Radioactive Waste Management

NDA Report no. NDA/RWM/141

Geological Disposal

Design Status Report

October 2016

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Executive Summary

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 geological disposal of the UK's higher activity radioactive waste. 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 to the surface environment. To identify potentially suitable sites where a GDF could be located, the Government is developing a voluntarism approach based on working with interested communities that are willing to participate in the siting process. 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 in the absence of a specific site, RWM has developed generic, illustrative disposal designs for three host geological environments and an associated generic transport system design. This approach also provides RWM with a basis for developing waste package specifications, using the established Letter of Compliance (LoC) disposability assessment process, to identify if waste packaging proposals from waste producers are consistent with the requirements currently foreseen for transport, operational and long-term safety. These host geological environments are typical of those being considered in other countries, and has been chosen because they cover the range of issues that may need to be addressed when developing a GDF in the UK. They are:

- higher strength rock, for example, granite;
- lower strength sedimentary rock, for example, clay;
- evaporites, for example, halite.

In the future, these illustrative designs will be tailored to the specific boundary conditions of UK geology and the waste inventory, and also constraints resulting from the siting process. It is expected that these illustrative designs will continue to be required and updated as the designs move forward through the process from their current illustrative status through the conceptual and preliminary design stages and until a detailed design for a GDF at a specific site is developed.

RWM has also developed a generic transport system design. This design describes the operations required commencing at waste producer's sites, to ensure safe and efficient transport of transport packages through the public domain to a GDF.

The purpose of this Design Status report is to document the rationale behind the key design developments, to provide an overview of the engineering design work undertaken and provides support to the published design reports (Generic Transport System Design and Generic Disposal Facility designs). It is not intended for this report to present the totality of the design work undertaken, but instead to support any future design development work by providing a summary of the extent and justification for the design decisions taken.

This report will be periodically updated to include design enhancements that are adopted to the geological disposal facility and its transport system to support any future design development work and to provide reference to the underpinning source information.

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List of acronyms and abbreviations

ANDRA	Agence Nationale pour la gestion des déchets radioactifs, French National Radioactive Waste Management Agency
BERR	Department for Business, Enterprise and Regulatory Reform
CoRWM	Committee on Radioactive Waste Management
DCTC	Disposal Container Transport Container
Defra	Department for Environment, Food and Rural Affairs
DOPAS	Demonstration of Plugs and Seals
DNLEU	Depleted, Natural and Low Enriched Uranium
DSS	Disposal System Specification
DSSC	Disposal System Safety Case
DTI	Department of Trade and Industry
EC	European Commission
EDRAM	International Association for Environmentally Safe Disposal of Radioactive Materials
EDZ	Excavation Damaged Zone
ENSREG	European Nuclear Safety Regulators Group
ESDRED	Engineering Studies and Demonstration of Repository Designs
GDF	Geological Disposal Facility
GDFD	Generic Disposal Facility Design
GTSD	Generic Transport System Design
HEU	Highly Enriched Uranium
HGV	Heavy Goods Vehicle
HHGW	High Heat Generating Waste
HLW	High Level Waste
IAEA	International Atomic Energy Agency
IGD-TP	Implementing Geological Disposal – Technology Platform’
ILW	Intermediate Level Waste
LHGW	Low Heat Generating Waste
LLW	Low Level Waste
LLWR	Low Level Waste Repository
LoC	Letter of Compliance
MBGWS	Miscellaneous Beta Gamma Waste Store
MoDeRn	Monitoring Developments for Safe Repository Operation and Staged Closure
MRWS	Managing Radioactive Waste Safely
NDA	Nuclear Decommissioning Authority
NEA	Nuclear Energy Agency
NORMS	National Objectives, Requirements and Model Standards
NNB	New Nuclear Build
NRVB	Nirex Reference Vault Backfill
OECD	Organisation for Economic Cooperation and Development
ONR CNS	Office for Nuclear Regulation Civil Nuclear Security
PDC	Phased Disposal Concept
PGRC	Phased Geological Repository Concept

Pu	Plutonium
RCF	Rock Characterisation Facility
RD&D	Research, Development and Demonstration
R&D	Research and Development
RSILW	Robust Shielded Intermediate Level Waste
RWM	Radioactive Waste Management
RWMD	Radioactive Waste Management Directorate
SILW	Shielded Intermediate Level Waste
SF	Spent Fuel
SKB	Svensk Kärnbränslehantering AB, Swedish Nuclear Fuel and Waste Management Company
SWTC	Standard Waste Transport Container
TBuRD	Technical Baseline underpinning Research and Development
TDC	Transport and Disposal Container
U	Uranium
UILW	Unshielded Intermediate Level Waste
UK RWI	United Kingdom Radioactive Waste Inventory
VRA	Vault Reception Area
WMOs	Waste Management Organisations

1 Introduction

1.1 Background

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 geological disposal of the UK's higher activity radioactive waste. 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 to the surface environment. To identify potentially suitable sites where a GDF could be located, the Government is developing a voluntarism approach based on working with interested communities that are willing to participate in the siting process [1]. 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 in the absence of a specific site, RWM has developed generic, illustrative disposal designs for three host geological environments. These host geological environments are typical of those being considered in other countries, and has been chosen because they cover the range of issues that may need to be addressed when developing a GDF in the UK. They are:

- higher strength rock, for example, granite;
- lower strength sedimentary rock, for example, clay;
- evaporites, for example, halite.

The generic illustrative design for a GDF is described in the following two reports:

- the Generic Transport Systems Design (GTSD) report [2] describes the operations required commencing at waste producer's sites, to ensure safe and efficient transport of transport packages through the public domain to a GDF. The report describes both the requirements and potential logistics associated with the transport operation based on road and rail scenarios.
- the Generic Disposal Facility Design (GDFD) report [3] describes the processes of construction, waste package receipt, handling and emplacement and the design characteristics that a disposal facility would need to include for the inventory of wastes for disposal. The report provides information on what a facility could look like and identifies the different packaging and disposal processes for different types of waste.

1.2 Purpose of Report and supporting documents

The purpose of this Design Status report is to document the rationale behind the key design developments and to provide an overview of the engineering design work undertaken and described in the GTSD and GDFD reports. The Design Status report is also an underpinning document to the RWM Technical Baseline Underpinning Research and Development (TBuRD) [4] highlighting areas where further Research, Development and Demonstration (RD&D) is required.

It is not intended for this report to present the totality of the design work undertaken, but instead to support any future design development work by providing a summary of the extent and justification for the design decisions taken to date.

This report will be periodically updated to include design enhancements that are adopted through the RWM Change Control process, to support any future design development work and to provide reference to the underpinning source information.

The GDFD, GTSD and the Design Status report are also supported by a number of other documents including:

- Engineering Design Manual - The Engineering Design Manual (RWM120) is the part of the internal RWM's management system which describes the engineering design process that will be followed to establish, maintain and update the engineering designs that will be used for the development, construction, commissioning, operation, closure and decommissioning of the waste disposal systems for a GDF. This manual provides users of the engineering design process with an overview of the requirements, expectations, steps and tools to work with confidence and compliance, to know how to obtain the detailed operational documentation, and understand how that fits with the wider arrangements.
- Science and Technology Plan - To prioritise the Research and Development (R&D) programme, RWM has developed a 'Science and Technology Plan' [5] which presents a plan to deliver future generic research and development activities. Generic is defined as those activities that can be undertaken without specific knowledge of the eventual host site for a GDF. The plan provides opportunities for dialogue and involvement of interested parties and stakeholders in the development of RWM's knowledge base for the safe geological disposal of radioactive waste. This document identifies areas in the GDF design where additional work is required to expand our knowledge base.

1.3 Report Structure

This report has been divided into a number of sections to provide the rationale covering different aspects of the design.

Section 2 provides a summary of the historical developments of the GDF programme.

Section 3 provides an overview of the GDF design process and development of the generic illustrative designs.

Section 4 summarises international collaboration and technology transfer used to support the GDF design process.

The transport system, surface and underground facilities, services and infrastructure are identified in Sections 5 to 11 inclusive.

Section 12 discusses the backfilling, sealing, closure and decommissioning design for a GDF.

Section 13 and 14 deal with the monitoring programmes that would be undertaken and matters affecting security and nuclear safeguards.

Section 15 addresses retrievability and how waste could be retrieved from a disposal facility.

The report is concluded in Section 16 which describes the way forward and how the design is expected to evolve over time.

2 Historical Developments of the GDF Programme

In the United Kingdom, the Government is responsible for formulating policy for the management of radioactive wastes. A Government review of radioactive waste management was published in 1982 [6] and this review acknowledged a lack of suitable disposal facilities for Intermediate Level Waste (ILW), and announced that the Government had agreed for Nuclear Industry Radioactive Waste Executive (Nirex) to be set up by the nuclear industry to provide a mechanism by which companies involved would successfully fulfil their responsibilities for the safe disposal of waste.

In July 1984, the Government's policy was set out in a publication, Radioactive Waste Management: The National Strategy [7]. This envisaged both shallow and deep disposal as the ultimate means of dealing with all wastes. The aim was seen as being to provide, as soon as practicable, disposal facilities for ILW. The document rejected the concept of indefinite storage and stated specifically that:

> *A policy of indefinite storage would leave future generations with the burden of maintaining stores, and replacing them from time-to-time.*

At that time it had been the intention to dispose of short-lived ILW in a near-surface facility and long-lived ILW in a deep repository site, but in 1986 the Government accepted the recommendation of the Environment Select Committee that no ILW should be disposed of in near-surface facilities. Nirex evaluated its plans, and following correspondence with the Company, the Secretary of State for the Environment explained in a statement to the House of Commons on 1 May 1987 that Nirex would concentrate on identifying a "suitable location for a deep multi-purpose facility."

In 1989, Nirex published site specific design studies on the Sellafield and Dounreay sites [8,9]. Also in 1989, Nirex published a non-site specific piece of work on a land-based deep repository conceptual designs [10]. All of these designs were for an ILW and Low Level Waste (LLW) facility. The study focused on engineering design work for three potential host geological environments; a hard rock site, a soft rock site and a site at Sellafield, Cumbria.

In its 1990 White Paper, '*This Common Inheritance*' [11] the Government said that Nirex should speed up investigations into a potential underground waste disposal site so that a well-founded proposal could come to a Public Inquiry as soon as possible. In response, Nirex announced in July 1991that it would concentrate its further investigations for a potential deep repository site near Sellafield and the generic design concept was adopted for the Sellafield site [12]. This generic design concept was then updated in December 1991 [13] on the Sellafield Repository Project.

In 1992, Nirex had stated its intentions to construct an underground rock characterisation facility (RCF) at Longlands Farm, near Sellafield, as a further phase of investigating the suitability of the site. This resulted in a RCF consultative document, which was issued in October 1992 to publicly announce the RCF proposal [14]. However, the planning application for the RCF was rejected following a Public Inquiry that was held in Cumbria during 1995-96.

In 1995 the Department of the Environment document, '*The Prospects for Nuclear Power in the UK'* [15] confirmed that the Government continued to favour a policy of deep disposal rather than indefinite storage for ILW and believed that it was no longer right to postpone decisions about its ultimate destination.

In March 1997 the Secretary of State for the Environment decided, on consideration of the Inspector's report [16], that the refusal of planning permission should be upheld and that Nirex should not be permitted to construct the RCF [17]. Following the Secretary of State's decision, Nirex produced a technical report, the Sellafield Repository Design Concept, which documented the initial design considerations in 1991 up to the point when the RCF planning application was rejected [18].

Since the Secretary of State's decision, the issue of radioactive waste management was reviewed by a House of Lords Select Committee on Science and Technology, which published its report in March 1999 [19]. After this report was published, the Government indicated that there would be a period of consultation to support the development of a White Paper setting out the forward approach for radioactive waste management.

During this period Nirex developed the Phased Disposal Concept (PDC) for ILW/LLW. A suite of documents described the system specification, the designs for the transport system and the repository, the transport and operational safety assessments, and the post-closure performance assessment. These reports are generic in the sense that they describe a repository concept that is not specific to a particular site in the UK.

In September 2001, a consultation paper on 'Managing Radioactive Waste Safely' (MRWS) was launched by the Department for Environment, Food and Rural Affairs (Defra), the Scottish Executive, the National Assembly for Wales and the Department of the Environment in Northern Ireland [20]. This set out proposals for developing a policy for managing solid radioactive waste in the UK and included a proposed programme of action for reaching decisions, which divided into stages. The consultation (Stage 1) was completed in March 2002 and the Government announced the next steps in July 2002 [21].

The MRWS programme set out two key decisions to be made. Firstly, a decision had to be reached on the option (or combination of options) selected for the long-term management of radioactive wastes in the UK. An independent committee, the Committee on Radioactive Waste Management (CoRWM), was set up by Government in November 2003 to oversee a public consultation on such long-term management options. CoRWM's key task was to recommend to Government what should be done with wastes for which no long-term management strategy existed. These include High Level Waste (HLW), ILW and some LLW unsuitable for surface disposal[1].

CoRWM set the framework for debate by establishing broad agreement on the wastes to be considered, the range of management options for each of them, and the criteria against which these options should be assessed. The second step was to assess each of the options.

In February 2005, CoRWM proposed a short-list of four options: interim storage, near surface disposal, geological disposal and phased geological disposal. CoRWM assessed these options in more detail and sought feedback on their proposals during 2005. CoRWM published its recommendations in July 2006 [22] stating that higher activity radioactive waste should be placed into a geological disposal facility and that disposal should be preceded by a period of safe and secure interim storage to allow time for optimised delivery of the disposal facility. This was followed by consultation on the siting methodology for the GDF, in preparation for implementation of the GDF.

In 2005, Nirex developed its Phased Geological Repository Concept (PGRC) to provide safe, long-term management for ILW and for LLW that was not suitable for disposal in existing near-surface facilities. The PGRC was developed from the previous generic designs but incorporated retrievability. With retrievability for up to several hundred years built into it, the concept was a multi-barrier, phased and reversible approach, based on storing waste deep underground. The generic PGRC was based on real data obtained from Nirex's investigation of Sellafield as a potential repository site. However, different rock types offer different qualities and present different challenges in terms of repository construction and repository safety and environmental performance. Hence Nirex investigated the implications for the generic design concept of constructing a repository in a

[1] However, for some ILW and LLW, the Letter of Compliance system has provided a framework that enables helpful progress to be made on their conditioning and packaging.

range of different host geological environments that might be suitable for a repository in the UK [23, 24].

Nirex also published, "*The viability of a phased geological repository concept for the long term management of the UK higher activity radioactive waste*", which set out why Nirex believed that the UK's higher activity radioactive waste should be placed in a phased geological disposal facility [25].

As a result of this consultation period, a White Paper was published by Defra, BERR and the devolved administrations for Wales and Northern Ireland entitled 'A Framework for Implementing Geological Disposal' [26]. This document was part of the MRWS programme, setting out the UK Government's framework for the long term management of higher activity wastes. The White Paper described the proposed way forward, identifying the wastes to be managed, summarising the preparation and planning underway, discussing the principles that will be used to protect people and the environment and detailing the processes that will be used for site selection and assessment.

The ownership of Nirex was transferred from the nuclear industry to the UK Government departments DEFRA and DTI in April 2005, and then to the UK's Nuclear Decommissioning Authority (NDA) in November 2006. In 2006, the NDA established the Radioactive Waste Management Directorate (RWMD), incorporating expertise and information from the former UK Nirex Limited, as the implementing body for deep geological disposal [27]. In 2013, RWMD became a wholly owned subsidiary of the Nuclear Decommissioning Authority and was renamed to RWM.

In the MRWS White Paper [26] the first step was for the UK Government to seek expressions of interest from volunteer communities that may wish to consider participating in a site selection process. As a result of Cumbria County Council not supporting the process in west Cumbria, the UK Government initiated a review of the MRWS siting process, considering what lessons could be learned from the experiences of the MRWS programme in west Cumbria and elsewhere. The consultation closed in December 2013 and Government published a revised White Paper – *Implementing Geological Disposal* in 2014 [1].

Over the past 25 years, RWM and its predecessors, has carried out extensive research and technical development relating to the science, engineering and technology of geological disposal of ILW and LLW. However, RWM's remit has since been broadened to include all types of radioactive materials and not to simply focus on ILW as it did in the past. RWM is now developing a comprehensive and coherent strategy for the management of all UK radioactive wastes and materials including those that has not yet been classified as wastes comprising; Spent Fuels (SF), Plutonium (Pu) and Uranium (U) as Depleted, Natural and Low Enriched Uranium (DNLEU) and Highly Enriched Uranium (HEU) forms.

As part of this work, RWM initially developed a reference geological repository concept in a higher strength rock which was capable of accepting HLW and SF [28]. A co-located design was then prepared for ILW/LLW and HLW/SF and a report, was published in June 2009 to address these issues [29].

In 2010, to underpin the generic Disposal System Safety Case (DSSC), illustrative engineering designs (herein referred to as illustrative designs) were developed for each of three generic geological environments; higher strength, lower strength sedimentary and evaporite rocks [30]. In such a 'co-located' disposal facility it is assumed that ILW, LLW, HLW, SF, Pu and U could all be disposed.

Developing these illustrative designs allows a representation of typical sizes of excavation, designs of rock support, and designs of disposal vaults[2] or tunnels[3] in a particular rock. The use of illustrative designs and safety assessments of these designs allows RWM to challenge and identify potential improvements to these designs and allows RWM to address appropriate disposal solutions for different waste types.

Developing these illustrative designs, in turn, helps to enhance the understanding of how waste disposal could be carried out in different geological environments; how safety can be addressed in all phases of development; how long it might take to develop; and what it is likely to cost. This approach also provides RWM with a basis for developing waste package specifications, using the established Letter of Compliance (LoC) disposability assessment[4] process, to identify if waste packaging proposals from waste producers are consistent with the requirements currently foreseen for transport, operational and long-term safety.

Since first publication in 2010, to support the generic DSSC, the generic illustrative designs have been updated to reflect updates to the inventory for disposal and to incorporate other changes identified endorsed for implementation by the RWM Change Control process to further improve and enhance the designs. Consideration has also been given to addressing comments made by regulators and other organisations that can be addressed at this early stage, whilst the designs are generic. These updated illustrative GDF designs and the transport system design have been updated to support the 2016 generic DSSC.

The latest inventory, the 2013 UK radioactive waste inventory (UK RWI) is defined in the Government White Paper on implementing geological disposal [1]. The inventory includes the higher activity radioactive wastes and other nuclear materials that could, potentially be declared as wastes in the future. For the purposes of developing disposal concepts, these wastes have been classified as follows:

- high heat generating wastes (HHGW), that is: SF from existing and future power stations and HLW from SF reprocessing;
- high fissile activity waste, that is: Pu and HEU;
- low heat generating wastes (LHGW), that is: ILW arising from operating and decommissioning of reactors and other nuclear facilities, together with a small amount of LLW unsuitable for near surface disposal, and stocks of DNLEU.

[2] Disposal vaults are used to dispose of low heat generating wastes e.g. LLW and ILW and DNLEU

[3] Disposal tunnels are used to dispose of high heat generating wastes e.g. HLW

[4] The process by which RWM undertakes assessments of waste-packaging proposals and provides advice to the waste-packaging site on the disposability of the proposed waste package. In cases where the proposal will lead to a waste package compliant with GDF safety and environmental cases this will be signified by the issue of a LoC.

3 GDF Design Development

3.1 Disposal Concepts

At the present generic stage of the programme, the range of geological settings that could be available to host a geological disposal facility is wide and diverse and a range of potentially suitable geological disposal concepts are being examined.

At this stage in the process, RWM has selected six illustrative geological disposal concept examples as the basis for RWM's current design work (Figure 1). A disposal concept is defined by the engineered barrier system and the layout required to deliver the safety functions and requirements defined in the disposal system specification. A disposal concept is specific to a waste category and geological environment.

These disposal concepts are predominantly based on mature, overseas programmes developed within specific geological constraints and are supported by extensively documented research and development and has been subject to detailed safety assessment, regulatory scrutiny and international review. However, this does not mean that a disposal concept developed now will necessarily be used in a particular geological environment; at this stage, no disposal concepts have been excluded.

Figure 1 Sources of illustrative geological disposal concepts for generic host geological environments and classes of waste

Host rock	Illustrative Geological Disposal Concept Examples[d]	
	LHGW	HHGW
Higher strength rocks[a]	UK LHGW Concept *(RWM, UK)*	KBS-3V Concept *(SKB, Sweden)*
Lower strength sedimentary rock[b]	Opalinus Clay Concept *(Nagra, Switzerland)*	Opalinus Clay Concept *(Nagra, Switzerland)*
Evaporites[c]	WIPP Bedded Salt Concept *(US-DOE, USA)*	Gorleben Salt Dome Concept *(DBE-Technology, Germany)*

Notes
a. Higher strength rocks – the UK LHGW concept and KBS-3V concept for spent fuel were selected due to availability of information on these concepts for the UK context.
b. Lower strength sedimentary rocks – the Opalinus Clay concept for disposal of long-lived ILW, HLW and spent fuel was selected because a recent OECD Nuclear Energy Agency review regarded the Nagra (Switzerland) assessment of the concept as state of the art with respect to the level of knowledge available. 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. Although we will use the Opalinus Clay concept as the basis of the illustrative example, we will also draw on information from the Andra programme. In addition, we will draw on information from the Belgian super container concept, based on disposal of HHGW in Boom Clay.
c. Evaporites – the concept for the disposal of transuranic wastes (TRU) (long-lived ILW) in a bedded salt host rock at the Waste Isolation Pilot Plant (WIPP) in New Mexico was selected because of the wealth of information available from this facility. The concept for disposal of HHGW in a salt dome host rock developed by DBE Technology (Germany) was selected due to the level of concept information available.
d. For planning purposes the illustrative concept for depleted, natural and low enriched uranium is assumed to be same as for ILW/LLW and for plutonium and highly enriched uranium is assumed to the same as for HLW/SF.

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It should be noted that these individual examples are not considered to be the 'best' available or even especially suited to implementation in the UK. They provide a range of options (disposal in tunnels with or without a supporting plinth, in boreholes and in vaults), which covers the range within the catalogue of concepts previously described for LHGW

[31] and HHGW [32]. This approach does not imply any preference over other national concepts or concept options or ones.

Development and the technical understanding of disposal concepts is a continuing process and work to select the most appropriate disposal concepts will continue as the GDF design is refined.

The decisions related to the choice of source illustrative geological disposal concept examples are documented in Geological Disposal: Steps Towards Implementation [33]. The relationship between RWMs illustrative designs and the concept examples is also discussed in [33].

3.2 Development of the GDF Design

The current three illustrative designs (higher strength rock, lower strength sedimentary rock and evaporite) are based on the six geological disposal concepts identified in Figure 1.

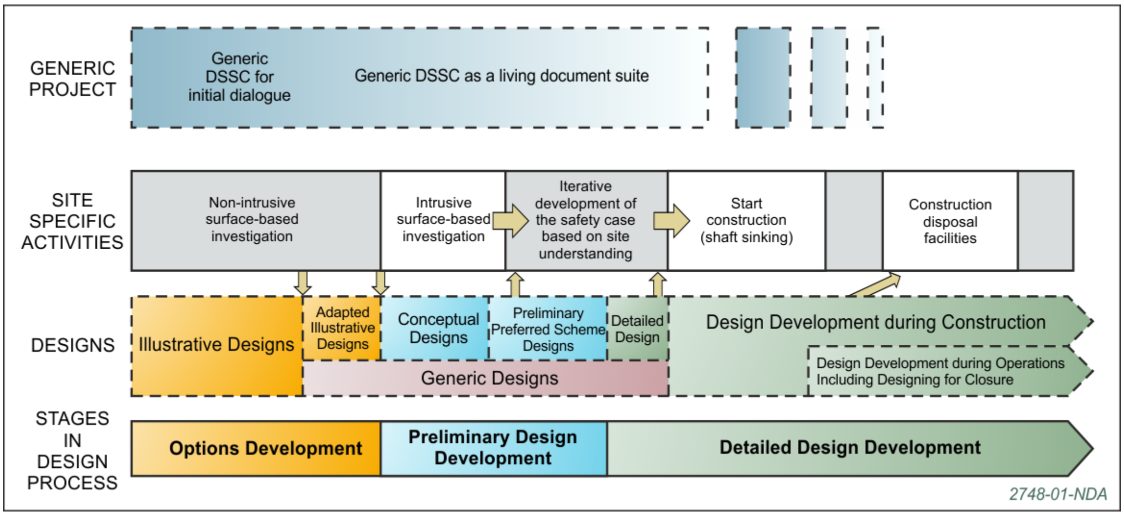
The illustrative designs are currently being used to:

- further develop the understanding of the functional and technical requirements of the disposal system;
- further develop the understanding of the design requirements;
- support the scoping and assessment of the safety, environmental, social and economic impacts of a GDF;
- support development and prioritisation of RWM's R&D programme;
- underpin the analysis of the potential cost of geological disposal;
- support assessment of the disposability of waste packages proposed by waste owners.

Work is currently focused on analysing and developing generic, illustrative designs. In the future, these illustrative designs will be tailored to the specific boundary conditions of UK geology and the waste inventory, and also constraints resulting from the siting process. It is expected that these illustrative designs will continue to be required and updated as the designs move forward through the process from their current illustrative status through the conceptual and preliminary design stages and until a detailed design for a GDF at a specific site is developed.

Generic illustrative designs will also be maintained in parallel with developing site-specific designs. The purpose of these generic illustrative designs will be to support generic assessments, to provide information to support the verification of site specific designs and also support the packaging assessment / Letter of Compliance process until a specific site is identified. The process for design development is shown in Figure 2.

Figure 2 Engineering Design Development



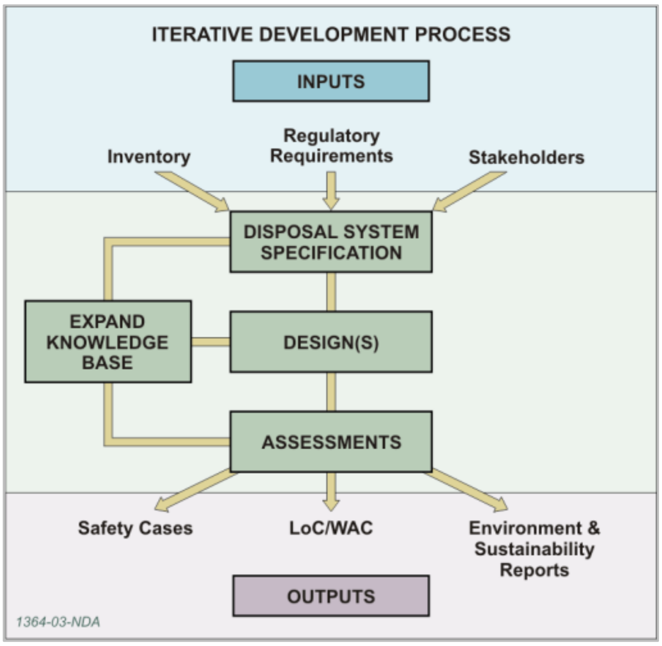
RWM has developed a generic Disposal System Specification (DSS) which describes the requirements on the disposal system and provides the starting point for design and assessment work. The DSS comprises two documents:

- Part A: High Level Requirements [34], which describes the high-level requirements on the disposal system and is in a form suitable for a wide range of stakeholders;
- Part B: Technical requirements [35], which describes in more detail the requirements on the disposal systems, together with a justification for each requirement.

The illustrative designs have been developed to be consistent with the requirements defined in Part B. These documents currently describe generic requirements, reflecting the fact that a site and a disposal concept has yet to be selected. They will be periodically updated throughout the implementation of the GDF programme, for example to respond to changes in regulations and to respond to issues identified from undertaking safety assessments. The Technical Requirements, in particular, will evolve from generic to site-specific requirements as site-specific information becomes available.

Figure 3 gives an overview of the process by which the DSS incorporates external sources of information to guide the design and assessment processes, which in turn leads to refinements and changes in the DSS. Since this figure represents a high-level illustration of the process, to avoid making the figure over-complicated feedback loops has not been explicitly represented. Nevertheless, this figure clearly identifies the main constraints on and outputs from the design process.

Figure 3 Iterative disposal system development



The use of illustrative designs and safety assessments of these designs allows RWM to challenge and identify potential improvements to these designs and allows appropriate disposal solutions for different waste types to be addressed and identify further research and development tasks.

The iterative process described in Figure 3 will continue as development of the design and safety case continues. There will be hold points throughout this process when regulators will be required to assess the safety case and agree or give consent to commence the next stage (for example; construction, commissioning, operation, decommissioning, and closure). Safety Functional Requirements will be used to provide the formal, auditable link between the safety assessment work and the design. Requirements will be developed in terms of design functionality so that designers have the freedom to provide the most appropriate way to implement the required functions. In the future, this will be integrated into a formal requirements management system that is likely to include a constraints set in order clearly articulate and agree the requirements and enable their delivery.

4 Technology Transfer and International Collaboration

To underpin the design process, it is sensible to take advantage of the work carried out in the area of geological disposal over the last three decades, both in the UK and overseas by other Waste Management Organisations (WMOs). RWM has developed relationships with sister waste management organisations in other countries in order to provide access to international good practice. Many of these organisations face similar challenges, therefore, it is sensible to share experiences, learn lessons and create synergistic relationships to enhance value for money. Where appropriate, this is achieved through establishing bilateral agreements or other formal or informal mechanisms.

These mechanisms provide a number of benefits, and importantly allow for international benchmarking, training opportunities and access to information which may otherwise not be available. They could also provide a basis for entering into commercial arrangements where appropriate. For example RWM is currently collaborating with both SKB and ANDRA on a technology transfer. The objective of this is to identify the potential benefits, costs and risks to RWM in adopting SKB’s and ANDRAs technology for a GDF in the UK. The technology transfer strategy considers:

1. The type of technology to be transferred
2. Whether the technology relates to all or some of the disposal system needs, that is all of the waste types requiring disposal
3. Which part of the programme the technology relates to (e.g. research, development and demonstration, site investigation, waste packaging, geological disposal facility construction, operation and closure).
4. At what stage of the programme the transfer should take place.

Technology transfer has the opportunity to influence RWM’s generic disposal facility designs by;

- Allowing RWM to develop its generic DSSC
- Improving RWMs detailed understanding of disposal concepts which form the illustrative geological disposal concepts.
- Providing an opportunity for RWM to increase the credibility of the technology with UK stakeholders through the use of demonstration facilities and presenting relevant evidence of the other country’s work.

It is assumed that RWM will continue to utilise similar approaches and undertake technology transfer studies with other relevant sister WMOs in the future.

RWM also undertake high level involvement with the United Nations International Atomic Energy Agency (IAEA), Nuclear Energy Agency (NEA) of the Organisation for Economic Cooperation and Development (OECD), the European Commission (EC), other organisations, and national governments, where our input (where appropriate in liaison with the Government Department for Energy and Climate Change) can help influence technical, legislative and policy development, and promote good relations.

In order to gain further experience and maximise financial leverage, RWM take part in internationally co-ordinated joint research and development, working groups or other collaborative mechanisms, such as through the EC’s R&D Framework Programme (including the Implementing Geological Disposal of Radioactive Waste Technology Platform), IAEA and NEA. RWM have and will continue to collaborate with other national programmes on research, demonstrations and trials for aspects of geological disposal. These include the completed Engineering Studies and Demonstration of Repository Designs (ESDRED), Monitoring Developments for Safe Repository Operation and Staged Closure (MoDeRn) and the ongoing Demonstration of Plugs and Seals (DOPAS) projects.

RWM is also continuing to collaborate with other national programmes on emplacement technologies for LHGW and HHGW. For example, full-scale mock-up trials for the emplacement of HHGW packages has been carried out in underground or surface research facilities in countries such as Germany, Sweden, Switzerland, France and Belgium. These collaborations are identified in more detail in the Science and Technology Plan [5].

5 Generic Transport System

5.1 Transport Modes

As no site has yet been identified for a GDF, RWM has designed the generic transport system to use a combination of rail and road transport.

The current assumption employed by the NDA, as set out in their '*Transport and Logistics Topic Strategy*' [36], will be to use rail over road where practical, although this does not preclude transport by sea or waterway if appropriate. In conjunction with RWM it is expected that each waste-producing site will use the most appropriate transport mode(s) for its own purposes.

The transport modes used will depend upon a wide range of factors, including the transport infrastructure available at the time a GDF becomes operational. Those responsible for defining the transport system at the time, whether it be waste producers, or some other controlling body, will need to take account of the economic, social and environmental factors applicable at that time when selecting suitable transport modes and routes.

The rail and road transport systems would need to have sufficient capacity to enable transport of the packages to the disposal facility in order to meet the anticipated rate of waste arisings and the currently assumed emplacement rate profile of a GDF. A key feature of the entire radioactive waste transport system is the requirement that routine above-ground storage of packaged waste at the GDF shall be as low as reasonably practicable.

It is currently assumed that no waste packaging or encapsulation would be undertaken at the disposal facility and all waste would arrive packaged in a form that meets the relevant specifications (as detailed in the Generic Transport Systems Design Report [2]). Therefore, waste would be suitable for emplacement on arrival at the facility and would not require any further handling or modification by operators at a GDF. Waste transport and receipt at a GDF is discussed in more detail in Section 6.3.

Recognising that many waste packages has yet to be manufactured and decisions about their ultimate design has not yet been made, it has been necessary to make the some assumptions regarding the form of conditioning and packaging for the purposes of these illustrative designs. The type of waste packages assumed to be disposed of in a GDF are described in the Table 1, but is recognised that there may be changes as container designs and disposal solutions are developed and optimised. Table 1 also details the assumed transport arrangements for specific waste packages. Information regarding the design of these waste packages can be found in [2].

The most hazardous materials, including some types of LHGW and all HHGW, are planned to be transported in large reusable transport containers made from high-integrity materials that provide containment of radioactive materials and shielding from radiation even under transport accident conditions (severe impact and fire). These reusable transport containers would either be the Standard Waste Transport Container (SWTC) or the Disposal Container Transport Container (DCTC).

Table 1 Summary of illustrative waste and transport packages

<table>
<tr><th>Waste type</th><th>Waste category</th><th>Waste package</th><th>Transport arrangement</th></tr>
<tr><td rowspan="14">LHGW</td><td rowspan="11">ILW</td><td>500 litre drum[5]</td><td rowspan="3">SWTC-70, SWTC-285</td></tr>
<tr><td>3 cubic metre box</td></tr>
<tr><td>3 cubic metre drum</td></tr>
<tr><td>6 cubic metre concrete box</td><td>6 cubic metre concrete box</td></tr>
<tr><td>2 metre box</td><td>2 metre box</td></tr>
<tr><td>4 metre box</td><td>4 metre box</td></tr>
<tr><td>MBGWS box</td><td>SWTC-150</td></tr>
<tr><td>500 litre robust shielded drum</td><td>Transport overpack, SWTC-150</td></tr>
<tr><td>3 cubic metre robust shielded box</td><td>Transport overpack</td></tr>
<tr><td>1 cubic metre concrete drum</td><td>Transport overpack</td></tr>
<tr><td>500 litre concrete drum</td><td>Transport overpack</td></tr>
<tr><td rowspan="2">LLW</td><td>500 litre drum</td><td>SWTC-70, SWTC-285</td></tr>
<tr><td>4 metre box</td><td>4 metre box</td></tr>
<tr><td rowspan="2">DNLEU</td><td>Transport and Disposal Container (TDC)</td><td>TDC</td></tr>
<tr><td>500 litre drum</td><td>SWTC-70, SWTC-285</td></tr>
<tr><td rowspan="6">HHGW</td><td>HLW</td><td rowspan="6">Disposal container</td><td rowspan="6">DCTC</td></tr>
<tr><td>Legacy SF</td></tr>
<tr><td>Plutonium</td></tr>
<tr><td>Highly Enriched Uranium</td></tr>
<tr><td>MOX</td></tr>
<tr><td>Spent Fuel arising from new nuclear power station</td></tr>
</table>

[5] 500 litre drums are placed in a stillage containing four drums for transport and disposal

5.2 Transport Packages

5.2.1 Standard Waste Transport Container (SWTC)

The purpose of the SWTC is to:

- Provide shielding for the waste packages
- Provide a verifiable containment boundary
- Provides confinement of the contents contributing to criticality safety
- Provides impact and fire protection for the waste package maintaining the shielding and the containment boundary following severe impact and fire accidents

There are three variants, each with a different shielding thickness (70mm, 150mm and 285mm), respectively designated as the SWTC-70, the SWTC-150 and the SWTC-285. These shielding thicknesses have been selected to suit the range of wastes to be transported.

The SWTC-70 and SWTC-285 have similar cavity dimensions determined by the dimensions of the contents: four 500 litre drums in a stillage, one 3 cubic metre box or one 3 cubic metre drum. The SWTC-150 has a slightly larger cavity dictated by the need to carry the MBGWS box.

The initial SWTC design was based on its predecessor, the Re-usable Shielded Transport Container. The RSTC was developed throughout the 1990's, where various aspects of the design were analysed, such as; the lid closure and sealing arrangements [37], the handling arrangements of the various RSTC packages [38] and an impact assessment of the RSTC-285 [39]. When the planning application appeal was dismissed for the Sellafield site, and it became clear that a facility may be located at a site other than Sellafield it was identified that the waste packages used by the waste producers differed from the Nirex waste packages, and would therefore not fit inside the RSTC. Therefore, there was a requirement to develop a new range of packages, the Standard Waste Transport container (SWTC) in 1999 [40].

Between 1999 and 2003, a number of design changes were made to the SWTC which are documented in an SWTC-285: Contract Design Report [41]. The major design developments included carrying out a detailed FE analysis of the packages, and the removal of lifting trunnions due to bending damage caused on the side walls during handling and the boring of holes in the body upstand to handle the packages. Since 2004 a considerable amount of design work has been carried out, including a successful drop test of a 1/3 model of a SWTC-285 package [42]. An overview of the design development of the SWTC-285 is contained within [43].

5.2.2 Disposal Container Transport Container (DCTC)

RWM has developed a conceptual design for the DCTC that will be used for the transport of disposal containers containing HHGW. The outline design developed for the DCTC [44] proposes that the DCTC has a dumbbell configuration consisting of:

- a cask body;
- a cask lid attached to the body by bolts; and
- a pair of impact limiters enclosed in steel housings at each end of the cylindrical cask body.

The cylindrical shape of the DCTC makes it necessary to support it within a transport frame during shipment. It is fixed by means of four trunnions, two on either side of the DCTC body. The transport frame will be secured to the transport conveyance.

Two pairs of trunnions are attached to the cask body. Each trunnion sits within a recess in the cast steel cylinder and is connected to the body by bolts. All four trunnions will be used as tie down points during transportation. The pair of trunnions at the bottom end of the cask can be used as pivots on the transport frame when rotating the cask from a vertical orientation to a horizontal orientation and vice versa. This will be done during installation onto the transport frame in preparation for transport and vice versa during removal of the transport frame on completion of a transport operation. The tilting operation is carried out with the end shock absorbers removed.

A key and potentially restrictive requirement for the DCTC is its loaded mass should not exceed approximately 60 tonnes or 65 tonne with its transport frame. This was to allow rail transport to be compatible with the current design of four axle wagon. A consequence of this mass limit was the importance of developing an optimised radiation shielding design with the lowest implications on mass.

The maximum diameter of the DCTC is currently limited to approximately 2.35m. This was determined from the DCTC being transported on the current ‘swan neck’ rail wagon design where shock absorbers with a diameter exceeding approximately 2.35m would start to encroach on the upper height limit of the rail loading gauge (W6a or W6b dynamic). If it were possible to mount the DCTC at a lower height above the rail head on another rail wagon design, then the maximum diameter limit could be increased.

5.2.3 Shielded Waste Packages

Less hazardous LHGW is assumed to be packaged in ‘industrial packages’; typically large steel (2m and 4m), concrete boxes (6 cubic metre box) and TDC’s for DNLEU. These would have external dose rates low enough to permit handling by conventional industrial means, such as forklift or stacker trucks. These packages are designed to meet all reasonably foreseeable conditions of waste management – including storage, transport and emplacement – in their own right, with no additional containment or shielding required at any stage [2].

5.2.4 Transport Overpack

It is currently assumed that Robust Shielded ILW (RSILW) containers and concrete drums will be transported to a GDF within a transport overpack. A transport overpack is an enclosure that forms one unit for convenience of handling and stowage during transport, but does not form part of the approved transport package. They provide no additional containment or shielding but would allow standardised lifting features during transport and handling. At this moment in time there is no design for the transport overpack and it is assumed to be a standard ISO freight container [2].

5.3 Transport Conveyances

5.3.1 Rail Wagon

A conceptual design for a main-line rail wagon design to transport the SWTC and DCTC has been developed [45] and is based on the rail design initially developed for Nirex and described in [46]. The rail wagon design has been developed to comply with the following requirements:

- The wagon will be capable of carrying any of the waste package types, loaded in a transport container where appropriate, to a maximum gross mass of 65 tonnes;
- The wagon will be capable of carrying all such packages singly, or in multiples or combinations that meet the other design requirements;
- The wagon will have an axle loading of no greater than 22.5t when fully loaded;
- The wagon will comply with the national rail infrastructure loading gauge (currently W6A); and

- The wagon will be designed for operation at 100km/h as part of a train with a trailing load of up to 1800t.

The resultant rail wagon design is a two-bogie, four-axle wagon with a central well deck and a length of 16.6m.

5.3.2 Road Vehicles

Road vehicles will be required for movements of transport packages containing radioactive waste for the following journeys:

- directly from waste producing sites to a GDF (or port) in the event that rail transport is not a viable option; and
- transfer from waste producing sites to a railhead where transport packages are transhipped to rail wagons for onward movement to a GDF.

Within the UK, road vehicles have to be designed, constructed and operated in accordance with the Road Vehicle (Construction and Use) Regulations (C&U) [47] which set out standards to which new road vehicles will be constructed, together with standards and restrictions regarding their safe ongoing use on the highway network.

The designs for road vehicles for the transport of radioactive waste packages are contained within [48]. These designs were based on those prepared by Nirex [49] and updated to reflect amended legislation and trailer features available.

5.4 Transport of Construction materials, excavated spoil and personnel

Construction materials, spoil and personnel associated with building and operating a GDF would also be expected to arrive at a GDF by road or rail.

Rail is assumed to be the primary means for importing bulk construction materials and for the export of any excess rock spoil. The transportation of bulk and palletised material using rail is widely practised and involves the use of open rail wagons to allow automatic or manual overhead loading. All movements of spoil, backfill and construction material by rail will be dependent on the payload (number of wagons multiplied by wagon payload) per freight train. Train length is governed by route restrictions on trailing weight and trailing length and length restrictions imposed by railheads and sidings. Clearly, the payload of a train will directly influence the number of train trips, and longer train lengths may only meet the trailing weight restrictions if the wagon payload is reduced. However the option of road transport for construction materials and other goods has to be retained for reasons of long-term robustness and flexibility. Facilities and resources have therefore been provided in the illustrative designs for both rail and road transport of construction materials, excavated spoil and other goods and it has to be recognised that the balance of these is very likely to vary with time.

Personnel would arrive at a GDF either as pedestrians, cyclists, public transport users or private car occupants on either road or by rail. A car park and bus terminal would be located outside of the boundary fence of a GDF and shuttle buses would take personnel from the car park and bus terminal onto the site. This would ensure that cars and regular service buses are not driven onto site and would enhance security (Section 14.1). The provision of staff car parking spaces will take into account the requirements of both the construction workforce and the operational workforce. Depending on the availability of public transport in the vicinity of the site, a significant proportion of site personnel may travel by public transport, thus reducing the need for on-site parking provision. A railway station has been included in the illustrative designs, located outside of the perimeter fence of a GDF. However, the viability of a rail service for workers has yet to be assessed in light of the numbers regularly commuting to and from the site.

Careful attention to the design of the transport system, selection of the most appropriate transport modes, transport routes and sympathetic infrastructure development will all serve to minimise any potential adverse environmental effect and, at the same time, will result in a transport system which can be operated in a safe and efficient manner.

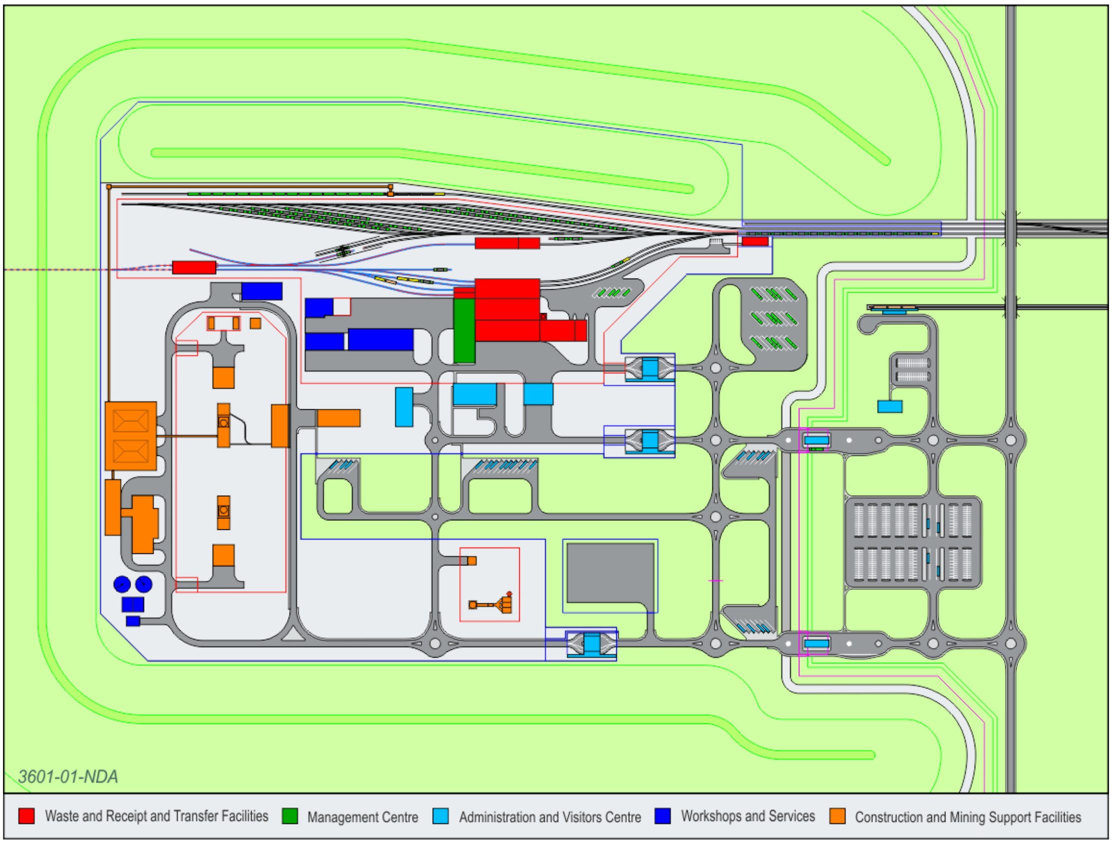
6 Surface Structures, Facilities and Infrastructure

In the absence of a specific site or sites, and for the purpose of developing illustrative designs, the current designs have been developed with all surface structures, facilities and infrastructure on one single site. The design does not address aspects of spatial and topographical detail which would only be possible once a specific site, or sites, has been identified. Consequently, the surface facilities have been configured to a simple flat-lying site. The illustrative surface layout is shown in Figure 4.

The surface layout initially occupied a $1km^2$ site but that has now increased to approximately $1.5km^2$ due to a review of the security, which identified a number of changes to the design (Section 14.1). The results of the most recent security assessment has been used to ensure the proposed security measures are robust and include an increase in fencing and barriers, relocation of car parking to outside of the perimeter fence and a reduction in the sections of straight road leading up to the facility [50].

There are a number of screening bunds on the site which would be designed, as far as possible, to integrate with the local topography and landscape character. These would be used to store excavated spoil from the underground prior to any potential re-use underground.

Figure 4 Illustrative Surface Layout



At this stage in the programme RWM has assumed generic industrial and office type buildings, however, in practice the design of the surface facilities would be an interactive process taking into account a landscape and visual impact assessment. The visual appearance and setting of a GDF in the landscape would be influenced by a combination of building design, materials, layout, structure, form and colour, landscape works (both on site and off site) and the local topography.

Surface facilities are to be designed to meet all stakeholder requirements including those of the host community. The buildings and structures, whose failure could affect the safe operation of the facility, would be seismically qualified and designed to cope with factors such as extreme weather conditions. The design of the buildings would also include appropriate security features as required for the waste types. The facility would operate under different categories through its lifecycle and more information regarding the various categories can be found at Section 14, Security and Safeguards.

The surface facilities have been arranged into three main areas, construction and mining support facilities, waste and container receipt and despatch facilities and surface infrastructure[6]. This grouping could also enable them to be located at different site(s) if required due to footprint constraints. Additionally, the facilities identified are considered to be the minimum required to enable the safe operation of a GDF in terms of construction and emplacement.

When considering conventional and radiological safety, it is prudent to physically segregate and thereby demarcate construction and waste handling operations, using security fences, with separate controlled access to each area. The waste handling and transfer operation would be classified for radiological protection based on the potential levels of radiation and contamination in each area.

The shafts associated with construction, offices and some associated infrastructure are not considered as requiring radiological security and are contained within their own security fence as is the emplacement return shaft. Controlled access to this area will still be required. Materials handling facilities associated with construction are located adjacent to the construction shafts but outside of their associated fence. Controlled access is required but to gain access to the construction shafts, offices and associated infrastructure would require passing through an additional controlled access point.

Emplacement related facilities including rail sidings are all contained within one security fence, the same fence that contains the waste and container receipt and despatch facilities, as the level of security is the same.

Administration buildings, visitor centre, car parking and rail station for personnel are located outside of the outer security fence as they are neither associated with the construction nor emplacement facilities.

6.1 Construction and mining support facilities

Surface construction support facilities can, typically, be described as:

- Materials handling (conveyors and crushing plant for excavated rock).
- Buffer materials' handling plant.
- Offices, workshops, stores and marshalling area.
- Fire and rescue.
- Explosives store (magazine).

There are other facilities that are required such as drill core store but the foregoing are the main requirements to support ongoing construction activities.

The materials handling elements are designed to allow:

- Excavated waste rock that arrives at surface from the underground environment to be crushed and:
  - stockpiled for further use;

[6] Surface Infrastructure includes administration and visitors centre, management centre and workshops and services as shown in Figure 1.

  - used on site for temporary or permanent screening bunds to minimise spoil generation and, where possible, to maximise its retention on site (not evaporite rock);
  - removed from site by rail if surplus to requirements;
  - returned back underground for use as backfill, if appropriate.
- Receive waste rock from off-site to be returned back underground for use as backfill, if appropriate.

An initial screening bund for the siding would be constructed from the surface strip and excavated spoil. This screening bund would be formed between the perimeter fence and the rail receipt sidings at an early stage of construction and before commencement of disposal operations. This would provide radiation isolation and visual screening for members of the public from transport packages in the rail sidings during GDF operations.

A buffer materials' handling plant (higher strength and lower strength sedimentary rock only) is located on surface and would be used to prepare buffer materials for emplacement around disposal containers. In the higher strength illustrative design, the facility would form pre-compacted blocks and rings for use in deposition holes as well as blocks and granulate for backfilling the HHGW disposal tunnels. In the illustrative design for a lower strength sedimentary rock, the buffer materials handling plant would be required to produce blocks of bentonite and granulate for use in HHGW disposal tunnels. The buffer materials handling plant would also use be used to mix crushed rock spoil or sand and bentonite to be used as mass backfill for common services area and roadway infrastructure in the higher strength and lower strength sedimentary illustrative designs respectively.

Construction activities are separate from emplacement activities, due to security and safety concerns, and so there is a need for separate offices and facilities (changing area) for construction personnel, control room, lamp room and medical room. Workshops (electrical and mechanical) and associated stores, are required to enable equipment servicing, maintenance and repair. A marshalling area linked to the construction return shaft is required for receipt of construction materials prior to onward transfer underground.

A fully equipped surface Fire and Rescue Station is required 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. Specialist personnel and equipment would be catered for so that prompt action could be taken. Supplementary, assistance would be sought from the local fire services and National Mines Rescue in the event of a large scale emergency.

6.2 Waste emplacement support facilities

The principle facilities located on surface that support waste emplacement activities include those for:

- Ventilation.
- Active effluent treatment.
- Management.
- Transport management.
- Drift and shaft transport vehicle maintenance.
- Shunting engine maintenance.
- Laboratories.
- Active laundry.
- Mechanical and electrical workshops and stores.
- Administration and reception.
- Visitor centre.

These support facilities would be located together to simplify the security arrangements and the control of ventilation. Ventilation facilities are required to provide ventilation of the nuclear facilities on the surface, and the normal provisions for ventilation and air conditioning on the surface. Facilities will also be required for the construction and emplacement activities in the underground environment and as the two ventilation circuits are separate there is one fan house on surface for the emplacement ventilation circuit (adjacent to the emplacement return shaft) with the construction ventilation circuit fans being located underground. The discharge stack would be located at least 100m from the underground accessways to minimise the risk of radiologically contaminated emplacement return air being recirculated underground through contamination of underground air intakes.

An active liquid effluent treatment facility is required to treat all active liquid effluent arising from the surface and underground operations. The need for treatment facilities for liquid effluents is related to the regulatory requirement to use best practicable means to reduce discharges. Facilities for collection, sampling and analysis of liquid effluent streams will be necessary.

A management centre is located within the emplacement surface facilities and will provide all management activities associated with the GDF.

A separate transport management centre is located close to the road and rail arrival and dispatch area to check and process documentation relating to transport packages on arrival and reusable transport containers on departure from site.

Maintenance facilities required for drift and shaft transport vehicles and for shunting engine and main-line wagons are located adjacent to the sidings and waste package receipt and transfer building. These facilities will be required as maintenance of these vehicles will be undertaken on site unless specialist services are required.

An active laundry would be provided on site. This would be a separate facility within the active area to handle the laundering of clothing used in the active operations area. Laboratories would share the same building as the active laundry. Their role would be to analyse active or potentially active liquid and gaseous samples taken from various operational processes on the site.

Mechanical and electrical workshops and stores would serve both surface and underground operational requirements for the supply and maintenance of equipment.

An administration and reception building would provide offices for staff engaged in managing the disposal facility.

A separate visitor centre is located outside the fenced site boundary. This will allow the public access to a static exhibition, a computer simulation of the disposal facility operation, conference facilities, meeting rooms and demonstration facilities.

6.3 Waste receipt and transfer

A key feature of the entire radioactive waste transport system is the requirement that the number of waste packages above-ground at the disposal facility should be as low as reasonably practicable. This eliminates the need to duplicate the storage facilities that already exist at the waste producing sites, reduces the potential number of package handling operations (and any associated dose) and minimises land use at the GDF. To do this, waste package deliveries to the disposal facility shall be scheduled to ensure that the required emplacement throughput can be maintained. The waste package delivery strategy schedules packages for delivery at a rate that allows immediate emplacement.

For the illustrative designs, the rail sidings have been designed to meet the following requirements [3]:

- To accommodate a main-line train, currently assumed to consist of up to 12 wagons (including two locomotives).

- To handle the expected peak daily arrival rate of approximately 10 waste packages per day.
- In conjunction with the dispatch sidings, to act as temporary short-term storage so that in the event of unplanned interruption to the disposal operations (assumed to be a maximum of 1 week in duration) all transport packages already in transit could complete their journey to the facility. In that event, further dispatches from waste producers' sites would be postponed until the backlog is cleared.
- Disposal container transport containers (DCTCs) would not be stored in the sidings but placed into the HHGW waste transfer building temporary storage area.
- In conjunction with the arrival sidings, the dispatch sidings provide sufficient storage for the entire facility fleet of rail wagons and sufficient space to marshal these wagons.

To eliminate the risks associated with unauthorised trains inadvertently entering the designated nuclear-licensed site boundary area, it is currently proposed that two off-site rail sidings parallel to the main line would be provided to receive the consignments of rail wagons carrying transport packages.

For road transport of waste packages, the current planning assumption for the illustrative designs is based on an average rate of approximately two waste vehicle arrivals per day [3]. Facilities has been provided at the site entrance to permit up to two heavy goods vehicles (HGVs) to park at any time while documentation is being checked at the gatehouse. In addition, a turning area would be provided outside the site security fence to turn back unauthorised vehicles.

Within the site, a parking area would be provided for up to 26 HGVs, to accommodate both arrivals and dispatches and also to provide parking for HGVs and trailers not in use. A segregated parking area would be provided for HGVs carrying transport packages, while waiting to enter the waste package transfer facility.

Transport packages will be delivered by road or rail to the relevant waste receipt and transfer building (HHGW or LHGW). To ensure this happens safely, a shunter would be used to transfer these rail or road wagon to the relevant facility. Due to the currently assumed transport arrangements, the LHGW receipt and transfer facility has been designed to accept both road and rail wagons whilst the HHGW facility has only been designed for rail wagons.

Transport packages will then be monitored and transferred from their transport vehicle to the drift or shaft wagons. Transfer will be undertaken by crane with drop heights kept to a minimum. Facilities will be provided to maintain and repair re-usable transport containers on-site.

6.4 Surface Infrastructure

Surface infrastructure comprises but is not limited to:

- Personnel access.
- Security fencing and vehicle access control points.
- Electrical sub-station and compound.
- Exterior lighting.
- Water supply.
- Site drainage.

Personnel would most likely arrive at a GDF either by road or rail. A car park, bus terminal and a railway station are located outside of the GDF perimeter fence. Shuttle buses would take personnel from the car park, bus terminal and railway station to the security gatehouse. Personnel would leave the bus and pass through security turnstiles before reboarding the bus. This would ensure that cars and regular service buses are not driven onto site.

The perimeter of the GDF would be controlled to prevent unauthorised access. Boundary fences will be designed to meet the appropriate regulatory standards for a licenced nuclear site.

Two independent electrical supplies will be taken from the distribution network to feed two surface sub-stations, one sub-station located within the operational area and a second sub-station within the construction area. The surface sub-stations should supply power to both the surface and underground facilities. The surface sub-station design would be based on duplication of in-feeds, transformers and distribution boards at each sub-station, with the capability to cross-connect sub-stations in order to supply power to the entire GDF in the event of loss of supply at either surface sub-station. The electrical system is described in more detail in Section 11.4.

There should be three types of exterior lighting on the site: operational, amenity and security. Particular care should be taken in the specification and siting of all surface lighting in order to minimise light pollution outside of the site without compromising safety and security. A screening bund around the site could be designed to help to minimise light pollution.

Water would be needed for various operations during construction (e.g. small volume concrete batching), emplacement (e.g. welfare facilities) and backfilling operations (e.g. for use in the preparation of NRVB/cementitious grout). Water would also be required for cleaning purposes, such as washing down equipment or flushing through grout pipes after construction or backfilling activities. Process water would be used for decontamination activities. Water would also be necessary for fire suppression systems and firefighting provision. A storage tank should be provided on site, of sufficient capacity to ensure an emergency water supply in the event of a failure in the normal supply.

The surface water drainage system would be designed in accordance with best practice, with due consideration for topography and the local drainage regime as required under Environmental Legislation.

7 Underground Access

Access to the underground facilities would be via a combination of shafts and a drift, or shafts only, depending upon the host geology. For the illustrative designs in a higher strength rock and lower strength sedimentary rock, access underground is assumed to be via a drift and three shafts constructed for ventilation and spoil removal. For evaporite rocks, access is assumed to be via four shafts. A shaft provides a shorter, more direct means of access to the disposal horizon when compared with a drift. This is considered a benefit in an evaporite host rock as there is a shorter excavation distance through the rock, which is likely to demonstrate creep (plastic deformation) over time resulting in convergence of the excavation (Note: creep of the host rock is required as part of the disposal concepts in an evaporite rock). This deformation will apply incremental stress to the rock support system and liner, leading to an increased maintenance requirement and a possible need to undertake refurbishment of the access during the operational period.

A drift would have a greater excavation length through the evaporite host rock, due to its shallower gradient. Therefore, a greater portion of the rock support system would be affected by the creep of the host rock thereby requiring more significant maintenance and refurbishment.

Four separate underground access routes provide security of access and egress, separation of construction and operational activities and separate ventilation circuits for both construction and operation. It is recognised that the detailed design and configuration of these facilities will require development as the project advances.

7.1 Drift

The drift, an inclined tunnel, also known as a ramp or decline, is considered to be the preferred option for access from the surface to the disposal horizon for higher strength and lower strength sedimentary rock illustrative designs only. It would be constructed at a maximum gradient of 1 in 6 [51] and would connect the surface waste transfer facilities with the underground emplacement support facilities. This gradient is considered to be the maximum feasible for a rack and pinion system given the masses assumed for transfer underground. It would also serve as the air intake for the emplacement ventilation circuit.

The drift would be the principal means of access from the surface site to the underground emplacement facilities. Its primary functions would be to:

- Allow the transport of waste packages and containers.
- Allow the transport of large components.
- Allow the transport of operational personnel.
- Allow the export of liquid effluents.
- Provide a second means of egress from underground.
- Provide a route for services.
- Provide an intake airway for emplacement ventilation.

The drift locomotive is proposed to be electrical to minimise particulate and gas emissions from contaminating the facility which could arise from diesel operated locomotives and to minimise fire loading.

The drift dimensions have been determined to provide the appropriate dynamic envelope for the specified transport system and for the installation and maintenance of services (power, water, pumping, communications and control).

The invert of the drift will be laid with concrete to support the rack and pinion trackwork of the permanent transport system.

A drift was originally chosen as the waste emplacement route as it was capable of handling and transporting heavier packages (up to 80 tonnes) than conventional shaft transport.

Recent studies into improved shaft winding technology has shown that shafts can now handle a maximum of 140 tonnes compared with current drift transport technology which can handle 120 tonnes [52]. This increase would enable the GDF to handle heavier and larger packages should it be required. Conversely, transporting such loads on roads is likely to have its implications such as the need for special permits and licencing.

The drift system would be on a separate rail system (rack and pinion) to that used for surface rail receipt (adhesion rail), to avoid direct connection to the underground access drift. In accordance with standard rack and pinion railway practice, the drift locomotives would always be at the downhill end of the train while in the drift. The locomotives and vehicles would be equipped with multiple failsafe braking systems and two locomotives would be used to ensure safety should there be a failure with one of them. All drift wagons would be specifically designed for rack and pinion operation. They would be equipped with brakes that engage with the fixed rack.

In the higher strength rock illustrative design, the drift would be approximately 4km long (including transition curves at the top and bottom) based on the assumed depth of 650m and gradient. The drift would comprise a 5.5m diameter lined section for 1,800m (to pass through the first 300m depth from which is assumed to be surface of overlying, water-bearing sedimentary rocks) and then ‘D’ shaped, rectangular with a slight convex, arched, roof (5.5m high by 5.0m wide) to the facility horizon.

In the lower strength sedimentary rock illustrative design, the drift would be approximately 3.3km long (including transition curves) based on an assumed facility depth of 500m. The drift would be 5.5m in diameter for its full length between surface and the facility horizon due to the nature of the host rock and the most suitable excavation technique.

7.2 Shafts

The primary functions of the three shafts common to the illustrative designs in all three geological environments would be to:

- Allow the transport of construction personnel.
- Allow the transport of construction plant and materials.
- Provide personnel working underground with an alternative means of egress to the surface, in line with mining practice.
- Provide ventilation to the construction and operational areas underground.
- Provide an export route for excavated rock.

The construction intake shaft would be the principal means of access underground for personnel and materials and act as the construction ventilation intake.

The construction return shaft would chiefly serve as the export route for excavated rock and also act as an air return for the construction ventilation system.

The emplacement return shaft would serve as a ventilation return shaft and as a means of egress from underground in an emergency. This third shaft in conjunction with the drift would enable separate ventilation of the waste disposal operations from the construction operations.

All shafts would be constructed with sumps for the installation of safety equipment (e.g. shaft bottom arrestors) and has a water storage capacity with pumps and pipe columns to the surface.

Shaft-only access is currently assumed in the illustrative design for evaporite rock. The waste for disposal will be transported underground via a fourth shaft, which would be constructed instead of the drift.

All the shafts in a higher strength rock and lower strength sedimentary rock illustrative design would have a finished internal diameter of 8.0m, to ensure that there is adequate space to convey personnel and materials, and would be excavated using well established technology such as drill and blast [53].

In the evaporite rock illustrative design, the shafts would have a finished diameter of 8.0m, with the exception of the emplacement intake shaft, which would be 9.0m [53] to accommodate the transfer underground of transport containers, specifically the DCTC.

Permanent shaft support would be provided by a mechanical lining (concrete) and hydrostatic pressure-resistant lining installed where necessary to prevent the ingress of water and ensure safety. The main difference between the two types of lining is their thickness, with the hydrostatic liner being thicker. However in the evaporite rock illustrative design, the bottom section of the shafts would have a concrete lining to give long-term integrity with minimal maintenance, however this lining will not need to be hydrostatically pressure-resistant, due to the lack of water present within an evaporite.

7.3 Arrangement of access routes

All access routes are, for the illustrative designs, located on a single surface site, the construction intake and return being separated from the emplacement intake and return by security fences. The possibility that access routes could be located on separate sites has not been discounted.

The construction intake is located in close proximity to the construction offices and marshalling area for ease of access for personnel and materials.

The construction return is located in close proximity to the rock crushing plant and stockpile for ease of transfer of excavated waste rock from underground.

In the higher strength rock and lower strength sedimentary rock illustrative designs, the emplacement intake, drift, is located close to the waste package receipt and transfer facility. This allows for the minimum distance for a waste package transfer between surface and underground. It is also close to the management centre for ease of access for personnel. The emplacement return shaft is located on a remote part of the site, however, in practice, it could be located at a different site independent from the surface facilities.

The emplacement intake shaft in the evaporite illustrative design is located adjacent to the waste package receipt and transfer facilities allowing the minimum distance for waste package transfer between surface and underground. It is also close to the management centre for ease of access for personnel. The emplacement return shaft is located adjacent to the emplacement intake shaft, however, as in the higher strength and lower strength sedimentary illustrative designs, in practice, it could be located at a different site independent from the surface facilities.

Currently, it is assumed that the surface facilities would be located directly above the underground disposal facility but it is recognised that surface facilities could be in a different location to the underground site and linked by access drifts or shafts and service tunnels. Dependent upon site specific factors, a lateral separation distance of the order of up to 10km between the surface facilities and the underground vaults could be feasible, based on an underground facility located at a depth of 1,000m. In such a scenario there may be a need for some surface facilities to be located directly above the underground facility, perhaps separated from the main surface site by several kilometres. This is the approach currently planned for ANDRA for their deep geological disposal facility for spent fuel, high level waste and intermediate level waste.

In the underground environment all access routes enter the facility horizon in close proximity to each other in the Common Services Area.

8 Underground Arrangements

8.1 Facility depth

The geological barrier is provided by the rock in which the GDF is constructed and the surrounding and overlying rocks. Many rock formations in the UK have been stable for many millions of years and so may has the ability to assist in the isolation of the wastes from the surface environment over the long timescales required.

The range of possible depths for a geological disposal facility has been specified as between 200m and 1,000m below ground surface [1]. In suitable formations deep underground, the GDF is protected from significant climate or landform changes at the surface and any movement from earthquakes is much reduced.

A minimum depth of 200 m is specified to provide a depth of cover greater than the likely maximum extent of erosion during the next one million years. Studies have indicated that the average depth of erosion that occurred in the UK during the Quaternary (the last 1.6 million years) was 130–160m. In contrast, 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. Minimum depths of cover above a potential geological disposal facility will need to be evaluated on a site-specific basis. However, for the purpose of the current illustrative designs it has been nominally assumed that the minimum depth of cover required over a geological disposal facility is 200 metres.

The maximum depth for a GDF is likely to be defined by practical and economic considerations. Ground temperature and in situ rock stresses increase with depth such that the stability of underground excavations (for a given set of rock mass properties) tends to reduce with increasing depth and increasing stress. These various factors related to increasing difficulties and costs of construction tend to impose a practical limit to the depth of a disposal facility. A maximum depth of a disposal facility of 1,000 metres below ground surface has been assumed. However, it may be possible to construct a GDF at a greater depth if necessary.

Based on the illustrative geological disposal facility concepts examples (Figure 1) that have been used to underpin the illustrative designs, the following depths has been assumed:

- higher strength rock - 650m
- lower strength sedimentary Rock - 500m
- evaporite rock - 650m.

8.2 Underground Layout and Construction

At this stage the underground facilities are assumed to be constructed on a single level or horizon to provide simplified indication of how a layout may look (Figure 1). In practice, it may be possible or desirable to build a GDF over multiple horizons or discrete, smaller areas. This could be by virtue of the host rock being sufficiently thick, the presence of geological structures such as faults or due to the presence of a different, suitable host rock above or below the proposed facility horizon. If such geological conditions prevailed and if the rock mass characteristics were acceptable, then it could be possible to develop the facility on multiple levels.

The illustrative underground layouts have been configured to limit the amount of construction work required up to first waste emplacement. This approach would allow the disposal facility to be developed using continuously improving systems and equipment over time.

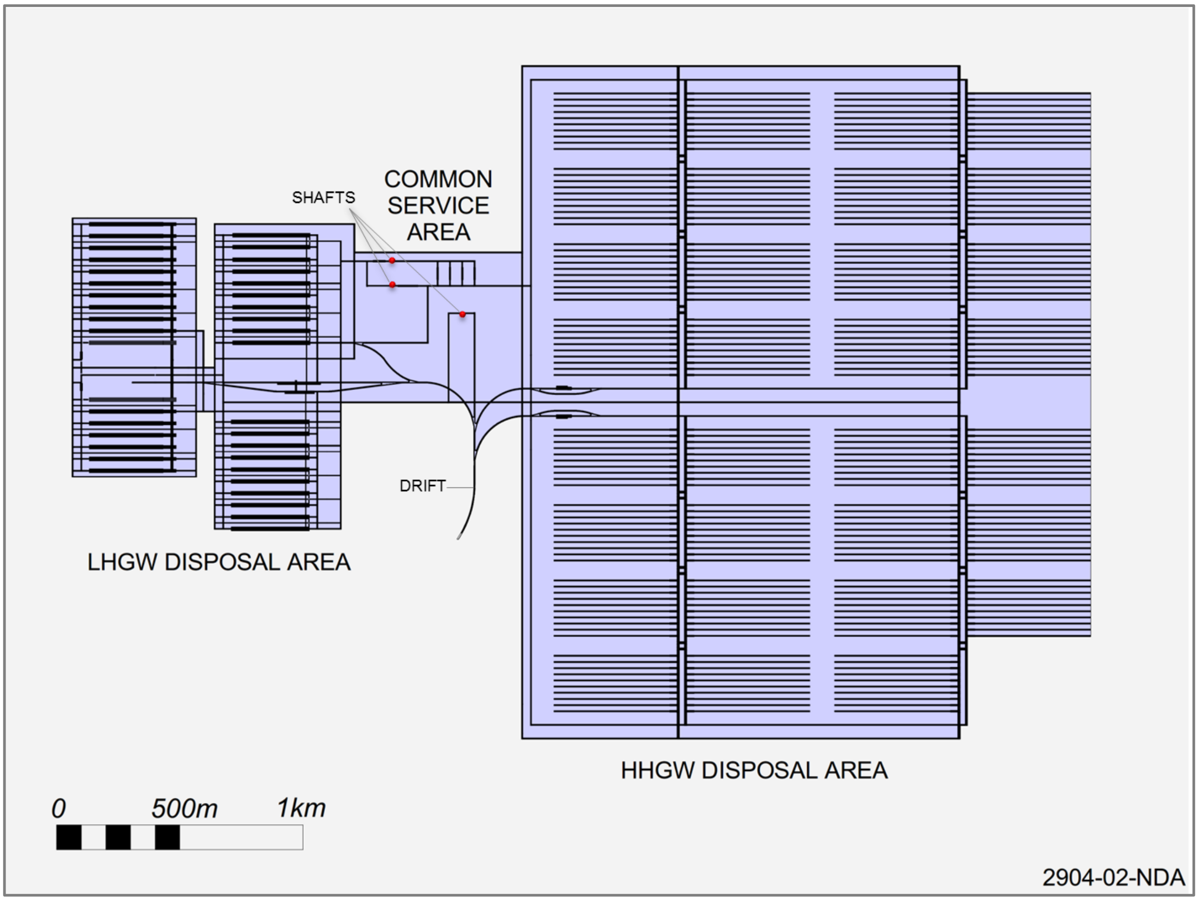
The underground infrastructure and support facilities has been designed to allow the disposal of waste to take place at the same time as ongoing construction, by providing segregation between these activities. This would be facilitated by utilising airlocks, bulkheads and seals between different zones and areas underground and by the provision of independent ventilation circuits (discussed below).

The underground layouts are idealised, in that disposal vaults and tunnels are constructed with uniform dimensions on a regular grid pattern. To provide flexibility, they have been arranged in groups / modules which would be constructed in 'blocks' on an as required basis. This would minimise the time the excavation would be open and allow construction techniques to improve taking into account technological developments and learning obtained for the previous construction and investigation activities.

Strict control would be maintained on the extent of excavation damage caused to the surrounding rock by controlling the blast design (where applicable) and by careful management of the excavation operations. This would limit the extent of the Excavation Damage Zone (EDZ) around the excavation, which could provide a preferential pathway for the movement of radionuclides.

It is currently assumed that the HHGW waste receipt and handling facilities would be constructed at a later date than LHGW disposal areas, allowing sufficient time for commissioning prior to waste acceptance at the facility. Provision would be made in the surface design for this facility to be constructed without interfering with ongoing LHGW emplacement activities.

Figure 5 Illustrative Underground Layout in a Higher Strength Rock



Two separate underground ventilation circuits are required, one for construction and one for emplacement. The construction ventilation circuit will be under positive pressure and the emplacement ventilation under negative pressure. This should ensure that any leakage will be from the high pressure construction circuit to the low pressure, emplacement one. Crossovers will allow personnel to cross between ventilation circuits, which could be required during an emergency.

The current illustrative disposal facility designs recognise the potential for interaction between co-located disposal areas of a GDF. Notably this includes the potential development of an alkaline plume related to the use of cementitious backfill materials for LHGWs, which could has negative geochemical impacts on the bentonite systems envisaged for disposal of HHGW (in higher strength and lower strength sedimentary rocks) and also thermal interactions. To minimise the effects of such interactions, the current planning assumption, irrespective of host geology, is to observe a minimum 500m separation distance between the LHGW and HHGW disposal areas. However this is an assumption and the characteristics of the host rock will determine the exact separation distance.

The termination points for the drift and shafts are assumed to be on the hydrogeological upstream side of the facility (i.e. groundwater flow would be away from these accesses) to minimise the risk of radionuclides using these as a preferential pathway for the return of activity to the surface environment during the post-closure phase.

Excavation profiles and dimensions would be determined based on the prevailing geotechnical characteristics of the host rock and the in-situ stress regime, and would be sufficient to provide adequate long-term stability for the duration of the construction, operation and closure phases. In the current illustrative designs the layouts assume that the excavations are aligned parallel to the maximum horizontal stress to aid excavation stability. In the recent design report [3] these has been updated to be consistent between all three host geological environments.

Excavation profiles and design of rock support systems has been taken from sister WMOs and international precedent in mining and tunnelling, tailored to the waste package types in the UK Inventory, and are summarised in the '*Design Assessment for Geological Repositories*' report [54]. Such an approach is regarded as appropriate for a generic study of repositories in circumstances where site specific data on rock mass conditions are not available, but where extensive information on precedent practice is available. The excavation profiles have been reviewed and rock pillar spacing has been calculated for each geological environment and these are detailed in the design enhancements report [55]. In practice, at a specific site, vaults and tunnels would be located and sized based on the site-specific geological, hydrogeological and geotechnical conditions.

The long-term stability of excavations is an important consideration, bearing in mind the currently assumed operating period of the facility; some features including the shaft, drifts, and common services area will be required to be stable and serviceable for up to 160 years. Excavation support, maintenance and associated monitoring considering this extended operating period will be a key area for future design activities to ensure this can be achieved. A system of ground monitoring would be established to enable decisions to be made regarding the need for maintenance to the excavations as required. The excavation design would be undertaken in such a manner to ensure, as far as is reasonably practicable, that the excavations require minimal maintenance. For the extended design life of approximately 160 years that is currently required based on the 2013 UK RWI, there would be a need for maintenance of the main underground accessways. It is assumed that access to the facility excavations for inspection and maintenance would be available in all but the remotely operated areas, which could be inspected using remote means. Maintenance requirements of the support systems will vary with the rock types, but as rock strength reduces and/or depth increases, then more reliance would be placed on the support systems rather than the rock itself.

To support these construction principles, a blasting study has been undertaken [56] to assess the vibration and air overpressure effects from blasting operations in a higher strength rock. The study assessed the vibration and air pressure in disposal vaults at distances of 50m and 100m from blast operations, which correspond to the distances for disposal vaults undergoing fit-out and emplacement operations adopted in the higher strength rock illustrative design. The sequence of Unshielded ILW (UILW) vault construction and disposal would mean that there would be at least one constructed but non-operational vault separating these activities. This separation, by pillars of rock coupled with the design of blast patterns, where required, would be sufficient to ensure that blast vibration would not affect the waste emplacement operations.

9 LHGW Handling and Emplacement

The current three illustrative designs (higher strength rock, lower strength sedimentary rock and evaporite) are based on the six geological disposal concepts identified in Figure 1. For LHGW, the illustrative designs, including waste handling and emplacement are based on the UK PGRC concept in a higher strength rock, the Nagra concept in the lower strength sedimentary rock and the concept used at WIPP in the evaporite rock.

The LHGW disposal area is currently assumed to consist of a series of disposal vaults connected by access/transfer tunnels. There would be four types of disposal vault within the LHGW disposal area to cater for the different LHGW waste package types in the 2013 UK RWI [3]:

- UILW disposal vaults to accommodate legacy UILW (including a small volume of DNLEU not considered for disposal within TDCs [58]);
- Shielded ILW (SILW) and LLW disposal vaults to accommodate legacy SILW and LLW waste packages;
- Dedicated disposal vaults to accommodate DNLEU packaged in TDCs;
- Dedicated disposal vaults to accommodate Nuclear New Build (NNB) SILW concrete drums from new nuclear power stations which will have specific handling requirements;
- Dedicated RSILW disposal vaults to accommodate RSILW containers which have specific handling requirements.

All of the disposal vaults are constructed to allow through flowing ventilation and the waste packages are placed on a concrete of sufficient strength.

It is currently assumed that UILW is not mixed with SILW/LLW, NNB SILW or RSILW due to different handling arrangements. Due to way UILW waste packages are transported remotely to the disposal vault through a transfer tunnel, the UILW vaults are in modules separate from other LHGW disposal vaults.

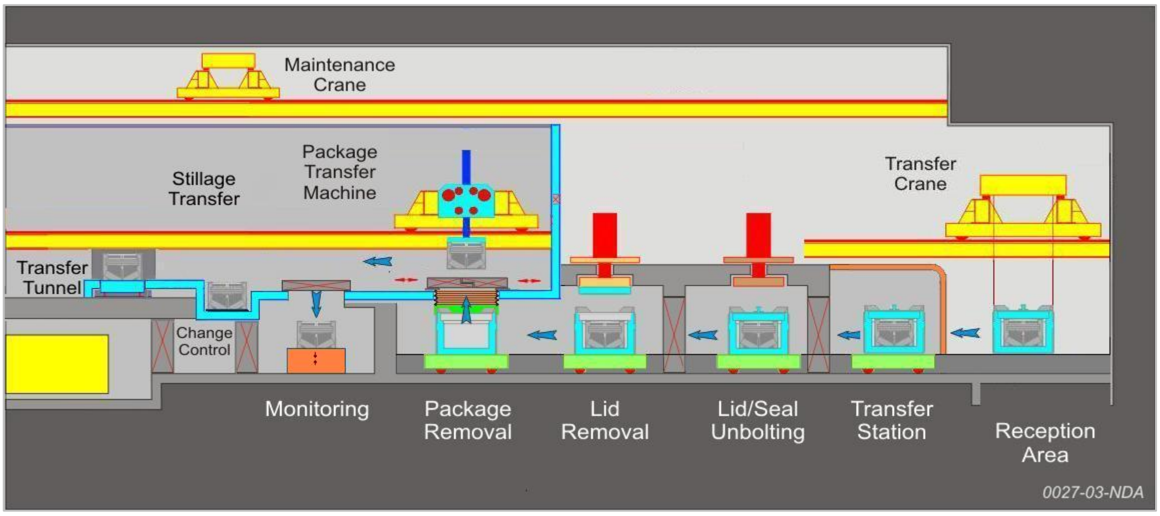
Within disposal vaults there are no mixed stacks or mixed arrays due to different handling and package stacking arrangements.

The disposal vaults are all 300m long in each of the three host geological environments. This length has been based on the PGRC design [25] and the length has been made consistent across all host geological environments to aid comparison between different geologies and for different inventory scenarios.

9.1 Unshielded Intermediate Level Waste Handling and Emplacement

UILW packages are transported underground in a standard transport container (SWTC) to the inlet cell where the waste package is remotely removed from its transport container. At the inlet cell the waste packages would be verified by their unique identified, they would be monitored and then transferred for emplacement in a designated disposal vault. The inlet cell is located underground to enable the waste packages to remain in their transport configurations virtually to the point of disposal. The inlet cell would be shielded and would also allow for the containment of any radioactive material. The process of the inlet cell is shown below in Figure 6.

Figure 6 Schematic Unshielded Intermediate Level Waste Inlet Cell

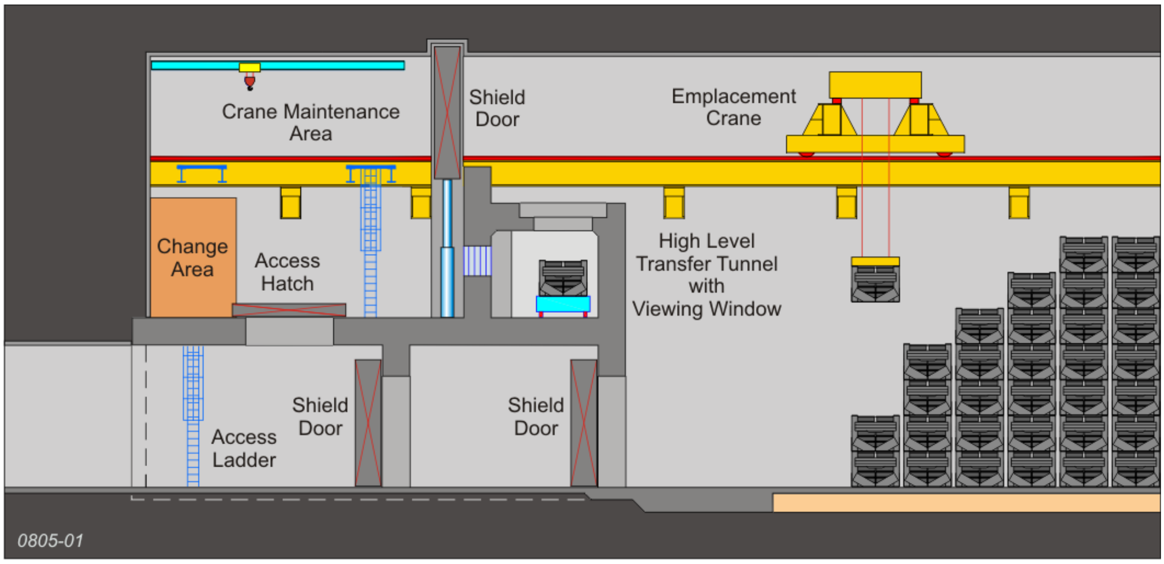


The inlet cell design is similar to all host geological environments although would be tailored to the rock mass properties. As the inlet cell would be required throughout the operational period for LHGW, it is currently assumed that a single inlet cell would be possible in a higher strength rock with suitable maintenance and refurbishment. However, in the lower strength sedimentary and evaporite rock illustrative designs, due to the decrease in rock strength and the potential for creep, ongoing deformation due to in-situ stresses, to occur it is proposed to construct a number of inlet cells over the operational period of the GDF.

The inlet cell has a throughput of 2,500 packages a year [57], which is within the currently assumed operational programme [3]. However should there be a requirement to increase the throughput, additional inlet cells would need to be constructed.

The waste package would then be transferred via a transfer tunnel to a disposal vault where it is remotely placed in the vault. A cross section of the UILW disposal vault in higher strength rock is shown in Figure 7. This design is similar across all host geological environments apart from the change in vault cross section due to the properties of the host rock.

Figure 7 Schematic UILW Disposal Vault in a Higher Strength Rock

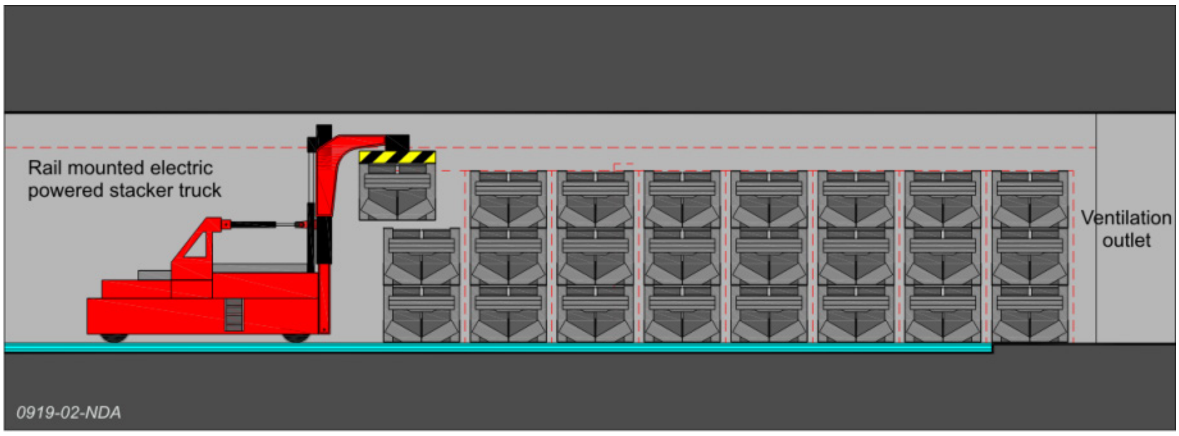


Disposal would start from the far end of the vault, and work back towards the transfer tunnel access hatch.

In higher strength rock and lower strength rock emplacement would be via a crane. A crane maintenance area has been included to allow for direct access to the crane and permit withdrawal into the maintenance area. The reliability of the emplacement crane would be essential to vault operation, so the design would incorporate redundancy and mechanical back-up. To deal with the unlikely event of crane failure, a retrieval system would also be provided to enable the crane to be pulled back into the maintenance area.

However in an evaporite rock illustrative design, the waste packages are emplaced in the vault by a rail mounted remotely operated stacker truck. These packages are not handled by overhead crane in the disposal vault due to headroom restriction from a reduced vault height. If an overhead crane was used it would impact on the volume of waste that can be emplaced in a disposal vault. This disposal vault is shown in Figure 8 below.

Figure 8 Schematic UILW Disposal Vault in an Evaporite Rock



9.2 Shielded Intermediate Level Waste and Low Level Waste Handling and Emplacement

SILW/LLW is transported underground in an industrial package to the SILW/LLW vault access tunnel where the packages are removed from the drift wagon by overhead crane and placed in a temporary store area. The waste package is then collected by a stacker truck and delivered to a disposal vault where it is subsequently emplaced. SILW/LLW can be manually handled and lends itself to direct emplacement in a disposal vault. A stacker truck has been proposed based on the movement and handling of similar sized packages at the Low Level Waste Repository (LLWR) surface facility, near Drigg, Cumbria. The use of a stacker truck also enables efficient use of underground space within the vault with no requirement for large crown spaces for an overhead crane to travel.

SILW/LLW packages would be stored underground in a temporary storage area until a sufficient number have accumulated for an efficient campaign of emplacement.

Disposal would start from the far end of the vault, and work back towards the vault entrance.

The ventilation requirements for SILW/LLW disposal vaults differ from the other LHGW disposal vaults as personnel can be present in a SILW/LLW disposal vault.

9.3 DNLEU in TDC Handling and Emplacement

Due to the inclusion of new package types within the 2013 UK RWI [3], there is a requirement for the majority of DNLEU to be emplaced in TDCs in dedicated disposal vaults [58]. These packages will be handled in a similar manner to the legacy SILW/LLW packages and will be emplaced in a dedicated disposal vault that has the same dimensions as SILW/LLW disposal vaults[7]. The handling and emplacement operations will be as described in Section 9.2, above.

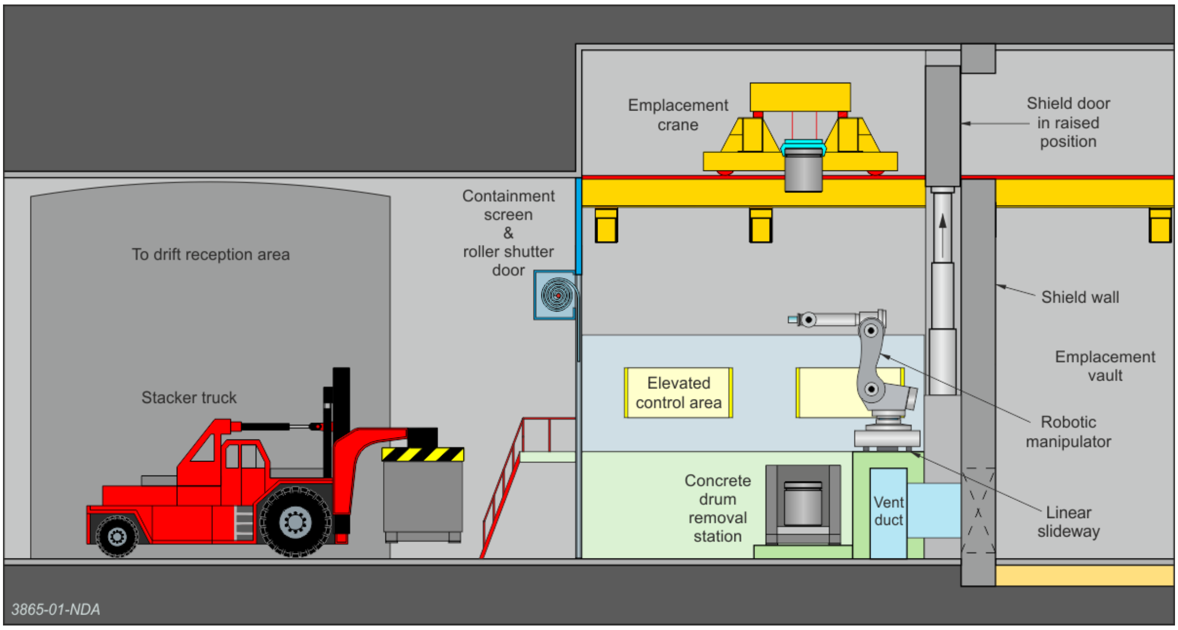
9.4 NNB SILW and RSILW Handling and Emplacement

Due to the inclusion of new package types within the 2013 UK RWI [3], there is a requirement for dedicated disposal vaults for NNB SILW and RSILW due to the different handling requirements. The illustrative designs assume that these packages are placed in dedicated vaults based on the design concepts for SILW/LLW vaults but using crane emplacement where plausible. In practice, crane emplacement would apply to the higher strength and lower strength sedimentary rock environments, but a remotely operated stacker truck would be used for the evaporite rock environment (due to the currently assumed vault height.).

NNB SILW and RSILW can be manually handled until the destination vault is reached when all subsequent operations are remote handled with the packages being emplaced in a disposal vault. Each vault has been designed with a Vault Reception Area (VRA) which unloads the packages from the transport overpack and remotely emplaces them within a disposal vault. This VRA is shown in Figure 9.

[7] The exception to this is in evaporite rock where the disposal vault dimensions have been reduced in width from 10m to 8m, to better accommodate the TDC and reduce the excavation volume.

Figure 9 Schematic Vault Reception Area



In an evaporite rock, the waste packages are emplaced in the disposal vault using a rail mounted remotely operated stacker truck. These packages are not handled by overhead crane in the disposal vault due to headroom restriction from a reduced vault height. If an overhead crane was used it would impact on the volume of waste that can be emplaced in a disposal vault.

Due to the RSILW packages only being able to be stacked a maximum of 3 packages high, the height of the disposal vault can be decreased for all three host geological environments, reducing the cross-sectional area of the excavation, and thus reducing the volume of excavated spoil created.

10 HHGW Handling and Emplacement

The current three illustrative designs (higher strength rock, lower strength sedimentary rock and evaporite) are based on the six geological disposal concepts identified in Figure 1. For HHGW, the illustrative designs are based on the SKB KBS-3V concept in a higher strength rock, the Nagra concept in the lower strength sedimentary rock and the DBE Gorleben concept in the evaporite rock.

HHGW comprises disposal containers that are transported underground in a DCTC via a drift or shaft.

The HHGW disposal area is currently assumed to consist of a series of disposal tunnels connected by service tunnels. The disposal tunnels are single/blind entry with access from one end only, which would simplify the construction requirements and reduce the amount of tunnelling necessary [29]. It would also reduce the number of seals that would be needed and the potential pathways forming after closure.

The disposal tunnels are all currently 500m long [3]. The lengths were originally based on the underpinning illustrative disposal concepts, and ranged from 340m to 800m, but have been made consistent across all host geological environments to aid comparison between different geologies and for different inventory scenarios. Further, a length of 500m is considered feasible to ventilate for a single entry tunnel.

The characteristics of the host rock will determine the exact separation distance and the length and size of the disposal tunnels. The spacing between disposal tunnels (rock pillar size) has been determined by both geotechnical calculations [55] and by thermal assessment [59]. The minimum pillar size in conjunction with the disposal container spacing was calculated using empirical formulae and assumed rock characteristics, and thermal calculations for different HHGWs were then used to model the thermal characteristics of bounding case scenarios to ensure that temperatures on the buffer materials were within thermal targets as specified in the Technical Requirements [35]; 100°C for higher strength rock, 125°C for lower strength sedimentary rock, and 200°C for evaporite rock[8].

It should be emphasised that the design of the HHGW handling and emplacement is deliberately high level at this stage. The aim is to focus on the layout as, according to the existing programme, emplacement of HHGW would not begin until 2075, by which point extensive experience of waste emplacement processes should has been gained from other national programmes that are further advanced with their facilities.

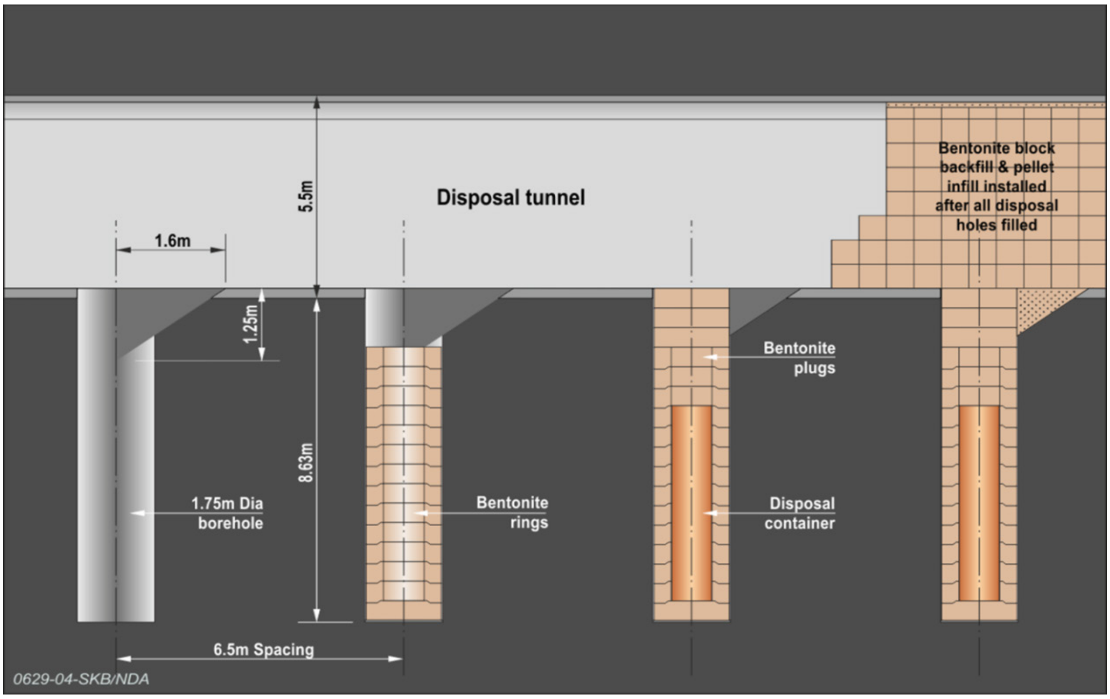
10.1 Higher Strength Rock

The higher strength illustrative design is based on the SKB KBS-3V concept [28] as that concept is in a higher strength rock. The concept is based on the disposal container being transported from surface, to the underground transfer hall on a drift wagon. At the transfer hall the DCTC is removed from the drift wagon and the shock absorbers removed. The DCTC and the disposal container are remotely handled in the same fashion as the SKB concept with the disposal container being removed from the DCTC in a vertical pit with gamma gates. The disposal container is then loaded into a deposition machine that delivers it to the designated disposal tunnel for final emplacement. The deposition machine then delivers the disposal container to the disposal tunnel for emplacement in the

[8] For the higher strength and evaporite rock, the temperature limit is specified for the surface of the buffer material adjacent to the disposal container. In the lower strength sedimentary rock, the temperature limit specified is for the mid-point of the buffer material between the disposal container and host rock.

deposition hole that has been pre-loaded with bentonite blocks and rings. The disposal tunnel can be seen in Figure 10.

Figure 10 Schematic HHGW Disposal Tunnel in a Higher Strength Rock



To ensure sufficient height in the disposal tunnel and minimise the volume of excavated spoil, a chamfer has been added to the top of the deposition hole.

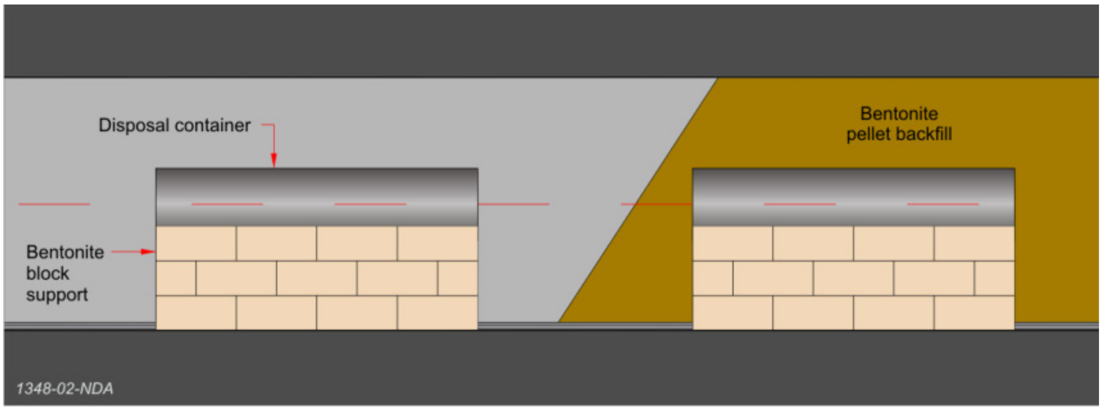
It is currently assumed that approximately 8% of the deposition holes will be lost due to intersecting large fractures, possible spalling of rock during excavation and groundwater inflow [28].

A maintenance area would be required in the HHGW side of the facility to allow routine maintenance and repair of the deposition machine.

10.2 Lower Strength Sedimentary

The illustrative design in the lower strength sedimentary rock is based on the Nagra concept in Opalinus Clay [32]. A disposal container, in its shielded transport container, is transported direct from surface to an underground disposal tunnel disposal container from surface to underground in its transport container on a locomotive hauled drift wagon. The drift locomotive operates on a standard gauge rail system but to comply with the Nagra concept, particularly in terms of excavation dimensions, the standard gauge rail system has to step down to a narrow, 1m, gauge. This is achieved at the transfer hall where the DCTC is removed from the drift wagon, shock absorbers removed, and the transport container loaded onto a narrow gauge system. At the entrance to the disposal tunnel the disposal container is removed from its shielding, under remote operation conditions, and transferred to an emplacement trolley that has been pre-loaded with bentonite blocks, after which it is emplaced in the disposal tunnel, see Figure 11.

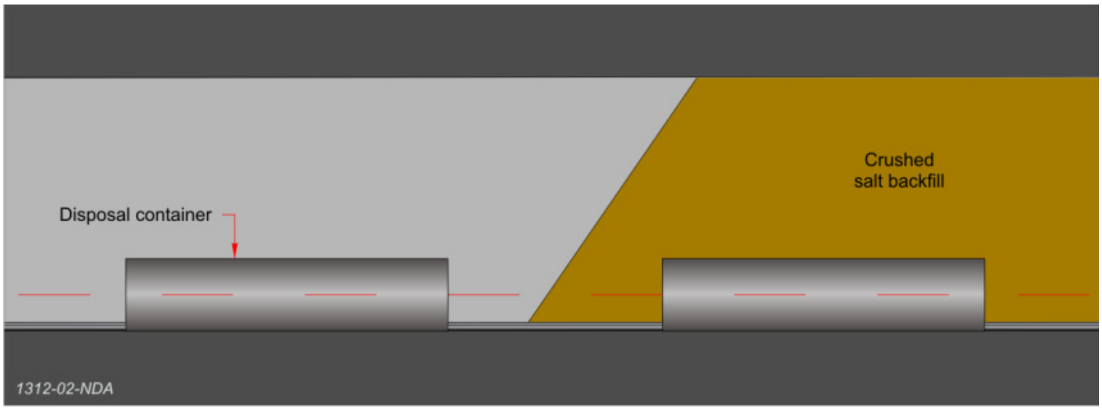
Figure 11 Schematic of an HHGW disposal tunnel – lower strength sedimentary rock



10.3 Evaporite Rock

The illustrative design in the evaporite rock is based on the Gorleben concept in an evaporite rock [32] adapted by reference to Nagra. The Gorleben concept is based on axial emplacement of the disposal container but originally the disposal container was emplaced with its transport shielding. The concept was adapted to that of Nagra, due to a number of similarities, so that the transport shielding could be reused. The DCTC is taken underground via a shaft and then delivered to a transfer hall on a standard gauge rail system, due to the size of the DCTC. The process thereafter is similar to that for the lower strength sedimentary rock illustrative design except that the disposal container is placed direct onto the disposal tunnel floor rather than on bentonite blocks (Figure 12).

Figure 12 Schematic of an HHGW disposal tunnel – evaporite rock



11 Underground Infrastructure and Services

11.1 Facilities

The underground facilities in the Common Services Area are currently assumed to be located between the LHGW and HHGW emplacement areas and would comprise:

- Active area support facilities including sampling laboratory to allow checks to be made on effluents and waste liquids for contamination control.
- Active Liquid Effluent Receipt and Dispatch Area containing the collection tanks for liquid effluents arising within the active areas, and the pumps and valves needed to circulate and export the liquid to the bowser filling station located adjacent to the inlet cell complex.
- Workshops to provide facilities where vehicle repair and maintenance could be undertaken. Workshops would also include a place for storage of materials and vehicle/plant spares.
- Spoil bunker constructed near the construction return shaft. This would act as temporary storage for excavated rock, to regulate the feed to the shaft. The bunker would also permit shaft downtime to be accommodated without the necessity to stop vault and tunnel construction activities. This would also allow spoil to be collected during restricted hours of operation that could be imposed on surface operations, such as overnight, if this became a site specific requirement.
- Personnel hall providing a rest area for construction staff during the shift as well as providing a safe area with additional refuge facilities in case of an emergency. A separate rescue room would contain a fire station and rescue facility as well as a safe haven, if required.
- Vehicles and equipment used during the construction phase would be housed in a dedicated hall when not in use. This hall would be located close to the drift or the waste emplacement shaft in the case of the evaporite illustrative design. This facility provides for free steered vehicle and locomotive maintenance and repair.
- Ventilation hall at the base of the construction intake shaft containing fans to draw air down the shaft and force the air into the construction areas and to ensure that the construction areas remain at a positive pressure relative to the waste emplacement areas. The possibility of locating these fans on surface has not been discounted.

11.2 Groundwater management (surface and underground)

Surface groundwater management is required to reduce flood risk and adverse effects on water quality. It should take into account the protection of groundwater resources and the potential effects on any groundwater abstractions.

Design and operational procedures for construction of both tunnels and shafts in the underground environment should be based on detailed data provided by exploratory boreholes in order to tailor counter-measures (such as, but not limited to, grouting, freezing or lining) to local conditions to prevent groundwater ingress.

The disposal vaults, disposal tunnels and underground accessways will have sufficient drainage to facilitate groundwater inflow management. The drainage will be connected to a network of sumps. The groundwater will be collected from the sumps and transported to the surface, where it will be monitored and treated in the active effluent treatment plant, as it may be contaminated.

11.3 Ventilation system

The purpose of the underground ventilation systems should be to provide adequate ventilation for both waste construction and emplacement activities throughout the life of the facility and to work with physical barriers to provide containment.

The ventilation system is designed using the cascade principle to ensure that the construction area remain at a positive pressure relative to the waste emplacement area. The waste disposal area ventilation would be kept at a negative pressure, relative to both the surface atmosphere and the construction areas. The pressure differential between the construction and disposal ventilation circuits plays an important role in maintaining segregation of air streams. It would also ensure that under fan fault conditions the system would fail to safety, and that the emplacement circuit air could not enter the construction side of the operations. This is consistent with the guidance on the design of nuclear ventilation systems where a flow would be between lower to higher activity areas [60] and is currently proposed by Andra for their underground ventilation system design.

11.4 Electrical power system

A secure electrical power supply and distribution system is essential for a GDF in order to maintain continuity of operational activities while ensuring plant and personnel safety and security.

The illustrative designs provide for two independent power supplies to the construction and operational areas, each with the capacity to meet the demands for maintaining the facility should one of the supplies fail. Back-up generation and emergency winding facilities would also be provided. The resilience of these designs was reviewed against the European Nuclear Safety Regulators Group (ENSREG) Stress Tests which resulted from the findings of ONR's review of site licensee's response to the Stress Tests and the recommendations in the review of the implications of the events at Fukushima for the UK nuclear industry carried out by the Chief Inspector of Nuclear Installations [61]. The review concluded that the GDF illustrative designs identify the requirement for a secure electrical power supply and distribution system to the GDF in order to maintain continuity of operational activities while ensuring plant and personnel safety and security. In addition, security and redundancy of electricity supply has been considered and the illustrative designs also incorporate an on-site back-up generator supply of up to 12 generator sets and associated reserve fuel tanks [62].The illustrative designs provide for systems which are sufficiently robust to remain safe in the event of system failures such as provision for the recovery of remote handling equipment.

The two surface substations would supply power to two underground substations, one in the emplacement area and the second in the construction area. Two independent and physically separated cables from the surface substations would feed each of the underground substations. These cables would be routed via the emplacement intake and emplacement return shaft for the waste operational activities and via the construction intake and return shafts for the construction activities. The underground substations would also have the capability to cross-connect in the event of loss of supply from one of the surface substations. Other local underground substations consisting of transformers and motor control centres would be established for major load items, such as pumping and ventilation/dehumidification plants, in addition to those for disposal and construction activities.

11.5 Fire safety systems

Fire prevention, detection and suppression are essential elements to ensuring the safe operation of a GDF and in the event of an emergency the safe and timely evacuation of personnel.

Fire detection options for the operational facility has been reviewed in detail in the GDF Fire Suppression and Consequence Management Study [63] and advice provided regarding technologies that may be available for the construction areas. The precise nature of the fire detection technologies to be adopted in both construction and operational areas of the GDF would be developed as the detailed design progresses.

The basic principles of the fire safety systems within the disposal facility would include [63]:

- Adoption of fire prevention measures, e.g. use of flame-resistant materials, minimisation of combustibles, control of ignition sources etc.
- Provision of rapid fire detection.
- Provision of effective fire-fighting capabilities.
- Minimisation of risk to workers and the general public.
- Provision of safe means of egress of personnel (and access for fire-fighters) by control of ventilation.

Facilities and precautions to manage fire safety would include the following [63]:

- Surface, fire and rescue station – serving both the surface and underground facilities, this would be a combination of a civilian fire station and a mines rescue station.
- Underground fire-fighting stations – two such facilities would be provided, one serving the construction area and the other the disposal area.
- Fire-fighting system – the fire water supply to a GDF would comprise duplicate, pressurised water mains with an emergency storage supply at the surface. Fire ranges would be sited in the ventilation intake roadways at suitable intervals and other locations of greatest fire risk.
- Portable or equipment-mounted fire extinguishers – these would be a combination of dry powder, carbon dioxide, foam or water sited at strategic locations, e.g. electrical substations and plant rooms.
- Fire-fighting and rescue plan – this would be prepared to show the position of all ranges, hydrants, valves, fire stations and fire points.

11.6 Control systems

Control systems will be required to provide for the control of systems and equipment performing safe operations throughout the GDF. They will allow local and remote control of equipment, monitoring of plant status, acquisition of data from various instrument safety systems including safety critical equipment such as ventilation fans, pumps and shaft winders, and would provide records of operational performance.

The current assumption is that virtually all the main emplacement activities would be controlled and monitored from the central control room on the surface. However, more complex operations such as those within the inlet cells would be likely at times to require local operation, with direct operator viewing through windows or remotely using cctv to identify and rectify problems and help in maintenance work. Also, the operations would be controlled locally during commissioning and during initial operation until confidence in remote operation is gained. These system requirements would be reflected in the philosophy to provide the options to control underground operations from, either a local control station, the underground control room or the surface central control room.

The control system would also include a number of safety circuits. These must be independent of normal control circuits. As these safety circuits and also other elements of the control system would be classified ‘essential’ for the safety of the plant, the entire control system would be powered from a battery-backed electrical supply.

11.7 Consequence Management

Consequence management includes those measures taken to protect health and safety, restore essential services and provide emergency relief to those affected by the consequences of construction and emplacement operations being undertaken in a GDF. The GDF design includes measures to provide safety for personnel in terms of additional means of egress, underground fire-fighting stations and safe havens.

12 Backfilling, Sealing, Closure and Decommissioning

Backfilling (including emplacement of buffer materials, local and peripheral backfill) and sealing of disposal areas is required as part of the multi-barrier functions for waste disposal.

Buffer or backfill is placed around the waste container to:

- protect the waste container from physical disruption (e.g. by movement in the bedrock);
- control the rate at which groundwater can move to and around the waste container (e.g. by preventing flow);
- control the rate at which corrosive chemicals in groundwater can move to the waste container;
- condition the chemical characteristics of groundwater and porewater in contact with the container and the wasteform so as to reduce corrosion rate and/or solubility of radionuclides;
- control the rate at which dissolved radionuclides can move from the wasteform into the surrounding rock;
- control or prevent the movement of radionuclide-containing colloids from the wasteform into the rock;
- suppress microbial activity in the vicinity of the waste;
- permit the passage of gas from the waste and the corroding container into the host rock.
- It must not significantly impair any of the other barriers and should be durable over a long time period.

Backfilling and sealing takes place at various times during the operational and closure phases of a GDF. In a higher strength rock illustrative the disposal tunnels are backfilled and sealed once the deposition holes in a disposal tunnel have been used or abandoned. The current assumption for disposal vaults in higher strength rock is to backfill only during the closure phase. In the lower strength sedimentary rock illustrative design the disposal vaults are backfilled once the disposal vault is full of waste packages and the disposal tunnels are backfilled progressively as the disposal containers are emplaced. In both cases the shield doors form the seal. In the evaporite illustrative design there is no backfill applied to the disposal vaults but the disposal tunnels are backfilled in a similar manner to the lower strength sedimentary rock illustrative design.

Otherwise, the key activities to be considered during the closure phase are:

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

12.1 LHGW backfill

In the higher strength rock illustrative design, emplacement of backfill is planned to be deferred until all waste emplacement operations in the disposal facility has been completed. This is based on the PGRC concept [25]. Nirex Reference Vault Backfill (NRVB) would be injected into a vault from backfill galleries with one gallery to two disposal vaults [64]. This will enable the backfill material to be pumped into the vaults to fill the remaining void including crown space.

In a lower strength sedimentary rock, it is planned that each disposal vault would be backfilled once it is full [31]. This process will ensure rock stability without the requirement for significant support. Cementitious grout is injected through distribution pipes located in the disposal vault roof as per the Nagra concept for LHGW.

It is currently assumed that a backfill ratio[9] of approximately 1:1 is achieved in the higher strength and lower strength sedimentary rock illustrative designs. This backfill is the material that is emplaced to fill the free space between and around waste packages in vaults and is required in order to produce the appropriate near-field chemistry that is assumed in post-closure performance.

No backfill is required in an evaporite rock as the strata is allowed to creep naturally. Magnesium Oxide (MgO) sacks are placed on the top of the package stacks to provide chemical conditioning [31].

12.2 HHGW backfill

In the higher strength rock illustrative design, the disposal tunnels are backfilled with bentonite blocks and pellets once all the deposition holes in that disposal tunnel are used. The SKB KBS-3V concept has adopted 100% bentonite backfill to meet the reference design requirements [65].

In the lower strength sedimentary rock the disposal tunnels are backfilled progressively as disposal containers are emplaced with bentonite pellets based on the Nagra concept [32].

Similarly, in the evaporite rock, disposal tunnels are backfilled progressively with crushed evaporite rock and the excavation allowed to creep naturally based on the Nagra philosophy.

12.3 Sealing Strategy

Seals, for all host geological environments would be constructed to provide all or a combination of the following:

- remove potential fast groundwater flow pathways within a backfilled geological disposal facility (e.g. at the interface between mass backfill and host rock);
- prevent access of people into a closed geological disposal facility or part of the facility during closure.
- Provide mechanical support to the backfill material in a disposal module.

Seals would provide different functions for different host geological environments and the requirements for these are identified in the Technical Requirements [35].

The designs for plugs and seals are based on a wide range of international designs underpinned by research programmes such as the DOPAS, in which RWM participate and lessons learnt from these programmes will be applied to a GDF in the UK.

Disposal vaults should be sealed at each end and disposal tunnels sealed at their entrance. Other seals would be constructed at suitable strategic locations such as where main tunnels meet at a crossroad, in main tunnels that access the LHGW and HHGW disposal areas, at the entrance to a disposal module, at the base of shafts or where a drift enters the facility horizon.

Seals would be constructed to a standard to maintain a permeability performance at least as low as the host rock in which the seal is constructed to minimise radionuclide movement through the EDZ. Care should be taken in relation to the excavation of those areas where seals were planned, in order to improve seal construction and performance.

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[9] The backfill ratio is the volume of backfill to the volume of conditioned waste.

To improve the efficiency of sealing, the cross-sectional area of entrances / exits would be kept to the minimum practicable for construction, ventilation and operation.

Access routes should be sealed at surface and at the facility horizon with additional seals placed as necessary.

12.4 Mass Backfill

Mass backfill will be placed in all service and transport tunnels and would:

- restore mechanical continuity and stability to the rock and engineered region of a geological disposal facility so that the other engineered barriers are not physically disrupted (e.g. as a clay buffer takes up water and expands);
- close voids that could otherwise act as groundwater flow pathways within a geological disposal facility.

Mass backfill that is placed between seals, except in disposal vaults and disposal tunnels is based on the underpinning illustrative disposal concepts and would comprise the following:

- 70% crushed rock and 30% bentonite in a higher strength rock.
- 70% sand and 30% bentonite in a lower strength sedimentary rock.
- Crushed evaporite rock in an evaporite host rock.

12.5 Decommissioning and Closure

The surface facilities would be decommissioned, stripped of engineering equipment and demolished. The surface environment would be remediated and landscaped to the end state agreed with the Government, regulators and the local community. Monitoring of the closure operation and the environment would continue throughout the closure phase. For planning purposes, a notional period of 10 years has been included, during which time backfilling, sealing and closure will be implemented.

Monitoring of the closure operation and the environment would continue throughout the closure phase. Records from a GDF would be placed in a national archive for use as required by future generations. Any physical marking of the site that might be required by the UK Government, regulators or in an agreement with the local community would be undertaken.

Following closure, the facility would be the responsibility of the authority charged with institutional control. A period of post-closure monitoring could be undertaken by that authority.

13 Monitoring

At each stage in the GDF lifecycle a wide range of parameters could be monitored to track performance of the disposal facility and its effects on the surrounding environment. Monitoring could be used to support the development of safety cases by contributing to the understanding of system behaviour, could provide assurance of safety by checking implementation conforms to safety case arguments and assumptions, and could be used to demonstrate compliance with regulatory requirements and conditions. In this way, monitoring can support decision making, help to build confidence in geological disposal and contribute to enhancement of the disposal system.

The monitoring programme will commence with the collection of data and information to support the establishment of baseline conditions, during the initial site characterisation phase. The monitoring programme will then evolve as monitoring is conducted during construction and throughout on-going construction, operation and closure activities. Any extension of the monitoring programme into the post-closure period would depend on decisions taken by future generations.

The IAEA recognises the importance of monitoring within the lifecycle of a GDF, and emphasises the importance of baseline monitoring and contingency plans to address unexpected or abnormal system behaviour. The guidance also includes the principle that a GDF should be designed to be intrinsically and passively safe during the post-closure period, with no further actions required from future generations, and in particular, that long-term safety should not rely on monitoring.

However at this generic stage in the GDF programme, it is not possible to define precisely what the monitoring will be. Any monitoring activities will need to be fully justified in terms of the benefit they offer weighed against any detriment they might bring.

In the UK, options for monitoring have been considered and the context for monitoring has been established [66]. However, monitoring specifications have only been developed for specific parts of a disposal system. Further development of the monitoring programme will need to respond to engagement with regulators and local public stakeholders once potential geological disposal facility sites has been identified A framework for addressing outstanding gaps is provided by a monitoring programme specification [67], which outlines a strategy for developing a detailed monitoring programme and identifies the current understanding of monitoring requirements, parameters and techniques based on a series of monitoring sub-programmes.

In terms of disposal system performance, development of the RWM monitoring programme will build on lessons learned from the EC MoDeRn Project, in which RWM was a partner and the on-going MoDeRn2020, in which RWM is also a partner.

In terms of environmental monitoring, RWM is collaborating with other European waste management organisations to establish a reference framework for long-term environmental monitoring and testing at potential geological disposal sites. This work is being carried out under the auspices of the European 'Implementing Geological Disposal – Technology Platform' (IGD-TP).

14 Security and Safeguards

14.1 Security

It is currently assumed that a GDF will be designed and constructed to provide appropriate physical security features to operate as a Category I facility from the outset, although it will operate initially as a Category III[10] facility from first receipt of ILW and LLW. This future-proofing will ensure sufficient surface area and infrastructure is available and minimise unnecessary disruption to GDF services and operations to prepare for subsequent upward re-categorisation when Category I[10] and II[10] nuclear materials arrive. It is also assumed that prior to receipt of HLW and SF, the GDF would be re-categorised to a Category II facility. In advance of plutonium and HEU disposal, it is assumed that a GDF will be re-categorised from a Category II to Category I civil licensed nuclear site. Each re-categorisation will involve increased control on access to all areas, and incorporate sufficient detection and surveillance systems to identify theft and sabotage attempts.

A number of security reviews of the illustrative GDF designs has been undertaken historically, the latest in accordance with the National Objectives, Requirements and Model Standards (NORMS) 2014, where the design was amended accordingly.

RWM will continually review the security of the GDF designs and update the designs accordingly to include additional security features. It is likely that a GDF security plan will be developed once site(s) has been identified, due to the site specific nature of a GDF security plan. RWM has developed a conceptual security framework which will, in due course, inform the illustrative GDF designs and provide the basis for the future GDF site security plan.

Transport of nuclear material to and within a GDF site would have to be described in a transport security statement and an associated transport security plan, also approved by Office for Nuclear Regulation Civil Nuclear Security (ONR CNS). Liaison with ONR and road and rail transport carriers including will take place at all stages of development of the transport system. In this way, all suitable security measures will be included in transport plans for a GDF for all stages of operation. The intent is to avoid the need to retrofit security measures once implementation is underway and this will enable regulators to make an early judgement on the most appropriate measures for any transport method.

14.2 Safeguards

The UK is a signatory of the Nuclear Non-Proliferation Treaty and the Euratom Treaty, and is committed to the nuclear non-proliferation regime to stop the spread of nuclear weapons. The aim of nuclear safeguards is to detect, and therefore deter, the diversion of nuclear materials from peaceful uses to nuclear weapons. Safeguards verification is carried out by inspectors from the IAEA, under its safeguards agreements with the UK [68] and by the European Commission, under regulatory requirements to meet Chapter 7 of the Euratom Treaty [69].

Nirex published a safeguards context note in December 2005 for CoRWM [70]. The note highlighted the difficulties in applying traditional safeguards to a geological disposal facility. At this stage, the concept did not explicitly include safeguard-specific features, as the development of the concept had previously assumed that the radioactive waste (ILW/LLW) would not contain significant quantities of safeguarded nuclear materials.

[10] The category classification given is related to quantities of various types of nuclear materials disposed of at a GDF.

In December 2010, RWM published *implications arising from safeguards considerations for RWMD and the GDF project*, to coincide with the publication of the generic DSSC suite of documents [71]. The report reiterated the way in which RWM should consider safeguards:

- To assess the potential impact of the application of safeguards on the GDF design and operational philosophy
- The consequences of nuclear material in packaged waste for which a letter of compliance (LoC) has been requested and provided.

The latest application of safeguards to a GDF can be found in *The Application of Nuclear Safeguards to a UK geological disposal facility* [72]. The purpose of this report was to consider the legal, regulatory and policy basis of safeguards and how to apply these to a conceptual design of a GDF. The report also identifies the safeguards practices which are being adopted by other countries in the development of their nuclear waste disposal plans, before considering the conceptual arrangements which could be applied by the UK during the three phases of a GDF life-cycle – its construction, operation and closure.

The emplacement of any nuclear material subject to safeguards in a GDF will require safeguards verification of the underground and surface facilities. This verification is to provide independent assurance that nuclear material is not being diverted from its declared disposal. It is preferable that the foundation for this verification system is established during the design and construction phases of the facility, via so-called “safeguards by design”. This requires very early consultation with safeguards inspectorates of the European Commission and the IAEA. While the verification system will be modelled on a generic approach to safeguarding a GDF, it will later be tailored to a site-specific GDF design, host rock, and the type and form of nuclear materials emplaced. The design will has to incorporate sufficient safeguards measures to give assurance on the absence of diversion of nuclear materials. An effective, operator-provided, nuclear material accountancy and control system will be an essential aspect of safeguards. This system may be independently verified by the IAEA and/or European Commission inspectors using a variety of technical measures (e.g. containment and surveillance systems) and by tracking and monitoring material.

The level of safeguards provisions at a GDF would depend on the nuclear material emplaced, its accessibility, the complexity of design, the ability to track nuclear material through to emplacement and ease of retrievability. The European Commission and IAEA will verify GDF construction activity against submitted designs and may also verify emplacement of nuclear material during the operational phase.

As the GDF design may initially allow for easy waste retrieval, safeguards verification is expected to continue until sealing and closure. The measures to safeguard nuclear material can only be terminated if the nuclear material is practicably irretrievable as described in [73] although this would conflict with any potential requirement for long-term retrieval.

15 Reversibility and Ease of Retrieval

The term retrievability is used as an overarching term to refer to a number of different approaches to the removal of radioactive waste from a GDF after it has been emplaced. The following terms were first proposed by CoRWM in their recommendations to Government [22] and have been subsequently adopted by RWM:

Reversibility: has been used in the UK to describe retrieval by reversing the original emplacement process (e.g. removal of emplaced ILW packages using the vault emplacement crane, similar to the process used for removal of waste packages from an interim store). In this context, reversibility is only possible before any form of backfilling or sealing has taken place and is dependent on the continued integrity of the waste packages, disposal vaults and tunnels, and emplacement equipment. In some other countries, the term 'reversibility' is used to denote an ability to reverse decisions as part of a phased decision-making process.

Retrievability: is the term used where it is possible to withdraw the waste from a GDF by building in a methodology that would allow access to the waste even after vaults and tunnels had been backfilled. This could be achieved, for example, by keeping service tunnels open for a period after emplacement and vault/tunnel backfilling, and by ensuring that any backfill materials could be readily removed.

Recoverability: is a term developed by CoRWM to define situations when removal of waste from a closed GDF by mining or similar intrusive methods. Once service tunnels have been backfilled and/or a GDF has been sealed, intrusive re-excavation operations would be required to recover the waste. These would be likely to pose greater technical challenges and be more expensive than other forms of retrievability.

The degree to which wastes are 'retrievable', and the type of retrieval approach required, depends on the range of factors, including:

- The type of waste;
- The disposal concept
- The time elapsed after emplacement
- The extent to which a GDF has been closed
- The nature of the surrounding geological environment

Between 1997 and 2007, in response to recommendation's by the House of Lords Select Committee and feedback from stakeholders, a programme of work was undertaken by Nirex to consider the issues associated with retrievability. This work is summarised in the Context Note published in 2005 [74] and a Position Statement published in 2010 [75].

RWM and Nirex have worked extensively with sister organisations on the issue of retrievability and between 2007 and 2011 were involved in the Nuclear Energy Agency (NEA) reversibility and retrievability project. The project included the development of a generic Retrievability scale [76] which illustrates the lifecycle stages of waste packages, the relationship between ease of retrieval and cost throughout this lifecycle, and how safety assurance changes from predominantly active controls to passive with each stage. The NEA Retrievability Scale is generic and can be applied to any geological disposal facility.

A review of the GDF illustrative designs against different stages of the NEA Retrievability Scale was undertaken to identify the design, cost and safety implications for the different stages. This study identified that retrieving placed waste would tend to become more difficult with time, particularly after the end of its operational stage (that is, once a GDF has been closed permanently) [77].

In line with Government policy, RWM currently carry out its activities developing the UK geological disposal programme in such a way that the option for retrievability is not excluded.

This position is reflected in our Disposal Functional Specification [34] which states that "*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. The generic design reports, which underpin the generic DSSC, will identify the extent to which retrievability is feasible for different geological environments, together with the measures that would be required to ensure that the option of retrievability is not excluded"*

A small number of design features relating to retrievability are included in the existing GDF illustrative designs and these features are:

- The waste packages for ILW are designed to remain intact for 500 years. This anticipated package integrity would reduce the risks related to retrievability in the longer term, if it was required.
- The disposal container has been designed with lifting features on both ends to enable disposal containers to be removed from the deposition holes / disposal tunnels, if required.
- Nirex Reference Vault Backfill (NRVB) is to be used as backfill in the higher strength rock illustrative design. This is an engineered grout that has alkaline properties to maintain package integrity and is of low strength to facilitate excavation of waste packages.

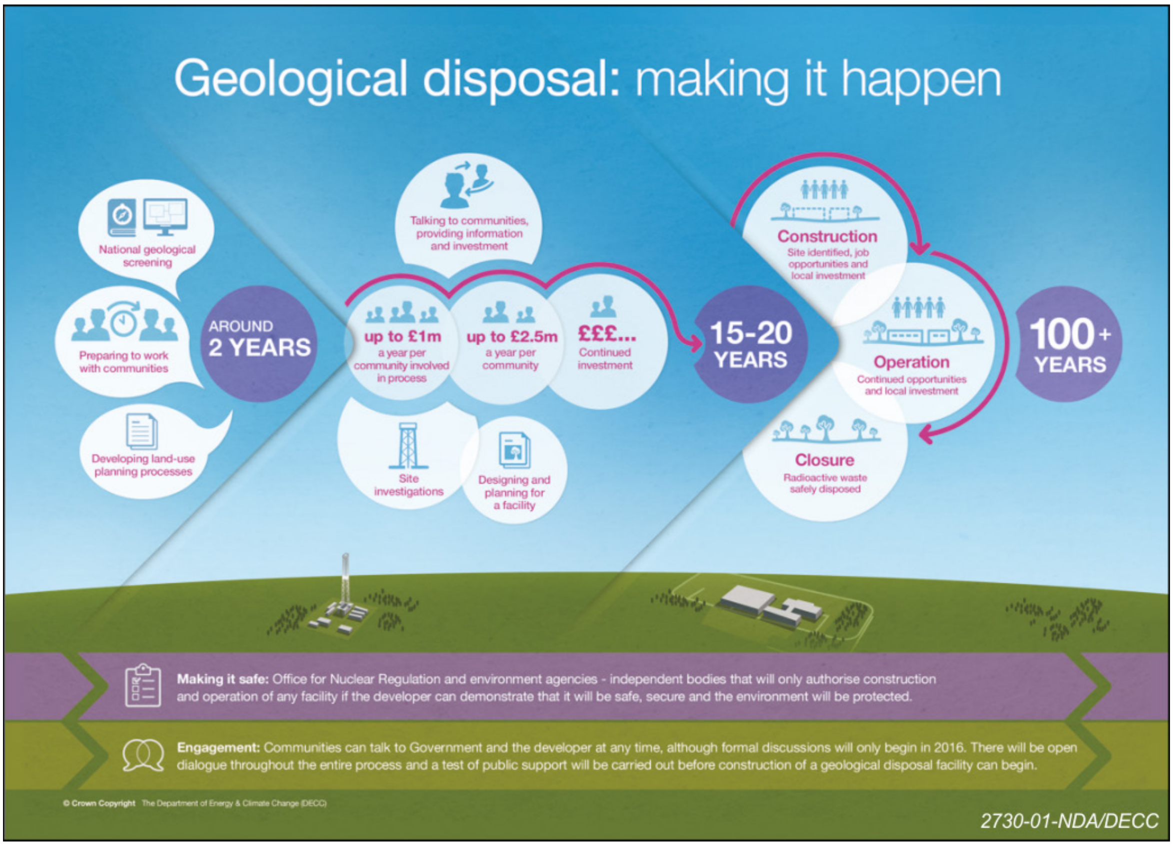
Future decision-making regarding retrievability will need to take account of relevant site-specific characteristics. RWM recognises the Government's view that a decision on whether or not to keep a GDF (or vaults and tunnels within it) open once a facility waste operations cease can be made at a later date, although RWM recognise that some geological disposal concepts has limitations with respect to delaying the emplacement of some types of backfill. It must also be recognised that backfilling, sealing at closure once all waste has been emplaced and permanently closing a GDF at the earliest possible opportunity once operations has ceased provides for greater safety, greater security, and minimises the burden on future generations. As the siting process progresses, decisions with respect to retrievability will be made in discussion with the independent regulators and local communities. The final design will then reflect the decisions made in light of those discussions.

16 The Way Forward

The purpose of this Design Status report is to document the rationale behind the key design developments and to provide an overview of the engineering design work undertaken. It summarises the generic designs that has been prepared for a geological disposal facility in the UK and describes the justification for the design characteristics for the transport and disposal of waste at an illustrative geological disposal facility.

The framework for implementing Geological Disposal is described in [1] and the process is shown in the Figure 13.

Figure 13 Diagram Showing Process Moving Forward



As the process above progresses, details of a geological environment and site specific characteristics will become available. Until such time as more specific information becomes available, the approach that will continue to be taken is to define a number of generic geological disposal concepts applied to typical, potentially suitable UK geological settings. The generic DSSC documents will initially describe generic requirements, reflecting the fact that a site and a disposal concept has yet to be identified. They will be periodically updated, for example to respond to changes in regulations and to respond to learning from undertaking assessments and further research. The Technical Requirements, in particular, will evolve from generic to site-specific requirements as site-specific information becomes available at the more detailed level and as issues that are recognised today are resolved. Some issues are of a general nature and faced by other countries in implementing geological disposal, and some are UK-specific.

As the process progresses, there will also be a requirement to maintain and periodically update the generic illustrative designs and this report to take account of future requirements and to support both wider stakeholder engagement and the waste packaging assessment process. It is expected that these illustrative designs will continue to be required and updated as the designs move forward through the process from their current illustrative status through the conceptual and preliminary design stages and until a detailed design for a GDF at a specific site is developed.

Generic illustrative designs will also be maintained in parallel with site-specific designs. The purpose of these generic illustrative designs will be to support generic assessments, to provide information to support the verification of site specific designs and also support the packaging assessment / Letter of Compliance process until a specific site is identified.

As the design progresses, this report will be periodically updated to include design enhancements that are adopted, in order to support any future design development work and to provide reference to the underpinning source information.

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