p> <p>Remote emplacement of unshielded ILW waste packages by crane. SILW/LLW waste packages emplaced by stacker truck (with shielded cab).</p> <p>Standardised containers to facilitate handling and stacking.</p> <p>Vaults open at both ends during operational period facilitating ventilation.</p>
Operational considerations	<p>Achieving a uniform distribution of backfill around the waste packages may present challenges, especially if the operation is carried out many decades after the equipment was installed.</p> <p>Delayed backfilling has associated maintenance requirements to ensure environmental conditions are maintained for decades after vaults have been filled; for example, prevention of rockfalls.</p> <p>Ventilation requirements – packages are vented and so radioactive and potentially flammable/explosive gases are released during the operational period.</p>
Post-closure safety concept	<p>Backfill is designed to condition the groundwater to a high pH for timescales of a million years or more and thereby provide a chemical barrier to release of radionuclides. High pH reducing conditions reduce the solubility and mobility of certain key radionuclides such as actinides.</p> <p>Low permeability host rock ensures very slow migration in groundwater.</p>

Attribute	Generic
Monitoring (of waste packages) and retrievability	<p>Retrieval is the reverse of emplacement during the operational phase that is prior to emplacement of the backfill.</p> <p>Crane emplacement would allow selective retrieval. However, cranes would need to be maintained for 100 years.</p> <p>Potential for monitoring either through inspection of selected (retrieved) waste packages or remotely, for example inspection by camera.</p>
Technical maturity	<p>This concept has been developed in the UK and is used as a reference for disposability assessments. Extensive research and development has been carried out but no site-specific safety case has yet been developed.</p>
References	[10]

A3 Illustrative Concept for High Heat Generating Waste in Lower Strength Sedimentary Rock

Attribute	Generic
Source example	Opalinus Clay Concept – Nagra, Switzerland
Waste to which concept applies	Suitable for all types of HHGW.
Geological environment on which illustrative concept is based	Lower strength sedimentary host rock in which the permeability is sufficiently low that solute transport is by diffusion. There will be a cover sequence but its nature is not specified, or important to the definition of the disposal concept.
Components	<p>2.5 m diameter unlined horizontal tunnel with a concrete floor, nominally 800 metres in length.</p> <p>Thick-walled carbon steel container.</p> <p>Pelleted bentonite buffer, although compacted bentonite pedestal used to support waste package.</p> <p>Sand and bentonite mixture mass backfill.</p> <p>Sealing system</p>
Waste handling and emplacement	<p>Waste package transported underground in re-useable transport container and then emplaced remotely.</p> <p>Robust sealed waste package prevents releases during operations.</p>
Post-closure safety concept	Waste container protected by buffer provides containment during the thermal period, and is expected to remain intact for tens of thousands of years. Long-term containment is dominantly provided by low permeability host rock, which ensures that solute transport is dominated by diffusion.
Monitoring and retrievability	Buffer is emplaced at the same time as waste packages so potential for monitoring and retrievability limited.
Technical maturity	Similar concept currently being developed by Nagra. Extensive research, including work in URLs, although rate of progress is modest owing to a site not yet having been selected in Switzerland.
References	[11,13]

A4 Illustrative Concept for Low Heat Generating Waste in Lower Strength Sedimentary Rock

Attribute	Generic
Source example	Opalinus Clay Concept – Nagra, Switzerland
Waste to which concept applies	Suitable for most LHGW in the UK inventory. Cementitious environment may not be optimal, or even suitable, for some vitrified wastes.
Geological environment on which illustrative concept is based	Lower strength sedimentary host rock in which the permeability is sufficiently low that solute transport is by diffusion. There will be a cover sequence but its nature is not specified, or important to the definition of the disposal concept.
Components	<p>Oval-shaped vaults (for example, 9.5 m (width) × 11.5 m (height) × 100 m) A lining may be installed to prevent rockfall and water ingress. Such support as required is provided by rock bolting, mesh and shotcrete. Cement grouted waste in standardised vented stainless steel containers.</p> <p>High pH, high porosity and permeability cementitious backfill surrounding waste packages. Backfill has some structural strength to resist creep of the host rock. Emplaced as soon as each vault has been filled.</p> <p>Sand and bentonite mixture mass backfill.</p> <p>Low permeability seals/plugs.</p>
Waste handling and emplacement	<p>Unshielded packages transported underground within transport container.</p> <p>Remote emplacement of unshielded ILW waste packages by crane. Shielded ILW/LLW waste packages emplaced by stacker truck (with shielded cab).</p> <p>Standardised containers to facilitate handling and stacking.</p> <p>Vaults open at both ends during operational period facilitating ventilation.</p>
Post-closure safety concept	<p>Backfill is designed to condition the groundwater to a high pH for timescales of a million years or more and thereby provide a chemical barrier to release of radionuclides. High pH conditions reduce the solubility and mobility of certain key radionuclides such as actinides.</p> <p>Low permeability host rock ensures very slow migration in groundwater.</p>
Monitoring (of waste packages) and Retrievability	Backfilling immediately after the vault has been filled limits the potential for retrievability and monitoring. However, the access tunnels will be fully lined and kept open until GDF closure.
Technical maturity	This concept is an adaptation of the opalinus clay concept for disposal of long lived ILW developed by Nagra. It was selected because an OECD Nuclear Energy Agency review regarded the Nagra assessment of the concept as state-of-the-art with respect to the level of knowledge available.

Attribute	Generic
References	[10, 13]

A5 Illustrative Concept for High Heat Generating Waste in Evaporite Rock

Attribute	Generic
Source example	Gorleben Salt Dome Concept – DBE-Technology, Germany
Waste to which concept applies	Suitable for all types of HHGW.
Geological environment on which illustrative concept is based	Evaporite host rock. There will be a cover sequence but its nature is not specified, or important to the definition of the disposal concept beyond it protecting the evaporite rock from low salinity groundwater.
Components	<p>Rectangular (4.5 m wide by 3.5 m high) unlined horizontal tunnel, nominally 800 metres in length.</p> <p>Thick-walled carbon steel container.</p> <p>Crushed host rock buffer.</p> <p>Crushed host rock mass backfill.</p> <p>Sealing system</p>
Waste handling and emplacement	<p>Waste package transported underground in re-useable transport container and then emplaced remotely.</p> <p>Robust sealed waste package prevents releases during operations.</p>
Post-closure safety concept	Evaporite host rock will creep and compact the buffer resulting in complete encapsulation of the waste packages in a dry environment. Dry environment will limit corrosion of thick-walled waste container so container is likely to remain intact for hundreds of thousands of years.
Monitoring (of waste packages) and retrievability	Buffer is emplaced at the same time as waste packages so potential for monitoring and retrievability limited.
Technical maturity	This concept was adapted from the concept for disposal of HLW and spent fuel in a salt dome host rock developed by DBE Technology; it was selected due to the level of concept information available.
References	[10]

A6 Illustrative Concept for Low Heat Generating Waste in Evaporite Rock

Attribute	Generic
Source example	WIPP Bedded Salt Concept – US-DOE, USA
Waste to which concept applies	Suitable for most LHGW in the UK inventory.
Geological environment on which illustrative concept is based	Evaporite host rock. There will be a cover sequence but its nature is not specified, or important to the definition of the disposal concept beyond it protecting the evaporite from low salinity groundwater.
Components	<p>Rectangular-shaped vaults (for example, 10 m (width) × 5.5 m (height) × 100 m), which are unlined.</p> <p>Cement grouted waste in standardised vented stainless steel containers. Sacks of magnesium oxide are placed on top of each waste stack to absorb carbon dioxide and water and buffer pH. Remaining void space left open. Vault closed as soon as it has been filled.</p> <p>Crushed host rock mass backfill.</p> <p>Low permeability seals/plugs.</p> <p>Note that underground access is by shaft instead of the more normal drift access.</p>
Waste handling and emplacement	<p>Unshielded packages transported underground within transport container.</p> <p>Remote emplacement of unshielded ILW waste packages by unmanned stacker truck and manual emplacement of shielded ILW/LLW waste packages by stacker truck (with shielded cab).</p> <p>Standardised containers to facilitate handling and stacking.</p> <p>Vaults open at both ends during operational period facilitating ventilation.</p>
Post-closure safety concept	Host rock creeps and completely encapsulates waste packages. Dry environment means that there is no transport via the groundwater pathway.
Monitoring (of waste packages) and retrievability	Closing the vaults immediately after they have been filled limits the potential for retrievability and monitoring. However, the access tunnels will be kept open until GDF closure, although creep may be an issue.
Technical maturity	This concept is an adaptation of the WIPP disposal concept for transuranic wastes, which is an operating facility.
References	[10]



Certificate No LRQ 4008580

Radioactive Waste Management Limited
Building 587
Curie Avenue
Harwell Oxford
Didcot
Oxfordshire OX11 0RH

t +44 (0)1925 802820

f +44 (0)1925 802932

w www.gov.uk/rwm

© Nuclear Decommissioning Authority 2016