Radioactive Waste Management

NDA Report no. DSSC/421/01

Geological Disposal

Technical Background to the generic Disposal System Safety Case

December 2016

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Preface

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

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

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

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

Executive Summary

In the White Paper on Implementing Geological Disposal, published in July 2014, the UK Government set out a renewed policy for the implementation of geological disposal of higher activity wastes in the UK. Radioactive Waste Management Limited (RWM), a wholly-owned subsidiary of the Nuclear Decommissioning Authority, is responsible for implementing this policy through the development of a geological disposal facility (GDF).

RWM has produced a generic Disposal System Safety Case (DSSC). The main purpose of the generic DSSC is to give confidence that a GDF can be implemented safely in the UK, by describing and assessing the safety and environmental implications associated with all aspects of geological disposal of higher activity wastes. In addition, environmental and sustainability assessments consider the non-radiological socio-economic and health impacts of the GDF.

The generic DSSC is a tiered suite of documents and supporting references. The top tiers include an overview report, which presents the main safety arguments and provides a way in to the suite, and the main safety case reports. Beneath these sit the safety assessments and the environmental and sustainability assessments, supported by the specification, and the design and inventory reports on which the safety cases are based. A series of research status reports and an extensive set of supporting references provide the underpinning knowledge base.

This document is the Technical Background document and is part of the knowledge base. Its purpose is to provide a source of disposal system technical information on which the generic DSSC is based. In presenting this information in one reference, with pointers to where additional detail can be found, the need for repetition across the suite is avoided.

This document is the primary source for technical background information for the generic DSSC and covers:

- the inventory for disposal
- the multi-barrier approach
- the Disposal System Specification
- potential host rocks
- the illustrative disposal concepts
- the generic illustrative designs
- packaging wastes in readiness for disposal
- on-going developments

The 2014 White Paper defines the inventory for disposal in the GDF, addressing the types of higher activity wastes and nuclear materials that could be declared as waste in the future. In order to support the implementation of geological disposal, RWM has developed a quantified description of this inventory, the Derived Inventory. The most recent version, the 2013 Derived Inventory, is the basis for the assessments in the generic DSSC. The packaged volume of all the higher activity wastes and material defined in the inventory for disposal is currently estimated at approximately 750,000 m^3.

The 2014 White Paper sets out the inventory for disposal in the GDF in terms of categories of radioactive waste and material. These categories are High Level Waste, Intermediate Level Waste, Low Level Waste, spent fuel, plutonium and uranium. These include wastes from an assumed 16 GW(e) new nuclear build programme.

The generic DSSC assesses the effect of uncertainty in the inventory for disposal by exploring the sensitivity of the 2013 Derived Inventory to a number of different scenarios. A range of scenarios has been considered in order to evaluate the implications of these uncertainties.

It is recognised that some of the wastes in the inventory may be potentially harmful due to the presence of non-radiological contaminants. RWM has commenced a programme of work in this area with a scoping study to identify those non-radiological hazardous substances which may be present in the inventory and are important in terms of geological disposal, particularly in relation to groundwater pathways in the post-closure period.

The high level requirements on the GDF are primarily to provide isolation and containment of wastes and confidence in long term safety. These requirements are met by a multi-barrier system in which engineered barriers work in combination with the natural barrier afforded by the geosphere, to isolate and contain the wastes so that they do not cause harm to life and the environment.

Procedures, systems and controls also deliver the high level requirements on the GDF. These, together with the components of the multi-barrier system, provide certain safety functions. RWM has developed approaches to the delivery of safety functions within the operational and post-closure safety cases, suited to the respective regulatory requirements.

Illustrative disposal concepts and designs have been developed for three types of host rock, typical of those found in the UK, for high heat and low heat generating wastes. The illustrative designs deliver the required safety functions and, together with the generic transport system design, are assessed for radiological safety and non-radiological, socio-economic and health impacts.

The illustrative designs and the transport system design are based on available technology. The transport system design, for example, is based on current and planned waste conditioning techniques, waste package handling and transport methods. It is expected that designs will evolve as technology matures.

RWM has developed and maintains a series of specifications for waste packages, based on generic waste containers, to assist waste producers in developing waste packages that will be acceptable for geological disposal. Alongside these generic specifications, the Disposability Assessment process provides a means by which RWM assesses and advises on waste producers' proposals for treating and packaging waste against the appropriate specification. The process also involves an assessment of safety against the benchmark of the generic DSSC. By allowing waste producers to submit information proportionate to the stage of development of their proposals, RWM is able to work proactively with waste producers to develop and optimise their waste management solutions.

During the past three decades many challenges to the viability of disposal concepts have been overcome. The key remaining uncertainties relate mainly to the disposal concepts and waste containers for high heat generating waste and depleted, natural and low enriched uranium. RWM is currently concluding work on three key topics in these areas. The evolution of RWM's work programme as the siting process progresses is set out in the Science and Technology Programme, and a Science and Technology Plan presents an analysis of the nature and timing of RWM's future generic research and development activities in support of its mission to deliver a GDF and provide radioactive management solutions.

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1 Introduction

This document is one of a suite of documents that together make up the generic Disposal System Safety Case (DSSC). It provides a source of technical background information common to the remaining documents in the suite. In addition, it provides pointers to where more detailed information can be found.

1.1 Background

The UK has accumulated a legacy of higher activity wastes and materials accumulated through many decades of operating nuclear facilities. Higher activity wastes are produced from the generation of electricity in nuclear power stations, associated production and reprocessing of nuclear fuel, the use of radioactive materials in industry, medicine and research and from defence-related nuclear programmes. They comprise High Level Waste (HLW), Intermediate Level Waste (ILW) and some Low Level Waste (LLW) that is not suitable for near-surface disposal in current facilities. Although the majority of radioactivity in the higher activity wastes will decay within the first few hundred years, some wastes will remain hazardous for hundreds of thousands of years.

Much of this radioactive waste has already arisen and is being stored on an interim basis at nuclear sites across the UK. More will arise in the future as existing facilities are decommissioned when they reach the end of their lifetime and as a result of the operation and subsequent decommissioning of any new nuclear power stations.

In a 2008 White Paper [1], the UK Government and devolved administrations of Wales and Northern Ireland gave the Nuclear Decommissioning Authority (NDA) responsibility for implementing the Government policy on the long-term management of radioactive waste, including the planning and implementation of geological disposal. Radioactive Waste Management Limited (RWM), a wholly owned subsidiary of the NDA, was subsequently established as the organisation responsible for implementing a safe, sustainable and publicly acceptable programme for the geological disposal of the UK's higher activity wastes. As the developer of a geological disposal facility (GDF), RWM is responsible for safety, security and environmental protection throughout the lifetime of the geological disposal programme and in particular has responsibility for complying with all regulatory requirements on geological disposal.

In July 2014, the Government[1] produced a new White Paper [2] setting out the policy framework for the future implementation of geological disposal in the UK (hereafter referred to as the 2014 White Paper). It updates (and replaces in England and Northern Ireland) the 2008 White Paper.

1.2 The generic DSSC

RWM is currently undertaking preparatory studies in readiness for commencing site investigation work, when the location of potential sites is known. As part of this preparatory work, RWM has produced a generic Disposal System Safety Case (DSSC). The main purpose of the generic DSSC is to give confidence that a GDF can be implemented safely in the UK, by describing and assessing the safety and environmental implications

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1 Hereafter, references to Government mean the UK Government and Northern Ireland Executive. Scottish Government policy is that the long term management of higher activity radioactive waste should be in near-surface facilities and that these should be located as near as possible to the site where the waste is produced. Geological disposal remains Welsh Government policy, however, the Welsh Government issued a Call for Evidence and is reviewing its current policy.

associated with all aspects of geological disposal of higher activity wastes. In addition, environmental and sustainability assessments consider the non-radiological socio-economic and health impacts of the GDF.

The first version was produced in 2010. The current version is the first update of the whole suite of documents that make up the generic DSSC.

The generic DSSC addresses three main areas:

- the safety of radioactive waste transport to the GDF – the generic Transport Safety Case (TSC) [3]
- the safety of the design, construction and operation of the GDF – the generic Operational Safety Case (OSC) [4]
- the protection of the surrounding environment during construction and operation of the GDF and in the long-term, after the GDF has been sealed and closed – the generic Environmental Safety Case (ESC) [5]

Safety assessments carried out in each of these main areas predict radiological doses to the public, workers or both, and compare them against RWM's published numerical safety assessment criteria [6] for normal operations and accident conditions. Limits and targets are defined based on the criteria in the Office for Nuclear Regulation (ONR) Safety Assessment Principles [7] and the environment agencies' Guidance on Requirements for Authorisation (GRA) for geological disposal facilities [8]. Criteria are specified for:

- the nuclear and radiological safety of the GDF up to the point in time where institutional control is withdrawn, that is to say the operational phase, closure and probably a period of time after closure
- the nuclear and radiological safety of the GDF after institutional control has ceased (post-closure)
- nuclear and radiological safety of off-site waste transport operations

In addition, RWM carries out generic non-radiological environmental and sustainability assessments, alongside its generic radiological safety case work, to support illustrative design development and to inform the early stages of the siting process for the GDF. These comprise: a non-radiological environmental assessment [9], a socio-economic assessment [10] and a health impact assessment [11]. In the future, site specific Environment Impact Assessments will support development consent applications for investigative borehole drilling and GDF construction.

At this early stage, there is uncertainty over many aspects of the disposal system. To address uncertainty in the site and therefore the geological environment, the generic DSSC covers a range of possible host geological environments and illustrative designs. Uncertainty in the inventory for disposal is managed by consideration of a range of inventory scenarios, as explained in Section 1.4. It is acknowledged that there will always be some level of uncertainty in data and assumptions and this is managed, for example, through use of parameter ranges supported by qualitative arguments. Uncertainty is greatest in the long term period after the GDF has been sealed and closed, and this is discussed in the generic ESC Main Report [5].

The generic DSSC is intended to be developed iteratively as plans and designs for the GDF are developed.

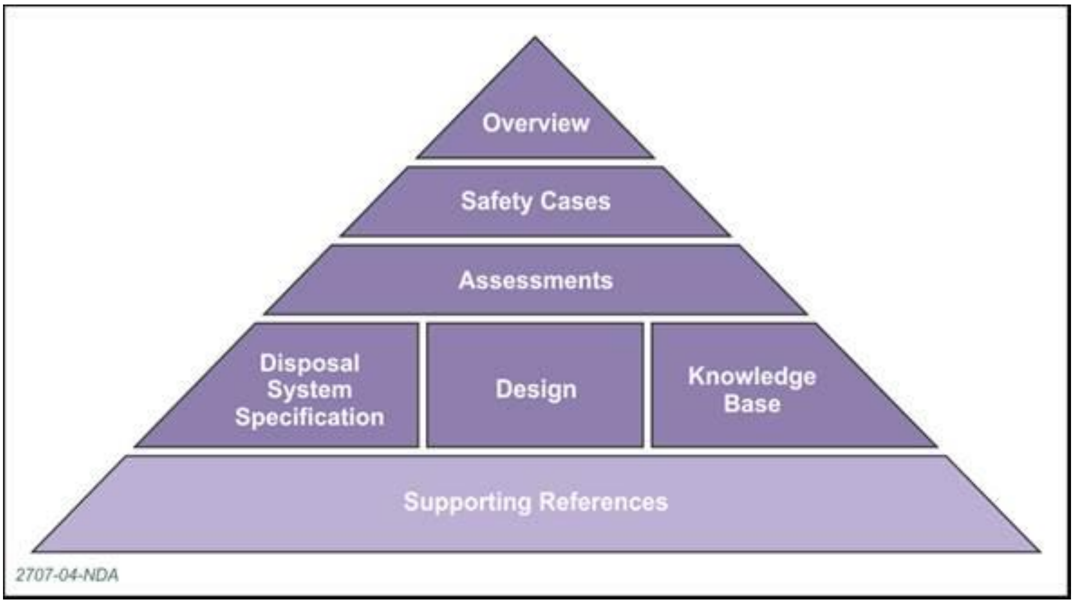
The generic DSSC consists of a tiered suite of documents and supporting references, the main components being the three Safety Cases. An Overview [12] summarises the key safety arguments for RWM's confidence that the waste can be disposed of safely, and provides a way in to the suite. The second tier comprises the safety cases themselves, which cover the transport of radioactive waste to the GDF (the generic TSC), the operation of the GDF (the generic OSC) and its long term safety following closure (the generic ESC). These are supported by detailed transport, operational and environmental assessments and underpinned by the Disposal System Specification, the designs, the knowledge base and supporting references. The knowledge base and supporting references present the current status of the technical understanding developed from over 30 years of UK and international research, development and application.

The document structure is depicted schematically in Figure 1 and a full list of documents that make up the generic DSSC is given in the Overview. The Technical Background is part of the Knowledge Base group.

The transport, operational and environmental safety assessments also form a benchmark for disposability assessments. Specific waste packaging proposals are submitted by waste producers for RWM assessment and advice through its Disposability Assessment process [13].

RWM's strategy for the future development of the generic DSSC and, ultimately a site-specific DSSC, is described in the Overview.

Figure 1 Structure of the generic DSSC



1.3 Purpose of the Technical Background

The purpose of this Technical Background is to provide a source for the primary technical information relating to the generic DSSC, together with pointers to where more detailed information can be found. As such it is designed to be used as a companion document to the safety case reports, providing an introduction to the requirements on the GDF, the inventory for disposal, the illustrative disposal concepts, the designs and the packaging arrangements. The aim is to bring together, in one reference, the background information that is common to many of the documents which make up the generic DSSC. Where more detailed information is required, the Technical Background directs the reader to the appropriate report.

1.4 Updates since the 2010 DSSC

This current version is the first update since the 2010 generic DSSC and incorporates refinements to the Disposal System Specification, illustrative designs and assessments, and progress made in the development of the knowledge base. Details of the key changes, which reflect revisions to Government policy and strategy, and feedback from the regulators and the Committee on Radioactive Waste Management (CoRWM) [14] are provided in the Overview. The most significant changes relate to improvements in the way the inventory for disposal is considered, which is defined in the 2014 White Paper. Other changes relate to the considering of the geological environments. A summary of the significant changes is as follows, and a full list is given in the Overview:

- **Changes to the inventory for disposal:** The inventory for disposal has been updated to align with the 2014 White Paper and the most recent update to the UK Radioactive Waste Inventory (UKRWI) [15]. The most significant changes are: the inclusion of wastes and spent fuel associated with the current industry ambition of a 16 GW(e) new nuclear build programme [2, §7.41.]; reuse of 95% of existing plutonium stocks as mixed oxide spent fuel; the exclusion of waste managed separately under the Scottish Government's policy for higher activity wastes [16] and the inclusion of material associated with UK defence activities.

  This inventory for disposal requires a larger underground footprint for the GDF than that required for the baseline inventory used in 2010 mainly due to the inclusion of high heat generating waste (HHGW) packages from new nuclear build. Inclusion of new nuclear build wastes also increases the operational lifetime of the GDF as these wastes arrive later and need to be cooled in storage before disposal.
- **A revised approach to consideration of the inventory for disposal:** The categories of waste are considered in a way that better aligns with the layout of the illustrative designs, according to their differing disposal requirements. ILW, LLW and depleted, natural and low enriched uranium (DNLEU) are low heat generating waste (LHGW) categories and are therefore considered separately to HLW, spent fuel, plutonium and highly enriched uranium (HEU), which are HHGW categories. Waste categories are further broken down into waste groups that reflect the key differences in time of arising, waste packaging and assumed emplacement methods. For example, new build spent fuel is distinguished from legacy spent fuels which will be emplaced earlier. This approach enables a greater understanding of the contribution of each waste category, and groups within those categories, to the design and safety arguments. It differs from that of the 2010 generic DSSC, where the inventory for disposal was discussed simply in terms of LLW, ILW, HLW and spent fuel.
- **Treatment of uncertainty in the inventory for disposal:** Understanding of the implications of uncertainty in the inventory for disposal has been improved through consideration of a range of inventory scenarios. These inventory scenarios have been developed to allow quick and efficient consideration of potential changes to the UK nuclear programme, for example, a decrease in Magnox fuel reprocessing or an increase in the anticipated operational lifetime of legacy reactors. This differs from the approach in the 2010 generic DSSC where inventory for disposal uncertainty was explored through the use of a single 'Upper Inventory' that made allowance for all of the major uncertainties, including use of upper estimates, new build arisings and defence materials.
- **A balanced approach to the presentation of safety in the host geological environments:** A more balanced assessment is now made, with equal consideration of three host rocks typical of UK geologies: a higher strength host rock, a lower strength sedimentary host rock and an evaporite host rock. For each host rock, illustrative disposal concepts for both LHGW and HHGW have been developed and used as the basis for illustrative designs. In addition, consideration of the geological environment now includes the cover rock overlying the host rock. This is an improvement on the 2010 generic DSSC approach which used an illustrative disposal concept for a higher strength host rock as a reference case, with quantitative or qualitative consideration of other host rocks.

These improvements relate mainly to the radiological inventory for disposal. RWM is currently working with the NDA, the Low Level Waste Repository (LLWR) in Cumbria and waste producers to ensure that more information on potential non-radiological contaminants is available in future for incorporation into the safety cases. Details of the approach taken are provided in Section 2 and the generic ESC [5,17].

2 Inventory

2.1 Introduction

The inventory for disposal at the GDF is defined in the 2014 White Paper. It includes all declared higher activity waste arisings and nuclear materials that are not currently classified as waste, but would require geological disposal if it were decided at some point that they had no further use. These materials include spent fuel (including spent fuel from new power stations), uranium and plutonium.

All existing and known future waste arisings are detailed in the UKRWI. The UKRWI is compiled by the NDA and the Department for Energy and Climate Change from information supplied by the waste producers. It is updated periodically, the latest version being the 2013 UKRWI, which contains information on the UK radioactive wastes that existed at 1 April 2013 and wastes projected to arise after that date, from existing sources. In addition to higher activity wastes, the UKRWI includes wastes that are not destined for disposal to the GDF, such as those arising from nuclear sites in Scotland and wastes destined for disposal at the existing LLWR in Cumbria.

To aid implementation of geological disposal, RWM has developed a Derived Inventory. The 2013 Derived Inventory [18] contains quantitative data on the higher activity wastes from the 2013 UKRWI destined for the GDF and the other materials defined in the inventory for disposal in the 2014 White Paper. In particular, the Derived Inventory assigns assumed package types to all wastestreams and derives inventory data on a per-package basis, which is required for RWM’s design and assessment work. As such, the Derived Inventory forms the basis for the generic disposal system design work and associated safety assessments, and the environmental and sustainability assessments.

Based on the 2013 UKRWI and other supporting information, the packaged volume of all the higher activity wastes and material defined in the inventory for disposal is currently estimated at approximately 750,000 m^3.

The Government has a strong preference to manage the inventory for disposal in a single GDF, on the basis that lower environmental impacts and major costs savings could be realised by developing on a single site. The planning assumption for the generic DSSC is therefore that only one GDF will be necessary for the inventory for disposal.

2.2 Waste Types

2.2.1 Inventory for disposal

The 2014 White Paper sets out the inventory for disposal in the GDF in terms of radioactive waste and material categories, as follows:

- **HLW** – defined in the UK as waste in which the temperature may rise significantly as a result of its radioactivity, such that this factor has to be taken into account in the design of the disposal facilities. HLW arises as a by-product from the reprocessing of spent fuel at Sellafield.
- **ILW** – defined in the UK as waste with radioactivity levels exceeding the upper boundaries for LLW, but not generating sufficient heat for it to be taken into account in the design of storage or disposal facilities. ILW arises from the reprocessing of spent fuel at Sellafield, general operations and maintenance at existing and future nuclear power stations, decommissioning works, and from defence, medical, industrial and educational activities.
- **LLW** – consists largely of paper, plastics and scrap metal items that have been used in hospitals, research establishments and the nuclear industry. A small fraction of

the total volume of LLW cannot be sent to the LLWR in Cumbria for disposal, due principally to higher than permissible concentrations of specific radionuclides, and will therefore need to be disposed of in the GDF.

- **Spent fuel** – currently arises in the reactors of operational power stations. Spent fuel is either reprocessed or stored pending decisions about its future disposal; spent fuel from Magnox reactors is currently reprocessed; spent fuel from Advanced Gas-cooled Reactors (AGR) is either reprocessed or stored; and spent fuel from Pressurised Water Reactors (PWR) is stored. Stored spent fuel, spent fuel yet to arise from the operational power stations and spent fuel from a new nuclear build programme may be declared as waste and are therefore included in the inventory for disposal for planning purposes. There is also some stored spent fuel from research reactors, and spent fuel from submarines.
- **Plutonium** – stocks of separated plutonium have been obtained from the reprocessing of spent fuel and are currently housed in safe and secure storage facilities. The Government's preferred policy for the long-term management of plutonium is for it to be re-used in the form of mixed oxide (MOX) fuel in civil nuclear reactors. Residual plutonium not re-used in new fuel manufacture may in future be declared as waste and is included in the inventory for disposal.
- **Uranium** – uranium stocks arise from fuel manufacture, enrichment processes or reprocessing of spent fuel and are stored securely, in different forms, at a number of nuclear sites. Uranium stocks are categorised as either HEU – defined as uranium with a fissile content (U-233 or U-235) of greater than 20%, or DNLEU – which comprises all types of uranium apart from HEU. These materials may be declared as waste and are therefore included in the inventory for disposal.

It is not anticipated that the categories of waste and material listed above will change significantly. However, the 2013 UKRWI recognises that projections may need to be amended as operational plans and arrangements are developed or changed for commercial, policy or funding reasons, or if improved data become available. Revisions can affect either, or both, the quantity and timing of future arisings.

The assumed 16 GW(e) new nuclear build programme includes electricity generation from 3 Westinghouse AP1000 reactors, 4 EDF Energy EPR reactors and 4 GE-Hitachi ABWR reactors. However, no inventory information is publicly available for the ABWR reactors and so for the purpose of producing the 2013 Derived Inventory, it was assumed that the 16 GW(e) is provided by six AP1000 reactors and six UK EPR reactors.

2.2.2 Non-radiological hazardous substances

It is recognised that some of the wastes in the inventory may be potentially harmful due to the presence of non-radiological contaminants. Consideration of non-radiological pollutants will be of particular importance in demonstrating compliance with the groundwater protection provisions of the Environmental Permitting (England and Wales) Regulations 2010 [19].

RWM has commenced a programme of work in this area, with the preparation of a scoping study to identify those non-radiological hazardous substances which may be present in the inventory of higher activity wastes for disposal and are important in terms of geological disposal, particularly in relation to groundwater pathways in the post-closure period.

An initial list of 20 substances has been compiled that are, or may be, present in the inventory for disposal in significant quantities. The results of preliminary assessments of these substances are discussed in the generic ESC.

The UKRWI currently contains very limited information on non-radiological substances. It is intended to request additional information from waste producers in future updates of the UKRWI, in preparation for site-specific assessments.

It is acknowledged that there may be other non-radiological hazardous substances associated with GDF construction and packaging and these will be considered as part of the ongoing programme of work on this topic.

2.3 The Derived Inventory

The UKRWI inventory information requires modification and enhancement in order to be suitable for use in the design and assessment work for the GDF. For this purpose, RWM prepares the Derived Inventory.

The Derived Inventory is typically updated by RWM in line with updates to the UKRWI, the current version being the 2013 Derived Inventory and the one on which this generic DSSC is based.

The 2013 Derived Inventory differs from the 2013 UKRWI in the following respects:

- unlike the 2013 UKRWI, the 2013 Derived Inventory only includes wastes destined for geological disposal, so it excludes:
    - higher activity wastes managed under the Scottish Government's policy for higher activity wastes
    - LLW that can be managed under the Government's policy for long-term management of such wastes [20]
- the 2013 Derived Inventory includes information on the following materials that are included in the inventory for disposal but excluded from the UKRWI as they are not at present declared as waste:
    - nuclear materials associated with UK defence activities
    - spent fuel, uranium and plutonium stocks
    - spent fuel and radioactive wastes associated with a 16 GW(e) new build programme
    - MOX spent fuel from the re-use of plutonium
- information is provided for waste packages in the 2013 Derived Inventory rather than for waste streams as in the UKRWI, and associated waste package properties such as heat generation and external dose rates are included
- the 2013 Derived Inventory includes packaging assumptions for all waste streams, unlike the UKRWI which does not do so where conditioning processes have not been finalised
- the allocation of waste containers to waste streams in the UKRWI has been reviewed (and, where necessary, revised) in the 2013 Derived Inventory to ensure that assumptions allow for waste to be packaged in a form suitable for its safe management, storage, transport, underground emplacement and potential disposal
- the UKRWI gives some estimates of volumes of irradiated fuel and material with a 'less than' prefix, whereas the 2013 Derived Inventory uses revised discrete estimates to avoid overestimated summations

The 2010 generic DSSC was based on the 2007 Derived Inventory [21]. Following its publication and prior to the current generic DSSC, the 2010 UKRWI was published and RWM estimated a corresponding 2010 Derived Inventory [22]. The differences between the 2007 and 2010 Derived Inventories were not sufficiently significant to warrant a holistic update to the generic DSSC; instead, a report on the implications of the interim update on the generic DSSC was produced [23].

2.3.1 Waste groups

Within LHGW and HHGW, the 2013 Derived Inventory specifies a more detailed breakdown. LHGW comprises LLW, ILW and DNLEU, and HHGW comprises HLW, spent fuel, plutonium and HEU. This classification aids RWM's design and assessments studies by reflecting the different emplacement locations, waste types, packaging and disposal processes involved, and time of arising. Thus, legacy wastes and spent fuel are distinguished from future wastes and spent fuel arising from new build reactors. Although HEU does not generate significant heat, it is destined for the HHGW disposal area because the disposal concept for HEU is very similar to that of the HHGW.

Presenting the inventory in this modular fashion allows the different components to be identified, and their contribution assessed. For this reason, some waste groups are further broken down by source so that, for example, the envisaged contribution of a 16 GW(e) new build programme can be easily determined.

The disposal of LHGW and HHGW in separate areas of the same facility is referred as co-location in the generic DSSC documents. Co-location refers to the emplacement of the inventory for disposal in a single facility with shared surface facilities, access tunnels, construction support and security provision.

The waste groups and sub-divisions used in the 2013 Derived Inventory, for both low and high heat generating wastes, are given in Table 1.

Table 1 Derived Inventory waste groups

<table>
<tr><th></th><th>Waste groups</th><th>Subdivision (if applicable)</th></tr>
<tr><td rowspan="6">LHGW</td><td colspan="2">Legacy LLW and ILW packaged in shielded containers</td></tr>
<tr><td colspan="2">Legacy LLW and ILW packaged in unshielded containers</td></tr>
<tr><td colspan="2">Wastes packaged in 500 litre robust shielded drums and 3 cubic metre robust shielded boxes</td></tr>
<tr><td colspan="2">DNLEU</td></tr>
<tr><td colspan="2">New build ILW packaged in shielded containers</td></tr>
<tr><td colspan="2">New build ILW packaged in unshielded containers</td></tr>
<tr><td rowspan="9">HHGW</td><td colspan="2">HLW</td></tr>
<tr><td colspan="2">Plutonium</td></tr>
<tr><td colspan="2">HEU</td></tr>
<tr><td rowspan="4">Legacy spent fuels</td><td>Spent fuel from AGRs</td></tr>
<tr><td>Exotic spent fuel</td></tr>
<tr><td>Metallic spent fuel</td></tr>
<tr><td>Spent fuel from Sizewell B PWR</td></tr>
<tr><td colspan="2">New build spent fuels</td></tr>
<tr><td colspan="2">MOX spent fuel</td></tr>
</table>

The different characteristics of the spent fuels influence the way that they are assessed and hence the legacy spent fuels are sub-divided into different fuel types, as indicated in Table 1.

Expanding on Table 1, the types of legacy spent fuel considered are:

- spent fuel arising from the AGR fleet that will not be reprocessed
- spent fuel arising from the Sizewell B PWR
- metallic spent fuels, which include only that fuel which will be recovered from Sellafield legacy ponds (and is assumed to be low burn-up Magnox spent fuel)
- exotic spent fuels: The NDA manages non-standard fuels, commonly referred to as ‘exotics’. Although the quantity is small when compared to other spent fuels (for example AGR and PWR), exotics present their own particular management challenges as a result of their diverse properties. Prototype Fast Reactor (PFR) spent fuel is a major component of this sub-division and is the only type of exotic spent fuel modelled in the 2013 Derived Inventory.

New build spent fuel from the UK EPR and AP1000 reactors will be similar in terms of size and it is envisaged that a common disposal container will be used for both. Since both cases are based on a common burn-up of 65 GWd/tU, the new build spent fuel is considered as a single waste group.

Further details of all waste groups are provided in the 2013 Derived Inventory.

2.3.2 Assumptions

The key assumptions on which the 2013 Derived Inventory is based are presented in Table 2 for each waste category.

Table 2 Key Assumptions for each waste and material category

Waste / material	2013 Derived Inventory assumptions
HLW	Includes all 2013 UKRWI HLW from reprocessing 55,000 tU Magnox spent fuel and 5,000 tU AGR spent fuel.
ILW	Includes all 2013 UKRWI ILW, excluding those wastes with an established management strategy of incineration, recycling or near surface disposal. Also includes ILW from a 16 GW(e) new build programme.
LLW	Includes 2013 UKRWI LLW reported as unsuitable for near surface disposal.
Spent fuels	Includes: 4,500 tU AGR spent fuel 1,050 tU Sizewell B PWR spent fuel 740 tU metallic spent fuel 10 tHM exotic spent fuel 8,260 tU EPR spent fuel (new build) 6,030 tU AP1000 spent fuel (new build) 1,460 tHM MOX spent fuel (includes fuel made from 7.6 t of defence Pu) Irradiated submarine fuel (not quantified)
DNLEU	Includes 170,000 tU from civil fuel enrichment and civil spent fuels reprocessing and 15,000 tU from defence programmes.
HEU	Includes 1.0 tU from civil programmes and 21.9 tU from defence programmes.
Plutonium	Includes 5.75 tHM separated Pu residues from reprocessing of civil spent fuels (representing the 5% of the total 115 tHM UK owned Pu that is unsuitable for re-use as MOX fuel).

2.3.3 Volumes and activities

Total volumes of the stored, conditioned and packaged forms of the different waste categories are presented in Table 3 along with the activities at 2040 and 2200 (the planning basis dates for the start of GDF operations and closure, respectively).

Table 3 Volumes of waste considered in the 2016 generic DSSC

Waste category	Stored volume (m^3)	Conditioned volume (m^3)	Packaged volume (m^3)	Activity (TBq)	
				2040	2200
HLW	1,410	1,410	9,290	35,200,000	1,090,000
ILW	267,000	353,000	456,000	1,930,000	1,170,000
LLW	9,330	11,100	11,800	0.908	2.48
Pu	0.567	174	620	62,000	43,700
SF	9,850	9,850	66,100	194,000,000	25,000,000
U	111,000	161,000	222,000	8,430	8,430
Total	**399,000**	**536,000**	**764,000**	**231,000,000**	**27,300,000**

At 2040, the activity of the wastes is dominated by that of the spent fuels and HLW, with the total activity standing at 232,000,000 TBq. However, by 2200 the activity has fallen by nearly an order of magnitude, despite the fact that more spent fuels and wastes have arisen in this period. The reason for this significant drop in activity in a short space of time is that the shorter lived radionuclides have decayed.

Figure 2 shows the activity of the different waste categories at 2200, broken down by waste category. The dominance of the contribution from the spent fuels is clear. The LLW, plutonium and uranium between them contribute approximately 0.2% of the total activity.

Figure 2 Activity of the different waste categories at 2200 broken down by waste category

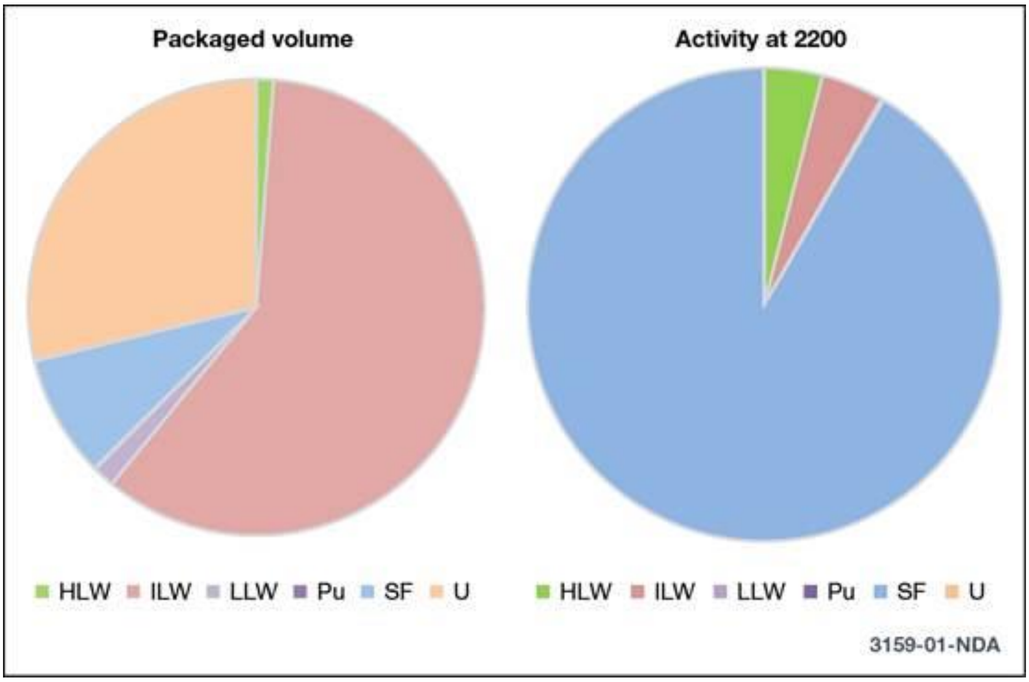
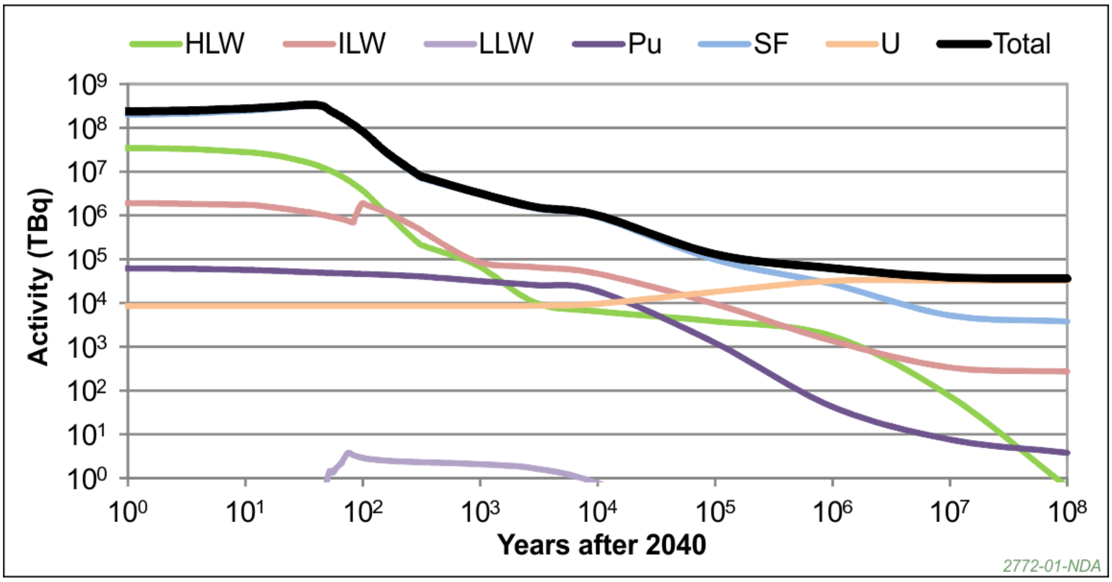


Figure 3 shows the evolution of the activity of the wastes and materials. The total activity increases initially as a result of spent fuels arising from legacy reactors, and the assumed arisings of MOX and new build spent fuels. Sharp changes in the activities of the LLW and the ILW can also be seen, and these are a result of final site clearance at reactor sites. In addition, the shorter lived radionuclides, which contribute significantly to the total activity, decay quickly and a large drop in the total activity is observed shortly after the waste has arisen. Unlike the other wastes, the activity of the uranium is seen to grow with time due to the in-growth of daughter radionuclides.

The spent fuels make the most significant contribution to the total activity until around one million years. At this point, the uranium becomes the biggest single contributor to the total activity. As a result of the long lived nature of the uranium isotopes (specifically U238 and U235), the total activity of the inventory changes very slowly with time after one million years, when compared to the earlier phases of its evolution.

Figure 3 Activity of the different waste categories as a function of time after GDF operations start in 2040



2.4 Inventory scenarios

The 2013 Derived Inventory presents information that is based on the best available data and assumptions regarding, for example, the timing and extent of a new nuclear build programme. Inevitably there are uncertainties associated with both the volumes and radionuclide contents of the currently identified wastes and materials and the postulated scenarios for the future operation of the nuclear plants that produce those wastes and materials.

The generic DSSC assesses the effect of uncertainty by exploring the sensitivity of the 2013 Derived Inventory to a number of different scenarios. A range of scenarios for the inventory of wastes that may require geological disposal has been considered in order to evaluate the implications of these uncertainties for the geological disposal programme.

Twelve scenarios have been identified in the Inventory Scenarios Report [24] as having potential to impact on the 2013 Derived Inventory and these are listed in Table 4. For example, an alternative packaging scenario (Scenario 10) explores the uncertainty in waste packaging, given that only 13% of ILW (by conditioned volume) has currently completed the Disposability Assessment process (see Section 3) and been granted a final stage Letter of Compliance. Further descriptions of the scenarios and how they differ from the key assumptions in the 2013 Derived Inventory are provided in an Inventory Scenarios Report.

Some of these scenarios have been assessed in the generic DSSC quantitatively and some qualitatively. The approach taken to the consideration of inventory scenarios in providing associated inventory data and in design studies is included in Table 4.

In the safety assessments, a qualitative approach to consideration of inventory scenarios has been taken, with the exception of the generic OSC which does not consider inventory scenarios; the overall approach of the generic OSC is to assess credible faults affecting single or small numbers of packages, and therefore inventory scenarios have no impact on the assessment.

Within the generic TSC, each inventory scenario is assessed qualitatively, with the exception of scenarios 1, 6 and 9 which are acknowledged but excluded from the discussion because they are bounded by other scenarios. The generic ESC assesses each scenario qualitatively.

The environmental and sustainability assessments make a qualitative assessment of uncertainty in general but do not consider inventory scenarios; these assessments are based on the disposal system designs and therefore only indirectly linked to the inventory.

At present, the uncertainty associated with the chemotoxic inventory is not addressed. This is because the UKRWI does not request extensive information on chemotoxic species and RWM does not therefore have sufficient information to include this as an enhancement to the Derived Inventory at this stage. RWM has initiated work that will determine which species it needs to quantify and, following delivery of this work, information will be requested from waste producers in a future UKRWI.

The benefit of the revised approach to defining the waste groups, described in Section 2.3.1, is that it facilitates the analysis of the alternative scenarios listed in Table 4 by enabling the impact of waste groups being excluded from the inventory to be assessed easily. In this way, the approach provides an understanding of the impact each waste group has on the illustrative designs, the safety assessments and the underpinning knowledge base.

Table 4 Inventory scenarios defined in the 2013 Derived Inventory and the method of assessment[2]

Scenario		Inventory approach	Design approach
1	More reprocessing of oxide fuel	Qualitative	Qualitative
2	Less reprocessing of Magnox fuel	Quantitative	Quantitative assessment of the impact on vault and tunnel numbers, and underground footprints.
3	Increased lifetime of operating legacy reactors, in line with a current application by EDF Energy		
4a	Recognise uncertainty estimates from UKRWI: Upper uncertainty volume		
4b	Recognise uncertainty estimates from UKRWI: Lower uncertainty volume		
4c	Recognise uncertainty estimates from UKRWI: Upper uncertainty activity		Qualitative
4d	Recognise uncertainty estimates from UKRWI: Lower uncertainty activity		
5	Plutonium not recycled and disposed of as MOX spent fuel	Qualitative	
6	Inclusion of LLW from the LLWR		
7	Increased volumes of depleted uranium	Semi-quantitative (per tU)	
8	Increased new nuclear build programme (additional reactors)	Semi-quantitative (per reactor inventories)	Quantitative assessments of the impacts of 1 extra EPR and 1 extra AP1000 reactor on vault and tunnel numbers, and underground footprints.
9	Inclusion of foreign wastes and materials	Qualitative	Qualitative
10	Alternative packaging (eg new waste packages, use of carbon steel disposal containers for spent fuel)	Semi-quantitative	
11	Graphite wastes not disposed of in the GDF	Quantitative	Quantitative assessment of the impact on vault and tunnel numbers, and underground footprints
12	Exclusion of ILW reported in the UKRWI as being disposed of as LLW		

2 "Qualitative" shown in grey cells to visually distinguish from "Quantitative"

3 The Multi-barrier Approach

The high level requirements that a geological disposal system must meet are:

- isolation of radioactive waste
- containment of radioactive waste
- confidence in long-term safety
- low likelihood of future generations inadvertently intruding into the GDF

In order to deliver these requirements over a long timescale, geological disposal systems are designed as multi-barrier systems. Engineered barriers work in combination with the natural barrier afforded by the geosphere, to isolate and contain the waste so that it does not cause harm to life and the environment.

The engineered barriers are designed to:

- contain the waste and its associated hazard
- be physically and chemically compatible with the geological environment
- provide specific safety functions during the operational period and after closure, that complement those features afforded by the geological environment. (Safety Functions are discussed in Section 4.2)

RWM's illustrative disposal concepts and designs are based on a multi-barrier approach and include high level descriptions of the engineered barriers.

The barriers that contribute to safety for geological disposal are:

- the waste package, comprising waste container and wasteform
- the local buffer or backfill
- the mass backfill
- the plugs and seals
- the geological environment (geosphere)

Examples of multi-barrier systems for both LHGW and HHGW are given in Figure 4.

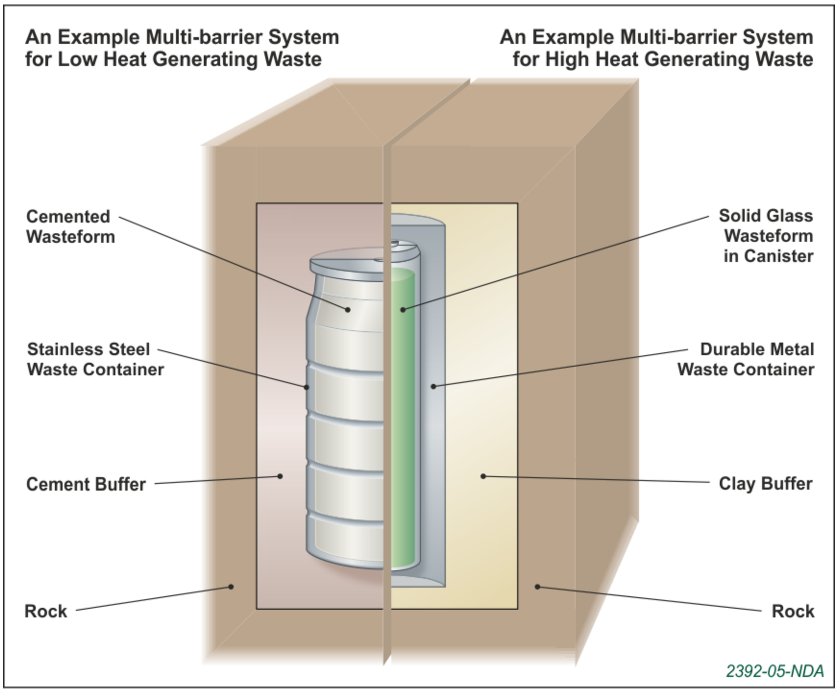
The waste container provides a physical barrier and also enables the waste package to be handled safely, while the wasteform may provide a significant degree of physical and/or chemical containment of the radionuclides, for example, immobilisation in a solid grout matrix or stable glass form. Waste packages will enter the post-closure period still able to provide a barrier to the release of radionuclides. However, over time, progressive degradation of the waste package will result in the eventual loss of these properties, and containment provided by the other barriers will then act to maintain the overall safety of the geological disposal system.

The local buffer or backfill immediately surrounding the waste packages is designed to protect the waste containers and limit the release of radionuclides by establishing a favourable chemical environment and limiting groundwater ingress / egress.

The mass backfill, in the access tunnels and service ways, and the associated plugs and seals, are designed to stabilise the structure and geometry of the engineered and geological barriers by filling voids and having the appropriate mechanical and hydraulic properties. These barriers will also limit the release of radionuclides by limiting groundwater movement.

Each barrier will not need to provide all the safety functions specified, since it is the overall contribution of the mutually complimentary engineered and natural barriers that deliver isolation and containment of the waste.

Figure 4 Schematic illustration of the multi-barrier approach



4 Disposal System Specification

4.1 Requirements

RWM has developed the Disposal System Specification [25, 26] to define the requirements on the disposal system. The Disposal System Specification states that the disposal system fundamentally is required to:

> *"Manage the inventory of higher activity waste for disposal to protect people and the environment, both now and in the future, taking into account; safety, security, safeguards, socioeconomic impacts, and value for money."*

This is achieved through the definition of requirements on the design of the GDF and its construction, operation and closure.

The generic Disposal System Specification comprises two documents:

- Generic Disposal System Specification Part A – High Level Requirements [25]. The purpose of Part A is to document the high level external requirements on the disposal system.
- Generic Disposal System Specification Part B – Technical Requirements [26]. The purpose of Part B is to capture the technical requirements defined by RWM to frame the development of a solution to meet the requirements of Part A.

The high level requirements specified in Part A are derived from legislation, regulations and international guidance, stakeholder requirements and the inventory for disposal, and are largely independent of a site. As part of a requirements management approach, the high level requirements in Part A are used to derive the technical requirements on the disposal system detailed in Part B for use in disposal system design and assessment at the generic and site-specific stages of the programme.

4.2 Safety functions

A key requirement in siting, designing and operating a GDF, is to ensure that safety is provided by means of multiple safety functions. A safety function is a property of the disposal system, or part of it, that has the potential to contribute to meeting one or more safety requirements. A safety function of the waste package, for example, is to limit radiation dose to workers and members of the public.

The use of safety functions is well established in nuclear safety, and applies primarily to operational and post-closure safety.

Multiple safety functions enhance both safety and confidence in safety by ensuring that the overall performance of the GDF is not unduly dependent on a single safety function. Each illustrative disposal concept delivers a number of safety functions with various components contributing to fulfilling different safety functions over different timescales.

With regards to radioactive materials transport, the functions and levels of performance required from the transport system design are specified by the International Atomic Energy Agency Regulations for the Safe Transport of Radioactive Material [27] for the various transport package and material designs. Performance is demonstrated in Design Safety Reports [28].

For operational safety, a safety function is defined in the ONR Safety Assessment Principles [7] as *"a specific purpose that must be accomplished for safety"*. Essentially, the safety functions define what is required to keep a facility safe and are specific to faults and routine hazards. Safety functions apply to administrative procedures as well as structures, systems and components, and therefore can be provided by human action as well as passive features. The ONR requirements regarding safety functions are detailed and numerous. As a consequence, safety functions are required to be identified and categorised in terms of their significance with regard to safety. Future site-specific operational safety cases will therefore be required to demonstrate that all structures, systems and components are designed, constructed, commissioned, operated and maintained in such a way as to enable them to fulfil their safety functions for their projected lifetimes.

Environmental safety functions are defined in UK guidance [8] on the requirements for authorisation of GDFs as *"the various ways in which components of the disposal system may contribute towards environmental safety, eg the host rock may provide a physical barrier function and may also have chemical properties that help to retard the migration of radionuclides"*. Hence, in the context of post-closure safety, safety functions are provided by the natural and engineered barriers of a given disposal concept, and not by human action. A post-closure safety function is often provided by a physical or chemical property or process that contributes to safety, by isolating or containing the disposed waste.

The generic DSSC considers operational and environmental safety functions separately, allowing for the different approaches specific to each of the generic OSC and generic ESC. RWM has documented its approach in an overview to defining safety functions [29].

One of the requirements on a GDF is that it should be constructed and operated in such a manner as to provide and preserve the environmental safety functions of the barrier system that contribute to long-term post-closure safety. This leads to an interface between the operational and environmental safety functions at the end of the operational phase, where it will be necessary to demonstrate that the appropriate environmental safety functions are provided at the start of the post-closure phase. The 'initial state' of the system in relation to the environmental safety functions will be demonstrated as part of the operational safety case for sealing and closure. Operational experience and understanding will build confidence in an ESC by confirming that the initial state (including the environmental safety functions provided by the barriers) is consistent with the expectations of the ESC; this will be achieved primarily through a monitoring programme, which is discussed in Section 7.6.

5 Geological Environment and Host Rock

Illustrative designs and concepts are specific to the host rock; the host rock and the engineered barriers work together to form the multi-barrier system. However, it is the geological environment, including the host rock, that impacts safety and is therefore the subject of underpinning research.

5.1 Geological environment

The geological environment comprises both the host rock within which the GDF is constructed and the rocks around it. It is the properties and structures of all these rocks taken together that determine the performance of the geological barrier (or geosphere) in preventing the movement of radionuclides away from the GDF. Features such as folds and faults not only influence the volume and shape of the bodies of the host rock, but may also dictate properties, such as permeability, that are critical to long term safety. Likewise, the nature of the rocks surrounding the host rock can make a major contribution to the long term performance of the GDF, for example, by contributing to the isolation of the host rock from groundwater systems that extend to the surface.

5.2 Host rock

RWM has identified the types of rock that may provide a suitable, low permeability host for a GDF for many years. Low permeability geological formations can be subdivided according to their geological origins into three idealised categories [30]: ‘hard rocks’ such as igneous and metamorphic rock; ‘soft rocks’ such as clay and mudstone; and ‘evaporite’.

For the purposes of the generic DSSC, the potential host rock types are considered in groups that can each be covered by a single safety case, and broadly aligned to their geological origin. Hence, in common with most other waste management organisations, RWM uses a three-fold division of potential host rocks:

- **Higher strength rocks –** which may be igneous, metamorphic or older sedimentary rocks, have a low matrix porosity and low permeability, with the majority of any groundwater movement confined to fractures within the rock mass.
- **Lower strength sedimentary rocks** - are fine-grained, sedimentary rocks with a high content of clay minerals that provides low permeability and are mechanically weak, so that open fractures cannot be sustained. They are interlayered with other sedimentary rock types.
- **Evaporite rocks** - these result from the evaporation of water from ancient seas and lakes and often contain bodies of halite (rock salt), for example, that provide a suitably dry environment. They are weak and creep easily so that open cracks cannot be sustained.

These potential host rock types are explained in more detail below.

5.2.1 Higher strength rock

Higher strength rocks typically comprise crystalline igneous, metamorphic rocks or geologically older sedimentary rocks. Granite is a good example of a rock that would fall into this category. In geological terms, a rock mass comprising ‘higher strength rock’ might not be a single rock type, but the different rock units would have similar mechanical properties (for example the different components of a composite igneous intrusion). A single unit within the higher strength rock might be selected for GDF construction. A key characteristic of higher strength rocks is that they are relatively brittle and so deform through fracturing, although fractures may become sealed by mineral growth or dissolution over extended periods of time.

Throughout the generic DSSC documentation, higher strength rock describes rocks which have high strength but low permeability and in which any appreciable radionuclide transport is by groundwater advection through fractures. Higher strength rocks that exhibited significant bulk permeability would be unsuitable as host rocks unless an adjacent rock was able to provide isolation from the near-surface environment.

Higher strength rocks in the UK at the relevant depths for a GDF contain water-filled fractures and if these interconnect, water may flow through them, potentially carrying radionuclides from waste and moving them towards the surface in solution. These fractures also provide a potential pathway for gas, reducing the likelihood of a pressure build-up at depth. Radionuclides transported by groundwater moving through higher strength rocks may be sorbed by a range of minerals that commonly line fractures and pores, including chlorite and other clay minerals, and iron oxy-hydroxides. This effect may significantly extend the return times for radionuclides to the surface.

In many parts of the UK, higher strength rocks are present at depth and are covered by younger sedimentary rocks. If the overlying rocks include clay-rich beds these may provide an effective impermeable cover over a GDF hosted in the underlying higher strength rock, and these sediments would have a role in preventing the return of radionuclides to the surface.

Where relatively permeable sedimentary rocks overlie much less permeable higher strength rocks, the two rock types may again be characterised by separate hydrogeological regimes. The permeable sedimentary layers reduce the hydraulic gradient in the rocks beneath, and if the groundwater in the underlying higher strength rocks is relatively saline and dense, this will minimise mixing with the overlying groundwater. Hence where higher strength host rocks are present at depths of a few hundred metres and are overlain by sedimentary rocks with a distinct and separate hydraulic regime, consideration of their permeability must take account of the effect of the overlying rocks.

5.2.2 Lower strength sedimentary rocks

Lower strength sedimentary rocks describe rocks which have low to moderate strength and contain a high proportion of clay. Any movement of water or dissolved chemical species are dominated by diffusion through the rock matrix, because any fractures that develop in these rocks will self-seal. In the UK, this category includes clay and mudstone-dominated formations.

Lower strength sedimentary host rocks are being considered in France and Switzerland. Such rocks have sufficient strength to allow excavation for a GDF, provided appropriate engineering support is provided. They may undergo brittle failure, but they are also able to creep to some degree so that fractures would not be able to act as flow paths in the long term.

Because clay-rich beds always have low permeabilities, groundwater does not pass through them, even if there is groundwater movement through the sediments above or below. This means that radionuclides dissolved into the pore waters around a GDF move only by diffusion and at an extremely slow rate. Many clay-rich rocks today appear to contain pore waters that date back to their original burial. Additionally, most radionuclides are strongly sorbed onto the surfaces of clay particles, providing additional retardation.

The low rate of water movement also reduces the rate of gas generation. Any gas formed in these environments would be likely to be trapped in the formation and the potential impact of gas build-up and pressurisation would need to be considered.

5.2.3 Evaporite rocks

Evaporite rocks are sedimentary rocks formed directly from the evaporation of surface water and commonly include abundant halite (rock salt) and beds of other minerals formed by evaporation, notably sulphate minerals. Other rock types present may include mudrocks, marls and dolomitic limestone.

Halite may occur as a layered deposit. It might also occur as a dome structure (known as a diapir), following mobilisation and movement into overlying sedimentary units. However, salt domes do not occur within the area of interest (England, Wales and Northern Ireland), so an evaporite host rock would be a bedded evaporite.

Halite merits a distinct safety case because it provides a dry environment that will not be infiltrated by water and because any cracks will be self-sealing over time scales appropriate to geological disposal. A halite safety case is not applicable to other evaporite rocks or minerals (such as anhydrite) because these may contain water and would not have the required self-sealing properties.

A GDF constructed in halite would provide a dry environment with no water available to dissolve and transport radionuclides. Even the water in the nearest porous sedimentary rocks is likely to be a very dense brine with no tendency to rise and mix with shallow fresh groundwater.

6 Disposal Concepts

As no site has yet been identified for the GDF, the host geological environment is not known. RWM has investigated a wide range of disposal concepts considered by waste management organisations around the world. From these, a smaller number of illustrative disposal concepts [26] have been defined for three host rocks appropriate to the UK, for the purpose of the current design and assessment work and as the basis for the generic DSSC.

All of the disposal concepts developed by waste management organisations around the world are based on a multi-barrier approach, the nature of the barriers depending on the geological environment and the type of wastes to be disposed of.

A disposal concept is the description of the engineered barriers, natural barriers and disposal facility layout required to ensure that the radioactivity in the wastes is sufficiently isolated and contained, so that it will not be released in unacceptable amounts that may cause harm to people and the environment. The engineered and natural barriers deliver the safety functions defined in the Disposal System Specification. The layout is a description of the shape of the emplacement spaces and the other underground excavations, and their arrangement with respect to each other and with respect to the host rock. A disposal concept is specific to the host rock and to either LHGW or HHGW. The GDF may incorporate more than one disposal concept.

The illustrative disposal concepts utilise the most appropriate engineered barriers, materials and facility layouts for each host rock. As the siting process progresses, a successive programme of optioneering and optimisation will be undertaken to ensure that the most appropriate disposal concepts are selected and developed for the chosen site.

The main role of the illustrative disposal concepts is to:

- provide the basis of assessment for the generic DSSC
- support the Disposability Assessment process

Through the iterative development of the disposal system, the illustrative disposal concepts also enable RWM to further develop its understanding of the requirements for the disposal system, develop and prioritise its research programme and underpin analysis of the potential cost of geological disposal.

The illustrative disposal concepts have been developed solely for these purposes. It is not the intention to select any of these concepts: instead, when the geological environment for the GDF is known, appropriate concepts will be developed specific to that setting and the wastes to be disposed of, based on the developing knowledge of the site and the understanding of the full range of concepts under consideration. At this stage, no disposal concepts have been ruled out.

The use of illustrative disposal concepts does not restrict RWM from considering other potentially appropriate concepts. When developing appropriate concepts, RWM aims to build on existing knowledge available in the UK and overseas. Knowledge relevant to the UK can be adapted to meet the needs of the UK disposal system and provides an opportunity to improve confidence in the UK programme, reduce programme risk, and provide cost and time savings [31].

6.1 The illustrative disposal concepts

RWM's illustrative disposal concepts are based on selected disposal concepts developed by waste management organisations across the world. These are listed in Table 5 along with an explanation of why those concepts were selected.

Table 5 Disposal concepts selected as the basis for RWM's illustrative disposal concepts

Host Rock	Disposal Concept (Developer, Country)	
	LHGW	HHGW
Higher strength rock[1]	UK LHGW Concept (RWM, UK)	KBS-3V Concept (SKB, Sweden)
Lower strength sedimentary rock[2]	Opalinus Clay Concept (Nagra, Switzerland)	Opalinus Clay Concept (Nagra, Switzerland)
Evaporite rock[3]	WIPP Bedded Salt Concept (US DOE, USA)	Gorleben Salt Dome Concept (DBE Technology, Germany)

Notes:

1. Higher strength rock – the UK LHGW concept and SKB's KBS-3V disposal concept for spent fuel were selected because of the availability of information on these concepts for the UK context.
2. Lower-strength sedimentary rock – the Opalinus Clay concepts were selected following an NEA review [32]. However, it should be noted that there is similarly extensive information available for the French (Andra) concepts (for Callovo-Oxfordian Clay), which have also been accorded strong endorsement from international peer review. Although the Swiss concepts are used as the basis of the illustrative disposal concepts, information is also drawn from the French programme and from the Belgian HLW/spent fuel supercontainer concept based on disposal of HHGW in Boom Clay.
3. Evaporite rock – the concept for the disposal of transuranic wastes (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 licensed facility. The concept for disposal of HHGW in a salt dome host rock developed by DBE Technology in Germany was also selected because of the level of concept information available.

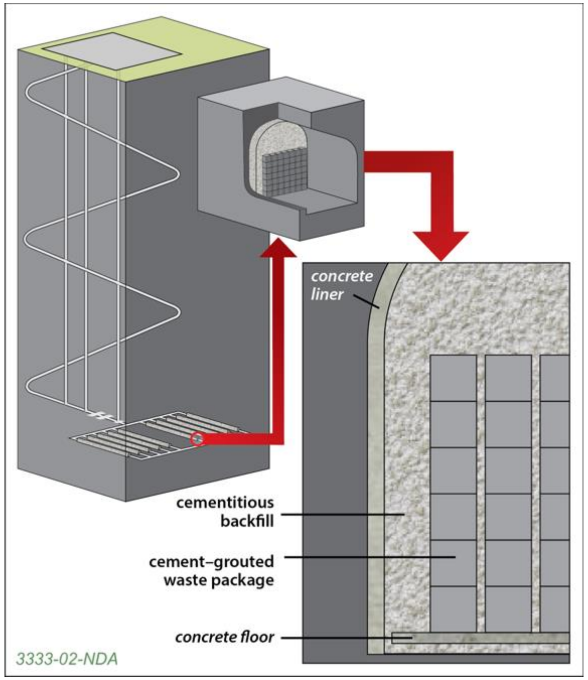
The disposal concepts in Table 5 form the basis of RWM's illustrative disposal concepts for both LHGW and HHGW, for each of the three host rocks described in Section 5. These illustrative disposal concepts are shown in Figure 7 and Figure 8 for LHGW and HHGW respectively, and described in more detail in Table 6 [33] and Table 7 [33]. The illustrations show shafts and a drift in some cases for context, although these are access details that are not part of the concepts. All these concepts are based on a multi-barrier approach.

If an evaporite rock environment were found for the GDF, it would be a bedded evaporite as salt domes do not occur in the area of interest. The design would be developed from knowledge on the WIPP bedded salt concept, the Gorleben Salt Dome concept, and other concept development work.

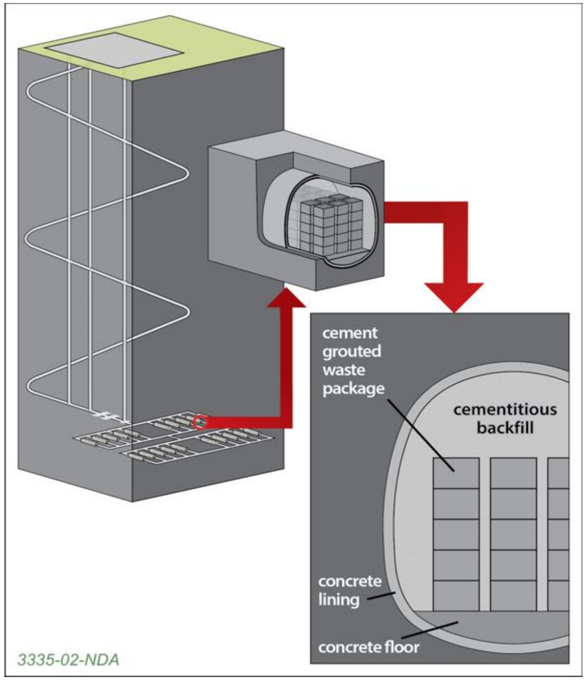
The wider geological environment is relevant to post-closure safety, and would influence decisions on access routes, although it does not affect the illustrative disposal concepts themselves.

Figure 5 Schematic of illustrative disposal concepts for low heat generating waste

Higher Strength Rock



Lower Strength Sedimentary Rock



Evaporite Rock

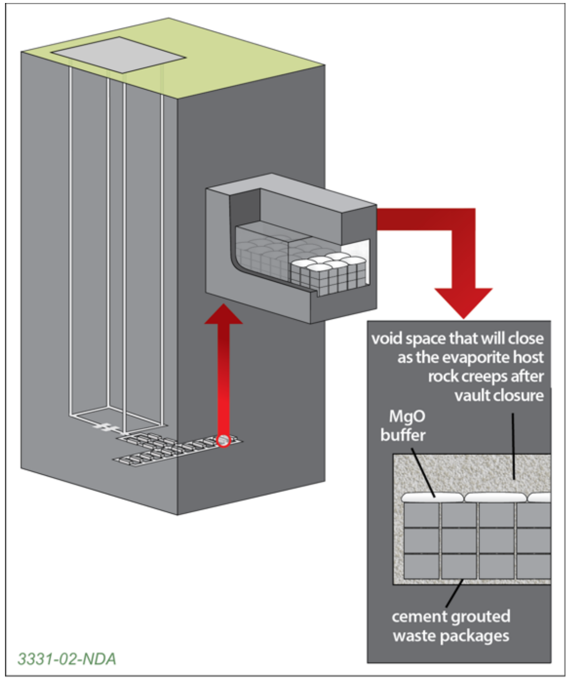


Figure 6 Schematic of illustrative disposal concepts for high heat generating waste

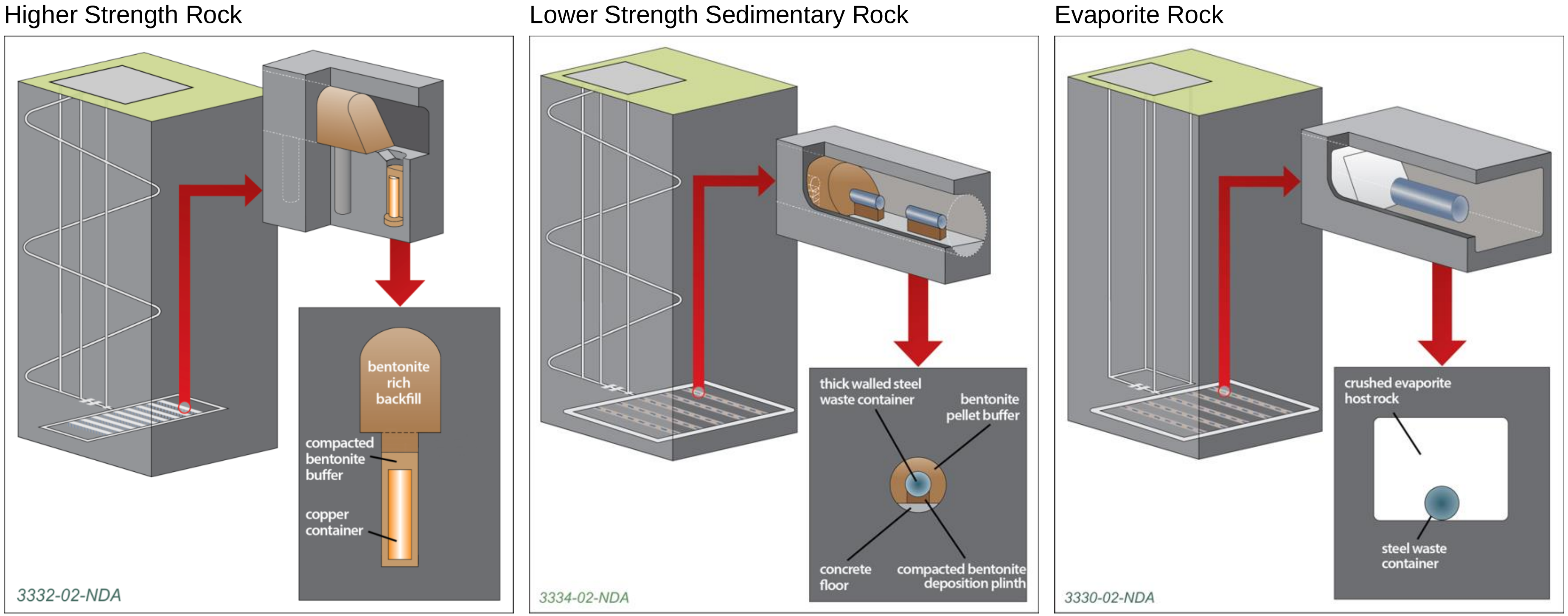


Table 6 Description of illustrative disposal concepts for low heat generating waste

Attribute	Higher strength rock	Lower strength sedimentary rock	Evaporite rock
Source example	UK ILW/LLW Concept – NDA, UK	Opalinus Clay Concept – Nagra, Switzerland	WIPP Bedded Salt Concept – US-DOE, USA
Waste to which concept applies	Suitable for LHGW in the UK inventory.	Suitable for most LHGW in the UK inventory. Cementitious environment may not be optimal, or even suitable, for some vitrified wastes.	Suitable for most LHGW in the UK inventory.
Geological Environment on which concept is based	Higher strength host rock overlain by sedimentary sequence that provides significant (tens of thousands of years) groundwater travel time.	Lower strength sedimentary host rock in which the permeability is sufficiently low that solute transport is by diffusion. There will be a cover sequence but its nature is not specified, or important to the definition of the disposal concept.	Evaporite host rock. There will be a cover sequence but its nature is not specified, or important to the definition of the disposal concept beyond it protecting the evaporite from low salinity groundwater.
Components	Large horseshoe-shaped vaults (eg 16 m × 16 m × 300 m). A lining may be installed to prevent rockfall and water ingress. Such support, as required, is provided by rock bolting, mesh and shotcrete. Cement grouted waste in standardised vented stainless steel containers. High pH, high porosity and permeability cementitious backfill (Nirex Reference Vault Backfill – NRVB) surrounding waste packages. Emplaced as part of closure engineering. Crushed host rock mass backfill. Low permeability seals/plugs.	Oval-shaped vaults (for example 9.5 m (width) × 11.5 m (height) × 100 m). A lining may be installed to prevent rockfall and water ingress. Such support, as required, is provided by rock bolting, mesh and shotcrete. Cement grouted waste in standardised vented stainless steel containers. High pH, high porosity and permeability cementitious backfill surrounding waste packages. Backfill has some structural strength to resist creep of the host rock. Emplaced as soon as each vault has been filled. Crushed host rock mass backfill. Low permeability seals/plugs.	Rectangular-shaped vaults (eg 10 m (width) × 5.5 m (height) × 100 m), which are unlined. Cement grouted waste in standardised vented stainless steel containers. Sacks of MgO are placed on top of each waste stack to absorb CO_2 and water and buffer pH. Remaining void space left open. Vault closed as soon as it has been filled. Crushed host rock mass backfill. Low permeability seals/plugs. Note that underground access is by shaft instead of the more normal drift access.

Attribute	Higher strength rock	Lower strength sedimentary rock	Evaporite rock
Waste handling and emplacement	Unshielded packages transported underground within transport container. Remote emplacement of unshielded ILW waste packages by crane. Shielded ILW/LLW waste packages emplaced by stacker truck (with shielded cab). Standardised containers to facilitate handling and stacking. Vaults open at both ends during operational period facilitating ventilation.	Unshielded packages transported underground within transport container. Remote emplacement of unshielded ILW waste packages by crane. Shielded ILW/LLW waste packages emplaced by stacker truck (with shielded cab). Standardised containers to facilitate handling and stacking. Vaults open at both ends during operational period facilitating ventilation.	Unshielded packages transported underground within transport container. Remote emplacement of unshielded ILW waste packages by stacker truck. Manual emplacement of shielded ILW/LLW waste packages by stacker truck (with shielded cab). Standardised containers to facilitate handling and stacking. Vaults open at both ends during operational period facilitating ventilation.
Operational considerations	Achieving a uniform distribution of backfill around the waste packages may present challenges, especially if the operation is carried out many decades after the equipment was installed. Delayed backfilling has associated maintenance requirements to ensure environmental conditions are maintained for decades after vaults have been filled; prevention of rockfalls etc. Continued ventilation requirements – packages are vented and so radioactive and potentially flammable/explosive gases are released during the operational period.	None specified	None specified

Attribute	Higher strength rock	Lower strength sedimentary rock	Evaporite rock
Post-closure safety concept	Backfill is designed to condition the groundwater to a high pH for timescales of a million years or more and thereby provide a chemical barrier to release of radionuclides. High pH conditions reduce the solubility and mobility of certain key radionuclides such as actinides. Low permeability host rock ensures very slow migration in groundwater.	Backfill is designed to condition the groundwater to a high pH for timescales of a million years or more and thereby provide a chemical barrier to release of radionuclides. High pH conditions reduce the solubility and mobility of certain key radionuclides such as actinides. Low permeability host rock ensures very slow migration in groundwater.	Host rock creeps and completely encapsulates waste packages. Dry environment means that there is no transport via the groundwater pathway.
Monitoring of waste packages and retrievability (ie the reverse of emplacement prior to backfilling)	Crane emplacement would allow selective retrieval prior to backfilling. However, cranes would need to be maintained for 100 years. Potential for monitoring either through inspection of selected (retrieved) waste packages or remotely, for example inspection by camera.	Backfilling immediately after the vault has been filled limits the potential for retrievability and monitoring. However, the access tunnels will be fully lined and kept open until GDF closure.	Closing the vaults immediately after they have been filled limits the potential for retrievability and monitoring. However, the access tunnels will be kept open until GDF closure, although creep may be an issue.
Technical maturity	This concept has been developed in the UK and is used as a reference for disposability assessments. Extensive research and development has been carried out but no site-specific safety case has yet been developed.	This concept is an adaptation of the opalinus clay concept for disposal of long lived ILW developed by Nagra. It was selected because a review by the Organisation for Economic Co-operation and Development (OECD) Nuclear Energy Agency regarded the Nagra assessment of the concept as state of the art with respect to the level of knowledge available.	This concept is an adaptation of the WIPP disposal concept for transuranic wastes, which is an operating facility.

Table 7 Description of illustrative disposal concepts for high heat generating waste

Attribute	Higher strength rock	Lower strength sedimentary rock	Evaporite rock
Source example	KBS-3V Concept – SKB, Sweden	Opalinus Clay Concept – Nagra, Switzerland	Gorleben Salt Dome Concept – DBE-Technology, Germany
Waste to which concept applies	Suitable for a wide range of HHGW, although the very long container lifetime provided by copper container may not be optimal for some wastes (eg HLW) which do not need to be contained for such a long period. Alternatives to copper will be considered.	Suitable for all types of HHGW	Suitable for all types of HHGW
Geological environment on which concept is based	Higher strength host rock overlain by sedimentary sequence that provides significant (tens of thousands of years) groundwater travel time.	Lower strength sedimentary host rock in which the permeability is sufficiently low that solute transport is by diffusion. There will be a cover sequence but its nature is not specified, or important to the definition of the disposal concept.	Evaporite host rock. There will be a cover sequence but its nature is not specified, or important to the definition of the disposal concept beyond it protecting the evaporite from low salinity groundwater.
Components	1.5 m diameter borehole approximately 8–10 m deep drilled vertically from the floor of the horseshoe shaped deposition tunnel. Borehole designed to take single waste package and buffer. Copper container with cast iron insert to provide mechanical strength. Compacted bentonite buffer. Bentonite-dominated deposition tunnel backfill. Crushed rock mass backfill in access tunnels. Low permeability sealing system.	2.5 m diameter unlined horizontal tunnel with a concrete floor, nominally 800 metres in length. Thick-walled carbon steel container. Pelleted bentonite buffer, although compacted bentonite pedestal used to support waste package. Crushed host rock mass backfill. Sealing system.	Rectangular (4.5 m wide by 3.5 m high) unlined horizontal tunnel, nominally 800 metres in length. Thick-walled carbon steel container. Crushed host rock buffer. Crushed host rock mass backfill. Sealing system.

Attribute	Higher strength rock	Lower strength sedimentary rock	Evaporite rock
Waste handling and emplacement	Waste package transported underground in re-usable transport container and then emplaced remotely. Robust sealed waste package prevents releases during operations.	Waste package transported underground in re-usable transport container and then emplaced remotely. Robust sealed waste package prevents releases during operations.	Waste package transported underground in re-usable transport container and then emplaced remotely. Robust sealed waste package prevents releases during operations.
Post-closure safety concept	A very long container lifetime ensuring no release for hundreds of thousands of years. Combination of protection provided by the buffer and choice of container material ensures extremely long container lifetime.	Waste container protected by buffer provides containment during the thermal period, and is expected to remain intact for tens of thousands of years. Long term containment is dominantly provided by low permeability host rock, which ensures that solute transport is dominated by diffusion.	Evaporite host rock will creep and compact the buffer resulting in complete encapsulation of the waste packages in a dry environment. Dry environment will limit corrosion of the thick-walled waste container so the container is likely to remain intact for hundreds of thousands of years.
Monitoring of waste packages and retrievability	Tunnel backfill must be emplaced as soon as possible after buffer emplacement so potential for monitoring and retrievability limited.	Buffer is emplaced at the same time as waste packages so potential for monitoring and retrievability limited.	Buffer is emplaced at the same time as waste packages so potential for monitoring and retrievability limited.
Technical maturity	The Swedish KBS-3V concept is an example of this concept. A site-specific safety case has been submitted for regulatory review but certain aspects of the concept are still subject to development for a UK geological environment.	Similar concept currently being developed by Nagra. Extensive research, including work in underground research laboratories, although rate of progress is modest owing to a site not yet having been selected in Switzerland.	This concept was adapted from the concept for disposal of HLW and spent fuel in a salt dome host rock developed by DBE Technology; it was selected due to the level of concept information available.

7 General Features of the Illustrative Designs

To progress the GDF implementation programme in the absence of a specific site, RWM has developed illustrative designs for the GDF based on the illustrative disposal concepts described in Section 6.1. By developing illustrative designs and assessing them for safety, RWM is able to develop appropriate disposal solutions for different waste types, iteratively improve the illustrative designs, and identify research and development needs. The illustrative designs also help enhance the understanding of how waste disposal could be carried out in different geological environments, how safety can be ensured in all phases of development and what the environmental, socio-economic and health implications might be. It is also possible to determine how long designs might take to develop, and what the costs might be.

The general features of the illustrative designs are summarised below. These are based on certain assumptions regarding the design, construction, operation and closure of the GDF, and do not represent decisions or requirements. The summary focuses primarily on those features which are common to all illustrative disposal concepts. Full details of the illustrative designs, which form the basis for the safety assessments, and details of construction methods and materials, are provided in the generic Disposal Facility Designs report [34]. Further information on the waste volumes and type of packaging of LHGW and HHGW can be found in Section 1 of this report and in the Generic Transport System Designs report [35].

7.1 Surface facilities

In the illustrative designs, the surface facilities are located on a single rectangular site with level topography. The surface site is located directly above the underground facilities although, in practice, they could be some distance apart. An idealised schematic layout has been prepared for each of the three host rocks [34] showing the construction facilities and, operational buildings, and the associated road and rail infrastructure.

The surface waste-handling facilities and infrastructure cater for the receipt of waste packages onto the site and their preparation for transfer underground. For each host rock this includes on-site rail sidings and HGV parking, to accommodate rail wagons and lorry trailers holding transport packages awaiting transfer underground.

7.2 Underground facilities and layouts

There are four access routes between the surface and underground facilities. For higher strength and lower strength sedimentary host rocks, the underground facilities are accessed by three shafts and a drift (inclined tunnel). The drift is used for the transport of waste packages underground. Personnel involved in waste package emplacement operations also travel via the drift but separately from the waste packages. For the evaporite host rock, the underground facilities are accessed by four shafts. In all host rocks, access for construction workers and equipment is by a vertical shaft located in the construction area. Excavated rock spoil is removed by a separate shaft, also located in the construction area.

Underground, the disposal facility is split into two separate disposal areas, one for LHGW and one for HHGW. There are vaults for LHGW with separate vaults for unshielded packages and the different categories of shielded packages. In a higher strength host rock, the HHGW disposal area comprises modules of disposal tunnels, with vertical deposition holes drilled in each tunnel floor. For both the lower strength sedimentary and evaporite host rocks, there are modules of long horizontal disposal tunnels. In all three host rocks, the two disposal areas are physically separate to ensure there are no thermal, hydraulic, mechanical, chemical or gas interactions that significantly affect post-closure performance.

The illustrative layouts for each host rock are shown in Figure 7 to Figure 9.

Figure 7 Illustrative underground layout for a higher strength rock

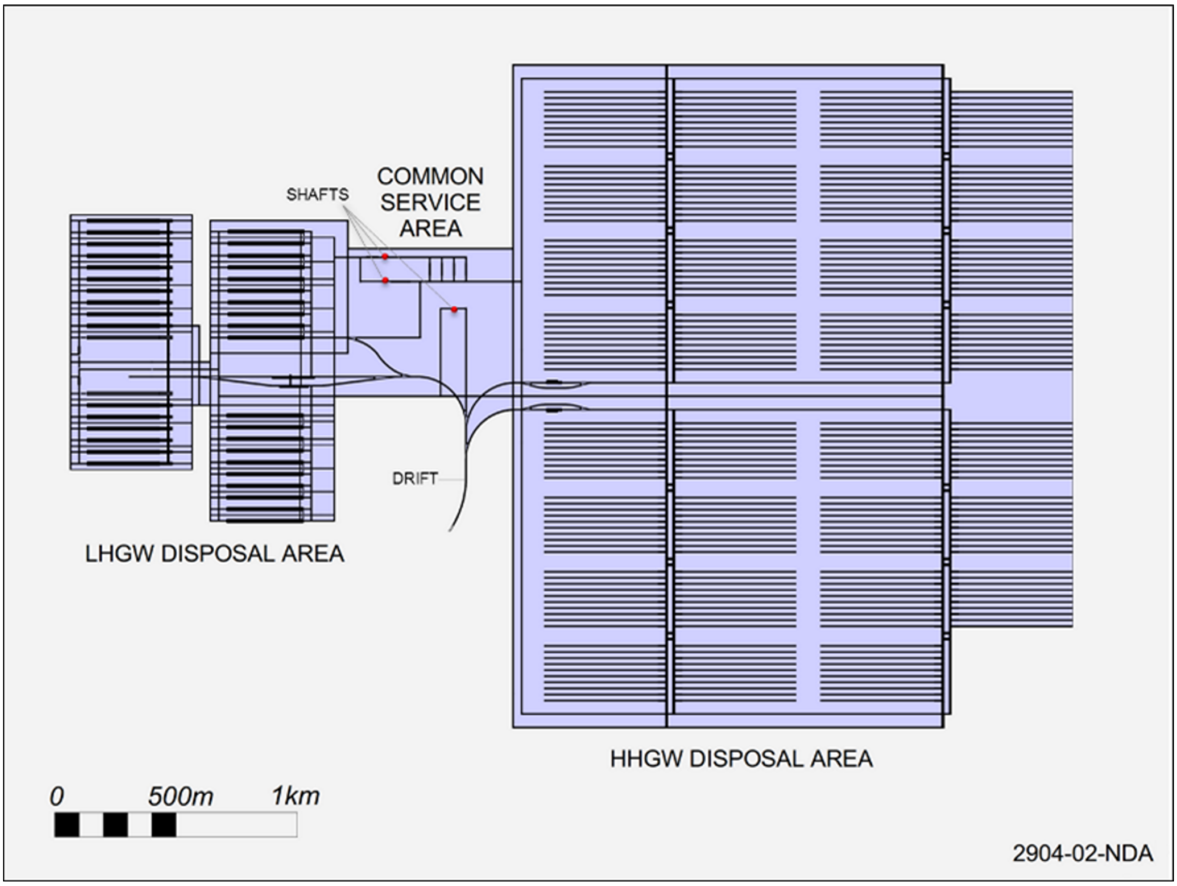


Figure 8 Illustrative underground layout for a lower strength sedimentary rock

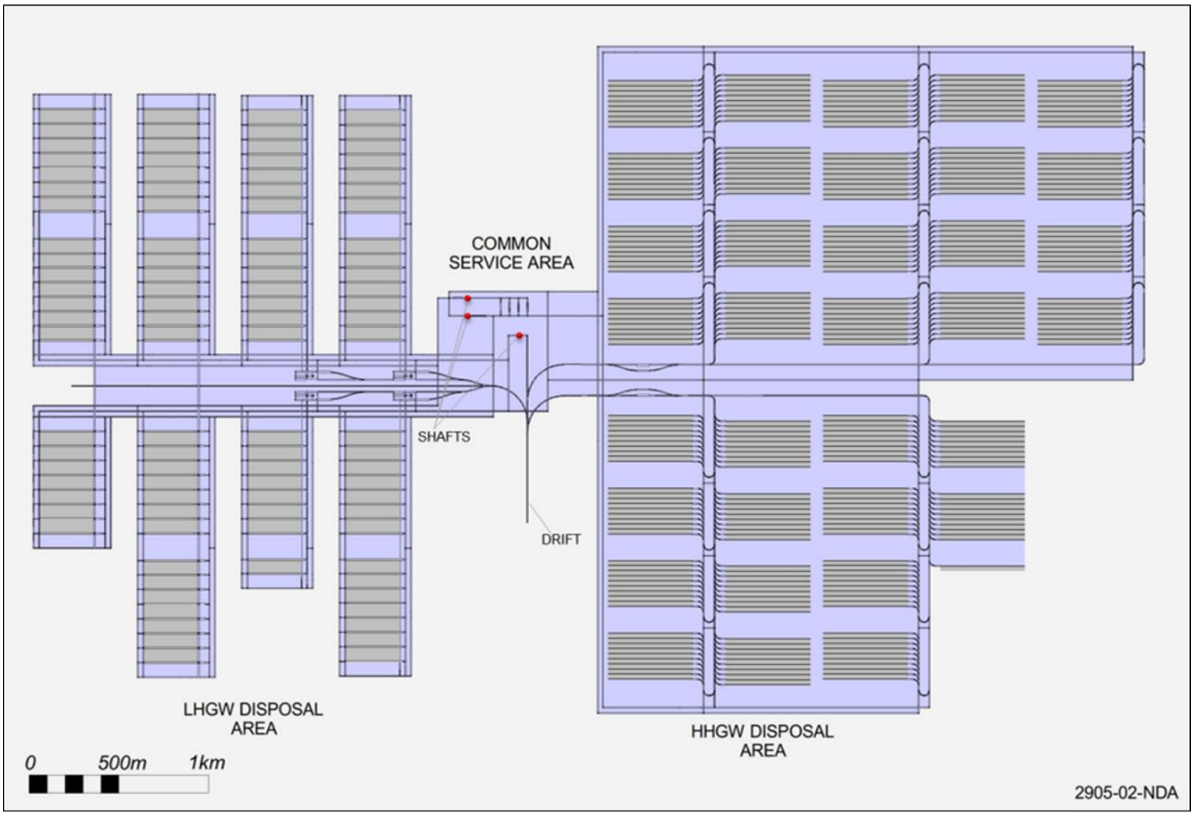
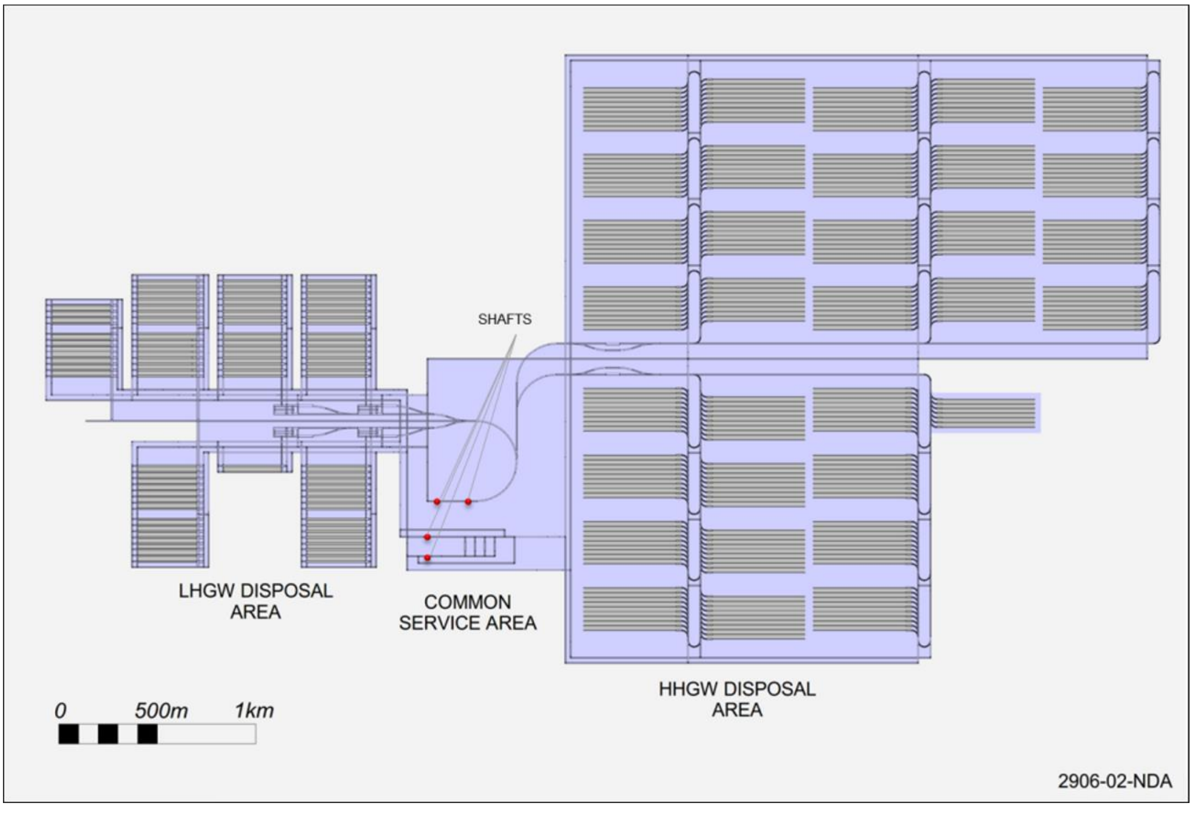


Figure 9 Illustrative underground layout for an evaporite host rock



For the 2013 Derived Inventory the footprints of the underground layout for a higher strength hock, a lower strength sedimentary host rock and an evaporite host rock are approximately 7.6 km^2, 15.3 km^2 and 10.3 km^2 respectively. The factors that influence the footprint are presented in the generic Disposal Facility Designs report.

7.3 Waste transport, receipt and transfer

The transport system for waste packages considers the use of rail, road and sea, with a preference for the use of rail transport where possible.

On-site rail sidings enable trains carrying LHGW to be separated into small numbers of wagons ready for shunting to the LHGW waste package receipt and transfer facility for onward transfer to the drift (or shaft in the evaporite rock illustrative design). Wagons carrying HHGW are not stored in the sidings but placed into a HHGW waste transfer building for temporary storage.

The LHGW receipt and dispatch facilities are capable of handling transport packages arriving by rail and road. The HHGW receipt and dispatch facilities are designed to handle transport packages arriving by rail only.

In the LHGW package transfer facility, routine health physics checks of the transport package and road vehicle or rail wagon are undertaken. Once accepted, the transport package is released from the trailer or wagon and transferred within the same building to an underground transfer wagon using an overhead travelling crane.

HHGW transport packages arriving by rail are handled in a similar way but in a separate adjacent facility. Rail wagons are shunted into one of three bays, each of which can accommodate two rail wagons. This enables a week's worth of deliveries to be temporarily stored within the facility, based on an arrival rate of 200 packages per year. Following routine health physics checks of the transport package and rail wagon, transport packages are directly transferred by overhead travelling crane from the wagon to the drift wagon (or shaft transfer system in the evaporite rock illustrative design).

7.4 Emplacement and backfilling

Unshielded LHGW packages are taken underground in the shielded transport containers used to transport the packages to the site. The waste packages are removed from the transport containers in an inlet cell, comprising a series of linked, shielded, containments. Removal of the packages from their transport containers in the inlet cell and their subsequent emplacement is undertaken using remote handling techniques. Shielded LHGW packages are emplaced directly in separate vaults in their transport configuration.

In a higher strength host rock, the LHGW vaults are backfilled in a single campaign once all LHGW has been emplaced. For a lower strength sedimentary host rock, each vault is backfilled immediately after its full complement of packages is emplaced. In the case of the evaporite host rock, the vaults are sealed when full and the strata allowed to naturally creep and close the excavations over time.

HHGW disposal containers are transported underground in their shielded transport containers. Remote handing techniques are used to remove the disposal container from the transport container and emplace it in the deposition hole. For the higher strength host rock, each disposal container is placed in a vertical deposition hole in the disposal tunnel. Each deposition hole is backfilled with an appropriate buffer material immediately following emplacement. The disposal tunnels are backfilled once all the deposition holes in the tunnel have been utilised.

In a lower strength sedimentary or evaporite host rock, disposal containers are transported to their emplacement positions and transferred directly onto the tunnel floor in a horizontal position. The area around the disposal container is then backfilled with the appropriate buffer material, providing progressive backfilling of the disposal tunnel.

On closure, a programme of backfilling of the remaining underground galleries and access ways is undertaken. This includes the construction of a series of plugs and seals with the final backfilling and sealing of the shaft and drift accesses. Surface facilities will be decommissioned.

7.5 Depth of disposal horizon

The Disposal System Specification Part B sets out the requirement that the depth of the disposal horizons shall be determined on the basis of results from geological and hydrogeological investigations at the site and development of the safety case. Within geologically suitable formations, the location of the disposal areas shall take into account the potential advantages and disadvantages of increased depth.

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

This depth range is shown compared to a UK landmark in Figure 10. To further aid in comparison, depths of the UK's two operational deep coal mines fall within the assumed range of 200 m to 1000 m. At Kellingley Colliery in Yorkshire, coal is extracted from seams 800 m below ground [36], and at Thoresby Colliery in Nottinghamshire, current operations are approximately 750 m below ground [36].

A minimum depth of 200 m is specified to provide a depth of cover greater than the likely maximum extent of surface change [37] in the very long term while the wastes are still hazardous.

The depth of the disposal horizons in conjunction with the properties of the geological environment will be important in determining the extent to which the geosphere provides isolation and containment of the radioactivity in the waste, and in determining the constructability, excavation characteristics, support requirements and longevity of any underground structures.

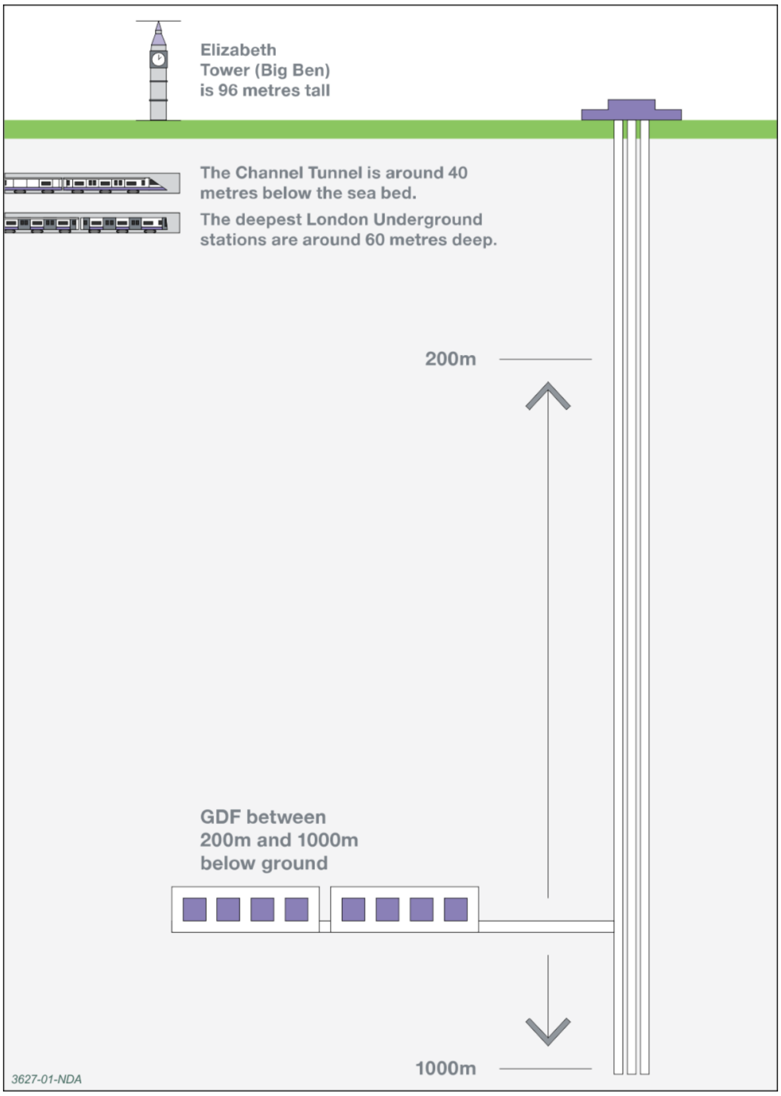
The maximum depth for disposal is likely to be defined by practical and economic considerations. In situ rock stresses increase with depth [38] such that the stability of underground excavations (for a given set of rock mass properties) tends to decrease with increasing depth and increasing stress. In addition, the deeper a disposal module, the greater the cost, from a simple consideration of the costs associated with the provision of access to that disposal module.

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

For planning purposes, the depth of horizon is assumed to be:

- 650 m below ground level in a higher strength host rock
- 500 m below ground level in a lower strength sedimentary host rock
- 650 m below ground level in an evaporite host rock

Figure 10 Depth range for the GDF



The depths of the disposal concepts developed by other waste management organisations on which RWM's illustrative disposal concepts are based are as follows:

Table 8 Depth of disposal concepts selected as the basis for RWM's illustrative disposal concepts

Disposal Concept (developer, country)	Geological Environment	Waste	Depth (m)
UK LHGW Concept (RWM, UK)	Higher strength rock	LHGW	Assumed 650
KBS-3V Concept (SKB, Sweden)	Higher strength rock	HHGW	457 – 470
Opalinus Clay Concept (Nagra, Switzerland)	Lower strength sedimentary rock	LHGW	~ 650
Opalinus Clay Concept (Nagra, Switzerland)	Lower strength sedimentary rock	HHGW	~ 650
WIPP Bedded Salt Concept (US DOE, USA)	Evaporite rock	LHGW	655
Gorleben Salt Dome Concept (DBE Technology, Germany)	Evaporite rock	HHGW	870

7.6 Monitoring

Monitoring of the GDF will be used to support the development of the safety cases by:

- contributing to the understanding of system behaviour
- providing safety assurance by checking implementation conforms to safety case arguments and assumptions
- demonstrating compliance with regulatory requirements and conditions.

Thus monitoring will support decision making, help build confidence in geological disposal and contribute to the development of the disposal system.

The monitoring programme will commence with the collection of data and information to establish baseline conditions. The programme will evolve as monitoring is conducted during construction and throughout operation and closure activities. Any extension of the monitoring programme into the post-closure period will depend on decisions taken by future generations.

7.7 Security and safeguards

As the GDF will be a civil licensed nuclear site, capable of accepting Category I to III nuclear material for disposal, a security plan must be approved by the ONR (Civil Nuclear Security) under the authority of the Nuclear Industries Security Regulations 2003 (as amended, 2013) [39].

The security plan will include detailed information on the security regime and the physical security arrangements assumed or planned to protect nuclear and other radioactive materials and sensitive nuclear information related to the GDF site.

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 the International Atomic Energy Agency, under its safeguards agreements with the UK [40] and by the European Commission, under regulatory requirements to meet Chapter 7 of the

Euratom Treaty [41]. 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'.

Security and safeguards are discussed more fully in the generic Disposal Facility Designs report.

7.8 Retrievability

The 2014 White Paper confirms that the purpose of the GDF is to dispose of waste and not to store it. It notes that permanently closing the GDF at the earliest possible opportunity once operations have ceased provides for greater safety and security and minimises the burden on future generations. Regulatory guidance [8] does not require emplaced waste to be retrievable.

During the operational stage of the GDF, waste packages already emplaced could potentially be retrieved if there was a compelling reason to do so. The operational phase will last about 150 years, based on forecasts that show that processing the current volume of legacy waste could take around 100 years with disposal of new build wastes taking a further 50 years.

However, retrieving emplaced waste packages would become more difficult with time, particularly after the end of the operational phase, that is, once the GDF has been closed permanently. The planning basis for the generic DSSC is that backfilling of the HHGW disposal tunnels will take place immediately after emplacement whereas, depending on the host rock, the LHGW vaults may be backfilled as part of the closure phase. Consequently, during the operational phase, retrieval of LHGW packages would be more straightforward than retrieval of HHGW packages.

The Government's view is that a decision on whether or not to keep the GDF (or vaults and tunnels within it) open once facility waste operations cease can be made at a later date. In the meantime, in line with Government policy as set out in the 2014 White Paper, design work is carried out in such a way that the option for retrievability is not excluded.

The term 'retrievability' is used to refer to a number of different approaches to recover radioactive waste from the GDF after it has been emplaced. RWM has adopted specific terminology to differentiate between the different approaches to retrievability, as follows:

- Reversibility – is the term used to describe retrieval where the waste is removed from the GDF by reversing the original emplacement process. This is only possible before any backfilling or sealing has taken place, and is dependent upon the continued integrity of the waste packages, disposal vaults and emplacement equipment.
- Retrievability – is the term used to describe the withdrawal of waste from the GDF by building in a methodology that would allow access to the waste even after vaults had been backfilled.
- Recoverability – is the term used to describe intrusive re-excavation operations that would be required to recover the waste once the GDF had been sealed. Such operations would be likely to pose greater technical challenges and be more costly than other forms of retrievability.

Detailed decisions linked to retrievability, such as the timing of backfilling, will, in any case, need to be based on site-specific characteristics. To support such future decision-making, RWM is investigating issues associated with early and late backfilling.

7.9 Flexibility of design

With uncertainties in the host rock and the inventory for disposal, it is important that the illustrative designs are flexibility and adaptable to change. By investigating a range of potentially suitable disposal concepts, RWM is positioned to make a well-informed assessment of options at appropriate decision points in the implementation programme.

The modular approach to developing the illustrative designs, in terms of layout and inventory, enables certain components of the illustrative designs, and associated learning, to be taken forward and adapted to future site conditions and inventory requirements.

For example, the planning basis is that the underground facilities are constructed on one level within a single rock formation. In practice, site-specific host rock properties may result in a need for a multi-level layout. To enable the design to be adapted, the underground facilities have been designed in banks of vaults and disposal tunnels that could be individually positioned to avoid structural features such as faults.

In addition, preparatory work is proceeding on the basis that only one GDF will be necessary. It is recognised however that the feasibility of a single GDF depends on whether a large enough volume of suitable rock exists (in an area with a community willing to host a GDF) in which the underground facilities can be safely constructed, and so the Government has not formally ruled out developing more than one site. Preparatory design work is therefore being undertaken in such a way that it could be adapted to more than one GDF if required.

7.10 Timescales

This section describes the provisional timescales that form the planning basis. The siting process is based on consent and partnership and consequently the process will be driven in a large part by discussions with local communities. Therefore dates, like all other aspects of the GDF programme, must not be seen as fixed but rather a reasonable basis for planning based on current assumptions.

The timing of the disposal programme is very important for planning, not only for RWM but also for the organisations with responsibility for the waste held in interim storage and for communities affected by the management arrangements for the waste. The durations of each stage leading up to the start of disposal operations can be estimated using information on the processes to be followed, combined with experience of technical aspects such as geological investigations drawn from the previous UK programme and from equivalent programmes in other countries.

The initial construction phase for the GDF will take approximately 10 years, during which time underground access is established and the facility constructed to the point where it can accept waste.

Construction continues after emplacement operations commence, that is, following an initial construction phase, construction and emplacement operations take place concurrently. To accommodate this, construction and waste handling operations are physically segregated, with separate controlled access to each area and separate ventilation systems.

The planning basis for receipt of wastes at the GDF takes into account information such as the time of waste arisings, when the waste is ready for transport and disposal, and the throughput rate of the GDF inlet cell. Waste producers have plans for consigning waste for disposal and close co-operation is envisaged in order to optimise the emplacement schedule.

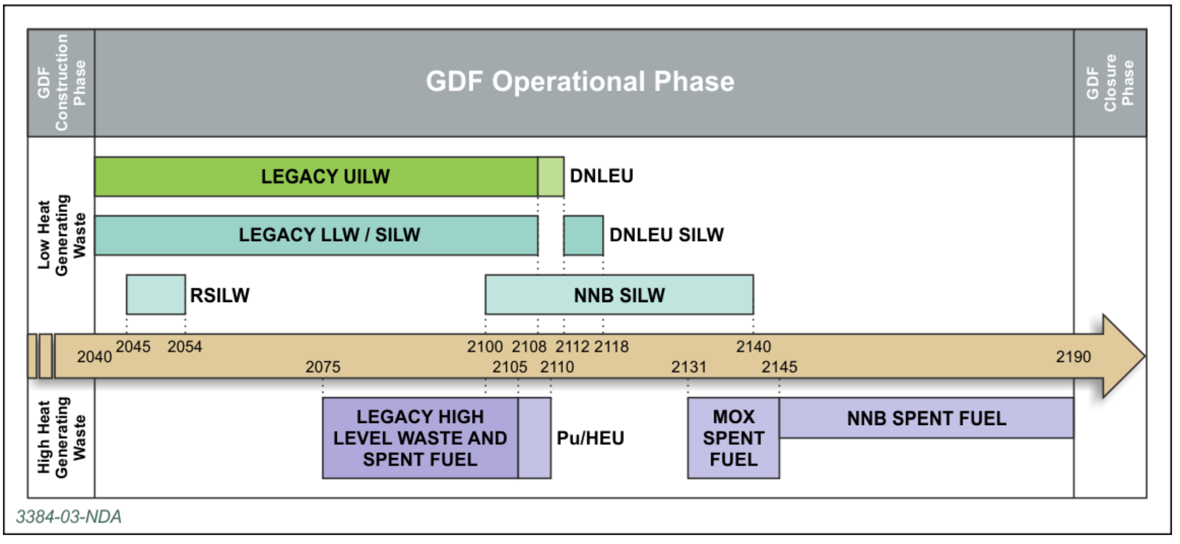
Emplacement of LHGW (including ILW from new nuclear power stations) begins in 2040 and continues until 2140. The throughput for LHGW is approximately 2,300 disposal units per year on average from 2040 to 2063. Then, between 2063 and 2106 the throughput reduces to an average of 1,500 disposal units per year. DNLEU is emplaced at a similar rate (1,500 disposal units per year) once the legacy unshielded ILW has been disposed of and will take approximately 32 years until 2138. ILW from new nuclear build is disposed of in parallel with the end of legacy ILW/LLW and DNLEU from 2100 to 2140.

Disposal of HHGW commences in 2075 and continues until 2190. The disposal of legacy HLW and spent fuel commences in 2075 and continues until 2105 at an assumed throughput of 200 disposal containers per year [42]. Disposal of residual plutonium and HEU will follow the disposal of HLW and spent fuel, from 2105 to 2110. MOX is assumed to be available for disposal at 2131 based on the rate of cooling, and will take approximately 14 years to dispose of. Subsequently, spent fuel from the new nuclear power station programme will take 45 years to dispose of up until 2190.

Following completion of all waste emplacement, closure of the facility will take place over the following 10 years. The phasing over time for the inventory for disposal is shown graphically in Figure 11.

Monitoring of surface and sub-surface parameters will be undertaken to develop further understanding of the effects that construction, operation and closure of the facility will have on the performance of the site relevant to the safety case over these timeframes. This is discussed in the generic Disposal Facility Designs report.

Figure 11 Waste emplacement timings



8 Packaging Waste

The majority of the wastes destined for geological disposal need to be conditioned and packaged in such a way as to render them:

- passively safe; such that they can be managed safely with the minimum need for active safety systems, monitoring or human intervention
- capable of safe handling: during interim storage, transport to, and emplacement in the GDF
- disposable; in that they can be shown to be compliant with all the relevant regulations and safety cases for transport to, and disposal in, the GDF

The waste package is comprised of the wasteform (the conditioned or immobilised solid product) and the waste container. These components provide safety functions and contribute to the multi-barrier approach.

8.1 Waste packaging specifications

RWM produces generic waste packaging specifications. These packaging specifications define standard properties and performance requirements for waste packages that are compatible with the anticipated transport, operational and environmental safety cases.

The RWM generic waste packaging specifications are produced for a number of reasons:

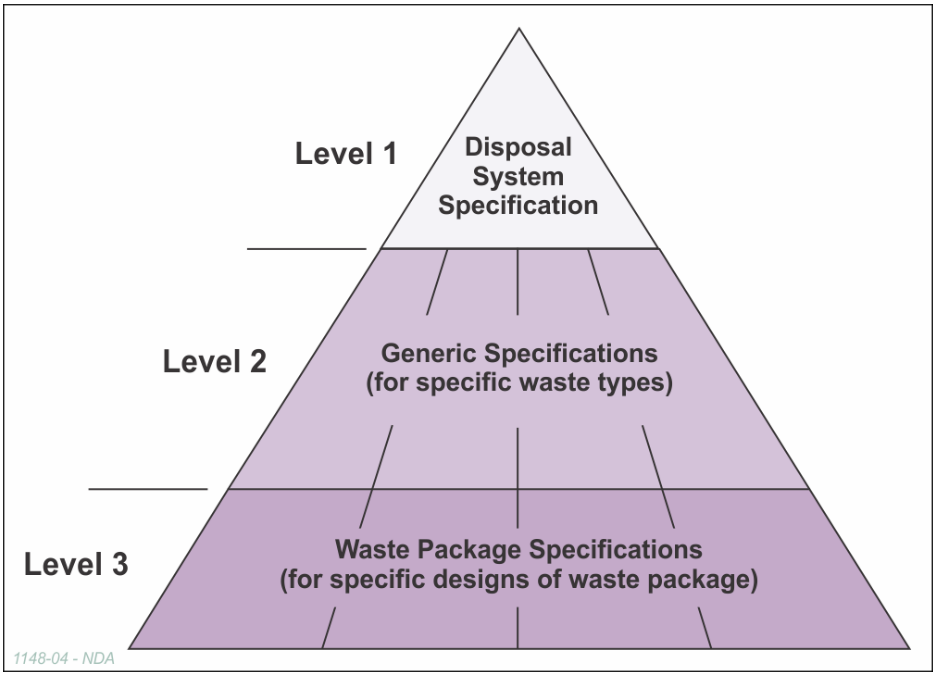
- to support the implementation of geological disposal for higher activity wastes
- to provide the UK nuclear industry and regulators with a clear definition of the requirements for packaged waste in advance of GDF construction
- to provide a basis for disposability assessments, thereby permitting early packaging of waste
- to permit scrutiny of disposability assessments

These generic waste packaging specifications play an important role in determining the disposability of waste packages and therefore may be considered as preliminary waste acceptance criteria (WAC). The development of packaging specifications for this purpose is consistent with International Atomic Energy Agency guidance [43] and with the approach adopted in a number of countries worldwide.

The generic waste packaging specifications form part of a hierarchy which comprises three levels, as shown in Figure 12:

1. The Disposal System Specification Part A defines the high level requirements for all waste packages destined for GDF disposal. It is aimed at regulators and stakeholders who are not directly involved with the packaging of waste.
2. Generic Specifications apply the high level packaging requirements defined by the Disposal System Specification to waste packages containing a specific type of waste; generic specifications contain bounding requirements for individual waste types.
3. Waste Package Specifications (WPS) apply the general requirements defined by a Generic Specification to waste packages manufactured using standardised designs of waste container. The WPS define standard features (eg dimensions, lifting features) and performance requirements (eg impact and fire accident performance).

Figure 12 Hierarchy of the waste packaging specifications



The nature and role of waste package specifications are described in greater depth in the generic DSSC report on waste packages and the assessment of their disposability [44].

8.2 Waste product specifications

Every waste package must be manufactured to comply with a waste product specification. A waste product specification is produced by the waste packager prior to implementation of a proposal to package a specific waste, and is endorsed by RWM as part of the disposability assessment of that proposal. It effectively defines a disposable waste package in terms of:

- a specific design of waste container
- the nature of the waste it contains
- the manner in which the waste is conditioned
- the maximum inventory of radionuclides and other components of the waste and conditioning materials

It is currently envisaged that the waste acceptance criteria for the GDF could be based on the waste product specifications used for the manufacture of the waste packages that the facility is expected to receive. Waste acceptance criteria would be produced for waste packages manufactured to comply with a particular waste product specification and the acceptance of individual waste packages demonstrated by the use of the Package Record produced as part of the manufacturing process.

8.3 Packaging advice

8.3.1 The Disposability Assessment process

The RWM Disposability Assessment process has been established in support of the UK nuclear industry's ongoing work on the conditioning and packaging of higher activity wastes for disposal. The process has been extensively developed over a period of more than 20 years in cooperation with the site operators and regulators, and in a manner that aligns with regulatory expectations for the long term management of higher activity wastes [45].

Evaluation and assessments undertaken during a disposability assessment include the comparison of waste package performance against the package specifications and the safety assessments in the generic DSSC. The generic DSSC thus provides a benchmark for the disposability assessments. The evaluation and assessments carried out as part of a disposability assessment are described in greater depth in the generic DSSC report on waste packages and the assessment of their disposability [44].

The philosophy that underpins RWM's approach to disposability assessments is set out in the Disposability Assessment Aim and Principles (DAAPs) document [46].

The main purposes of the Disposability Assessment process are to:

- give confidence to site operators that the implementation of their proposals to package waste will result in waste packages that meet the anticipated needs of the disposal system
- aid in the identification of optimised solutions for the packaging of specific types of waste
- provide RWM with confidence that the disposal concepts considered within the generic DSSC are appropriate for inventory for disposal
- permit the identification of wastes and proposed approaches to packaging that could challenge current disposal concepts and thereby allow early consideration of what changes may be required to those concepts to permit the resulting waste packages to be accommodated

In the event that a disposability assessment identifies that there are no significant uncertainties in the ability of the proposed packaging approach to produce disposable waste packages, RWM issues a Letter of Compliance to endorse the approach and the resulting waste packages. The issue of a Letter of Compliance indicates that RWM is satisfied that the resulting waste packages would be compliant with the generic designs of the disposal system, including the transport system, and with the safety cases for the transport of the waste packages to the GDF, the operational period and the post-closure period.

Disposability assessments are based on periodic interactions over an extended timescale of continuing development and implementation of a proposed waste packaging process. This offers considerable benefits to both the waste packager and to RWM. This approach provides the waste packager with the opportunity to submit information proportionate to the state of development of the proposals and allows the information to be accumulated in consultation with RWM. The approach provides step-wise reduction in project risk for the waste packager, ideally aligned with their staged decision-making or sanctioning within the development of a packaging process.

RWM has, therefore, established a standardised approach for staged disposability assessments, based on an idealised packaging development project. Four stages are recognised in this approach: pre-conceptual, conceptual, interim and final; and a packaging proposal may be assessed at some or all of these stages. The stages and their objectives are described in [44].

Advice given by RWM through these periodic interactions is underpinned by the generic DSSC, and a generic disposal system that has been developed to cover a broad range of UK waste characteristics. This advice is therefore applicable to the packaging of all UK wastes, including Scottish wastes, even though these do not form part of the inventory for disposal.

At present, around 13% of the ILW (by conditioned volume) has a final stage Letter of Compliance, and a further 41% is currently within the process.

Since the 2010 generic DSSC, use of a number of new package types has been proposed by some of the waste producers and, as a result of endorsements and advice from RWM made through the Disposability Assessment process, these are now included in the 2013 Derived Inventory and hence in the current DSSC. These are:

- **500 litre and 1 cubic metre concrete drums:** These are cylindrical waste containers made from reinforced concrete. They have been proposed for packaging a wide range of power station operational wastes, including dewatered sludges, ion exchange resins, filters and other heterogeneous solid wastes. As shielded waste containers, they can be used to produce waste packages which can be transported without additional protection.
- **500 litre robust shielded drum:** This is a cylindrical container, which can be fabricated with a range of wall thicknesses, and which can be used to manufacture robust shielded waste packages. It is currently assumed that 500 litre robust shielded drum waste packages will be transported within an SWTC-150 as part of a Type B transport package.
- **3 cubic metre robust shielded box:** This is cuboidal container, which can be manufactured with a range of wall thicknesses, and which can be used to produce robust shielded waste packages. It is currently assumed that 3 cubic metre robust shielded box waste packages will be transported within a transport container similar to an ISO container, as part of a Type IP-2 transport package.

A full list of waste containers considered in this generic DSSC is given in Appendix A.

8.3.2 Packing proposals that require change to the disposal system

A disposability assessment may identify some aspect of a packaging proposal that could result in waste packages not being compliant with the relevant packaging specification, or some other aspect of the current disposal system. In such an event a Letter of Compliance will not be issued. It may be appropriate to change some aspect of the disposal concept to accommodate the proposed waste packages, if this can be done without any undue consequences for the overall safety and/or efficiency of the geological disposal system. Indeed, it may be that such a change could result in an improvement in overall safety and/or efficiency. Depending on the nature of the change, this could have consequences for the packaging specifications alone or for the disposal concept and the DSSC in general.

8.4 Waste containers

In general terms it is expected that the waste container will be required to provide the waste package with adequate:

- mechanical strength, to
  - withstand handling and stacking forces (where the latter is required by the disposal concept)
  - resist damage due to pressurisation by internally generated gases
  - ensure that the specified impact accident performance can be achieved
  - withstand other loads that may occur during the long-term management of the waste package, as required by the ESC
- radiation shielding (unless this is to be provided by a transport container or similar device) to ensure that the external dose rate is minimised and that specified limits are not exceeded

- thermal properties to ensure that the thermal requirements of the waste package (including those which could arise as a result of a fire accident) and the disposal system will be achieved
- resistance to degradation to ensure that overall integrity, notably of the containment, provided by the waste container, is maintained for an appropriate period

A variety of waste container designs have been considered for the packaging of the different types of waste and material in the inventory for disposal.

Designs of waste container for use with LHGW are the most developed, as many waste producers have been packaging such wastes for the past ~20 years. As a result a number of standardised designs of waste container have been developed. Twelve standardised designs are identified in the Disposal System Specification Part B for LHGW and these can be grouped into three basic types:

- *shielded waste packages* – for use with wastes with low specific activity, such as would not generally require the extensive use of remote handling techniques; these may contain integral concrete shielding
- *robust shielded waste packages* – thick-walled (ie many 10s of mm) waste containers, which can be used for all types of LHGW, to provide both radiation shielding and physical containment of their contents; typically fabricated from ductile cast iron
- *unshielded waste packages* – relatively thin-walled (ie a few mm) metal containers for higher activity LHGW, such as would generally require the use of remote handling techniques

For the purpose of concept development work, RWM currently considers two basic designs of standardised waste container for HHGW:

- *Variant 1* – sealed canister fabricated from copper, with a cast iron insert, used in the illustrative disposal concept for a higher strength host rock
- *Variant 2* – sealed canister fabricated from carbon steel, used in the illustrative concepts for lower strength sedimentary or evaporite host rock

The standardised waste container designs considered in the generic DSSC are described in [44], while further details of the waste packages and, where required, their associated transport containers are provided in the Generic Transport System Designs report [35].

9 Ongoing developments

During the past three decades many challenges to the viability of disposal concepts have been overcome. The key remaining uncertainties relate mainly to the disposal concepts and waste containers for HHGW and DNLEU. RWM is currently investigating four key topics. These are being managed and researched by multi-discipline integrated project teams that comprise relevant RWM staff, waste holders and experts from the supply chain. These four topics, the latter three of which are drawing to a conclusion, are:

- **Concept development work:** Work in this area will start with the development of a framework for setting out disposal concept options for each waste type, including consideration of the level of technical maturity and the level of confidence. Following that, there will be activities to develop the knowledge base and explore more novel concepts and concepts for new waste streams or packaging proposals. An approach to future concept selection will be developed and tested.
- **High heat generating wastes:** HHGW provide a number of technical challenges that differ to those associated with the disposal of LHGW. Thermal management of the disposal system must be taken into consideration in GDF design; temperature constraints often apply to the wasteform, waste container, buffer and host rock. The HHGW integrated project has investigated a number of topics relevant to quantifying, understanding, evaluating and managing HHGW in the GDF. The findings of the project are presented in the HHGW Final Report [47].
- **Uranium:** DNLEU, which is classified as a zero-value asset, represents less than 1% of the total radioactivity of the packaged UK higher activity materials but comprises a significant fraction (~17%) of the volume. Over the first 10,000–100,000 years, DNLEU has a relatively low radioactivity and radiotoxicity compared to other waste streams, however, due to the extremely long half-life of U-238 and the ingrowth of U-238 daughters, DNLEU could become the most radiologically significant component of the UKRWI after 100,000 years. The project team has worked collaboratively with DNLEU owners, focusing on the disposability and associated full lifecycle implications of managing the UK inventory of these materials through disposal, should they be classified as waste. The findings of the project are presented in the DNLEU Final Report [48].
- **Carbon-14:** C-14 is a radionuclide of importance for safety assessments, due to the potential radiological impact of gaseous C-14 bearing species. It has a half-life of 5,730 years. The integrated project has developed a holistic approach to the management of C-14 in the GDF. Further details of the work undertaken and the findings to date are provided in the Carbon-14 Project Phase 2 Overview Report [49].

RWM will continue to assess waste producers' packaging proposals for disposability and provide packaging advice. Waste producers, including those considering alternative waste containers such as the 6 cubic metre concrete box, will submit their proposals for advice and disposability assessment against the benchmark of the generic DSSC. As Letters of Compliance are granted, such waste containers will be incorporated into the generic DSSC through a formal change control process.

The evolution of RWM's work programme as the siting process progresses is set out in the Science and Technology Programme [50], including a description of a number of key deliverables (termed 'Major Products') necessary to deliver RWM's mission. A Science and Technology Plan [51] presents an analysis of the nature and timing of RWM's future generic research and development activities in support of its mission. Specific packages of technical work required to deliver the Major Products are described in task sheets.

10 Summary

This document provides a source of technical background information common to the documents that make up the generic DSSC. In addition, it provides pointers to where more detailed information can be found. A number of aspects of geological disposal are covered, namely:

- the inventory for disposal
- the multi-barrier approach
- the Disposal System Specification
- the potential host rocks
- the generic illustrative designs
- the packaging of wastes in readiness for disposal
- on-going developments.

References

1 UK Government and the Devolved Administrations for Wales and Northern Ireland, *Managing Radioactive Waste Safely – A Framework for Implementing Geological Disposal,* June 2008.

2 DECC, *Implementing Geological Disposal – A Framework for the Long-Term Management of Higher Activity Wastes,* July 2014.

3 Radioactive Waste Management, *Geological Disposal: Generic Transport Safety Case – Main Report,* DSSC/201/01, December 2016.

4 Radioactive Waste Management, *Geological Disposal: Generic Operational Safety Case – Main Report,* DSSC/203/01, December 2016.

5 Radioactive Waste Management, *Geological Disposal: Generic Environmental Safety Case – Main Report,* DSSC/203/01, December 2016.

6 Radioactive Waste Management, *Radiological Protection Criteria Manual*, RWM02, Revision 2, 2016.

7 Office for Nuclear Regulation, *Safety Assessment Principles for Nuclear Facilities*, 2014 Edition, Revision 0.

8 Environment Agency, Northern Ireland Environment Agency, *Geological Disposal Facilities on Land for Solid Radioactive Waste: Guidance on Requirements for Authorisation*, February 2009.

9 Radioactive Waste Management, *Geological Disposal: Generic Environmental Assessment*, DSSC/331/01, December 2016.

10 Radioactive Waste Management, *Geological Disposal: Generic Socio-economic Assessment*, DSSC/332/01, December 2016.

11 Radioactive Waste Management, *Geological Disposal: Generic Health Impact Assessment*, DSSC/333/01, December 2016.

12 Radioactive Waste Management, *Geological Disposal: Overview of the generic Disposal System Safety Case,* DSSC/101/01, December 2016.

13 Radioactive Waste Management, *Geological Disposal: Guide to the RWM Disposability Assessment Process*, WPS/650/03, 2014.

14 CoRWM*, Assessment of the generic Disposal System Safety Case*, CoRWM doc. 2994, March 2012.

15 NDA & DECC, *Radioactive Wastes in the UK – A Summary of the 2013 Inventory,* Report URN 14D039, February 2014.

16 Scottish Government, *'Scottish Government Higher Activity Waste Policy'*, January 2011.

17 Radioactive Waste Management, *Geological Disposal: Generic Post-Closure Safety Assessment Report,* DSSC/321/01, December 2016.

18 Radioactive Waste Management, *Geological Disposal: The 2013 Derived Inventory,* NDA/RWM/120, 2015.

19 HMSO, *The Environmental Permitting (England and Wales) Regulations*, Statutory Instruments No. 675, 2010.

20 DEFRA, DTI and the Devolved Administrations, *Policy for the Long Term Management of Solid Low Level Radioactive Waste in the UK,* 2007.

21 Pöyry Energy Ltd, *Summary of the Derived Inventory based on the 2007 UKRWI,* Pöyry Report No: 390761/05, 2010.

22 Pöyry Energy Ltd, *An Explanation of the Differences between the 2007 Derived Inventory and the Equivalent Wastes and Materials in the 2010 UKRWI,* Pöyry Report No: 390761/23, 2011.

23 Radioactive Waste Management, *Geological Disposal: Implications of the 2010 UK Radioactive Waste Inventory on the Generic Disposal System Safety Case,* NDA/RWMD/082, August 2011.

24 Radioactive Waste Management, *Geological Disposal: The 2013 Derived Inventory – Scenarios,* NDA/RWM/125, December 2016.

25 Radioactive Waste Management, *Geological Disposal: Generic Disposal System Specification Part A: High Level Requirements,* DSSC/401/01, December 2016.

26 Radioactive Waste Management, *Geological Disposal: Generic Disposal System Specification Part B: Technical Requirements,* DSSC/402/01, December 2016.

27 International Atomic Energy Agency, *Regulations for the Safe Transport of Radioactive Material – Safety Requirements No. SSR-6*, 2012.

28 Standing Working Group on Safe Transport of Radioactive Material, *Technical Guide – Package Design Safety Reports for the Transport of Radioactive Material*, European DSR Guide Issue 3, December 2014.

29 NDA, *Geological Disposal: Overview of RWMD Approach to Definition of Safety Functions,* NDA Technical Note 17229445, August 2012.

30 Chapman, N. and Hooper, A. 2012. *The Disposal of Radioactive Wastes Underground. Proceedings of the Geologists' Association*, 123, 46-63.

31 Radioactive Waste Management*, Geological Disposal: Approach to developing a strategy for technology transfer,* NDA/RWMD/099, 2013.

32 Nuclear Energy Agency, *Safety of Disposal of Spent Fuel, HLW and Long-Lived ILW in Switzerland – An International Peer Review of the Post-Closure Radiological Safety Assessment for Disposal in the Opalinus Clay of the Zurcher Weinland,* NEA, Paris, 2004.

33 T. Hicks, T. Baldwin, P. Hooker, P. Richardson, N. Chapman, I. McKinley I., F. Neall, *Concepts for the Geological Disposal of Intermediate-level Radioactive Waste*, Galson Sciences Report 0736-1, April 2008.

34 Radioactive Waste Management, *Geological Disposal: Generic Disposal Facility Designs,* DSSC/411/01, December 2016.

35 Radioactive Waste Management, *Geological Disposal: Generic Transport System Designs*, DSSC/412/01, December 2016.

36 UK Coal website, 2016.

37 Nirex, *Large Underground Caverns – Precedent Experience Study, Phases I and II*, Nirex Report SA/97/019, 1997.

38 Nirex, *Assessment of the In-situ Stress Field at Sellafield*, Nirex Report S/97/003, 1997.

39 HMSO, *Nuclear Industries Security Regulations,* 2003 and *Nuclear Industries Security (Amendment) Regulations*, 2013.

40 International Atomic Energy Authority, A*greement of 6 September 1976 between the United Kingdom of Great Britain and Northern Ireland, the European Atomic Energy Community and the International Atomic Energy Agency for the Application of Safeguards in the United Kingdom of Great Britain and Northern Ireland in Connection with the Treaty on the Non-Proliferation of Nuclear Weapons (with Protocol)*, INFCIRC/263, October 1978.

41 International Atomic Energy Authority, *Protocol Additional to the Agreement of 2004 between the United Kingdom of Great Britain and Northern Ireland, The European Atomic Energy Community and the International Atomic Energy Agency for the Application of Safeguards in the United Kingdom of Great Britain and Northern Ireland in Connection with the Treaty on the Non-Proliferation of Nuclear Weapons,* INFCIRC/263/Add.1, February 2005.

42 United Kingdom Nirex Ltd, *Outline Design for a Reference Repository Concept for UK High Level Waste / Spent Fuel*, Technical Note, September 2005.

43 International Atomic Energy Authority, *Development of Specifications for Radioactive Waste Packages,* IAEA TECDOC-1515, 2006.

44 Radioactive Waste Management, *Geological Disposal: Waste Packages and the Assessment of their Disposability,* DSSC/441/01, December 2016.

45 Health and Safety Executive, Environment Agency, Scottish Environment Protection Agency, *The management of higher activity radioactive waste on nuclear licensed sites. Joint guidance from the Health and Safety Executive, the Environment Agency and the Scottish Environment Protection Agency to nuclear licensees*, Revision 2, February 2015.

46 NDA, *Disposability Assessment Aims and Principles*, NDA RWM Policy Document RWP60, Revision 2, 2015.

47 Radioactive Waste Management, *Geological Disposal: High Heat Generating Waste Project: Final Report,* NDA/RWM/136, 2016.

48 Radioactive Waste Management, *Geological Disposal: Investigating the implications of managing depleted, natural and low enriched uranium through geological disposal: Final Report,* NDA/RWM/142, 2016.

49 NDA, *Geological Disposal: Carbon-14 Project Phase 2 – Overview Report*, NDA/RWM/137, May 2016.

50 Radioactive Waste Management, *Geological Disposal: Science and Technology Programme*, NDA/RWM/112, 2016.

51 Radioactive Waste Management, *Geological Disposal: Science & Technology Plan*, NDA/RWM/121, Version 2, 2016.

Appendix A – Glossary of terms

Terms specific to the generic DSSC, and commonly used across the suite are given here.

A1 Waste packages

<table>
<tr><th>Name</th><th>Endorsed variants</th></tr>
<tr><td colspan="2">Unshielded waste containers</td></tr>
<tr><td rowspan="3">500 litre drum</td><td>Enhanced 500 litre drum (pre-cast)</td></tr>
<tr><td>Enhanced 500 litre drum (basket)</td></tr>
<tr><td>500 litre drum (DNLEU)</td></tr>
<tr><td>Side lifting variant of 3 cubic metre box</td><td></td></tr>
<tr><td rowspan="2">Corner lifting variant of 3 cubic metre box</td><td>3 m^3 Sellafield box</td></tr>
<tr><td>3 m^3 Enhanced Sellafield box</td></tr>
<tr><td>3 cubic metre drum</td><td></td></tr>
<tr><td>Miscellaneous Beta Gamma Waste Store Box</td><td></td></tr>
<tr><td colspan="2">Shielded waste containers</td></tr>
<tr><td>2 metre box</td><td>With or without concrete liner (100 or 200 mm)</td></tr>
<tr><td>4 metre box</td><td>With or without concrete liner (100, 200 or 300 mm)</td></tr>
<tr><td>6 cubic metre concrete box</td><td>WAGR Box (made with either normal density or high density concrete)</td></tr>
<tr><td>500 litre concrete drum</td><td>With or without steel liner (40 or 70 mm)</td></tr>
<tr><td>1 cubic metre concrete drum</td><td>With or without steel liner (40, 70 or 100 mm)</td></tr>
<tr><td colspan="2">Robust shielded waste containers</td></tr>
<tr><td>500 litre robust shielded drum</td><td>With or without lead liner (Up to 120 mm in 10 mm increments)</td></tr>
<tr><td>3 cubic metre robust shielded box</td><td></td></tr>
</table>

A2 Other terms

Term	Definition
adapted illustrative design	An illustrative design for a geological disposal system that has been adapted to a specific location.
alkaline disturbed zone (ADZ)	A volume of rock in the vicinity of the GDF that either contains water with an elevated *pH* (above that of the natural environment) as a result of the presence of cementitious materials (eg in waste packages, backfill or structural items), or has contained high pH water in the past and has been permanently modified by the reaction of alkaline water with the original rock. A volume of rock in the vicinity of the GDF containing water with an elevated pH (above that of the natural environment) as a result of the presence of cementitious materials (eg in waste packages, backfill or structural items).
backfill	A material to fill voids in the GDF. Three types of backfill are recognised: • local backfill, which is emplaced to fill the free space between and around waste packages • peripheral backfill, which is emplaced in disposal modules between waste and local backfill, and the engineered barrier system rock or access ways • mass backfill, which is the bulk material used to backfill the excavated volume apart from the disposal areas
bentonite	A clay material that swells when saturated with water which is used as a backfill and buffer material in some disposal concepts.
biosphere	That part of the environment normally inhabited by living organisms.
borehole	The generalised term for any cylindrical excavation into the ground made by a drilling device for purposes such as site investigation, testing and monitoring.
borehole disposal	The concept of disposing of some forms of radioactive waste in extremely deep boreholes, a number of kilometres down in the Earth’s crust.
buffer	An engineered barrier that protects the waste package and limits the migration of radionuclides following their release from a waste package.
canister	The vessel in which a HLW/spent fuel/Pu/HEU wasteform is placed
colloid	A state of subdivision of matter in which the particle size varies from that of true ‘molecular’ solutions to that of a coarse suspension. The diameters of the particles range between 1 and 1000 nm and the particles are dispersed in a liquid phase and do not sediment out.
co-location	Co-location is: Separate disposal modules at the same location with common infrastructure, such as access shafts or drifts, and Separate disposal facilities different types of waste at the same location

Term	Definition
conditions for acceptance (CfA)	Quantitative and/or qualitative criteria, specified by the operator of a waste handling facility, which define the conditions under which waste will be accepted into that facility. (In the case of a disposal facility such criteria are usually referred to as waste acceptance criteria).
deposition hole	A hole made into the rock and accessed from an access tunnel, disposal tunnel or disposal vault, into which a waste package (or packages) and sometimes buffer material is placed in certain disposal concepts
Devolved Administrations	Collective term for the Scottish Government, National Assembly for Wales and the Northern Ireland Assembly.
disposability	The ability of a waste package to satisfy the defined requirement for disposal.
disposal area	Underground, the GDF would be split into two distinct disposal areas, separated by an appropriate distance, one for LHGW and another for HHGW.
disposal concept	A high level description of the engineered and natural barriers required to ensure that the radioactivity in the wastes is sufficiently contained so that it will not be released back to the surface in unacceptable amounts that may cause harm to people and the environment.
disposal module	Collective term for a group of disposal tunnels. The number of disposal tunnels in a module could vary for different rock types.
disposal unit	A waste package, or group of waste packages, which is handled as a single unit for the purposes of transport and/or disposal.
environmental safety function	Environmental safety functions are defined in the GRA as “the various ways in which components of the disposal system may contribute towards environmental safety, eg the host rock may provide a physical barrier function and may also have chemical properties that may help to retard the migration of radionuclides”.
excavation disturbed zone (EDZ)	A region of the geosphere surrounding the engineered barrier system which has been affected as a result of construction of the GDF. Excavation damaged zone is a related term sometimes used to describe either a region of the geosphere where irreversible deformation occurs as a result of GDF construction, or a region of the geosphere where the extent of the disturbance due to construction is sufficient to require consideration within the safety cases, to ensure that there is no detrimental impact on safety.
features, events and processes (FEP)	FEPs are any features, events or processes that may affect the safety of a geological disposal facility. These can either be natural features and processes, or ones which are designed into the system. Properties of such FEPs that contribute to safety are known as safety functions. Features-are typically components of the disposal system that might have a safety function. Events and processes are typically things that will, or might, happen that may affect (impair or enhance) the ability of a feature to deliver its safety function(s). Example of a feature: Geological Fracture. Examples of an event: Earthquake. Example of a process: Degradation of organic waste

Term	Definition
generic waste package specification (GWPS)	The RWM packaging specifications define the bounding features and performance requirements for waste packages that would be compatible with the anticipated needs for transport to and disposal in the GDF. Part of a hierarchy of three levels, the top-level GWPS (Level 1) defines the high level requirements for all waste packages destined for geological disposal (for additional classifications see waste package specification).
geological attribute	A geological attribute is a characteristic of a region that would be relevant to the safety of the GDF. It may be a characteristic of either the rock or the groundwater or the way that they are likely to be affected by geological processes or events.
geological barrier	In the context of geological disposal this comprises the host rock in which a disposal facility is constructed, and the surrounding rocks. The geological barrier provides long-term isolation of wastes, containment of the radionuclides associated with the wastes and protection of the engineered barrier system.
geological environment	The structure, composition and physical and chemical characteristics of the rocks that make up the geosphere.
geosphere	The rock surrounding the GDF that is located below the depth affected by normal human activities and is therefore not considered to be part of the biosphere.
Habitats Regulations Assessment (HRA)	A process that assesses potential effects on the integrity of 'Natura 2000' sites, which are internationally, designated nature conservation sites. It is a statutory requirement for certain plans, programmes and projects under the European Habitats Directive (Directive 92/43/EEC).
halite	Also commonly referred to as Rock Salt, is a mineral with the composition of sodium chloride. Halite occurs primarily in evaporite sequences where it may form layers or beds, or be concentrated into thicker but more localised bodies termed salt domes. Halite is a resource used to grit roads in cold weather, but is also the essential constituent of an evaporite host rock.
highly enriched uranium (HEU)	Uranium containing 20% or more by mass of the isotope U-235.
high heat generating waste (HHGW)	Spent fuel from existing and future power stations, and High Level Waste from spent fuel reprocessing and high fissile activity wastes: that is, plutonium and highly enriched uranium
illustrative disposal concept	An example disposal concept, developed by RWM for illustrative purposes, drawing on work done in the UK and in international radioactive waste disposal programmes, and applicable to one of three generic geological settings

Term	Definition
illustrative design	An example design for a geological disposal system, developed by RWM for illustrative purposes, drawing on work done in the UK and in international radioactive waste disposal programmes. Illustrative designs can be both generic or site-specific. Illustrative designs describe, amongst other things, the process of construction, waste emplacement and closure of a geological disposal facility; and the characteristics that a disposal facility would need to include, recognising that different packaging and disposal processes are appropriate for different types of waste and the characteristics of different geological environments.
Kärnbräns-lesäkerhet-3 (KBS-3)	A disposal concept for spent fuel developed by SKB.
low enriched uranium (LEU)	Uranium in which the proportion of U-235 is greater than ~0.7% but less than 20%.
low heat generating waste (LHGW)	That is Intermediate Level Waste (ILW) arising from operating and decommissioning of reactors and other nuclear facilities, together with a small amount of Low Level Waste (LLW) unsuitable for near surface disposal, and stocks of depleted, natural and low-enriched uranium (DNLEU)
operational safety function	Operational Safety Function is defined in the ONR Safety Assessment Principles (SAPs) as *"A specific purpose that must be accomplished for safety"*. Safety Function example: Prevent access to the inlet cell when a UILW package is in an unshielded configuration. This leads to identification of Safety Functional Requirements, for example: Inlet cell door to lock-out if dose rates exceed X or Inlet cell door to lock out following loss of power. Thus a Safety Measure is put in place, for example: Interlock to dose rate or Interlock to power supply
optimisation	Optimisation is the principle of ensuring that radiation exposures are as low as reasonably achievable (ALARA) in the given circumstances. Optimisation is a key principle of radiation protection recommended by the International Commission on Radiological Protection (ICRP) and incorporated into UK legislation.
overpack	A secondary or additional outer container used for the handling, transport, storage or disposal of waste packages.
recoverability	The ability to recover waste from a closed GDF by mining or similar intrusive methods.
retardation	A feature of a component of the GDF that contributes to safety. The engineered barriers and host geological environment provide retardation of radionuclides through physical and chemical processes that reduce the concentration of contaminants or their rate of release from the barrier. Retardation processes may result in effective containment of the radionuclides if they would only be released through the barriers after the time at which they and their daughters have decayed to negligible levels.

Term	Definition
retrievability	A feature of the design of the GDF that enables the waste to be withdrawn, even after the disposal vaults have been backfilled. The term ‘retrievability’ is also sometimes use as an umbrella term, to refer to various different approaches to remove radioactive waste from a geological disposal facility after it has been emplaced, including ‘reversibility’, ‘retrievability’ and ‘recoverability’.
reversibility	Term used internationally to denote the ability to reverse decisions, as part of a phased decision-making process. Has been used in the UK to describe retrieval by reversing the original emplacement process.
safety argument	A statement about the safety of the geological disposal system, backed up by supporting evidence and qualitative and/or quantitative reasoning.
safety function	A safety function is a property of the disposal system, or part of it, that has the potential to contribute to meeting one or more safety requirements. For example, the waste package limits radiation dose to workers and members of the public.
safety function indicator	A measure for the performance of a system component or several components to support the development of system understanding and to assess the quality, reliability and effectiveness of particular aspects or components of a disposal system (eg activity over time in components, radiotoxicity flux over time from components).
safety requirement	Safety requirements specify what the disposal system, or parts of it (systems), must do in order to protect humans and the environment against hazards arising from geological disposal and transport of higher activity waste, and therefore meet regulatory and other relevant standards and requirements. For example, the disposal system shall ensure that harmful quantities of radionuclides or toxic substances will not reach the surface.
stakeholders	People or organisations, having a particular knowledge of, interest in, or who are affected by, radioactive waste, examples being the waste producers and owners, waste regulators, non-Governmental organisations and local communities and authorities.
total system model	A model that captures all significant aspects of a geological disposal system, including representing the uncertainties, in order to calculate overall system performance.
transient criticality models	The Quasi Steady State, Rapid Transient and Bounding Approach models.
transport assessment	An assessment of the potential transport effects of a proposed project.
transport system	The transport system covers the transport modes, infrastructure, design and operations. It can be divided in two main areas: the transport of construction materials, spoil and personnel associated with building the GDF and the more specialised transport of the radioactive waste to the GDF by inland waterway, sea, rail and/or road.

Term	Definition
waste acceptance criteria (WAC)	Quantitative and/or qualitative criteria specified by the operator of a disposal facility and approved by the regulator, for solid radioactive waste to be accepted for disposal.
waste package specification (WPS)	The RWM packaging specifications define the bounding features and performance requirements for waste packages that would be compatible with the anticipated needs for transport to and disposal in the GDF. Part of a hierarchy of three levels, each WPS (Level 3 and the most detailed of the specifications) defines the requirements for the transport to and geological disposal of waste packages manufactured using a standardised design of waste container that have been shown to be compatible with RWM's current plans for geological disposal for the packaging of a specific category of waste. These can sometimes be generic (see generic waste package specification).

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