

# Geological Disposal:

## Generic Specification for waste packages containing high heat generating waste

February 2016



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**WASTE PACKAGE SPECIFICATION AND GUIDANCE DOCUMENTATION  
GENERIC SPECIFICATION FOR WASTE PACKAGES CONTAINING HIGH HEAT  
GENERATING WASTE**

This document forms part of the Waste Package Specification and Guidance Documentation (WPSGD), a suite of documents prepared and issued by Radioactive Waste Management Ltd (RWM). The WPSGD is intended to provide a 'user-level' interpretation of the RWM packaging specifications, and other aspects of geological disposal, to assist UK waste packagers in the development of plans for the packaging of higher activity waste in a manner suitable for geological disposal.

Key documents in the WPSGD are the *Waste Package Specifications* (WPS) which define the requirements for the transport and geological disposal of waste packages manufactured using standardised designs of waste container. The WPS are based on the high level requirements for all waste packages as defined by the generic *Disposal System Specification* and are derived from the bounding requirements for waste packages containing a specific category of waste, as defined by the relevant *Generic Specification*.

The purpose of this Generic Specification is to define the generic requirements for waste packages containing high heat generating waste (HHGW). The packaging requirements defined herein are derived from the high-level requirements defined in the Disposal System Specification, as part of the suite of documents that describe RWM's plans for a GDF.

This Generic Specification also acts as the basis for the definition of the WPS which define the requirements for the waste packages containing HHGW that would result from the use of standardised designs of waste container.

The WPSGD is subject to periodic enhancement and revision. Users are therefore advised to refer to the RWM website to confirm that they are in possession of the latest version of any documentation used.

<b>WPSGD DOCUMENT NUMBER WPS/240 - VERSION HISTORY</b>		
<b>VERSION</b>	<b>DATE</b>	<b>COMMENTS</b>
WPS/240/01	February 2016	Based on 2015 drafts of the 2016 DSS, GTSD and GDFD and the 2010 safety cases for transport and the GDF operational and post-closure periods.  Issued for trial use by and comments from waste producers.

**Abbreviations and acronyms used in this document**

ACT	accident conditions of transport
AGR	Advanced Gas-cooled Reactor
ALARP	as low as reasonably practicable
BSL	Basic Safety Level
BSO	Basic Safety Objective
DCTC	disposal container transport container
DSS	Disposal System Specification
DSSC	Disposal System Safety Case
EBS	engineered barrier system
EVR	evaporite rock
ESC	Environmental Safety Case
GDF	geological disposal facility
GDFD	Generic Disposal Facility Designs
GTSD	Generic Transport System Designs
HHGW	high heat generating waste
HLW	high level waste
HSR	higher strength rock
IAEA	International Atomic Energy Agency
ILW	intermediate level waste
LHGW	low heat generating waste
LoC	Letter of Compliance
LSSR	lower strength sedimentary rock
NDA	Nuclear Decommissioning Authority
NM	nuclear material
ONR	Office for Nuclear Regulation
OSC	Operational Safety Case
PWR	Pressurised Water Reactor
RWM	Radioactive Waste Management Ltd
SAPs	Safety Assessment Principles
SF	spent (nuclear) fuel
TSC	Transport Safety Case
WAC	waste acceptance criteria
WVP	Wastes Vitrification Plant (Sellafield)

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## 1 Introduction

The Nuclear Decommissioning Authority (NDA) has established Radioactive Waste Management Ltd (RWM) as the body responsible for implementing UK Government policy for the management of higher activity radioactive wastes, as set out in the 2014 *Implementing Geological Disposal White Paper* [1]. The White Paper outlines a framework for managing those wastes in the long-term through geological disposal, which will be implemented alongside the ongoing interim storage of waste packages and supporting research.

As implementer of a geological disposal facility (GDF), and therefore as the ultimate receiver of wastes for disposal, RWM will be responsible for establishing waste acceptance criteria (WAC) for such a facility. The plans for the construction of a GDF are at an early stage and the information necessary to define final WAC is not available. In the meantime, and as a precursor to WAC, RWM produces packaging specifications, the primary purpose of which is to enable the holders of radioactive wastes to condition that waste into a form that will be compatible with the anticipated needs of transport to and disposal in a GDF.

The packaging specifications, together with a wide range of explanatory material and guidance that users will find helpful in the development of proposals to package waste, make up a suite of documentation known as the *Waste Package Specification and Guidance Documentation* (WPSGD). For further information on the extent and the role of the WPSGD, all of which can be accessed via the RWM website, reference should be made to the *Introduction to the RWM Waste Package Specification and Guidance Documentation* [2].

The RWM packaging specifications form a hierarchy defined in such a manner to ensure that the needs of all users are satisfied. *Generic Specifications*, such as this document, form the second tier of this hierarchy and are aimed at those involved in the development of concepts for the packaging of specific categories of waste for geological disposal.

The specific purpose of this Generic Specification is to apply the high-level packaging requirements defined by the *Generic Waste Package Specification* (GWPS) [3] to waste packages containing vitrified high level waste (HLW), spent nuclear fuel<sup>1</sup> (SF) and other radioactive materials that fall into the broad category of 'high heat generating waste' (HHGW)<sup>2</sup>. The generic requirements defined herein are derived from the anticipated needs for the transport and geological disposal of waste packages containing such wastes. These requirements are applied to specific designs of waste package, manufactured using a standardised design of waste container, in the form of *Waste Package Specifications* (WPS).

This Generic Specification makes no assumptions regarding the geographical location of a GDF, the geological environment in which it will be constructed, or a specific concept which could be adopted for the disposal of waste packages containing HHGW. Accordingly, the packaging requirements are defined so as to be bounding of a number of illustrative disposal concepts that could be implemented for the disposal of HHGW in a range of geological environments that exist at a number of locations throughout the UK.

The remainder of this document is structured in the following manner:

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<sup>1</sup> The 2014 White Paper notes that SF is not currently classified as waste but would, if it were decided at some point that it had no further use, need to be managed as waste through geological disposal. For planning purposes, including the definition of packaging specifications, SF is included in the category of HHGW.

<sup>2</sup> A full description of the wastes covered by this Generic Specification can be found in Section 4.

- Section 2 provides background information on geological disposal in general, and on RWM's approach to defining the requirements for, and demonstrating the safety of, a UK GDF. It also summarises the role played by packaging specifications in assessing the disposability of waste packages.
- Section 3 explains the nature of the role of the RWM packaging specifications, and of this Generic Specification in particular.
- Section 4 describes the types of HHGW to which this Generic Specification applies.
- Section 5 outlines the approach adopted in the development of this Generic Specification and defines the basis for the definition of the packaging requirements and the assumptions that are made as part of that process.
- Section 6 defines the packaging requirements together with a brief commentary on their derivation.
- Appendix A lists the parameters used in the thermal modelling of waste packages containing HHGW reported in Section 6.3.4.
- A glossary of important terms and phrases used in this Generic Specification is included as Appendix B.

## 2 Background

### 2.1 Geological disposal of radioactive waste

A key aspect of UK Government policy for the long-term management of the UK's higher activity wastes<sup>3</sup> is the geological disposal of such waste, following a period of safe and secure interim storage. Whilst the precise manner in which geological disposal would be implemented in the UK is not yet defined it is envisaged that it would comprise a number of distinct stages. These could include:

- The manufacture of passively safe and disposable waste packages;
- A period of interim surface storage, usually at the site of waste arising or packaging;
- Transport of the waste packages to a GDF;
- Transfer of waste packages underground and emplacement in the disposal areas;
- Backfilling of the disposal areas; and
- Eventual sealing and closure of the facility.

The exact nature, timing and duration of each stage would depend on a number of factors, including the geographical location and host geology of a GDF, as well as the nature of the waste and the disposal concept selected for implementation for that waste type.

The key aim of all of the geological disposal systems implemented or under development worldwide is the containment and isolation of radionuclides and other hazardous materials associated with the waste [4]. Containment and isolation are provided by a system of engineered and natural barriers which, for a typical geological disposal system, include those provided by the waste package and any backfilling material<sup>4</sup>, and the geology surrounding the disposal facility. Safety is achieved by these mutually complementary barriers working together to ensure that radionuclides, and other hazardous materials associated with the waste, will not return to the surface at concentrations that could cause harm to people or the environment.

### 2.2 The Disposal System Specification

As part of RWM's programme for the implementation of geological disposal in the UK, and to set out a clear definition of the requirements of the disposal system, the *generic Disposal System Specification* (DSS) has been developed [5]. The DSS includes regulatory and stakeholder requirements, as well as a consideration of the nature, characteristics and quantities of the higher activity wastes and other radioactive materials that may be destined for geological disposal.

The DSS is a starting point for the development of designs for the geological disposal system, which includes those for the transport of waste packages from their site of manufacture and/or interim storage to a GDF. The details of the current illustrative designs can be found in the following documents:

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<sup>3</sup> The description 'higher activity waste' encompasses all wastes and radioactive materials identified in the 2014 White Paper as being potentially destined for geological disposal.

<sup>4</sup> These two components of the geological disposal system are referred to collectively as the engineered barrier system (EBS).

- The *Generic Disposal Facility Designs* (GDFD) report [6] which describes the illustrative GDF designs developed for three generic geological environments, based on different host rock types (see Section 5.3). It presents RWM's understanding of how geological disposal could be carried out in a range of different geological environments.
- The *Generic Transport System Designs* (GTSD) report [7], which outlines potential designs for moving waste packages to a GDF, by road, rail and/or sea. It summarises the hardware, logistical and operational bases for the generic transport system.

The development of the DSS, and the associated system designs for the transport of waste packages and their disposal in a GDF, is an iterative process with the assessments of safety, environmental impacts and cost. The requirements that the DSS defines are periodically refined in light of the results from RWM's ongoing programmes of work. Updating the DSS will take into account the results from work on the waste inventory, engineering design, site investigations, safety, environmental and sustainability assessment, consideration of security and safeguards issues, research, and public and stakeholder engagement.

### 2.3 The Disposal System Safety Case

The generic *Disposal System Safety Case*<sup>5</sup> (DSSC) [8] has been developed as a means of presenting the methods, evidence and arguments by which RWM demonstrates the safety of plans for geological disposal. The DSSC, which is founded on the generic DSS and the associated designs for transport and disposal, comprises a suite of documents which consider the safety of all aspects of:

- the long-term management of waste packages, following their export from the site of interim storage to a GDF;
- Construction, operation, decommissioning and closure of the GDF; and
- The safety of the GDF in the long-term, after it has been sealed and closed.

Of direct relevance to the definition of the requirements for waste packages are the generic safety cases for these three periods of the management of waste packages, namely:

- The generic *Transport Safety Case* (TSC) [9], which summarises why RWM has confidence that the system for transporting wastes to a GDF would be safe. It gives an overview of how safety would be demonstrated for individual waste packages, and a summary of an illustrative safety assessment of the transport system as a whole.
- The generic *Operational Safety Case* (OSC) [10], which presents an illustrative safety case for a GDF under both normal operations and fault conditions, for each of the different geological environments. It provides a preliminary assessment of operational risk, including that during construction, against regulatory limits and targets.
- The generic *Environmental Safety Case* (ESC) [11], which considers the environmental safety of a GDF during the operational period and after closure of the facility. It explains in principle why RWM has confidence in the environmental

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<sup>5</sup> It should be noted that this Generic Specification is based on the 2010 DSSC. The DSSC and its accompanying documents are to be updated during 2016 and this Generic Specification will be updated, as necessary, following the publication of the 2016 DSSC.

safety of a GDF and the approach to developing the necessary safety case to demonstrate that confidence, with reference to the different generic geological environments.

In addition, the generic *Environmental Assessment* [12] considers the environmental, socio-economic and health implications of implementing geological disposal. It explains how the design of waste packages, through consequent effects on GDF design and waste package transport, can influence the environmental and sustainability performance of the disposal system.

The generic DSSC also summarises the current status of RWM's underlying science base in key areas such as waste package evolution and longevity [13], accident performance [14], criticality safety [15], and the behaviour of radionuclides in a GDF [16].

## **2.4 Assessing the disposability of waste packages**

The 'Letter of Compliance' Disposability Assessment process has been established as a means of supporting the UK nuclear industry's ongoing work on the conditioning and packaging of higher activity waste for disposal. The process has been extensively developed over a period of more than 20 years, in cooperation with the site operators and industry regulators, and in a manner that aligns with regulatory expectations for the long-term management of higher activity waste [17].

The main purposes of the Disposability Assessment process [18] 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 for transport to and disposal in a GDF;
- Aid in the identification of optimised solutions to the packaging of specific types of waste;
- Provide RWM with confidence that the geological disposal concepts considered within the DSS and DSSC will be appropriate for the wastes they are expected to accommodate; and
- 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 no significant uncertainties in the ability of the proposed packaging approach to produce disposable waste packages, a Letter of Compliance can be issued to endorse the waste packages that would result from its implementation.

### 3 Specifications for packaged waste

Packaging specifications define the standard properties and performance requirements for waste packages which are compatible with the anticipated systems and safety cases for their transport to and disposal in a GDF.

As discussed above, in the absence of the necessary information to permit the production of WAC for a GDF, RWM produces generic packaging specifications, their principal purpose being to expedite the conversion of unconditioned wastes into passively safe and disposable forms. The packaging specifications therefore play an important role in determining the disposability of waste packages (see Section 2.4) and, in this sense, may be considered to act as the 'preliminary' WAC for a future GDF. This approach is consistent with that outlined in guidance produced by the International Atomic Energy Agency (IAEA) [19] and with that adopted in a number of countries worldwide (e.g. Sweden, France, USA).

The packaging specifications are also produced with a number of other key purposes in mind, notably:

- To support the development of RWM's plans for the implementation of geological disposal for higher activity radioactive waste;
- To provide the UK nuclear industry and regulators with a clear definition of the requirements for packaged waste in advance of the construction of a GDF; and
- To permit scrutiny of this aspect of RWM's plans to implement geological disposal for higher activity waste in the UK.

#### 3.1 The role of the waste package in geological disposal

The engineered and natural barriers provided by a geological disposal system are illustrated schematically in Figure 1 and can include those provided by:

- The EBS comprising:
  - the waste package consisting of:
    - the contents of the waste package, or wasteform<sup>6</sup>; and
    - the waste container.
  - any local buffer/backfill placed around the waste package;
  - mass backfill in the rest of the underground excavations, and;
  - other sealing materials.
- The surrounding geology, consisting of:
  - host rocks; and
  - overlying strata.

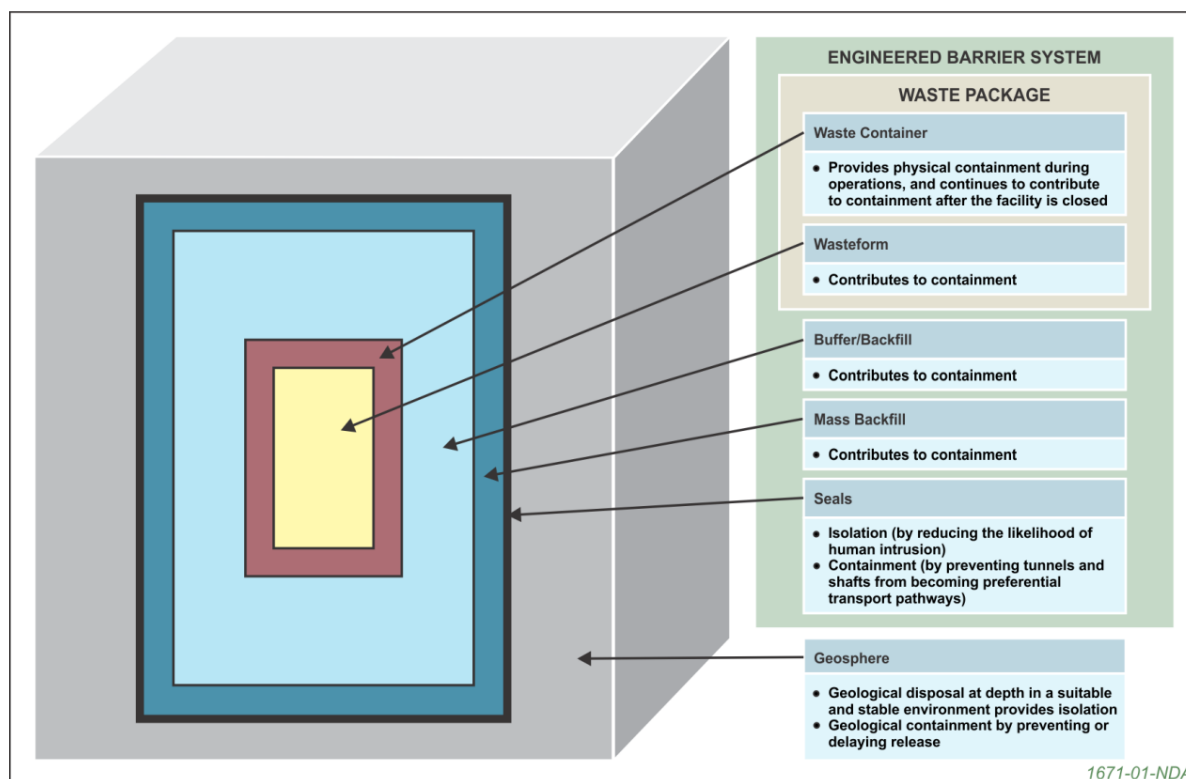
As shown in Figure 1, the barrier provided by the waste package can be considered to comprise two components, these being provided by the waste container and the wasteform. The relative contributions of each of these two components will depend on the

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<sup>6</sup> A wasteform may comprise waste which has been immobilised (e.g. by the use of an encapsulant), that which has received more limited treatment prior to packaging (e.g. size reduction or drying), or that which may require no additional treatment prior to disposal.

physical and chemical nature of the waste, the manner in which it has been prepared for disposal (i.e. 'conditioned'), and the design of the waste container.

**Figure 1 Schematic representation of the multiple barrier concept for geological disposal**



### 3.2 The definition of packaging specifications

Much of the waste destined for geological disposal does not arise in a form that is immediately suitable for such disposal. It must therefore be conditioned and packaged in such a way as to render it:

- Passively safe, such that it can be managed safely with the minimum need for active safety systems, monitoring or prompt human intervention;
- Capable of safe handling during interim storage<sup>7</sup>, transport to and emplacement in a GDF; and
- 'Disposable', in that it can be shown to be compliant with all the relevant regulations and safety cases for transport to and disposal in a GDF.

In order for packaging specifications to play an effective role in assessing the disposability of waste packages, they must reflect all of the relevant aspects of the disposal system. Specifically waste packages must be physically compatible (i.e. by virtue of their dimensions, weight and handling features) with the handling systems anticipated for transport and disposal. It will also be necessary that their contents and performance can be shown to be compliant with the assumptions underpinning the safety cases for both transport and disposal.

<sup>7</sup> It is expected that many waste packages will need to be stored for an extended period (i.e. several decades), either at their site of manufacture or elsewhere, pending the availability of a GDF.

By considering the role played by the waste package as part of a multiple barrier geological disposal system the DSS identifies a number of safety functions that must be achieved by waste packages destined for geological disposal. These may be provided by the waste container or the wasteform, or by a combination of the two, and comprise:

- During transport and the GDF operational period:
  - provide containment of radionuclides during normal operations and under accident conditions;
  - limit radiation dose to workers and members of the public;
  - preclude criticality;
  - provide the means of safe handling; and
  - withstand internal and external loads.
- During the GDF post-closure period:
  - provide containment of radionuclides;
  - contribute to the overall performance of the EBS;
  - contribute to ensuring that, following GDF closure, a criticality event is not a significant concern; and
  - withstand internal and external loads.

To provide a basis for judging the ability of specific waste package designs to satisfy these safety functions the packaging specifications define requirements for the 14 packaging criteria<sup>8</sup>, as shown in Table 1.

**Table 1 The packaging criteria**

External dimensions	Handling feature	Identification
Stackability	Durability of waste container integrity	Wasteform properties
Gross mass	Surface contamination	Activity content
Gas generation	External dose rate	Heat output
Criticality safety		Accident performance

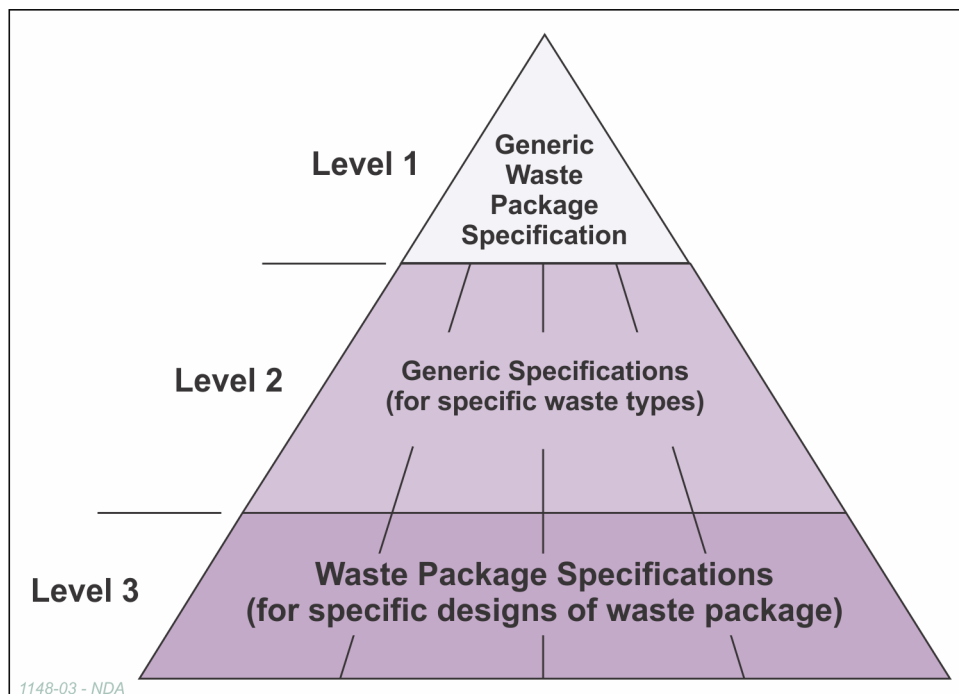
<sup>8</sup> The manner by which the packaging criteria are derived from the waste package safety functions is explained in the GWPS [3].



### 3.3 The form of the RWM packaging specifications

In order to ensure that the packaging specifications satisfy the needs of all users RWM have devised a hierarchical structure as illustrated in Figure 2.

**Figure 2 Hierarchy of the RWM packaging specifications**



The hierarchy comprises three 'levels' of packaging specifications in which each successive level represents an increasing degree of specificity, both to the nature of the waste and the design of the waste package. Each of the levels in the hierarchy satisfies a specific function and is produced for a particular audience:

- The GWPS<sup>9</sup>, which defines high-level requirements for all waste packages destined for disposal in a GDF. It is aimed at industry regulators and stakeholders who are not directly involved with the packaging of waste.
- Generic Specifications, which define the requirements for all waste packages that will be disposed of in accordance with a specified range of concepts, and which will contain wastes with similar radiological characteristics. They are produced for industry regulators and for use by waste packagers involved in the development of new or innovative approaches to the packaging of waste.
- WPS, which define, where applicable, quantitative requirements for waste packages containing a specific type of waste and manufactured using a standardised design of waste container<sup>10</sup>. They are produced for use by waste packagers intending to use such a waste container for the packaging of waste.

This document is the 'Level 2' Generic Specification for waste packages containing HHGW.

<sup>9</sup> It should be noted that the current function of the GWPS will be subsumed into the 2016 DSS.

<sup>10</sup> These are designs which have been shown to be suitable for the manufacture of waste packages that are compatible with the anticipated needs of transport and disposal.

### 3.4 Generic Specifications

For the purposes of GDF design the GDFD report splits the full range of higher activity wastes<sup>11</sup> into two broad categories, low heat generating waste (LHGW) and HHGW, and further sub-divides these categories as shown in Table 2 [6].

**Table 2 Categories of higher activity waste**

Waste category	Sub-division
LHGW	Low level waste (LLW)
	Shielded intermediate level waste <sup>12</sup> (ILW)
	Unshielded ILW <sup>12</sup>
	Depleted, natural and low enriched uranium (DNLEU)
HHGW	HLW
	Legacy SF
	Plutonium
	Highly enriched uranium (HEU)
	Mixed oxide (MOX) SF

In order that the packaging specifications are applicable to the full range of higher activity wastes, whilst ensuring that a proportionate approach is adopted to the packaging and disposal of each category of waste, a suite of Generic Specifications will be required. As a means of identifying the extent of such a suite RWM has used two properties of radioactive waste, namely radiogenic heat output and fissile nuclide content, to divide the whole range of higher activity waste into groups of wastes for which distinct approaches to packaging and/or disposal may be required. This has resulted in RWM envisaging the production of at least four Generic Specifications, for waste packages containing:

- LHGW; such as ILW and LLW, for wastes with limited, but potentially significant, heat output and fissile nuclide content [20];
- HHGW (i.e. this Generic Specification); including HLW and SF, for wastes with high heat output and potentially significant fissile nuclide content
- Fissile waste; including separated plutonium and HEU, for wastes with low to significant heat output and high fissile nuclide content; and
- DNLEU; for predominantly uranic wastes with very low heat output and low to potentially significant fissile nuclide content [21].

<sup>11</sup> The 2014 White Paper defines these as ILW, HLW and LLW that is not suitable for near surface disposal, together with any other radioactive materials which may be declared as waste in the future (e.g. spent fuel, plutonium, and uranium).

<sup>12</sup> These sub-categories of ILW are differentiated by the manner in which they are expected to be packaged.

It should be noted that heat output and fissile nuclide content are not the only two discriminators for waste types that could be used in this way. Other properties such as the specific activity of long-lived radionuclides, and/or the timescales required for the containment of radionuclides by the EBS could also be used.

Generic Specifications may also be produced for other types of waste with particular physical, chemical and/or radiological characteristics and for which disposal in accordance with bespoke geological disposal concepts may be necessary (e.g. irradiated graphite from the cores of commercial nuclear reactors).

## 4 The wastes covered by this Generic Specification

This Generic Specification defines packaging requirements that are applicable to all waste packages containing a broad range of wastes which are described as HHGW. That description is intended to cover wastes which contain high concentrations of radionuclides such that their heat generation would be a major factor in the design of transport and disposal systems. It should be noted that whilst heat generation will be a key issue for the safe transport and disposal of HHGW, other issues such as criticality safety, radiation shielding and the long-term containment of radionuclides are also important aspects in the design of waste packages for HHGW.

As shown in Table 2 the definition of HHGW used in the GDFD report includes two distinct types of material (i.e. HLW and SF) which are characterised by high heat output, together with two others (i.e. plutonium and HEU). This issue of the Generic Specification for HHGW is primarily aimed at 'legacy' wastes, which is restricted to 'standard' products<sup>13</sup> from the Sellafield Wastes Vitrification Plant (WVP) and two types of SF; that arising from the UK's fleet of Advanced Gas-cooled Reactors (AGR) and that from the Sizewell B Pressurised Water Reactor (PWR).

The generic requirements contained herein are however also applicable to waste packages containing other types of HHGW including:

- i.) 'Technical wastes' arising from operation and decommissioning of WVP.
- ii.) Other types of SF including that from Magnox power stations, research reactors, submarine propulsion reactors, and that which would arise from the operation of a new generation of UK nuclear power stations (see Section 4.2.3).
- iii.) Other types of waste characterised by high heat output and/or fissile nuclide content, and for which concepts developed for HHGW may be suitable for their geological disposal (see Section 4.3).

The suitability of any of these other types of waste for disposal in accordance with the concepts identified for legacy HHGW would be assessed against this Generic Specification, by way of the Disposability Assessment process (see Section 2.4).

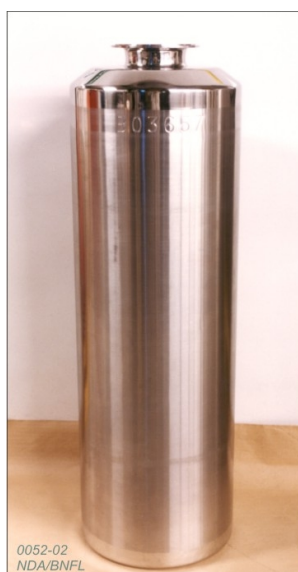
### 4.1 Vitrified HLW

Vitrified HLW is generally produced as a result of the reprocessing of irradiated nuclear fuel. It is initially produced as a liquid but, after a period of cooling (to allow for the decay of short-lived radionuclides) it is 'vitrified' to convert it into a solid, more stable form. This is achieved, in the WVP, by immobilising the waste in a borosilicate glass matrix, which is poured into stainless steel containers to form 'vitrified product containers' (Figure 3). Vitrified product containers are currently held in the Sellafield Vitrified Product Store where it is anticipated that they will remain until they are packaged in preparation for their export to a GDF.

It is expected that all WVP vitrified product containers will have the same basic properties (external dimensions and shape), and similar gross mass (Table 3), although there may be significant variations in the physical, chemical and radiological properties of their contents.

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<sup>13</sup> These being products containing only vitrified HLW (see Section 4.1)

**Figure 3** Vitrified product container for HLW**Table 3** Typical properties of vitrified product containers

Physical characteristics		
Containment		Stainless steel <sup>14</sup> , 5 mm nominal wall thickness
Dimensions		433 mm diameter 1347 mm high
Gross mass		Up to~550 kg
Radiological properties		
Total radionuclide inventory		~10 <sup>3</sup> TBq
Uranium content		~1 kg
Fissile nuclide content		~10 g
Heat output at 2075	Magnox HLW	Average: 200 W Maximum: 215 W
	Blended <sup>15</sup> HLW	Average: 280 W Maximum: 320 W

<sup>14</sup> To date Type 309 stainless steel has been exclusively used for vitrified product containers although the possibility exists for other grades of stainless steel to be used in the future.

<sup>15</sup> 'Blended' HLW indicates a mixture of HLW arising from the reprocessing of Magnox and AGR fuel.

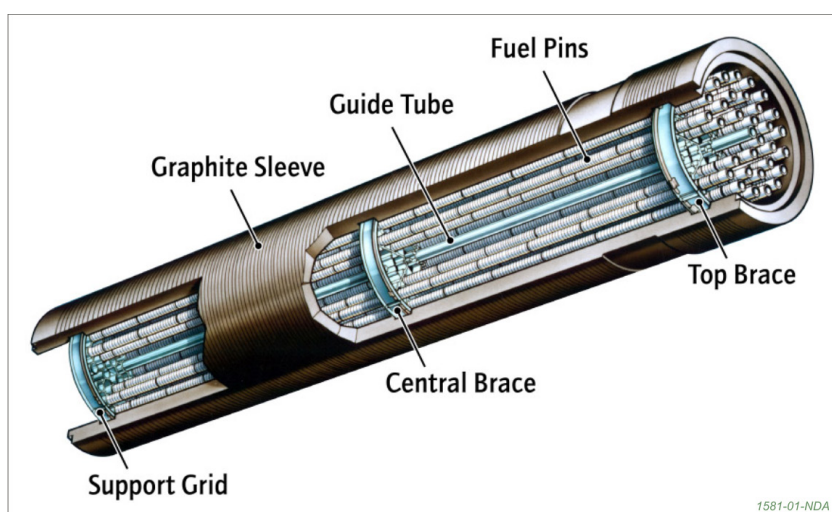
## 4.2 Spent nuclear fuel

A number of different types of SF exist in the UK, some or all of which may be destined for geological disposal. This SF has a wide range of physical (i.e. size, shape, mass etc.) and chemical characteristics (of both the fuel itself and the cladding materials), initial fissile nuclide content and burn-up. All of these fuels types have high inventories of a wide range of radionuclides, notably those with long half-lives, which have significance to the long-term safety of a GDF, and those which have significance to criticality safety.

### 4.2.1 Consolidated AGR fuel

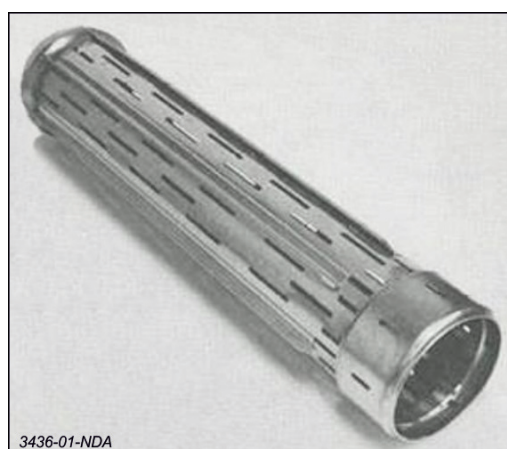
An AGR fuel element (Figure 4) has an overall length of ~1m and consists of an array of 36 fuel pins, each comprising a stack of uranium dioxide fuel pellets clad in a stainless steel tube. The fuel pin array is held in place by an assembly of stainless steel grids, guide tube and braces, the whole array being placed inside a graphite sleeve.

**Figure 4** AGR fuel element



When AGR fuel elements are received at Sellafield, they are 'consolidated' by separating the fuel pins from the other components of the fuel element and loading the former into stainless steel slotted cans (Figure 5), each of which holds up to 108 fuel pins. The slotted cans are then stored under water in ponds.

**Figure 5** Slotted can for AGR fuel pins



It is expected that most consolidated AGR consolidated fuel 'bundles' will have the same basic physical properties (external dimensions, shape and gross mass) but there may be

significant variations in their radiological properties. Table 4 lists some typical values for these properties.

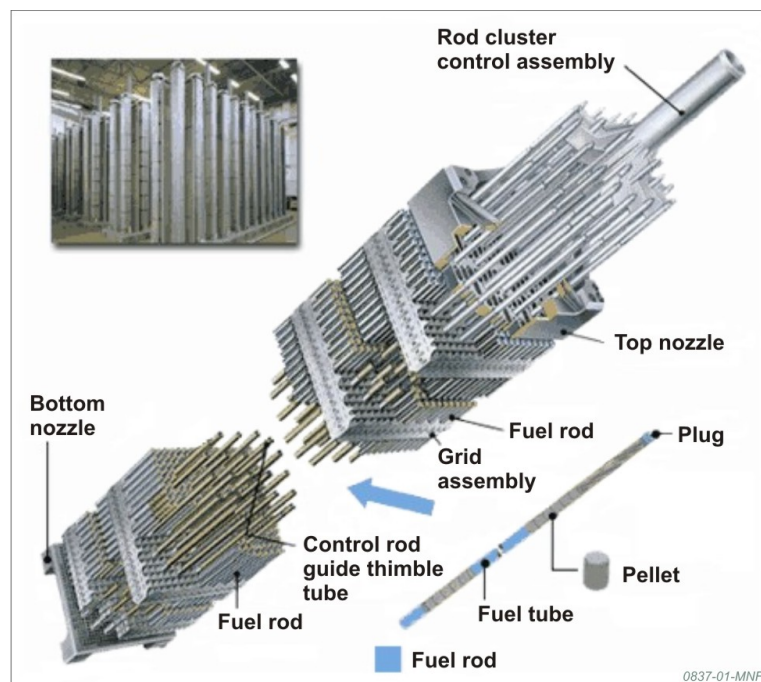
**Table 4 Typical properties of consolidated AGR fuel bundles**

Physical characteristics	
Containment	Stainless steel (fuel cladding)
Dimensions	240 mm diameter 1000 mm high
Gross mass	~200 kg
Radiological properties	
Total radionuclide inventory	~500 TBq
Uranium content	~125 kg
Fissile nuclide content	~1 kg
Heat output at 2075	Average: 45 W Maximum: 55 W

#### 4.2.2 Sizewell B PWR Fuel

The SF assemblies that arise from the Sizewell B PWR (Figure 6) consist of a square array of fuel pins held together by a structural skeleton made up of top and bottom nozzles, intermediate spacer grids and guide tubes.

**Figure 6 Typical PWR fuel assembly**



The standard Sizewell B fuel assembly consists of 264 fuel pins, each comprising a stack of uranium dioxide pellets in a sealed Zircaloy tube. The skeleton's components are a combination of Zircaloy, Inconel and stainless steel, the details of which varies between different fuel assembly designs.

SF arising at Sizewell B is currently stored under water in on-site ponds, but may in the future be transferred to dry storage.

Table 5 lists typical values for the properties of the fuel, which is all expected to have the same basic physical characteristics, but for which there may be significant variations in radiological properties.

**Table 5 Typical properties of Sizewell B PWR fuel assemblies**

Physical characteristics	
Containment	Zircaloy (fuel cladding)
Dimensions	240 mm plan 4100 mm high
Gross mass	~700 kg
Radiological properties	
Total radionuclide inventory	~3x10 <sup>3</sup> TBq
Uranium content	~500 kg
Fissile nuclide content	~8 kg
Heat output at 2075	Average: 280 W Maximum: 500 W

#### 4.2.3 Other fuel types

Whilst this Generic Specification is primarily aimed at waste packages containing legacy HHGW (i.e. vitrified HLW and the two SF types described above), it can also be applied to waste package containing other types of SF. This is on the basis that the physical properties (i.e. dimensions and mass) of such fuels could be accommodated by waste containers with similar properties and dimensions to those anticipated for legacy HHGW. This includes SF from Magnox power stations, from experimental and submarine propulsion reactors, and that arising from the operation of a new generation of UK power stations, including MOX fuel.

#### 4.3 Other materials that could be classed as HHGW for disposal

The descriptions of HHGW set out above are of the 'standard' HLW and SF that is considered to be HHGW for the purposes of geological disposal. There may also exist some variants of these standard types which may also be classed as HHGW. For example, it is expected that WVP will be used to condition a range of 'technical' wastes (e.g. melter parts contaminated with vitrified HLW, extract filters and loose calcine) that are expected to be generated during the post-operational clean out of WVP and various other HLW treatment and storage facilities at Sellafield. Such wastes are expected to be



conditioned using the same product containers as is used for vitrified HLW. Similarly not all SF will exist in a pristine form and it is anticipated that limited quantities of damaged SF may also have to be disposed of as HHGW.

HLW and SF are the two most obvious examples of wastes that would be described as HHGW. There are however other categories of waste for which geological disposal concepts developed for HHGW could be the optimum approach for their long-term management. This could include wastes with high actinide content, where long-term containment is a key requirement and/or where heat generation is significantly higher than that typical of ILW (e.g. plutonium rich waste streams containing significant quantities of plutonium-238 and/or americium-241).

Conversely, it should be noted that some SF, such as that arising from the operation of experimental reactors, which may have relatively low burn-ups (i.e. of the order of 1 MWd/tU) may best be managed as LHW or as 'fissile waste' (see Section 3.4). Similarly there are wastes associated with the operation and eventual decommissioning of WVP that, although nominally classed as HLW, would have heat outputs significantly lower than that of normal WVP products. In such cases a different disposal concept may offer a more optimal approach to their geological disposal and a different Generic Specification would apply to their packaging. RWM is developing illustrative disposal concepts for a range of such waste types and, when suitable concepts are identified, they will form the basis of future Generic Specifications.

As noted above, separated plutonium and HEU are currently included in the category of HHGW for the purposes of disposal, should that be the approach selected for their long term management. The radiogenic heat output from HEU will generally be very small (i.e.  $\sim 6 \times 10^{-5}$  W/kg) unless significant quantities of fission products are present. The heat generated by plutonium is higher but still relatively small (i.e.  $\sim 8 \text{Wkg}^{-1}$  for typical plutonium<sup>16</sup>), although the presence of certain radionuclides, notably plutonium-238 ( $\sim 570 \text{Wkg}^{-1}$ ) and americium-241 ( $\sim 110 \text{Wkg}^{-1}$ ), can result in significantly higher heat outputs. For such materials the most significant issues for their packaging and disposal is usually long-term containment and criticality safety, and these issues could both be addressed by adopting the same approach as for legacy HHGW. However, as discussed in Section 3.4, a bespoke approach to their geological disposal may be more suitable.

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<sup>16</sup> Plutonium produced by the reprocessing of Magnox fuel.

## 5 Basis for the definition of the packaging requirements

### 5.1 The role of the waste container and wasteform in achieving waste package performance

The fundamental aims for the packaging of waste are to ensure that the resulting waste packages are:

- Passively safe and suitably robust physically, so as to ensure containment and safe handling during all ensuing periods of the long-term management of the waste;
- Suitable for safe transport through the public domain in compliance with the relevant regulations; and
- Compatible with the safety cases for the operational and post-closure periods of a GDF.

The waste package provides the most immediate barrier to the release of radionuclides and other hazardous materials from the waste it contains, during interim storage, transport and within a multiple barrier geological disposal system. It may also play a role in protecting individuals from the radiation emitted by the radionuclides it contains during interim storage, transport and the GDF operational period.

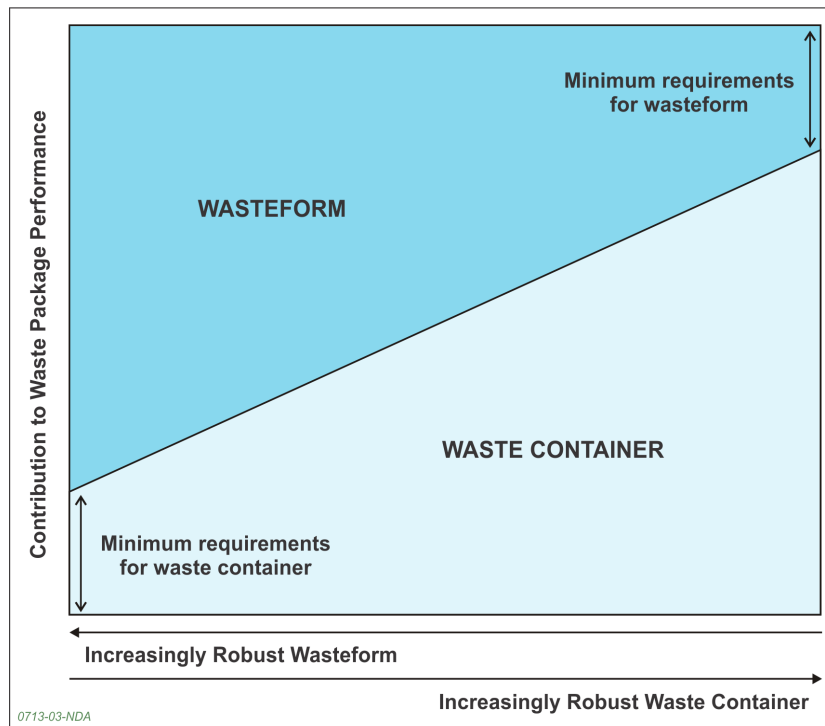
The barrier provided by a waste package can be considered to comprise two components, each of which can act as a barrier in its own right:

- The waste container; which provides a physical barrier and also enables the waste to be handled safely during and following waste package manufacture. Waste containers can be manufactured from a range of materials with designs selected to suit the requirements for the packaging, interim storage, transport, and disposal of the wastes they contain.
- The wasteform; which can be designed to provide a significant degree of physical and/or chemical containment of the radionuclides and other hazardous materials associated with the waste. The wasteform may comprise waste in which the radionuclides have been 'immobilised' (e.g. in the case of HLW where the waste has been vitrified), or which may have received more limited pre-treatment prior to packaging (e.g. in the case of SF where fuel assemblies may be reduced in size and/or dried to remove excess water).

Both the waste container and the wasteform contribute to achieving the required performance of the waste package, the relative importance of each generally depending on the robustness of the former. This is illustrated in Figure 7, which shows in stylised form how the use of a more robust waste container can reduce the required contribution of the wasteform to overall waste package performance. Figure 7 also shows that for all waste packages both the waste container and the wasteform will be required to play some role in the achievement of the required performance of the waste package. It should be noted that it is the overall performance of the waste package as a whole, rather than that of its components, that is the governing factor in judging its disposability.

In the case of the legacy HHGW considered in this Generic Specification it is likely that the wasteform will generally be well defined (see Section 4) and that this will have a significant influence on the requirements for the waste container, notably its durability (Section 6.1.5). This is further discussed in Section 6.2.

**Figure 7** Relative contribution of the waste container and wasteform to waste package performance



## 5.2 The transport of waste packages to a GDF

In the absence of a geographical location for a GDF, the TSC currently assumes that all waste packages will have to be transported, through the public domain, from their interim storage location to a GDF.

The transport of radioactive materials is subject to a number of requirements implemented into UK law<sup>17</sup>, notably the *IAEA Regulations for the Safe Transport of Radioactive Material*<sup>18</sup> [22]. The IAEA Transport Regulations, which are supported by extensive guidance [23], define general requirements and, in some cases, quantified limits for a range of properties of radioactive materials which are to be transported through the public domain and these are, where relevant, incorporated into this Generic Specification.

The distinction between a 'waste package' and a 'transport package' is important here as it influences the manner by which the requirements of the IAEA Transport Regulations are applied in this Generic Specification:

- A waste package will, in general, comprise a container in which waste is placed and which is suitable for disposal without further treatment.
- A transport package is an assembly which is suitable for transport, and which may or may not require additional protection for that purpose.

Some waste packages will be capable of satisfying the requirements of the IAEA Transport Regulations, without additional protection, and are described as 'transport packages in their own right'<sup>19</sup>. The requirements of the IAEA Transport Regulations are therefore applied

<sup>17</sup> The Radioactive Materials Transport Team of the ONR has regulatory responsibility for the transportation of radioactive material in Great Britain.

<sup>18</sup> This reference will be referred to as the 'IAEA Transport Regulations' in the remainder of document, and direct reference made to relevant Paragraphs in those Regulations.

<sup>19</sup> It is unlikely that any waste packages containing HHGW will fall into this category.

directly to such waste packages. However, some designs of waste package will not be suitable for transport without some additional protection (e.g. to provide additional radiation shielding and/or physical containment of the contents of the waste package) which can be provided, for example, by way of a reusable 'transport container'. In such cases a transport package would comprise a transport container into which one or more waste packages are placed. On receipt at the GDF, the waste packages would normally be removed from the transport container prior to disposal. For such waste packages significant benefit can be claimed for the protection that is provided by the transport container as the requirements of the IAEA Transport Regulations are applied to the transport package as a whole, i.e. the transport container and the waste package(s).

The constraints of the transport system and the regulations which apply to the transport of waste packages through the public domain are, in many cases, the most limiting in the definition of the packaging requirements that make up this Generic Specification. It is therefore important that the assumptions regarding the transport of waste packages are clearly defined. At the highest level this includes an assumption that all waste packages will be transported using the systems and operational procedures defined by the GTSD [7].

The IAEA Transport Regulations define a number of categories of transport package of which only Type B is of relevance to the transport of HHGW. Type B transport packages are defined in a manner that permits the transport of relative large quantities of activity, and for which the protection of transport workers and members of the public relies on the design and properties of the transport package as a whole (i.e. the transport container and its contents), rather than solely by controls on the nature of its contents.

The approval of Type B transport package can take two routes; Type B(U) or Type B(M); Type B(U) transport packages are approved to the full requirements of the IAEA Transport Regulations whereas Type B(M) transport packages may be approved to less onerous standards at the discretion of the Competent Authority that is responsible for granting approval. The IAEA Transport Regulations require that the requirements for Type B(U) transport packages are met as far as possible and this requirement is used as a basis for the derivation of the requirements defined by this Generic Specification.

The IAEA Transport Regulations define two regimes under which transport packages can be carried, these being under the conditions defined as 'exclusive use'<sup>20</sup> and 'non-exclusive use'. The packaging requirements that make up this Generic Specification are based on an assumption that the transport of waste packages containing HHGW will take place under the conditions of exclusive use.

### 5.3 The disposal of waste packages in a GDF

For a waste package to be deemed 'disposable' it must be both physically compatible with the systems defined for transport and the GDF, and with the assumptions that underpin the safety cases for transport and the operational and post-closure periods of the GDF. The design of the GDF, which will be strongly influenced by the geological environment in which it is constructed, will therefore place constraints on the required properties and performance of waste packages.

A wide range of different geological environments that could be suitable for hosting a GDF for higher-activity radioactive wastes exist in the UK. However, at this point in time, no site for a GDF has been selected and so the actual design of a GDF has not been fully defined. RWM has identified three example geological environments that are considered potentially suitable for hosting a GDF in the UK, these are described by the generic nature of the host

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<sup>20</sup> Paragraph 221 defines 'exclusive use' as: '...the sole use, by a single consignor, of a conveyance or of a large freight container, in respect of which all initial, intermediate and final loading and unloading is carried out in accordance with the directions of the consignor or consignee'.

rock they comprise and are; higher strength rock (HSR), lower strength sedimentary rock (LSSR) and evaporite rock (EVR). By drawing on work to investigate geological disposal concepts that have been planned or implemented worldwide [24], 'illustrative' concepts for the geological disposal of HHGW have been identified, which could be implemented in the three generic host rock types [25]. These are listed in Table 6.

**Table 6 Illustrative geological disposal concepts for HHGW**

Host rock	Generic Concept	Illustrative Concept
HSR	Vertical boreholes containing the waste packages, which are surrounded by pre-compacted bentonite blocks, within a horizontal access tunnel.	KBS-3V Concept (SKB, Sweden)
LSSR	Horizontal tunnels containing the waste packages, which are surrounded by emplaced granular bentonite.	Opalinus Clay Concept (NAGRA, Switzerland)
EVR	Horizontal tunnels, containing the waste packages, which are surrounded by crushed salt	Gorleben Salt Dome Concept (DBE, Germany)

RWM is using these illustrative concepts to further develop an understanding of the requirements of the disposal system for HHGW, to aid in the development of packaging specifications and thereby support waste packagers in the development of plans to package such waste for geological disposal. It should however be noted that it will not necessarily be the case that one of these illustrative concepts will be implemented in a particular geological setting, and no geological disposal concepts have been ruled out. Accordingly, whilst the packaging requirements defined by this Generic Specification are based on the illustrative concepts, some account needs to be taken of any additional constraints that other viable concepts could impose on the waste packages of the type considered herein. To date this has been considered by the definition of the 'bounding parameters' imposed on waste packages by a wider range of concepts [26].

## 6 Requirements for waste packages containing HHGW

This Generic Specification is founded on the anticipated requirements for the geological disposal of HHGW, as defined by the DSS. Waste packages should be capable of being safely transported to a GDF in accordance with the systems defined by the GTSD [7] and, following receipt at a GDF, of being safely handled by way of the processes and equipment defined in a GDFD [6]. Also included is a consideration of the required performance of waste packages in the GDF post-closure period, as defined by a set of environmental safety functions.

This Section defines the requirements, for each of the packaging criteria listed in Table 1, for all waste packages containing wastes that fall into the category of HHGW.

In general, the packaging requirements specified below are defined for the complete waste package. In practice the manner in which they are achieved will depend on a number of factors, including:

- The nature of the waste container;
- The physical, chemical and radiological properties of the waste; and
- The manner by which the waste is conditioned.

Accordingly, the packaging requirements are grouped in a manner to reflect those which are most directly related to the waste container (Section 6.1), the wasteform (Section 6.2), and the waste package as a whole (Section 6.3). In addition, a number of requirements are defined for the controls that will need to be applied during the manufacture and storage of waste packages (Section 6.4).

RWM has undertaken development work aimed to standardise waste container designs for HHGW, notably their external dimensions and lifting features, with the aim of [27]:

- Reducing the number of waste packages to be disposed, and therefore the size of a GDF 'footprint'.
- Reducing the extent of underground excavation, spoil generated and materials used for construction of a GDF.
- Providing additional flexibility in emplacement (and retrieval) operations for waste packages in either a horizontal or vertical orientation.

Three pairs of standardised waste container designs have been developed, with a common external diameter and handling feature design, and with overall length and radiation shielding provision to suit the three types of waste to which this Generic Specification primarily applies [28]. The waste container designs have differing internal configurations in order to accommodate:

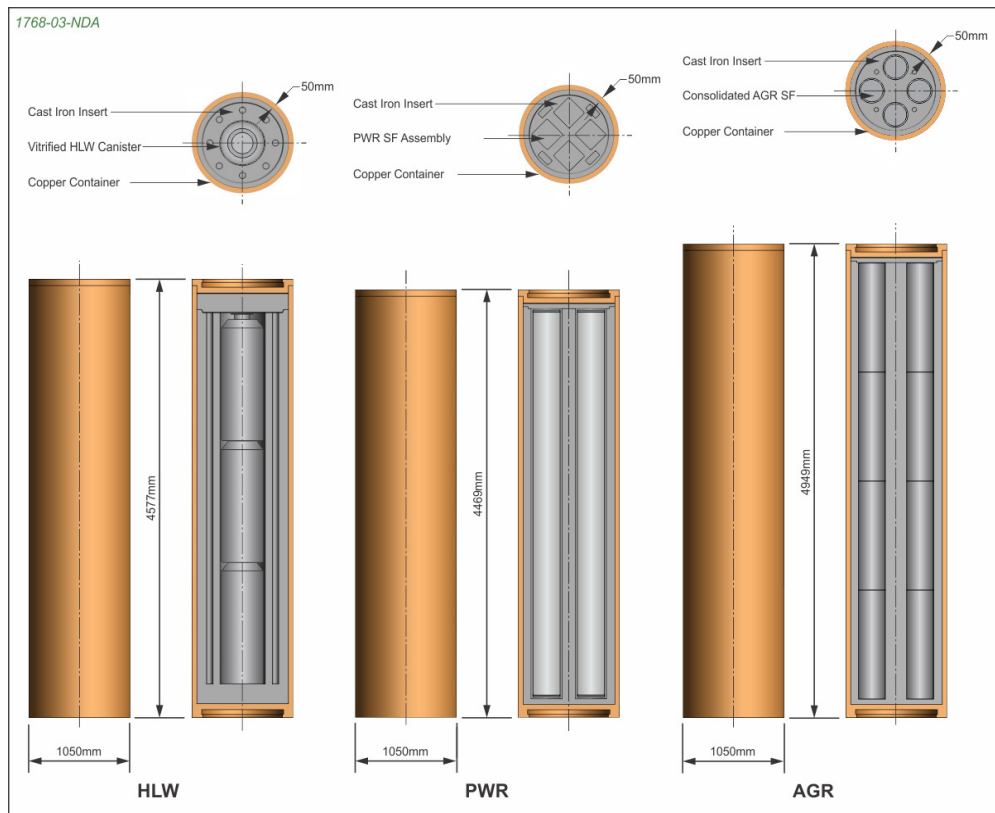
- i.) 3 vitrified product containers (i.e. for HLW); or
- ii.) 16 consolidated AGR fuel bundles; or
- iii.) 4 PWR SF assemblies.

The development of the wastes container designs has been based on the assumed requirements for disposal in accordance with the adoption of each of the three illustrative disposal concepts (Section 5.3). This has resulted in two basic design variants:

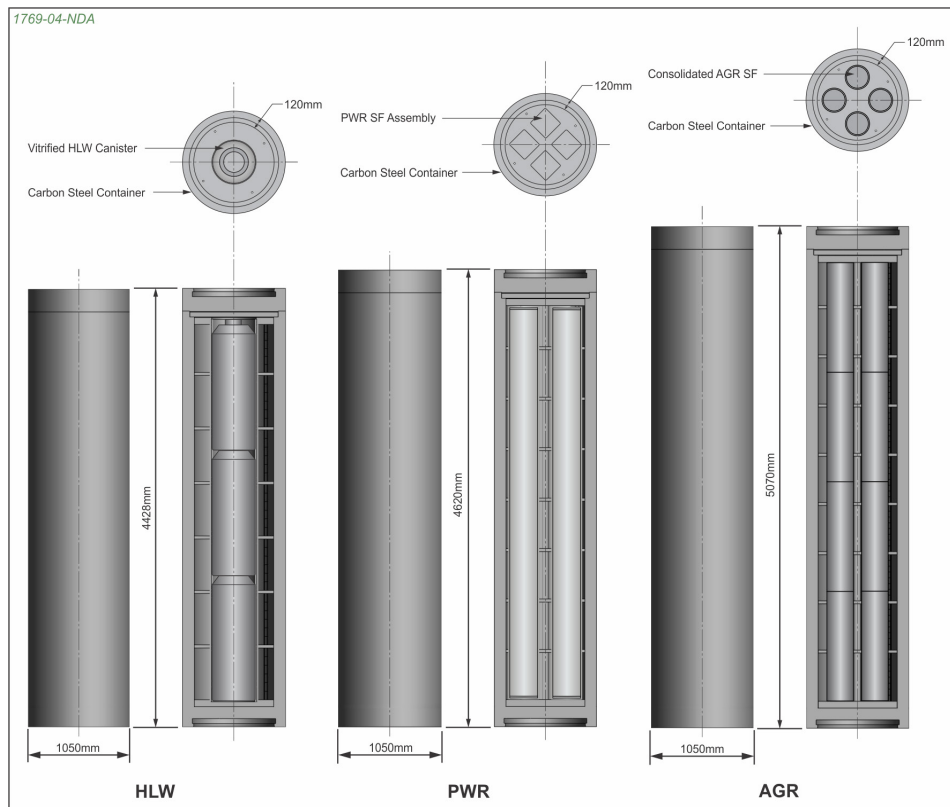
- Variant 1: Fabricated from copper, with a cast iron insert (i.e. based on the SKB KBS-3 container), for compatibility with the needs of a GDF constructed in HSR (Figure 8); and

- Variant 2: Fabricated from carbon steel (i.e. based on the NAGRA container), for compatibility with the needs of a GDF constructed in LSSR or EVR (Figure 9).

**Figure 8 Variant 1 waste container designs**

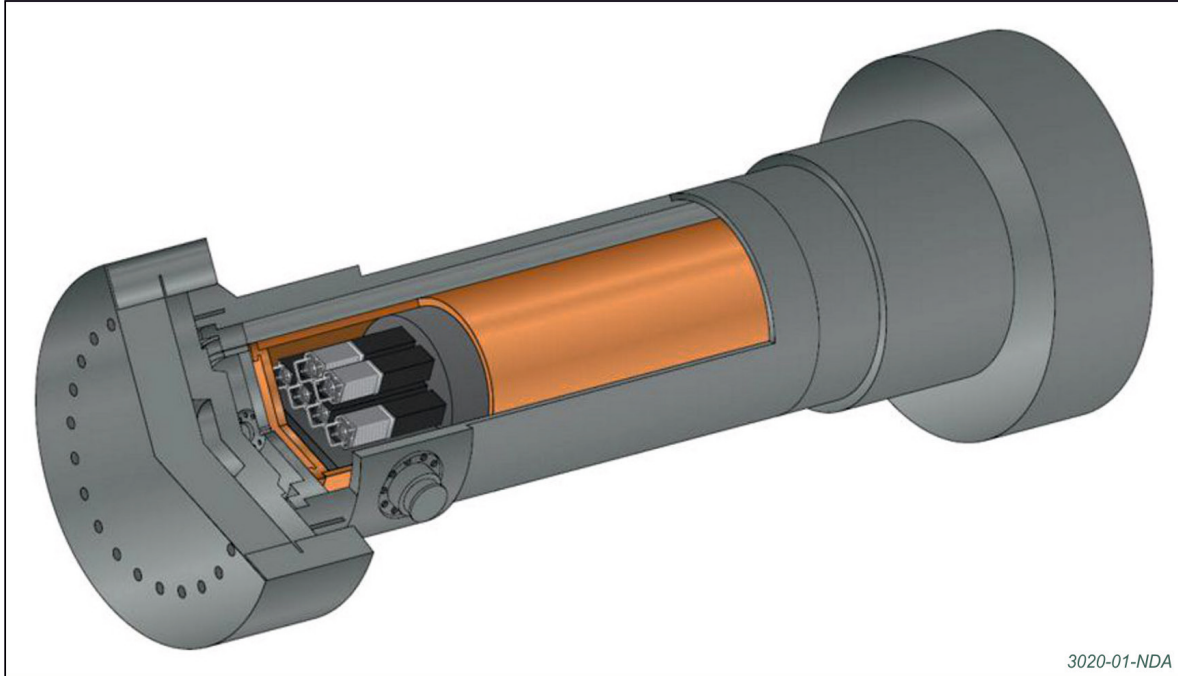


**Figure 9 Variant 2 waste container designs**



To facilitate the transport of waste packages manufactured using these standardised waste container designs, the *Disposal Container Transport Container* (DCTC - Figure 10) has been developed [29]. The DCTC is designed to carry individual waste packages of the types shown in Figures 8 and 9<sup>21</sup>, as part of Type B transport packages, and with external dimensions and gross masses within those defined by the GTSD report [7].

**Figure 10 DCTC for HHGW waste packages**



The requirements defined in this Section are firstly defined in a manner that could be applied to any design of waste package containing HHGW that could be accommodated by the existing transport and disposal systems designs and safety cases. This is followed by an illustration of how each requirement would apply to waste packages containing legacy HHGW, manufactured using the standardised waste container designs and transported using the DCTC.

It should be noted that, where the words ‘shall’ and ‘should’ are used in the packaging requirements, their use is consistent with the recommendations of BS 7373:1998 [30] in that they have the following meaning:

- ‘shall’ denotes a limit which is derived from consideration of a regulatory requirement and/or from a fundamental assumption regarding the current designs of the transport or disposal facility systems;
- ‘should’ denotes a target from which relaxations may be possible if they can be shown<sup>22</sup> not to result in any significant reduction in the overall safety of the geological disposal system.

The format of this Section is to define each packaging requirement in terms of that defined by the GWPS (shown in ***bold italic type***) together with any additional requirements for the waste packages containing HHGW (shown in ***bold type***).

<sup>21</sup> The DCTC is also intended to be able carry other designs (i.e. of greater length) of HHGW, as discussed in Section 6.1.1).

<sup>22</sup> This would generally be via the Disposability Assessment process (see Section 2.4).



## 6.1 Requirements for waste containers

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

In Section 5 the contribution that the waste container can make to the overall properties and performance of a waste package was discussed. For some of the required waste package properties (e.g. external dimensions, lifting features, and identification) the waste container will generally satisfy the requirement, whereas for others (e.g. criticality safety, accident performance) it may only play a partial role. The extent of the role played by the waste container in complying with any of the waste package requirements listed below, will depend on its robustness, as illustrated by Figure 7. It should however be noted that, whilst the designs of waste container that would be expected to be used for the packaging of HHGW will be able to provide most aspects of required waste package performance, this will not preclude the need for the wasteform to satisfy the requirements defined in Section 6.2.

The generic requirements for waste containers, not all of which will apply to some disposal concepts, are that they should provide the waste package with adequate:

- Mechanical strength to:
  - resist damage due to pressurisation by internally generated gases;
  - ensure that the specified impact accident performance can be achieved; and
  - withstand all loads that may occur during the long-term management of the waste package, as required by the ESC.
- Radiation shielding<sup>23</sup> to ensure that the external dose rate is minimised and that specified limits are not exceeded;
- Thermal properties to ensure that the required fire accident performance and other thermal requirements of the waste package will be met; and
- Resistance to degradation to ensure that the integrity of the waste container is maintained for an extended period, thereby:
  - provide complete containment of radionuclides during the thermal period (see Section 6.1.5) such as to permit essentially complete decay of short-lived radionuclides (i.e. up to ~100 years) and a significant reduction in those with medium length half-lives (i.e. up to ~10<sup>4</sup> years) ;
  - maintaining the contents of the waste in a sub-critical condition during transport and a GDF operational period, including providing physical location of the fissile material and preventing the entry of water into the waste package; and
  - preventing the early accumulation of fissile material from more than a single waste package during the post-closure period.

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<sup>23</sup> It should be noted that some designs of waste container will not provide sufficient radiation shielding to satisfy the requirements of transport and that this would be provided by the use of a transport container or similar device.

### 6.1.1 External dimensions

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

**The waste package shall be cylindrical in shape with external dimensions that should not exceed a diameter of 1.05 m and a length of 5.20 m.**

The external dimensions of waste packages are limited by the systems used during transport and handling at a GDF. For most designs of waste package containing HHGW the high external radiation dose rates will require them to be provided with additional shielding and impact protection during transport, in the form of a transport container. In such cases this will significantly increase the external dimensions of the transport package.

The current GDF handling systems are based on transport packages having dimensions that lie within the envelope defined for Series 1 freight containers as specified in ISO668 (i.e. 6.058 m x 2.438 m plan x 2.591 m high) [31]. The DCTC, intended for the transport of waste packages containing HHGW (Figure 10), has been designed to comply with this dimensional envelope.

Waste packages are assumed to be transported to a GDF by road, rail, sea or inland waterway, or by a combination of these means. In general, transport by rail is the most restrictive from the point of view of the external dimensions of waste packages. The maximum overall dimensions of a transport package must be compatible with the dimensions envelope defined by Standard W6A Rail Gauge [32]. This leads to a maximum transport package width of 2.67 m<sup>24</sup> and a maximum height of 2.40 m [33]. Transport by rail will also impose limits on the length of transport packages although these will be generally less restrictive than a GDF limit (i.e. ~6m). Less restrictive rail gauges exist although this could limit which parts of the network could be used. Larger waste packages could be transported by road; although the dimensions of transport packages transported in this manner may ultimately be limited by restrictions on their gross mass (see Section 6.3.2).

The DCTC is currently designed to be able to accommodate waste packages with external dimensions up to those of the largest of the standardised containers for both legacy SF and other types of SF<sup>25</sup> (see Section 4.2.3), whilst remaining within the constraints defined by the transport system. The former leads to the maximum waste package size specified above (i.e. a diameter of 1.05 m and a length of 5.20 m). Larger (i.e. longer) waste packages could be accommodated by a modified design of DCTC, but this is outside the current version of this Generic Specification.

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<sup>24</sup> These values represent the total envelope permitted by the W6A rail gauge and therefore the effects of any peripheral equipment (e.g. weatherproofing covers, impact limiters etc.) used during transport would have to be taken into account.

<sup>25</sup> Such as SF that would arise from the operation of a new generation of UK power stations, and MOX fuel.

### 6.1.2 Handling feature

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

The waste package shall incorporate handling features to enable lifting under a load equivalent to twice the maximum specified gross mass without any effect that would render it non-compliant with any of the requirements defined in this Specification.

**Where tie down within a conveyance is necessary for their safe transport, waste packages which are transport packages in their own right shall incorporate tie-down features suitable for their maximum specified gross mass.**

**The design of the waste package shall enable remote handling**

To permit their safe and efficient handling waste packages need to incorporate standardised designs of handling feature, designed in such a manner as to be compatible with the handling systems that are assumed to be used during transport and following receipt at a GDF. These handling features must be able to withstand the full range of forces which could be applied during all normal waste package handling operations. This includes a requirement for them to be able to withstand the loads that would result from the lifting of a waste package with twice the specified maximum gross mass, to take into account the so-called 'snatch factor' [34].

In order to retain flexibility in the definition of operational procedures at a GDF (and during transport), and to ensure that operator doses will be as low as reasonably practicable (ALARP), the design of the handling features of all waste packages containing HHGW shall permit their remote handling during all transport and GDF operations.

Waste packages may be transported and/or emplaced in a vertical or horizontal orientation and may need to be rotated from one attitude to the other during either of those operations. For disposal concepts where such rotation is required the design of the handling feature will be required to permit this.

For some designs of cylindrical waste containers, such as the standardised designs discussed above, it is prudent to include handling features at both ends of the waste package as this would increase flexibility in waste package handling and reduce the consequences of damage to one end of the waste package. To this end, each of the standardised designs of waste container identified in Section 6.1.1 incorporates the same design of recessed lifting feature at both ends of the container.

### 6.1.3 Stackability

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

None of the illustrative concepts identified for the disposal of HHGW (Section 5.3) envisage the stacking of waste packages during transport or disposal.

### 6.1.4 Identification

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

**The waste package shall be marked at multiple defined locations with a unique alpha-numeric identifier.**

The application of a unique identifier enables the identification and tracking of every waste package throughout the different stages of its long-term management, and helps to ensure the permanent assignment of the appropriate data record to that waste package.

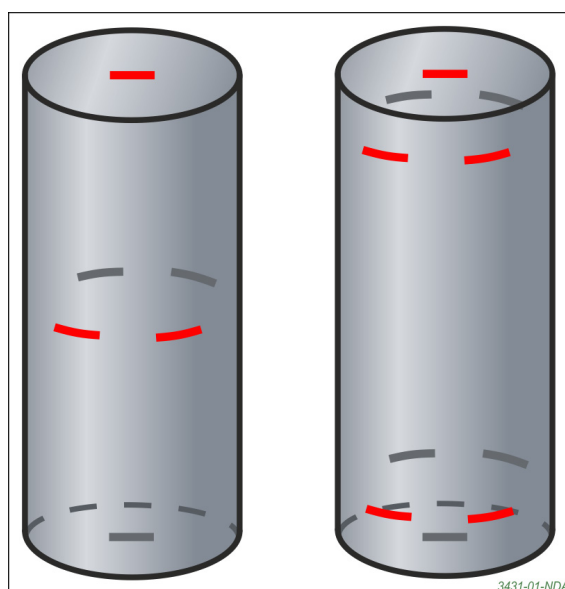
It is recognised that vitrified product containers, AGR fuel pins, slotted cans for AGR fuel pins, and PWR fuel assemblies will bear unique identifiers and that these will play a role in the identification and tracking of these materials prior to packaging. The presence of such identifiers does not however obviate the need for the unique identification of waste packages.

The use of a waste package identification system based on alpha-numeric identifiers ensures the maximum flexibility and capacity of a system which will need to be capable of ensuring that large numbers of waste packages, arising from multiple sites and packaging plants, will be handled safely and efficiently following receipt at a GDF.

For automated reading systems to operate effectively, multiple standardised locations will be specified for identifiers. This will aid in the ease of reading by reducing the need for the waste package to be moved to facilitate identification or of identifiers being obscured by handling equipment. It also provides redundancy in the event of damage to individual identifiers (for example that caused by corrosion) and will reduce the risk of waste packages becoming unidentifiable. Identifier locations are selected to ensure that the application of the identifiers does not compromise the durability of the integrity of the waste container (Section 6.1.5). This latter aspect is also a consideration when the method of applying identifiers is selected.

Making the identifier 'machine-readable' and the use of a format containing check digits allows the waste package to be identified remotely by automated systems and the veracity of its identifier confirmed. The use of a standard character set, such as OCR-A characters [35], of a specified size, permits waste package identification by either automated or direct visual (i.e. by human operators) means. The location of identifiers on a waste package should be such as to permit easy access by reading equipment at all stages during the handling of the waste package at a GDF. For cylindrical waste packages these locations should include both of the 'ends' and the 'sides' of the waste package (e.g. Figure 11).

**Figure 11 Examples of locations for identifiers on HHGW waste packages**



Waste packages should remain identifiable at least until the time at which it is no longer readily available for inspection and identification. Depending on the nature of the disposal concept this may be up to the time of emplacement, disposal area backfilling or when the disposal area has been closed and sealed.

### 6.1.5 Durability of waste container integrity

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

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

**The waste container shall maintain containment during the thermal period defined for the waste it is intended to contain.**

The integrity of a waste container provides two of the five operational safety functions defined for waste packages in the DSS, namely the containment of contents and safe handling.

Meeting both of these requirements relies heavily on the maintenance of waste container integrity for an appropriate period. Other operational safety functions, notably the ability of the waste package to withstand internal and external loads, will also rely at least in part on such integrity. The requirement for the durability of waste container integrity is therefore defined in terms of the period for which the waste container needs to maintain the containment of its contents, the surety of its handling features and its ability to withstand any loads to which waste packages could be subject during transport or disposal.

The DSS also defines a number of environmental safety functions that the waste container will be required to provide for waste packages in the post-closure period. These include preventing groundwater from reaching the wasteform, which is identified as a means of delaying the release of radionuclides from the waste package. In the case of waste packages containing HLW, a large proportion of radionuclides will decay on a timescale of a few centuries. Waste packages containing SF will also contain significant quantities of much longer lived radionuclides (i.e. isotopes of uranium and plutonium), for which retention until significant decay has occurred is not a realistic aim.

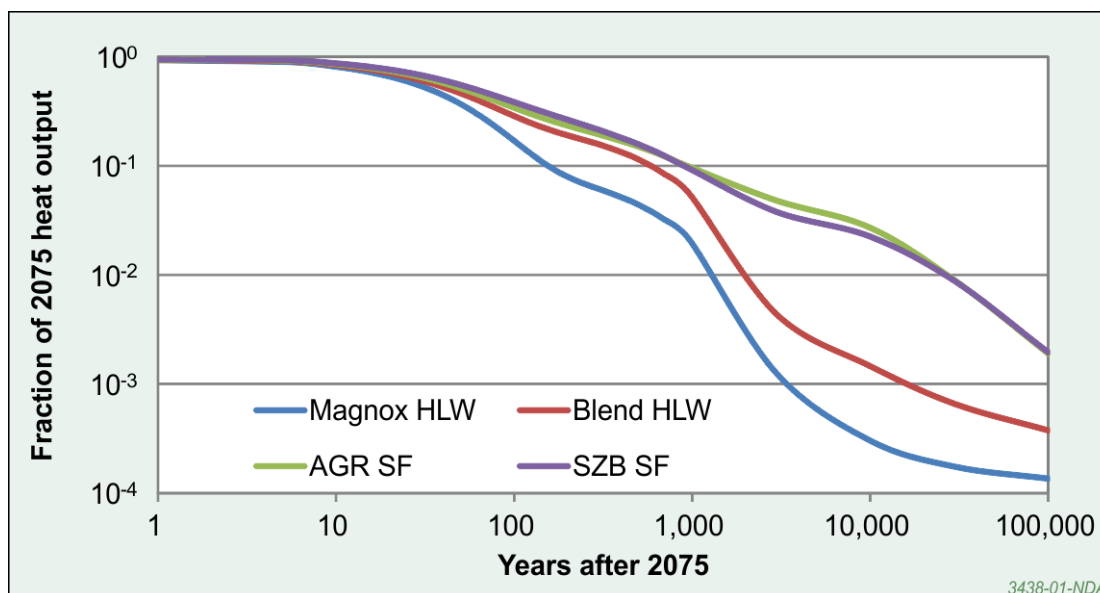
The potential for retrieval of waste packages from a GDF for a period beyond the anticipated end of the operational period must be taken into account when defining the period over which the integrity of the waste container is required to be maintained. The DSS requires that activities concerned with the development and implementation of geological disposal should be carried out in such a way that the option of retrievability is not foreclosed. RWM's position on retrievability is that activities concerned with the development and implementation of geological disposal will be carried out in such a way that the option of retrievability is not excluded [36].

Regulatory guidance on the conditioning and disposability of higher activity waste states that *'A minimum package lifetime of 150 years should be set for design purposes'* [17]. This period has been defined with the uncertainty of the date of the availability of a GDF in mind, and to ensure that waste packages maintain their integrity during an extended period of on-site interim storage. Whilst it is accepted that a significantly longer period would be required for maintenance of the containment function of a waste package containing HHGW, the 150 years period would be applicable to the integrity of the handling features of such waste packages.

The question as to how long the containment of waste packages containing HHGW must be maintained has been addressed by the IAEA [37] and a number of countries who are developing disposal concepts for such wastes [38]. The former requires containment to *'be provided until radioactive decay has significantly reduced the hazard posed by the waste'* and *'while the waste is still producing heat energy in amounts that could adversely affect the performance of the disposal system.'* This has led to the concept of the 'thermal period' which the IAEA requirements suggest would be *'several thousands of years'*. The actual duration of the thermal period will depend on the nature of the disposal concept (notably the EBS), and the radionuclide inventory of the waste packages. In the latter context SF is

different to HLW in that the former contains a much larger proportion of long-lived actinides and these contribute significantly to heat generation, particularly after ~100 years (Figure 12). The IAEA requirements also point out the importance of the durability of the wasteform in achieving adequate containment of radionuclides, which reinforces the role of the waste package as a whole in achieving the required performance (Section 5.1).

**Figure 12 Comparison of typical heat decay profiles of HLW and SF**



A survey of international practice has shown that many countries, in which different disposal concepts are being developed, assume a thermal period of approximately 1,000 years for either HLW or SF [39, 40]. By contrast ONDRAF/NIRAS (Belgium) assumes a 'few hundred years' for HLW and 'thousands of years' for SF.

RWM has carried out work which shows that current designs of waste container for LHW, fabricated from stainless steel and ductile cast iron and designed to meet the durability requirement of 150 years, would also be expected to maintain an appropriate level of integrity for at least 500 years [41]. Using similar reasoning it is reasonable to assume that a waste container designed to ensure containment for 1,000 years, would typically be expected to provide containment for a significantly longer period.

In the case of waste packages containing SF the durability of the waste container also has significance for criticality safety, in that failure of the container will allow water to enter, thereby changing neutron moderation and possibly, in the very long-term, leading to the separation of plutonium from uranium. This would reduce the neutron poisoning effects of uranium-238.

For some wastes, the retention of specific radionuclides by the waste container may be a requirement. An example of this is carbon-14, which may be present in significant quantities in certain fuel types (e.g. nitride fuels), and which has a half-life of ~5,600 years.

It should be noted that any assumption for the use of a particular material (e.g. copper or carbon steel) for the fabrication of the waste containers does not form part of this Specification. Such a choice would be made for compatibility with the selected disposal concept(s) and its consequences for waste container integrity determined as part of the disposability assessment of a packaging proposal.

## 6.2 Requirements for wasteforms

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

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

The physical, chemical, biological and radiological properties of the wasteform shall:

- make an appropriate contribution to the overall performance of the waste package; and
- have no significant deleterious effect on the performance of the waste container.

The wasteform should provide a stable, low-solubility matrix that limits the rate of release of the majority of radionuclides by dissolution in groundwater.

Evolution of the wasteform shall not have a deleterious effect on the waste package properties that are necessary for safe transport and operations at a GDF, or on meeting the required safety functions for post-closure performance, as set out in the ESC.

As discussed in Section 5.1 the required performance of a waste package will be provided by a combination of the properties of the waste container and the wasteform it contains. Waste packages containing HHGW will generally be manufactured using highly robust waste containers with which the wasteform will play a relative lesser role. However, this will not completely preclude the need for certain wasteform properties in order to ensure appropriate waste package performance.

The properties of the wasteform will play a key part in ensuring the passive safety of a waste package, irrespective of the nature of the waste container. Wastes should therefore be conditioned to satisfy some basic requirements as to their physical, chemical and biological properties. This should extend to ensuring the compatibility of the wasteform and the material from which the waste container is fabricated, and the appropriate control of the quantities of some types of material, or wasteform properties, that could affect the overall performance of the waste package, or the other barriers that make up the geological disposal system. These include:

- Free liquids;
- Activity or hazardous materials in particulate form;
- Voidage;
- In-homogeneity;
- Reactive materials;
- Other hazardous materials<sup>26</sup>; and
- Materials that could have a deleterious effect on the other barriers that make up the EBS.

The extent of the controls on these properties will be dependent on the nature of the disposal concept, and on the robustness of the waste container, and the consequences of the presence of these materials and wasteform properties for waste package and disposal system performance.

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<sup>26</sup> Hazardous materials include flammable, explosive, pyrophoric, chemically toxic and oxidising materials.

Evolution of the wasteform, resulting from chemical, biological and/or radiation induced processes will change the properties of the wasteform with time. It is important that such evolution will not result in changes that render the waste package incompatible with the needs of transport or the requirements for safety in a GDF operational period.

In the post-closure period the wasteform may continue to play a role in the overall safety of a GDF. The DSS defines a single environmental safety function for wasteforms requiring them to *'provide a stable, low-solubility matrix that limits the rate of release of the majority of radionuclides by dissolution in groundwater that comes into contact with the wasteform'*. Accordingly the consequences of evolution should be such that this requirement is satisfied and that the wasteform will continue to make an appropriate contribution to the overall performance of the waste package, and to the geological disposal system as a whole.

In the case of the two basic types of HHGW identified in Section 4, the 'wasteforms' are likely to take the form of well-defined components (i.e. either WVP vitrified product containers, or intact or partially dismantled fuel elements). In such cases it will be the role of the waste container 'furniture' (e.g. internal racks) to ensure that the wasteform has the required mechanical properties.

Deterioration in the condition of the waste during storage prior to packaging may be an issue, as this may result in a loss of mechanical integrity of the waste components or the creation of corrosion products (i.e. particulate). For SF such storage is often in water filled ponds and it will be important that the fuel is sufficiently dried prior to packaging to ensure that water is only present in quantities that would not lead to excessive corrosion after packaging. RWM has commissioned some initial work to consider the potential consequences of the presence of water inside waste packages containing HHGW. Using waste packages containing AGR SF and manufactured using the standardised waste container designs as an example, this work concluded that the presence of ~1.5 kg of water in such a waste packages would result in minimal structural damage to the waste container due to corrosion processes and only limited potential for internal pressurisation of the waste package [42, 43].

The presence of water in the waste package could also have implications for criticality safety (see Section 6.3.7).

The packaging of non-pristine HHGW could present issues for both transport and disposal. The physical disruption of the wasteform could lead to 'slumping' of the waste materials inside the waste package and the creation of in-homogeneities in the distribution of radionuclides. This could have consequences, in particular, for external dose rate and, in the case of SF, criticality safety. The IAEA Transport Regulations (Paragraph 652) require Type B transport packages (and thereby the waste packages they contain) to be able to withstand normal conditions of transport<sup>27</sup> without any changes that would lead to a greater than 20% increase in the maximum external dose rate at any point on the external surface, or a dose rate of greater than 10 mSv<sup>-1</sup> at 1 metre from the surface (Paragraph 659(b)(i)). In the case of damaged SF, slumping of the fissile material from a previously sub-critical condition into a critical configuration could potentially occur during transport or the GDF operational period (i.e. during handling or emplacement).

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<sup>27</sup> Defined by Paragraphs 719 - 724.



## 6.3 Requirements for waste packages

### 6.3.1 Activity content

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

The allowable activity content of waste packages may be limited by one or more of a number of radionuclide related parameters which are dealt with separately in this Generic Specification. These comprise:

- External dose rate (Section 6.3.3)
- Heat output (Section 6.3.4)
- Release of activity in gaseous form (Section 6.3.6)
- Criticality safety (Section 6.3.7)
- Accident performance (Section 6.3.8)

The IAEA Transport Regulations define limits for the activity contents of different classes of transport packages. In the context of this Generic Specification the relevant limit for Type B transport packages which have not been qualified to satisfy the requirement of an 'enhanced water immersion test' (Paragraph 730) is  $10^5 A_2$  is placed on the total activity of their contents. It is assumed that the design of the DCTC will be such that it will be capable of satisfying these requirements and, as a consequence, limits on the activity content of waste package will derive from the requirements to limit one or more of the five parameters listed above.

### 6.3.2 Gross mass

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

**The gross mass of a transport package should not exceed 65 t.**

The maximum gross mass of waste packages must be such that it will permit them to be safely and efficiently handled using the systems defined for transport to, and emplacement in, a GDF. The gross masses of transport packages must also be compatible with the UK transport infrastructure such that no undue limits are placed on the mode of transport that can be used (i.e. by road, rail, sea or inland waterway).

The GDFD [6] currently includes a number of assumptions regarding the safe working loads for GDF lifting and handling equipment. This includes a capability to transfer underground and subsequently handle transport packages with gross masses (including any handling equipment such as lifting frames) of up to 80 t.

For waste packages which are transport packages in their own right, emplacement is assumed to be by the use of a stacker truck with a safe working load of 65 t. For waste packages transported within transport containers the lifting and handling equipment used to remove waste packages from the transport container and emplace them may place a more onerous limit.

The GTSD [7] currently assumes the use of a four-axle rail wagon for the transport of packaged waste to a GDF. Such a wagon would permit transport packages with a gross

mass of up to ~65 t<sup>28</sup> to be carried on a large proportion of the UK rail network. The design of the DCTC for use with the legacy HHGW considered in this Specification, packaged using standardised containers identified in Section 6.1.1 has been based on the assumption that it will be transported by rail using such a wagon. The tare mass of the DCTC will depend upon the radiological characteristics of the contents of the waste packages that it is to carry. Design work on the DCTC has shown that the 65 t limit<sup>29</sup> can be achieved for waste packages manufactured using each of the standardised designs of waste container with the anticipated contents [28].

As noted above, the possibility exists for the DCTC to be modified to accommodate longer waste packages, but this would increase its mass such that the gross mass of the transport package would exceed 65 t. The possibility of using an eight-axle rail wagon for carrying transport packages with masses of greater than 65 t does exist, but these would only be suitable for use on a reduced proportion of the rail network.

### 6.3.3 External dose rate

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

**The external dose rate of the waste package should be compatible with the dose rate of a transport package, under routine conditions of transport, not exceeding 10 mSv<sup>-1</sup> on its external surface, or 0.1 mSv<sup>-1</sup> at 2 metres from any external surface.**

The IAEA Transport Regulations define limits for the external dose rate from transport packages which depend on the operational controls under which transport operations are carried out. The GTSD assumes that the limits defined for transport under the conditions of exclusive use will be applied to transport packages containing HHGW. The design of the DCTC for use with HHGW packaged using standardised containers identified in Section 6.1.1 has been based on this assumption, taking into account the expected dose rates from the different types of HHGW they are expected to accommodate, and the shielding that would be provided by the waste containers for each type [28].

It should be noted that the external dose rate limits identified above apply to the vehicle that carries the transport package rather than to the transport package itself. However, in the absence of a firm design for such a vehicle for the transport of the DCTC, this Generic Specification conservatively applies the limits directly to the transport package.

Following receipt at a GDF, the removal of waste packages from the DCTC and their emplacement in the disposal areas will be carried out remotely, but the potential for worker dose from transport packages prior to this will exist. This will be considered by the OSC which will initially<sup>30</sup> be based on transport packages having external doses rates bounded by the requirements for transport. However, the need to ensure that worker doses are ALARP during the operational period might place more stringent limits on waste package external dose rates than those set by transport.

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<sup>28</sup> This value is equal to the maximum permitted gross mass of such a wagon (90 t) less the estimated mass of the unladen 4-axle rail wagon (~25 t).

<sup>29</sup> Which includes a transport frame for the DCTC, which has a mass of ~5 t.

<sup>30</sup> In due course the OSC will use the actual dose rates predicted for specific waste packages.

### 6.3.4 Heat output

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

- *thermal effects result in no significant deterioration in the properties of the wasteform, the performance of the waste package, or of the transport and/or disposal systems as a whole; and*
- *regulatory limits on the surface temperature of transport packages are not exceeded.*

**The heat generated by the waste package shall not result in the temperature of any component of the EBS exceeding the limit defined for the disposal concept.**

By its definition the radiogenic heat output generated by waste packages containing HHGW will be high, typically of the order of 1 kW per cubic metre of waste. As a result the heat emitted by waste packages containing HHGW is an important issue to be addressed during all stages of their long-term management.

Heat generation by waste packages has the potential to result in damage to the contents of the waste package (i.e. the wasteform) and/or the waste container, and could affect the performance of the geological disposal system as a whole, by causing damage to other components of the EBS, notably any buffering materials. Damage to the waste package could result from the accelerated corrosion of either the wasteform or the waste container. For some types of HHGW specific heat-accelerated degradation processes could occur including 'de-vitrification' of vitrified HLW and disruption of previously intact cladding of SF, leading to the loss of a containment barrier and a subsequent increase in the mobility of radionuclides.

The IAEA Transport Regulations define qualitative and quantitative controls on the heat generated by the contents of transport packages. These include ensuring that heat generation will not alter the basic physical properties of the transport package or its contents (Paragraph 651). Paragraph 655 specifies a maximum temperature of 85°C for any accessible surface of a Type B transport package carried under the conditions of exclusive use. The heat generated by waste packages will also have to be limited to ensure that the transport container lid seals remain in their safe operating range under normal and accident conditions. Similarly, other aspects of transport container performance, (e.g. neutron shielding) should not be impaired by heat generated by the waste package contents.

The design of the DCTC for use with legacy HHGW packaged using standardised containers identified in Section 6.1.1 has been based on the assumption that it will be compliant with these requirements [28]. An initial thermal performance analysis of the DCTC [29] has demonstrated that, under both normal and accident conditions a waste package heat output of 1,200 W would not result in accessible surface temperatures in excess of 85°C and seal temperatures would be well below established limits. However if this is increased to 2,000 W accessible surface temperatures could exceed 85°C and thermal guards would be required during transport.

Limits on the heat generated by waste packages following emplacement in a GDF will depend on the disposal concept selected, specifically on the temperature limits placed on the different components of the EBS. Heat-induced degradation of the backfill or buffer material could impact its ability to perform its safety function, will impose a limit on the maximum allowed temperature of the EBS and may limit acceptable waste package heat output.

For planning purposes the bounding EBS temperatures for the three illustrative concepts for HHGW are defined in the DSS as:

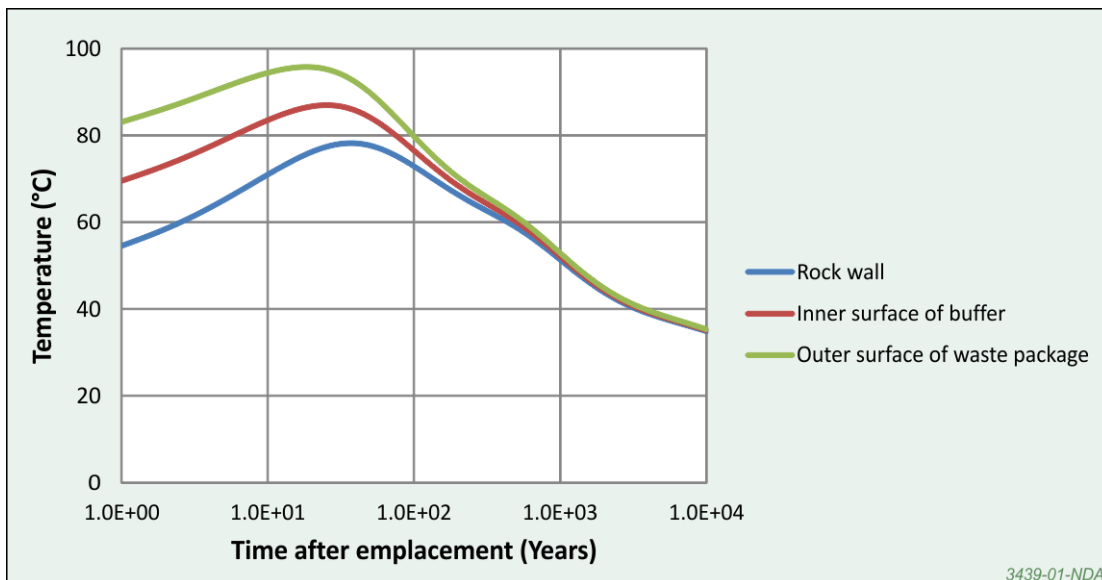
- For HSR; a maximum temperature of 100°C on the inner surface of the bentonite.

- For LSSR; a maximum temperature of 125°C at the mid-point of the buffer material.
- For EVR; a maximum temperature of 200°C in the backfill material.

RWM uses the Thermal Dimensioning Tool (TDT) to model the thermal evolution of the EBS [44]. Inputs to the TDT include the nature of the disposal concept, the external dimensions and thermal properties of the waste package, information on the radiogenic heat source, the dimensions of the EBS, notably the layout of the disposal tunnels, the spacing of the waste packages within the tunnels, and the thermal properties of the EBS and the host rock.

Outputs of the model take the form of temperature time histories at various locations within the EBS, notably the external surface of the waste package and at different points within the buffer and/or backfill. Figure 13 illustrates a typical output<sup>31</sup> from the TDT showing the predicted temperature profiles for the external surface of the waste package, the buffer and the inner surface of the surrounding rock following emplacement. This shows that the temperature of the EBS increases gradually during the first few decades following emplacement, reaching a maximum value after ~20-30 years and declining gradually afterwards.

**Figure 13 Typical temperature evolution of an emplaced waste package**



The TDT can be used to determine the waste package heat output that would result in the temperature of the buffer/backfill exceeding the defined limits. However RWM has recognised that both the heat output from waste package at the time of emplacement and its variation thereafter are both important factors in the thermal evolution of the EBS [45] and therefore a definition of the thermal evolution of the contents of waste packages must be included in any determination of a limit on waste package heat output at the time of emplacement.

At this stage in the development of plans for the geological disposal of HHGW, notably with regard to site selection, the details of the GDF design and the thermal properties of the EBS (notably the host rock and the buffer/backfill) are uncertain. To enable these example calculations, the reference parameters that describe the illustrative concepts have been used, together with typical thermal properties of legacy HHGW, as listed in Appendix A.

<sup>31</sup> The example shown is for a waste package containing four consolidated AGR assemblies in a standardised copper canister (Figure 8) and emplaced in the manner defined by the illustrative concept for HSR. A full list of the modelling parameters can be found in Appendix A.

Guidance values for the maximum heat outputs for waste packages containing three types of HHGW are listed in Table 7, on the basis that they were disposed of in accordance with the conditions defined in Appendix A, and such that the bounding temperatures for the three illustrative concepts would not be exceeded.

It should be noted that the values shown in Table 7 are not definitive limits for the different types of HHGW as they are based on a single, albeit 'typical', heat profile for each of them as well as a single set of modelling parameters for the GDF and the EBS, and that changing any of the modelling parameters could result in different values. Accordingly, the thermal performance of each specific design of waste package containing HHGW will have to be determined using the TDT using information on both the heat output at the time of emplacement, and its variation thereafter, and with due consideration of any uncertainties in these parameters.

**Table 7 Guidance values for maximum heat output of waste packages containing HHGW**

Waste package contents	Maximum heat output at time of emplacement <sup>1</sup> (W)		
	HSR	LSSR	EVR
3 @ HLW vitrified product containers <sup>2</sup>	1600	1800	2870
16 @ consolidated AGR fuel bundles <sup>3</sup>	1540	1940	3160
4 @ PWR fuel elements <sup>4</sup>	1420	1780	2890

Notes on Table 7:

<sup>1</sup> Emplacement at 2075

<sup>2</sup> WVP products containing Blended HLW, UKRWI waste stream 2F01/C

<sup>3</sup> UKRWI waste stream M2D100

<sup>4</sup> UKRWI waste stream M3S100

It should be noted that all of the values given in Table 7 exceed the design value for the DCTC (i.e. 1,200 W, see above) [29]. This means that, on the basis of the current DCTC design, transport would be the bounding factor for waste package heat output. However, the sensitivity studies carried out as part of the thermal modelling of the DCTC suggest that waste packages with heat outputs of up to 2,000 W could be transported, provided that the external dose rate of the transport package was within the required limits (see Section 6.3.3). A limit of 2,000 W limit for transport is higher than the maximum values for the disposal of waste packages in a GDF constructed in HSR and LSSR and would only be bounding for disposal in a GDF constructed in EVR.

### 6.3.5 Surface contamination

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

The non-fixed surface contamination of a waste package, when averaged over an area of 300 cm<sup>2</sup> of any part of the surface of the waste package, should not exceed:

- 4.0 Bqcm<sup>-2</sup> for beta, gamma and low toxicity alpha emitters; and
- 0.4 Bqcm<sup>-2</sup> for all other alpha emitters.

Limits on the non-fixed<sup>32</sup> surface contamination of all waste packages are specified to ensure that:

- Regulatory limits are achieved for waste packages which are transported without additional protection;
- Contamination of transport and GDF systems can be maintained at appropriate levels; and
- Routine doses to workers and the members of the public will be ALARP and in accordance with good industry practice.

The limits specified are those defined in Paragraph 507 of the IAEA Transport Regulations for the non-fixed surface contamination of transport packages but are here used as targets for the non-fixed contamination of all waste packages on the basis that they represent realistic and achievable levels and will reduce any potential requirement for the decontamination of the internal surfaces of transport containers and the areas of a GDF where 'bare' waste packages are handled.

The surface contamination limits only apply to 'non-fixed' contamination on the basis that such material could become detached from the waste package during routine operations and inhaled or ingested by humans. Contamination deemed as being 'fixed' cannot be as readily removed and therefore cannot result in exposure and dose by such mechanisms. It should be noted however that 'fixed' contamination can become 'non-fixed' as a result of the effects of waste package ageing, weather or handling and that the level of non-fixed contamination could increase with time.

### 6.3.6 Gas generation

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

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

**Pressurisation of the waste package by internally generated gases shall not compromise the long-term integrity of the waste container.**

Gases can potentially be generated by the contents of waste packages by a number of different mechanisms although for most HHGW these are likely to be limited to:

- corrosion of the waste and waste container;
- radiolysis of water (see Section 6.2);
- generation of helium by  $\alpha$ -decay;

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<sup>32</sup> Non-fixed contamination is defined by the IAEA Transport Regulations (Paragraph 215) as '...contamination that can be removed from a surface during routine conditions of transport'.

- generation of radon-222 by the decay of radium-226; and
- the release of radioactive gases entrained in the waste.

It is expected that all designs of waste packages containing HHGW will be sealed, so any radionuclides in gaseous form generated by the wastes will not be released from the waste package until loss of the waste container containment function.

Internally generated gases will however cause pressurisation of a sealed waste container and thereby could have the potential to cause damage to the waste container and the waste itself. Internal pressurisation of waste packages could also have consequences for their transport as they could be subject to legislation under the Pressure Systems Safety Regulations [46]. In the longer term internal pressurisation of the waste container could result in early failure of the containment and damage to other components of the EBS and the surrounding host rocks, leading to the potential modification of groundwater flow patterns and/or mineralogical changes to buffer materials. Work to investigate the likely magnitude of this latter effect has shown that for timescales of  $\sim 10^5$  years, internal overpressures of up to  $\sim 1$  MPa<sup>33</sup> could result for waste packages manufactured using the standardised waste container [47]. Such an overpressure is not considered to be a threat to the integrity of any of the standardised waste containers.

In the post-closure period failure of the integrity of the waste container and the subsequent migration of gases from the disposal areas is one of the main potential pathways by which radionuclides could be released to the accessible environment. Gases released by waste packages in this period could thus have a significant effect on post-closure safety, if the potential for their generation is not managed appropriately at the packaging stage. Management is either by ensuring adequate robustness of the waste container, or by limiting the gas generating capacity of the waste package contents.

### 6.3.7 Criticality safety

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

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

**The quantities of fissile material, neutron moderators and reflectors in the waste package shall be controlled to ensure that the transport package satisfies the criticality safety requirements of the IAEA Transport Regulations.**

Criticality safety is a key requirement for the transport and disposal of some waste packages containing HHGW<sup>34</sup>. The passive criticality safety of waste packages is generally achieved by controlling the quantities of fissile nuclides, neutron absorbers moderators and/or reflectors that are present in a waste package. In addition, controls can be applied to the geometry of such materials within the waste package, or by taking deliberate steps to prevent criticality, such as the use of neutron poisons and/or the creation of guaranteed water barriers in the waste container design.

<sup>33</sup> This worst case value being for Variant 1 waste packages containing PWR SF.

<sup>34</sup> In general this will only affect SF as HLW contains only small quantities (i.e. of the order of a few grams) of fissile radionuclides.

From the criticality safety viewpoint the range of materials that could be disposed of as HHGW vary significantly, requiring differing means by which adequate criticality safety is achieved, for example:

- Vitrified HLW in general contains very little fissile material (i.e. of the order of 10 g, see Table 3) and achieving criticality safety will rely on ensuring that this is the case when vitrified product containers are packaged.
- SF contains larger quantities of fissile nuclides, albeit generally with significantly quantities of neutron absorbers (i.e. uranium-238). Criticality safety will generally be achieved by a combination of waste package inventory control, the use of neutron poisons, such as boron or cadmium, and/or the provision of multiple water barriers during transport.
- Other materials that could be disposed of as HHGW, notably separated plutonium and HEU, may have very high concentrations of fissile nuclides and may require bespoke approaches to ensuring adequate criticality safety. This could include control of the geometry of fissile material within the waste package and/or the incorporation of neutron poisons in the design of the waste container.

With specific regard to transport, the IAEA Transport Regulations define requirements for transport packages containing fissile material (Paragraphs 673 to 686) which can be used to define the permitted quantities of fissile nuclides that can be carried in Type B transport packages. Work to identify a preferred transport criticality solution for the DCTC [48] has recommended the incorporation of multiple water barriers. The conceptual design of the DCTC incorporates such features and initial work has shown that adequate criticality safety will be achieved for each of the standardised waste container designs containing AGR or PWR fuel. It should be noted that although criticality safety of the DCTC is predicated on its ability to provide a water barrier, it is also assumed that no significant quantity of water is present within the waste package (see Section 6.2).

During the development of proposals to package waste containing fissile nuclides, waste packagers will be required to demonstrate that the requirement for the criticality safety of the proposed waste packages will be satisfied in practice (i.e. during packaging).

### 6.3.8 Accident performance

***Under all credible accident scenarios the release of radionuclides and other hazardous materials from the waste package shall be low and predictable.***

***The waste package should exhibit progressive release behaviour within the range of all credible accident scenarios.***

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

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

Waste packages may be subject to a range of accident conditions during their long-term management, up until the end of a GDF operational period<sup>35</sup>. Such accidents, which could include impacts and/or fires, are a potential mechanism for the release of radionuclides from waste packages into the environment.

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<sup>35</sup> For some disposal concepts (e.g. that for HSR) the potential for accidents may cease after emplacement.



Waste packages must be capable of complying with the assumptions that are made in the safety cases for transport and a GDF operational period regarding their performance in response to specified accident scenarios. Additionally the radiation doses to workers and members of the public resulting from the release of radionuclide from waste packages as a consequence of accidents must be ALARP and less than the relevant regulatory limits.

The IAEA Transport Regulations define 'accident conditions of transport' (ACT) as a basis for demonstrating the ability of transport packages to withstand impact and fire accidents during transport without causing excessive exposure of transport workers or members of the public to radionuclides released during such accidents. For Type B transport packages, safety under ACT is conferred by defining requirements for the performance of the containment and for the physical protection provided by the transport package itself. Type B transport packages are required to be capable of being subject to the cumulative effects of defined mechanical and thermal challenges<sup>36</sup> following which the accumulated loss of activity from the transport package in a period of one week must not exceed  $1 A_2$ <sup>37</sup>. For waste packages containing HHGW, which are to be transported within a DCTC, the role of the waste package will be limited to supporting the ability of the transport container in achieving this requirement. It should also be noted that the waste container is assumed to be one of the multiple water barriers required to ensure the required level of criticality safety during transport (see Section 6.3.7) and that this function will need to be maintained under ACT.

During the GDF operational period, the potential exists for a range of accidents which could result in damage to waste packages, the release of radionuclides and radiation dose to workers on-site and/or members of the public off-site. As well as requiring that the doses resulting from accidents in which radionuclides are released are ALARP, the ONR *Safety Assessment Principles* (SAPs) [49] define Basic Safety Objectives (BSOs) for the cumulative annual on-site and off-site doses due to accidents on nuclear sites. The SAPs also define Basic Safety Levels (BSLs) as targets for the maximum on-site and off-site dose that could result from release of radionuclides as a result of design basis accidents, on the basis of the expected frequency of the initiating event that would result in such an accident.

A realistic aim is to design waste packages containing HHGW such that there will be no release of activity following all credible design basis accidents during transport and a GDF operational period. This would generally be achieved by the use of a sufficiently robust design of waste container.

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<sup>36</sup> Comprising a 9 m drop on to a flat unyielding surface, a 1m drop on to an aggressive feature, a dynamic crush test and exposure to a fire with a flame temperature of 800°C for 30 minutes.

<sup>37</sup> Or not more than  $10 A_2$  for krypton-85.

## 6.4 Requirements for the manufacture and storage of waste packages

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

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

### 6.4.1 Quality management

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

All activities relevant to licensing of a GDF will be conducted in accordance with appropriate quality management arrangements. The objective in establishing and operating a quality management system is to provide an integral framework of procedures which will ensure that the work is adequately controlled, documented and recorded. It is the responsibility of the waste packager to develop, operate and maintain appropriate quality management arrangements for all aspects of the retrieval and packaging of waste and the interim storage of waste packages. As a minimum all quality management systems shall comply with BS EN ISO9001 [50] and should comply with RWM specification [51] and its supporting guidance [52].

### 6.4.2 Waste package data and information recording

***Information shall be recorded for each waste package covering all relevant details of its manufacture and interim storage. This information shall be sufficient to enable assessment of the characteristics and performance of the waste package against the requirements of all stages of long-term management.***

***Information shall be recorded regarding the quantity of all radionuclides of relevance to the safe transport and disposal of the waste package.***

Compliance with the various regulations that apply to the transport and disposal of radioactive waste will rely in part on the existence of appropriate records regarding all relevant aspects of waste package manufacture, notably information regarding their radionuclide inventory. The recording of such data and information should be carried out in accordance with the RWM specification [53].

Not all of the radionuclides that could be present in the wastes to which this Generic Specification applies will have relevance to the safety of long-term management of those wastes. A methodology has been developed for the identification of those radionuclides which have relevance to the safety of the geological disposal of ILW [54]. Whilst this methodology was not developed with HHGW in mind, the principles it enshrines are broadly applicable to the disposal of HHGW and other categories of wastes.

Waste packagers will be required to identify which of those radionuclides will be present in the waste to be packaged at levels which will require their quantities to be determined and recorded during waste package manufacture.

### 6.4.3 Requirements for waste packages containing nuclear material

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

Most of the wastes to which this Generic Specification applies will contain radionuclides that are described as 'nuclear materials' (NM)<sup>38</sup>. All operations involving NM are subject to regulatory control and from the viewpoint of the long-term management of wastes containing NM this will include retrieval from storage, packaging, and the interim storage, transport and disposal of waste packages. Waste packagers will be required to address all of the requirements for nuclear materials accountancy and the security of NM up to the point of their receipt at a GDF site and also will need to ensure that appropriate records are available to permit RWM to assume responsibility for the NM in waste packages from that point.

#### **International safeguards**

**The safeguards status of any nuclear material contained within the waste package shall be ascertained and recorded.**

Packaged wastes that contain NM derived from the UK civil nuclear programme may be subject to controls known as 'safeguards' allowing independent verification by international nuclear safeguards inspectorates (i.e. Euratom and IAEA) to confirm that nuclear material has not been diverted from peaceful use.

In order that the contents of waste packages that contain safeguarded materials can be fully verified, SLCs will be required to provide sufficient information on the quantity, nature and status of all safeguarded material that will be incorporated into proposed waste packages.

The IAEA has published a comprehensive overview of the techniques and equipment underlying the implementation of IAEA safeguards, including those used for nuclear material accountancy, containment and surveillance measures, environmental sampling, and data security [55]. The ONR has also produced guidance on good practice for nuclear material accountancy and safeguards on nuclear licensed sites [56].

From the point of view of safeguards, the two main categories of HHGW (i.e. vitrified HLW and SF) will present significantly different challenges. The NM content of vitrified HLW is relatively small (Table 3) and its form is such that it may be considered as 'irrecoverable' and that its safeguards status can be 'terminated'. By contrast SF contains significant quantities of uranium and plutonium which is classed as 'special fissile/fissionable material' and for which safeguards will continue to apply at least until emplacement in a GDF, and possibly until closure of the facility.

Such material would be expected to remain 'on inventory' at the site of storage until it is transported to a GDF, at which time it will be transferred to the GDF site inventory. RWM has produced guidance on the manner in which safeguards can be applied during the packaging of waste for geological disposal [57].

#### **Physical protection nuclear security**

**The quantity of nuclear material contained within the waste package shall be controlled such that the waste package can be transported subject to standards of physical protection no higher than those defined for the transport system.**

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<sup>38</sup> NM is generally defined as material containing plutonium, uranium, neptunium, americium, and thorium.

The Nuclear Industries Security Regulations 2003 (NISR) lay down the requirements for security of nuclear premises, security of transport of nuclear material and security of sensitive nuclear information. The ONR has issued National Objectives, Requirements and Model Standards (NORMS) for the protective security of civil licensed nuclear sites, other nuclear premises and nuclear material in transit [58] to support implementation of the NISR.

The security standards in NORMS are offered as a benchmark (i.e. Model Standard) to reflect internationally agreed recommendations on the physical protection of NM published by the IAEA [59]. IAEA guidance on the physical protection of NM [60], which accords with NISR in this regard, specifies mass limits for the quantities of NM that can be transported with four 'categories' of physical protection (Categories I to IV, Category I being the most restrictive).

The transport of waste packages containing HHGW will be subject to the NISR although the categories of physical protection that will be required may vary. The low NM content and the manner in which it is incorporated in vitrified HLW will mean that physical protection to no higher than Category III standards will be required. The transport of SF will, due to the presence of significant quantities of NM, generally require protection to at least Category II standards of physical protection. Category I standards of protection may be required for some types of HHGW (e.g. separated plutonium), unless arguments can be made that the radiation emitted by such material provides 'self-protection' of the NM. ONR advice will need to be sought regarding this latter point.

## **7 Summary**

This Generic Specification defines requirements for waste packages containing HHGW that will be the subject of geological disposal. These requirements derive directly from the application of the high-level requirements defined by the GWPS to the waste packages containing such wastes.

The form of this Generic Specification is to define bounding requirements for waste packages such that it can be used as the basis for the development of proposals to package HHGW using a limited range of different waste container types and waste conditioning processes. To assist in the development of such proposals users are referred to the WPSGD, specifically to the guidance which explains the basis for the derivation of the packaging requirements and the manner in which they can be achieved for practical packaging projects.

This Generic Specification provides a baseline for the conduct of Conceptual stage disposability assessments of proposals to package HHGW for geological disposal.

This Generic Specification also provides the basis for the definition of the WPS which will define the requirements for waste packages manufactured using a standardised design of waste container and containing HHGW.

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## Appendix A Parameters used in thermal modelling

The following parameters were used in the thermal modelling discussed in Section 6.3.4:

### Properties of legacy HHGW:

The heat generated by the waste packages was defined on the basis of them containing:

- Vitrified HLW: Blended HLW, emplaced at 2075.
- AGR fuel: A burn up of ~32 GWd/tU and a post-irradiation cooling time of 60 years.
- PWR fuel: A burn up of ~50 GWd/tU and a post-irradiation cooling time of 60 years.

### Modelling parameters for illustrative concept for HSR:

Property	Value	Units
Container separation	6.50	m
Deposition hole diameter	1.75	m
Repository depth	650	m
Tunnel disposal length	470	m
Tunnel separation (Rock pillar separation)	19.5	m
Pellet-filled gap (between buffer and rock)	0.025	m
Air gap width (between waste package and buffer)	0.010	m
Ambient temperature at 650m depth	28	°C
Temperature gradient	$2.79 \times 10^{-2}$	°C.m <sup>-1</sup>
Air thermal conductivity	0.03	W.m <sup>-1</sup> .K <sup>-1</sup>
Compacted bentonite thermal conductivity	1.2	W.m <sup>-1</sup> .K <sup>-1</sup>
Bentonite pellets thermal conductivity	0.6	W.m <sup>-1</sup> .K <sup>-1</sup>
Rock density	2700	kg.m <sup>-3</sup>
Rock specific heat capacity	820	J.kg <sup>-1</sup> .K <sup>-1</sup>
Rock thermal conductivity	3.0	W.m <sup>-1</sup> .K <sup>-1</sup>

**Appendix A Parameters used in thermal modelling (Continued)****Modelling parameters for illustrative concept for LSSR.**

Parameter	Value	Units
Tunnel diameter	2.5	m
Repository depth	500	m
Tunnel length	445	m
Gap between containers	3	m
Tunnel spacing (Rock pillar separation)	28.5	m
Buffer conductivity (pelleted bentonite)	0.4	W.m <sup>-1</sup> .K <sup>-1</sup>
Rock conductivity	1.9	W.m <sup>-1</sup> .K <sup>-1</sup>
Rock heat capacity	1400	J.kg <sup>-1</sup> .K <sup>-1</sup>
Rock density	2100	kg.m <sup>-3</sup>
Ambient rock temperature at 500m depth	24	°C
Temperature gradient	0.0279	°C.m <sup>-1</sup>

**Modelling parameters for illustrative concept for EVR**

Parameter	Value	Units
Tunnel diameter	3.4	m
Repository depth	650	m
Tunnel length	470	m
Container spacing (centre-to-centre)	7.62	m
Tunnel spacing (Rock pillar separation)	23	m
Buffer conductivity (Crushed evaporite)	0.8	W.m <sup>-1</sup> .K <sup>-1</sup>
Rock conductivity	4.8	W.m <sup>-1</sup> .K <sup>-1</sup>
Rock heat capacity	860	J.kg <sup>-1</sup> .K <sup>-1</sup>
Rock density	2500	kg.m <sup>-3</sup>
Ambient rock temperature at 650m depth	28	°C
Temperature gradient	0.0279	°C.m <sup>-1</sup>

## Appendix B Glossary of terms used in this document

### *activity*

The number of atoms of a radioactive substance which decay by nuclear disintegration each second. The SI unit of activity is the becquerel (Bq) equal to one radioactive decay per second.

The IAEA Transport Regulations define a unit of activity, the  $A_2$ , as a means of standardising the dose consequences of different radionuclides on the basis of the different possible exposure pathways that could occur following the release of radionuclides from a transport package.  $A_2$  values (in TBq) for a wide range of radionuclides are listed in Table 2 of the IAEA Transport Regulations [22].

### *alpha activity*

Alpha activity takes the form of particles (helium nuclei) ejected from a decaying (radioactive) atom. Alpha particles cause ionisation in biological tissue which may lead to damage. The particles have a very short range in air (typically about 5cm) and alpha particles present in materials that are outside of the body are prevented from doing biological damage by the superficial dead skin cells, but become significant if inhaled or swallowed.

### *backfill*

A material used to fill voids in a 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 near-field rock or access ways; and
- mass backfill, which is the bulk material used to backfill the excavated volume apart from the disposal areas.

### *backfilling*

The refilling of the excavated portions of a disposal facility after emplacement of the waste.

### *barrier*

A physical or chemical means of preventing or inhibiting the movement of radionuclides.

### *beta activity*

Beta activity takes the form of particles (electrons) emitted during radioactive decay from the nucleus of an atom. Beta particles cause ionisation in biological tissue which may lead to damage. Most beta particles can pass through the skin and penetrate the body, but a few millimetres of light materials, such as aluminium, will generally shield against them.

### *buffer*

An engineered barrier that protects the waste package and limits the migration of radionuclides following their release from a waste package.

### *canister*

A sealed waste container with high integrity and long-term durability.

### *conditioning*

Treatment of a radioactive waste material to create, or assist in the creation of, a wasteform that has passive safety

*containment*

The engineered barriers, including the waste form and packaging, shall be so designed, and a host geological formation shall so be selected, as to provide containment of the waste during the period when waste produces heat energy in amounts that could adversely affect the containment, and when radioactive decay has not yet significantly reduced the hazard posed by the waste

*criticality*

A state in which a quantity of fissile material can maintain a self-sustaining neutron chain reaction. Criticality requires that a sufficiently large quantity of fissile material (a critical mass) be assembled into a geometry that can sustain a chain reaction; unless both of these requirements are met, no chain reaction can take place and the system is said to be sub-critical.

*criticality safety*

A methodology used to define the conditions required to ensure the continued sub-criticality of waste containing fissile material.

*disposability*

The ability of a waste package to satisfy the defined requirement for disposal.

*disposability assessment*

The process by which the disposability of proposed waste packages is assessed. The outcome of a disposability assessment may be a Letter of Compliance endorsing the disposability of the proposed waste packages.

*disposal*

In the context of solid waste, disposal is the emplacement of waste in a suitable facility without intent to retrieve it at a later date; retrieval may be possible but, if intended, the appropriate term is storage.

*disposal facility (for solid radioactive waste)*

An engineered facility for the disposal of solid radioactive wastes.

*disposal system*

All the aspects of the waste, the disposal facility and its surroundings that affect the radiological impact.

*dose*

A measure of the energy deposited by radiation in a target.

*dose rate*

The effective dose equivalent per unit time. Typical units of effective dose are sievert/hour ( $\text{Svh}^{-1}$ ), millisieverts/hour ( $\text{mSvh}^{-1}$ ) and sievert/year ( $\text{Svy}^{-1}$ ).

*emplacement (of waste in a disposal facility)*

The placement of a waste package in a designated location for disposal, with no intent to reposition or retrieve it subsequently.

*Environment Agency (EA)*

The environmental regulator for England and Wales. The Agency's role is the enforcement of specified laws and regulations aimed at protecting the environment, in the context of sustainable development, predominantly by authorising and controlling radioactive discharges and waste disposal to air, water (surface water, groundwater) and land. The

Environment Agency also regulates nuclear sites under the Environmental Permitting Regulations and issues consents for non-radioactive discharges.

*environmental safety case*

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

*fissile material*

Fissile material is that which undergoes fission under neutron irradiation. For regulatory purposes material containing any of the following nuclides is considered to be 'fissile': uranium-233, uranium-235, plutonium-239 and plutonium-241.

*gamma activity*

An electromagnetic radiation similar in some respects to visible light, but with higher energy. Gamma rays cause ionisations in biological tissue which may lead to damage. Gamma rays are very penetrating and are attenuated only by shields of dense metal or concrete, perhaps some metres thick, depending on their energy. Their emission during radioactive decay is usually accompanied by particle emission (beta or alpha activity).

*geological disposal*

A long term management option involving the emplacement of radioactive waste in an engineered underground geological disposal facility or repository, where the geology (rock structure) provides a barrier against the escape of radioactivity and there is no intention to retrieve the waste once the facility is closed.

*geological disposal facility (GDF)*

An engineered underground facility for the disposal of solid radioactive wastes.

*half-life*

The time taken for the activity of a given amount of a radioactive substance to decay to half of its initial value. Each radionuclide has a unique half-life.

*hazardous materials*

Materials that can endanger human health if improperly handled. As defined by the Control of Substances Hazardous to Health Regulations, 2002.

*Health and Safety Executive (HSE)*

The HSE is a statutory body whose role is the enforcement of work-related health and safety law. HSE is formally the licensing authority for nuclear installations in Great Britain, although the licensing function is administered on HSE's behalf by its executive agency the ONR.

*higher activity radioactive waste*

Generally used to include the following categories of radioactive waste: low level waste not suitable for near surface disposal, intermediate level waste and high level waste.

*high level waste (HLW)*

Radioactive wastes in which the temperature may rise significantly as a result of their radioactivity, so this factor has to be taken into account in the design of storage or disposal facilities.

*immobilisation*

A process by which the potential for the migration or dispersion of the radioactivity present in a material is reduced. This is often achieved by converting the material to a monolithic form that confers passive safety to the material.

*intermediate level waste (ILW)*

Radioactive wastes exceeding the upper activity boundaries for LLW but which do not need heat to be taken into account in the design of storage or disposal facilities.

*International Atomic Energy Agency (IAEA)*

The IAEA is the world's centre of cooperation in the nuclear field. It was set up as the world's "Atoms for Peace" organization in 1957 within the United Nations family. The Agency works with its Member States and multiple partners worldwide to promote safe, secure and peaceful nuclear technologies.

*Letter of Compliance (LoC)*

A document, prepared by RWM, that indicates to a waste packager that a proposed approach to the packaging of waste would result in waste packages that are compliant with the requirements defined by relevant packaging specifications, and the safety assessments for transport to and disposal in a GDF, and are therefore deemed 'disposable'.

*low level waste (LLW)*

Radioactive waste having a radioactive content not exceeding 4 gigabecquerels per tonne (GBq/t) of alpha or 12 GBq/t of beta/gamma activity.

*Nirex (United Kingdom Nirex Limited)*

An organisation previously owned jointly by Department for the Environment, Food and Rural Affairs and the Department for Trade and Industry. Its objectives were, in support of Government policy, to develop and advise on safe, environmentally sound and publicly acceptable options for the long-term management of radioactive materials in the United Kingdom. The Government's response to Committee on Radioactive Waste Management in October 2006 initiated the incorporation of Nirex functions into the NDA, a process which was completed in March 2007.

*Nuclear Decommissioning Authority (NDA)*

The NDA is the implementing organisation, responsible for planning and delivering a GDF. The NDA was set up on 1 April 2005, under the Energy Act 2004. It is a non-departmental public body with designated responsibility for managing the liabilities at specific sites. These sites are operated under contract by site licensee companies (initially British Nuclear Group Sellafield Limited, Magnox Electric Limited, Springfields Fuels Limited and UK Atomic Energy Authority). The NDA has a statutory requirement under the Energy Act 2004, to publish and consult on its Strategy and Annual Plans, which have to be agreed by the Secretary of State (currently the Secretary of State for Trade and Industry) and Scottish Ministers.

*Nuclear Installations Act 1965 (NIA65)*

UK legislation which provides for the operation and regulation of nuclear installations within the UK.

*nuclear material (NM)*

Fissile material or material that can be used to produce fissile material (i.e. source material). This includes all isotopes of uranium, plutonium and thorium, together with certain isotopes of neptunium and americium.

*Office for Nuclear Regulation (ONR)*

The HSE's executive agency ONR is responsible for regulating the nuclear, radiological and industrial safety of nuclear installations and the transport of radioactive materials in Great Britain under the Nuclear Installations Act 1965 (NIA 65) and the Carriage of Dangerous Good Regulations.

The Government intends to bring forward legislation to establish ONR as a new independent statutory body outside of the HSE to regulate the nuclear power industry, formally responsible in law for delivering regulatory functions. The creation of the ONR as a statutory body will consolidate the regulation of civil nuclear and radioactive transport safety and security regulation through one organisation. Pending the legislation, and in the interim, the HSE has established the ONR as a non-statutory body. The Government will review the functions and processes of the interim body in order to inform its planned legislation.

*operational period (of a disposal facility)*

The period during which a disposal facility is used for its intended purpose, up until closure.

*passive safety*

Not placing reliance on active safety systems and human intervention to ensure safety.

*plutonium (Pu)*

A radioactive element occurring in very small quantities in uranium ores but mainly produced artificially, including for use in nuclear fuel, by neutron bombardment of uranium.

*post-closure period (of a disposal facility)*

The period following sealing and closure of a facility and the removal of active institutional controls.

*quality management system (QMS)*

A quality management system is the overall system by which an organisation determines, implements and ensures quality.

*radioactive decay*

The process by which radioactive material loses activity, e.g. alpha activity naturally. The rate at which atoms disintegrate is measured in becquerels.

*radioactive material*

Material designated in national law or by a regulatory body as being subject to regulatory control because of its radioactivity.

*radioactive waste*

Any material contaminated by or incorporating radioactivity above certain thresholds defined in legislation, and for which no further use is envisaged, is known as radioactive waste.

*Radioactive Waste Management Ltd (RWM)*

A wholly owned subsidiary of the NDA, established to design and build an effective delivery organisation to implement a safe, sustainable, publicly acceptable geological disposal programme. Ultimately, it will evolve under the NDA into the organisation responsible for the delivery of a GDF. Ownership of this organisation can then be opened up to competition, in due course, in line with other NDA sites.

*radioactivity*

Atoms undergoing spontaneous random disintegration, usually accompanied by the emission of radiation.

*radionuclide*

A radioactive form of an element, for example carbon-14 or caesium-137.

*remote handling*

The use of technology and/or engineering management systems to enable operators to safely, reliably and repeatedly perform the manipulation of items without being in personal contact with those items.

*retrievability*

A feature of the design of a GDF that enables the waste to be withdrawn, even after the disposal vaults have been backfilled

*safeguards*

Measures used to verify that nation states comply with their international obligations not to use nuclear materials (plutonium, uranium and thorium) for nuclear explosives purposes. Global recognition of the need for such verification is reflected in the requirements of the Treaty on the Non-Proliferation of Nuclear Weapons for the application of safeguards by the IAEA. Also, the Treaty Establishing the European Atomic Energy Community (the Euratom Treaty) includes requirements for the application of safeguards by the European Community.

*safety case*

A 'safety case' is the written documentation demonstrating that risks associated with a site, a plant, part of a plant or a plant modification are as low as reasonably practicable and that the relevant standards have been met. Safety cases for licensable activities at nuclear sites are required as license conditions under NIA65.

*safety function*

A specific purpose that must be accomplished for safety.

*Scottish Environment Protection Agency (SEPA)*

The environmental regulator for Scotland. SEPA's role is the enforcement of specified laws and regulations aimed at protecting the environment, in the context of sustainable development, predominantly by authorising and controlling radioactive discharges and waste disposal to air, water (surface water, groundwater) and land. SEPA also regulates nuclear sites under the Pollution Prevention and Control Regulations and issues consents for non-radioactive discharges.

*shielding*

Shielding is the protective use of materials to reduce the dose rate outside of the shielding material. The amount of shielding required to ensure that the dose rate is as low as reasonably practicable (ALARP) will therefore depend on the type of radiation, the activity of the source, and on the dose rate that is acceptable outside the shielding material.

*spent nuclear fuel (SF)*

Nuclear fuel removed from a reactor following irradiation that is no longer usable in its present form because of depletion of fissile material, poison build-up or radiation damage.

*transport container*

A reusable container into which waste packages are placed for transport, the whole assembly then being referred to as a transport package.

*transport package*

The complete assembly of the radioactive material and its outer packaging, as presented for transport.



### *Transport Regulations*

The IAEA Regulations for the Safe Transport of Radioactive Material [22] and/or those regulations as transposed into an EU Directive, and in turn into regulations that apply within the UK. The generic term 'Transport Regulations' can refer to any or all of these, since the essential wording is identical in all cases.

### *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 a GDF and the more specialised transport of the radioactive waste to a GDF by inland waterway, sea, rail and/or road.

### *uranium (U)*

A heavy, naturally occurring and weakly radioactive element, commercially extracted from uranium ores. By nuclear fission (the nucleus splitting into two or more nuclei and releasing energy) it is used as a fuel in nuclear reactors to generate heat.

Uranium is often categorised by way of the proportion of the radionuclide uranium-235 it contains.

### *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.

Quantitative or qualitative criteria specified by the regulatory body, or specified by an operator and approved by the regulatory body, for radioactive waste to be accepted by the operator of a repository for disposal, or by the operator of a storage facility for storage.

### *waste container*

The vessel into which a wasteform is placed to form a waste package suitable for handling, transport, storage and disposal.

### *wasteform*

The waste in the physical and chemical form in which it will be disposed of, including any conditioning media and container furniture, but not including the waste container itself.

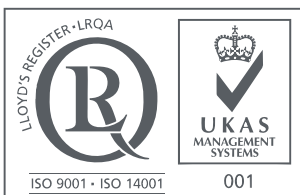
### *waste package*

The product of conditioning that includes the wasteform and any container(s) and internal barriers (e.g. absorbing materials and liner), as prepared in accordance with requirements for handling, transport, storage and/or disposal.

### *waste packager*

An organisation responsible for the packaging of radioactive waste in a form suitable for transport and disposal.





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