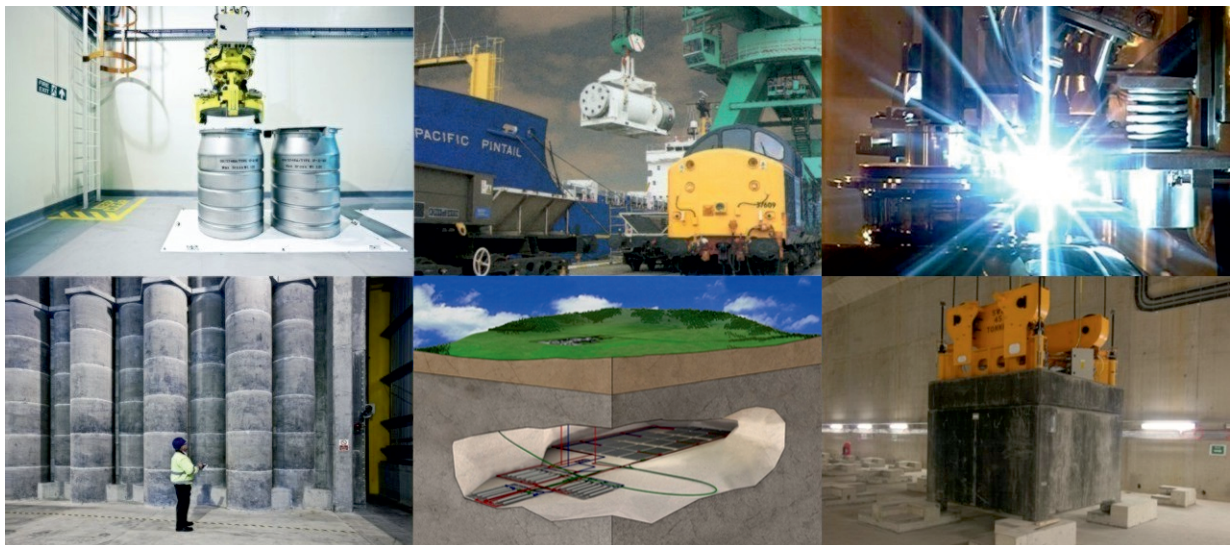


Geological Disposal

Guidance on the application of the Waste Package Specifications for shielded waste packages

August 2014



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**WASTE PACKAGE SPECIFICATION AND GUIDANCE DOCUMENTATION
GUIDANCE ON THE APPLICATION OF THE WASTE PACKAGE SPECIFICATIONS
FOR SHIELDED WASTE PACKAGES**

Executive Summary

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 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 Waste Package 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 WPSGD are intended to provide a 'user-level' interpretation of the RWM packaging specifications and to assist the holders of radioactive wastes in the development of plans and strategies for their long-term management.

This document provides guidance to support the WPS that have been produced for the 'shielded waste packages' which are identified by the generic Disposal System Technical Specification as suitable for the packaging of low heat generating waste for geological disposal. It provides an explanation of the rationale behind the definition of the requirements together with information to assist waste packagers in the development of approaches for the packaging of waste in a manner that will allow those requirements to be achieved.

The WPSGD is subject to periodic enhancement and revision. Users are therefore advised to refer to <http://www.nda.gov.uk/RWM/producers/detail.cfm#specifications> to confirm that they are in possession of the latest version of any documentation used.

WPSGD DOCUMENT NUMBER WPS/702 - VERSION HISTORY		
VERSION	DATE	COMMENTS
WPS/702/01	September 2014	Aligns with Generic Specification for waste packages containing low heat generating waste (NDA/RWMD/068) as published August 2012 Replaces WPS/730 and WPS/750.



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Abbreviations and acronyms used in this document

ALARA	as low as reasonably achievable
ALARP	as low as reasonably practicable
BSL	Basic Safety Level
BSO	Basic Safety Objective
DBA	design basis accident
DSS	Disposal System Specification
DSSC	Disposal System Safety Case
DSTS	Disposal System Technical Specification
EBS	engineered barrier system
ESC	Environmental Safety Case
GDF	geological disposal facility
GDFD	Generic Disposal Facility Designs
GTSD	Generic Transport System Designs
GWPS	Generic Waste Package Specification
HGV	heavy goods vehicle
HSE	Health and Safety Executive
IAEA	International Atomic Energy Agency
ILW	intermediate level waste
LLW	low level waste
LoC	Letter of Compliance
MRWS	Managing Radioactive Waste Safely
NDA	Nuclear Decommissioning Authority
ONR	Office for Nuclear Regulation
RWM	Radioactive Waste Management Limited
SAPs	Safety Assessment Principles
SFM	safe fissile mass
SWL	safe working load
SWTC	standard waste transport container
WAC	waste acceptance criteria
WPS	Waste Package Specification
WPSGD	Waste Package Specification and Guidance Documentation

1 The packaging of radioactive waste for geological disposal

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

RWM produces packaging specifications as a means of providing a baseline against which the suitability of plans to package higher activity waste for geological disposal can be assessed. In this way RWM assists the holders of radioactive waste in the development and implementation of such plans, by defining the requirements for waste packages which would be compatible with the anticipated needs of transport to and disposal in a geological disposal facility (GDF).

The packaging specifications form a hierarchy which comprises three levels:

- The *Generic Waste Package Specification* (GWPS) [2]; which defines the requirements for all waste packages which are destined for geological disposal;
- *Generic Specifications*; which apply the high-level packaging requirements defined by the GWPS to waste packages containing a specific type of waste; and
- *Waste Package Specifications* (WPS); which apply the general requirements defined by a Generic Specification to waste packages manufactured using standardised designs of waste container.

For waste packages containing low heat generating waste¹ (LHGW), RWM has produced the *Generic Specification for waste packages containing low heat generating waste* [3].

As a means of making the full range of RWM packaging specifications available to waste producers and other stakeholders, a suite of documentation known as the *Waste Package Specification and Guidance Documentation* (WPSGD) is published and maintained for ready access (via <http://www.nda.gov.uk/RWM/producers/detail.cfm#specifications>).

The WPSGD includes the WPS for the waste packages that produced from the standardised designs of waste container that are identified by the generic Disposal System Technical Specification (DSTS) [4], together with explanatory material and guidance that users will find helpful in the development of proposals to package waste.

For further information on the extent and the role of the WPSGD, reference should be made to the *Introduction to the RWM Waste Package Specification and Guidance Documentation* [5].

The DSTS identifies a number of standardised designs of waste container that have been shown to be suitable for the packaging of such wastes for transport to and disposal in a GDF, including five² which can be used to produce 'shielded waste packages'. This document provides guidance on the application of the requirements specified by the WPS to proposals to package waste using those waste container designs. Users are directed to guidance on the achievement of the required properties of wasteforms [6, 7] which should be considered alongside this document when they are developing plans for the packaging of waste.

¹ This broad category of waste includes intermediate level waste (ILW), and other wastes with similar radiological properties.

² The 2 and 4 metre boxes, the 6 cubic metre concrete box and the Type 1 and 4 concrete drums.

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

- Section 2 provides background information on the manner in which RWM defines the requirements for waste packages, and the role that packaging specifications play in assessing the suitability of proposed waste packages for geological disposal.
- Section 3 provides a brief summary of the properties of shielded waste packages and the manner in which they are handled during transport to and disposal in a GDF.
- Section 4 explains the manner in which the requirements of the Generic Specification for waste packages containing LHGW are applied to shielded waste packages. This is achieved by:
 - (i) explaining the rationale behind the definition of the requirements in the Generic Specification;
 - (ii) summarising how those requirements are applied to the shielded waste packages that could be manufactured using the existing standardised designs of waste container; and
 - (iii) providing guidance as to how those requirements can be achieved.

2 Background

2.1 The definition and purpose of packaging specifications

When radioactive waste is disposed of in an operational GDF it must be compliant with the waste acceptance criteria (WAC) defined for that facility. WAC would be expected to be produced by the facility operator, overseen by the relevant regulatory authorities, and would be based on the safety cases produced for the operational and post-closure periods of the facility.

In the UK, plans for the geological disposal of higher activity radioactive waste are still at an early stage, so the information necessary to develop WAC is not available. However, in order that wastes can be converted into passively safe and disposable forms, as soon as is reasonably practicable, RWM produce packaging specifications. These specifications define the standard features and performance requirements for waste packages which will be compatible with the anticipated systems and safety cases for transport to and disposal in a GDF. In this way they play an important part in the assessing the suitability of waste packages for geological disposal and may thus be considered as the *preliminary* WAC for a future GDF.

RWM has established the *Disposability Assessment Process* [8] to support those responsible for the packaging of higher activity wastes by demonstrating that the waste packages they propose to produce will be passively safe and disposable, and in line with regulatory expectations for the long term management of the waste [9]. In this manner RWM also demonstrates that waste packages will be capable of providing the barrier to the release of radionuclides and other hazardous materials that is required of them as part of a multiple barrier geological disposal system. A *Letter of Compliance* (LoC) is issued for each specific design of waste package which has been shown to be disposable by way of the Disposability Assessment Process.

The Disposability Assessment Process also plays an important role in underpinning the generic Disposal System Safety Case (DSSC) [10] by demonstrating that the geological disposal concepts considered therein will be appropriate for the actual wastes they will be expected to cover. The process also serves to identify wastes that could challenge the disposal concepts currently assumed for particular categories of waste and thereby allow early consideration of what changes may be required to these concepts to permit such wastes to be accommodated. RWM has produced guidance on the manner by which waste packagers should prepare submissions for the disposability assessment of their proposals to package waste [11].

With waste packages being manufactured at many sites throughout the UK, and by a number of different organisations, the needs of ensuring cost-effectiveness, safety and environmental protection in the long-term are promoted by the adoption of common approaches to waste packaging. In support of these needs, RWM has defined a range of waste containers with standardised features (e.g. dimensions, handling/stacking arrangements) which can be used to produce waste packages. The definition of waste containers in this way will help to ensure a high level of confidence that all waste packages manufactured according to the requirements set out in the WPSGD will be compatible with future transport and GDF infrastructure and facilities.

RWM consider that the existing range of standardised waste containers will be suitable for use in the packaging of the majority of the ILW³ predicted to arise in the UK. However, RWM acknowledge that these waste containers may not suit all of the needs of

³ These containers may also be suitable for use in the packaging of a wider range of LHGW, as discussed in the Generic Specification [3].

individual waste producers, and that additional designs may be required for the packaging of particular wastes. RWM use the Disposability Assessment Process to consider the suitability of alternative designs of waste container to produce disposable waste packages, by way of a demonstration of compliance of the proposed design with the relevant Generic Specification. If such compliance can be shown RWM can then use the concept change control management process to ensure that the waste packages that would result from the use of the new container design would be compatible with all aspects of RWM's plans for disposal concept. If this can be shown to be the case, the container will be added to those identified by the DSTS, and a WPS produced for the waste packages it could be used to manufacture.

2.2 The role of the waste package in geological disposal

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 when it forms part of a multiple barrier geological disposal system. It can 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. Containers can be manufactured from a range of materials with designs selected to suit the requirements for the packaging, transport and disposal of the wastes they contain.
- The wastefrom, 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 wastefrom may comprise waste which has been 'immobilised' (e.g. by the use of an encapsulating medium such as cement) or that which may have received more limited pre-treatment prior to packaging (e.g. size reduction and/or drying).

It is the performance of the barrier(s) provided by the waste package that the packaging specifications seek to address, as well as defining requirements which take into account the other needs the long-term management of waste packages, notably their transport.

In the generic Disposal System Technical Specification (DSTS) the concept of *safety functions* was developed as a means of defining the roles played by each of the barriers to the post-closure performance of a GDF. This concept is further developed in the DSSC in which the safety functions that are required of waste packages during transport and the GDF operational period are also considered [12]. The GWPS identifies the safety functions specific to waste packages which will be required during transport, the period up to the time required in these phases can be summarised as:

- During transport and the GDF operational period:
 - Provide containment of radionuclides and other hazardous materials during normal operations and under accident conditions;
 - Limit radiation dose⁴ to workers and members of the public;
 - Preclude criticality;
 - Provide the means of safe handling; and

⁴ In this context radiation dose is that which could result from exposure to direct radiation from the surface of the waste package.

- Withstand internal and external loads.
- During the GDF post-closure period:
 - Provide containment of radionuclides and other hazardous materials;
 - Contribute to the overall performance of the engineered barrier system (EBS);
 - Contribute to ensuring that, following GDF closure, a criticality event is not a significant concern; and
 - Withstand internal and external loads.

Both the waste container and the wasteform can contribute to the achievement of the required performance of the waste packages, the relative importance of each generally depending on the robustness of the former. This is illustrated in Figure 1 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 1 Relative contribution of the waste container and the wasteform to waste package performance

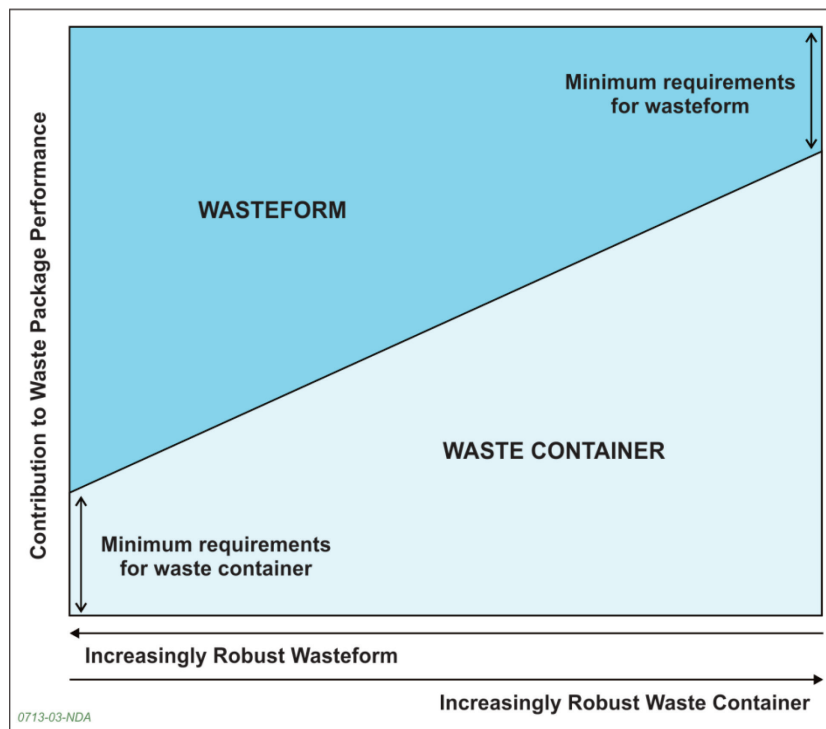


Figure 1 also shows that for all waste packages both the waste container and the wasteform will be required to play some role. It should also be noted that it is the overall performance of the waste package, rather than that of its two components, that is the governing factor in judging its disposability.

2.3 The definition of waste package types

A variety of waste container designs have been proposed for the packaging of LHW for geological disposal. These designs can be grouped into three basic types, on the basis of the general nature of the waste packages are used to produce:

- For use with wastes with low specific activity, such as would not generally require the extensive use of remote handling techniques, waste containers

incorporating integral radiation shielding⁵ can be used to create *shielded waste packages*. Such waste packages would generally be expected to be capable of being transported through the public domain without additional protection and would therefore qualify as transport packages in their own right.

- For higher activity LHGW, such as would generally require the use of remote handling techniques, relatively thin-walled (i.e. a few mm) metal containers can be used to create *unshielded waste packages*. Because of their high external radiation dose rate, or requirements for the containment of their contents, such waste packages would be expected to be transported through the public domain in reusable shielded transport containers.
- For all types of LHGW, thick-walled (i.e. many 10's of mm thick) waste containers can be used to provide both radiation shielding and physical containment of their contents, and to create *robust shielded waste packages*. Such waste packages are capable of being stored, transported and disposed of without the need for remote handling techniques or for additional shielding or containment.

⁵ If needed, to ensure that external radiation dose rates do not exceed the regulatory limits for transport

3 Shielded waste packages

As stated above the main distinguishing feature of a shielded waste package is that it does not require additional (i.e. external) radiation shielding to permit it to be handled or transported. Indeed the term 'shielded' derives from the fact that the containers that are used in the manufacture of such waste packages generally include integral shielding, either in the form of a concrete 'liner' or as provided by the walls of the container itself.

The DSTS [1] identifies five standardised designs of waste container that can be used to produce shielded waste packages, and for which WPS have been produced. Each WPS includes the following features:

- a dimensional envelope;
- standardised lifting, tie-down and/or stacking features;
- an identifier format and locations; and
- a requirement for the durability of integrity.

Also included are a number of required waste package properties, namely:

- a maximum gross mass; and
- a stacking requirement.

Finally the WPS includes a number of waste package performance requirements for:

- wastefrom properties;
- radionuclide inventory related properties:
 - external dose rate;
 - heat output; and
 - criticality safety.
- surface contamination;
- gas generation; and
- impact and fire accident performance.

3.1 Existing standardised designs of waste containers for the manufacture of shielded waste packages

Five standardised designs of waste container have been shown to be suitable for the packaging of LHGW to form shielded waste packages; three cuboidal 'boxes' and two cylindrical 'drums'. The following sub-sections describe the basic features of each.

3.1.1 4 metre box

The 4 metre box [13] (Figure 2) is intended to be used predominantly for large waste items arising from the decommissioning of nuclear facilities. Depending on their physical and/or chemical properties, and the nature of the radionuclides associated with them, such wastes may be encapsulated using, for example, a cementitious grout, or left unencapsulated. The outer containment of the 4 metre box will generally be manufactured using stainless steel, and the container can be used with or without integral shielding depending on the external radiation emitted by its contents. It is anticipated that shielding thicknesses of 100mm, 200mm or 300mm could be used.

Figure 2 4 metre box waste container**3.1.2 2 metre box**

The 2 metre box [14] (Figure 3) is effectively a half-length counterpart of the 4 metre box and is designed for use where space at the packaging plant is more limited, or when the option for rail transport does not exist and the gross mass limit of 30t for transport by an ordinary heavy goods vehicle (HGV) would apply to the transport of waste packages to the GDF.

The 2 metre box can be used with encapsulated or unencapsulated wastes, and with or without integral concrete, which could typically be either 100mm or 200mm thick.

Figure 3 2 metre box waste container

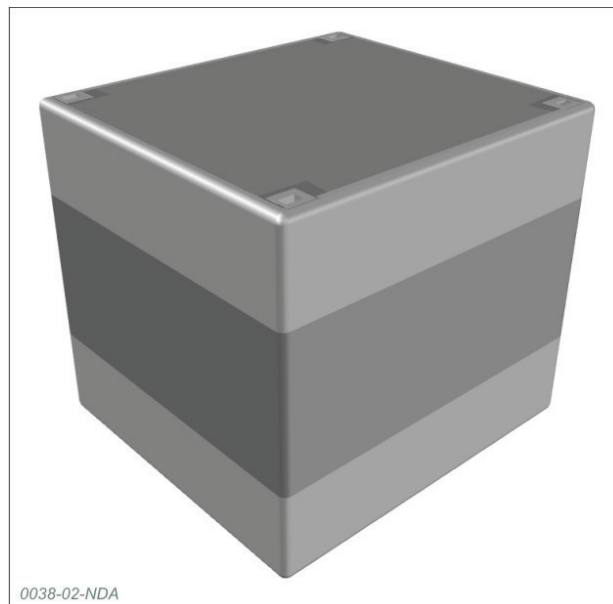
3.1.3 6 cubic metre concrete box

The 6 cubic metre box [15] (Figure 4) has traditionally been manufactured from reinforced concrete⁶, with walls 240mm thick. It was originally developed for the packaging of LLW and ILW arising from the decommissioning of the Windscale Advanced Gas-cooled Reactor (WAGR)⁷ and was mainly used for the packaging of large items of steel and graphite encapsulated using cementitious grout.

The 6 cubic metre box can be used for the packaging of a range of heterogeneous wastes which are placed into the container and backfilled with cementitious grout. After conditioning of the waste in this way the waste package is completed by the *in situ* casting of a 'lid'.

Corrosion protected carbon steel collars can be incorporated around the top and base of the box to minimise damage and spalling of the external concrete surfaces during normal handling operations and in case of impact accidents. The walls of the container, being gas permeable, allow for the release of internally generated gases and therefore the waste container does not require an engineered vent.

Figure 4 6 cubic metre concrete box waste container



3.1.4 Type 1 and Type 4 drums

The Type 1 and Type 4 drums [16, 17] (Figure 5) are cylindrical waste containers made from reinforced concrete with walls typically 160mm thick. They have been proposed for use in the packaging of a wide range of power station operational wastes, including dewatered sludges, ion exchange resins, filters and other heterogeneous solid wastes. In general such wastes would be encapsulated using cementitious grout and the waste package completed by the *in situ* casting of a lid.

⁶ The concrete used can incorporate high density materials (e.g. haematite) to maximise its radiation shielding properties.

⁷ This led to the waste container being known colloquially as the "WAGR Box"

Figure 5 Type 1 and Type 4 concrete drum waste containers

3.2 The transport of shielded waste packages

The transport of radioactive materials is subject to a number of regulatory requirements, as implemented into UK law⁸, notably the IAEA *Regulations for the Safe Transport of Radioactive Material*⁹ [18]. The IAEA Transport Regulations define general requirements and, in some cases, quantified limits for a range of properties of radioactive materials which apply to their transport and these are, where relevant, incorporated into the RWM packaging specifications.

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 to waste packages. A waste package will in general comprise a container in which conditioned waste is placed and which is suitable for disposal without further treatment, whereas a transport package is an item suitable for transport and which may comprise waste packages contained within a transport container which may provide physical protection and/or radiation shielding. All of the current designs of shielded waste package are therefore defined in such a way as to be classed as *transport packages in their own right* and are capable of being transported through the public domain without additional protection.

The IAEA Transport Regulations define two categories of transport package which are suitable for the transport of LHW, Type B and Type IP. Type IP transport packages are generally used for the transport of low activity materials and the necessary degree of safety during transport through the public domain is ensured by placing controls on the physical nature and activity of their contents. All of the current designs of shielded waste package are designed to comply with the requirements for Type IP transport packages, which are summarised in Appendix A.

Two regimes exist under which transport packages can be carried, these being under the conditions of 'exclusive use' or 'non-exclusive use'. Paragraph 221 defines 'exclusive use' as:

⁸ The Radioactive Materials Transport Team of the ONR has regulatory responsibility for the transportation of radioactive material in Great Britain.

⁹ Referred to as the 'IAEA Transport Regulations' in the remainder of document.

'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', where so required by these Regulations'.

If any of these provisions do not apply to a transport operation it is deemed to take place under the conditions of 'non-exclusive use' which are less onerous in terms of the operational controls placed on transport, but which place more onerous limits on some transport package properties, such as external radiation dose rates.

In the Generic Specification which applies to waste packages containing LHGW (i.e. [3]) it is assumed that the properties of transport packages would be such qualify them for transport under the conditions of non-exclusive use and therefore the more onerous limits are applied. However this does not preclude transport under the conditions of exclusive use so that benefit can be gained from the less onerous limits, provided that this would result in a 'lifetime dose'¹⁰ from the waste which can be shown to be as low as reasonably achievable (ALARA).

The definition of shielded waste packages as Type IP transport packages means that they will be subject to a number of controls on the nature and activity of their contents. Specifically this limits their use to the transport of solid materials which can satisfy the definitions of low specific activity (LSA) material¹¹ or surface contaminated objects¹¹ (SCOs). All of the existing designs of shielded waste package are actually classed as Type IP-2 transport packages which permits them to be used for the transport of LSA material with the highest specific activity (i.e. LSA-III, see Section 4.3.1) under the conditions of exclusive use.

It is further currently assumed in the Transport System Safety Assessment (TSSA) [19] that the fissile material contents of all shielded waste packages will be limited such as to permit their transport not to be subject to the IAEA Transport Regulations requirements for packages containing fissile material. The possibility does exist for shielded waste packages to be transported as 'Type IF'¹² transport packages, and thereby be approved to carry larger quantities of fissile material. However, this is not currently part of the geological disposal concept and is therefore beyond the scope of this guidance.

3.3 The disposal of shielded waste packages

Following receipt at the GDF, shielded waste packages will be transferred from the road or rail vehicle on to a transporter for transfer underground. Once underground the waste packages will be removed from the transporter and transferred to the disposal vaults by means of a manually driven stacker truck. Shielded waste packages will be stacked in the disposal vaults up to five-high, depending on their height and the geological environment in which the GDF is constructed (see Section 4.1.3), as shown in Figure 6.

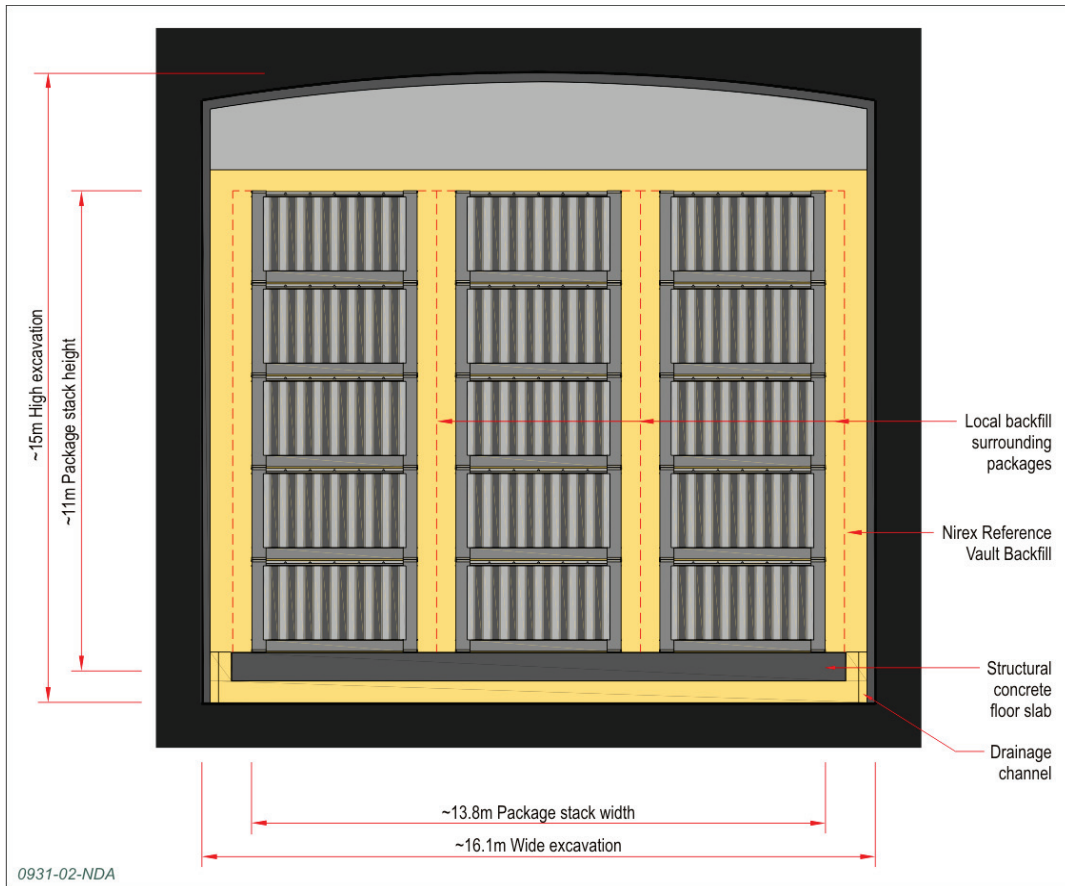
At some point in the future, the disposal vaults would be closed, prior to which, depending on the geological environment in which the GDF is constructed, they may be backfilled as a means of filling voids and, in some cases, providing additional chemical conditioning of the waste. The period during which emplacement of waste packages occurs, up until the time when the vault is permanently closed, is generally referred to as the 'operational period'. Following the end of the operational period, the GDF will enter the 'post-closure period'.

¹⁰ The lifetime dose includes all doses to workers and members of the public that would result from the retrieval, packaging, interim storage, transport and disposal of the waste.

¹¹ See Section 4.3.1.

¹² Described in the IAEA Transport Regulations (Paragraph 832) as an '*Industrial package design for fissile material*'.

Figure 6 Cross-section through disposal vault for shielded waste packages in higher strength rock environment



4 Packaging requirements for shielded waste package

This Section defines the requirements for shielded waste packages which are derived directly from the high-level requirements for all waste packages containing LHGW which are defined by the Generic Specification for such wastes (i.e. [3]).

The format of this section is to:

- identify the generic packaging requirements for all waste packages (shown in ***bold italic*** type) as defined by the GWPS, together with those defined for waste packages containing LHGW (shown in **bold** type) by the Generic Specification, as they apply to all potential designs of shielded waste package;
- explain the basis for the definition of those requirements;
- describe how those requirements are applied to shielded waste packages manufactured using each of the existing standardised designs of waste container; and
- discuss the factors that influence their means of achievement.

In general the packaging requirements discussed below apply to the waste package as a whole, but 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 means by which the waste is conditioned for disposal. Accordingly, to aid the application of the packaging requirements in the development of plans to package waste, they are grouped in a manner to reflect those which are most directly related to the waste container, the wasteform, and the waste package as a whole.

It should be noted that, where the words 'shall' and 'should' are used in the definition of packaging requirements, their use is consistent with the recommendations of BS7373:1998 [20] 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 shown¹³ not to result in any significant reduction in the overall safety of the geological disposal system.

A number of the packaging requirements (e.g. heat output and gas generation) include quantified 'screening levels'. These values are defined to provide guidance to waste package designers by indicating the levels below which no specific justification of waste package performance would be required as part of a submission for the disposability assessment of a packaging proposal. It should be noted that these screening levels are not intended to be used as a sole basis for the development of packaging proposals as, in many cases, the actual limiting values for specific designs of waste package may be significantly higher.

¹³ This would generally be by way of the Disposability Assessment Process.

4.1 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 2.2, 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. stackability, accident performance) it may only play a partial role, the actual extent of the role played by the waste container depending on its robustness, as illustrated by Figure 1.

In general terms it is expected that the waste containers for the existing designs of shielded waste package will provide the waste package with adequate:

- mechanical strength to:
 - withstand stacking forces (Section 4.1.3);
 - resist damage due to pressurisation by internally generated gases (Section 4.3.6);
 - ensure that the specified impact accident performance (Section 4.3.8) can be achieved; and
 - withstand other loads that may occur during the long-term management of the waste package, as required by the generic Environmental Safety Case (ESC) [21].
- radiation shielding to ensure that the external dose rate is minimised and that the limits specified for transport are not exceeded (Section 4.3.3);
- thermal properties to ensure that the required fire accident performance (Section 4.3.8) and other requirements for the thermal performance of the waste package will be achieved; and
- resistance to degradation to ensure the overall integrity of the waste container is maintained for an adequate period (Section 4.1.5).

The standard features of the existing standardised designs of shielded waste container are shown in Figures 7 to 10.

Figure 7 Standard features of the 4 metre box

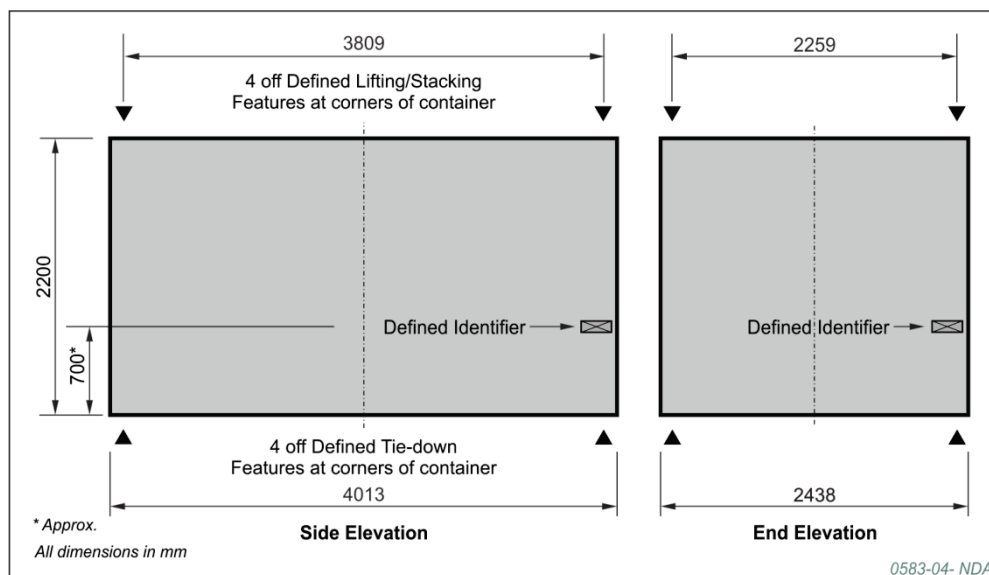


Figure 8 Standard features of the 2 metre box

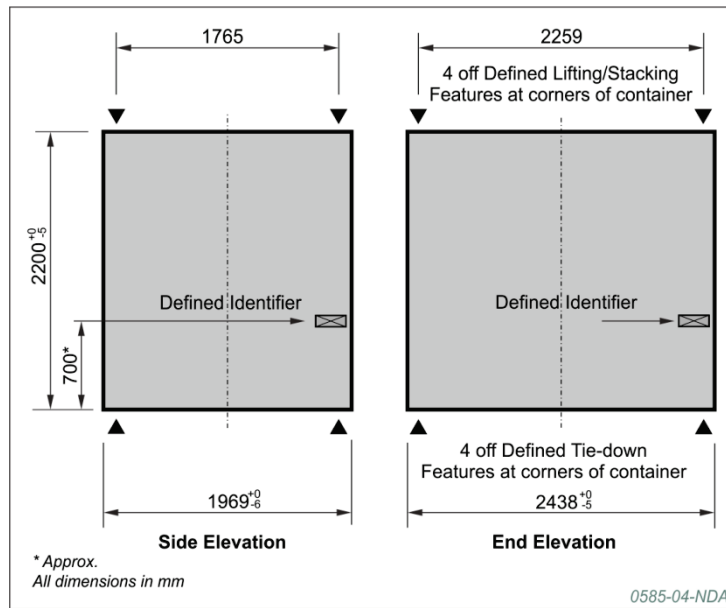


Figure 9 Standard features of the 6 cubic metre box

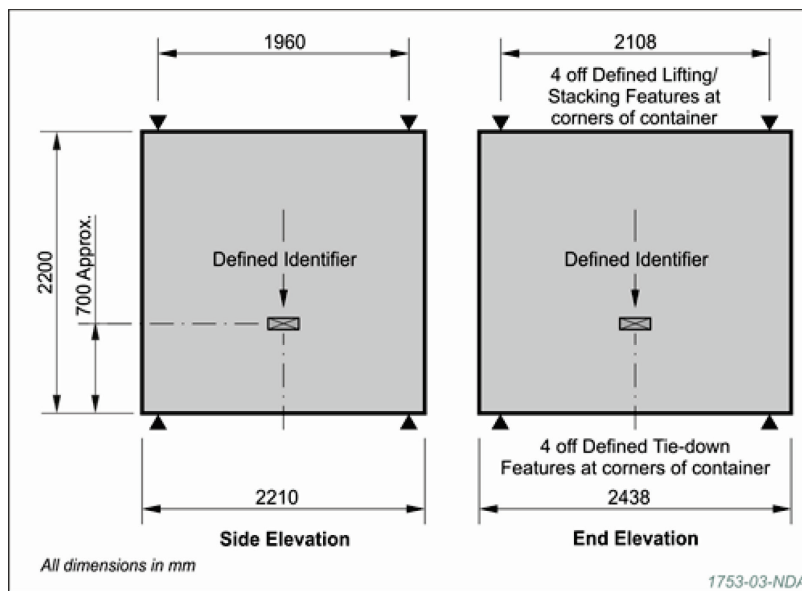
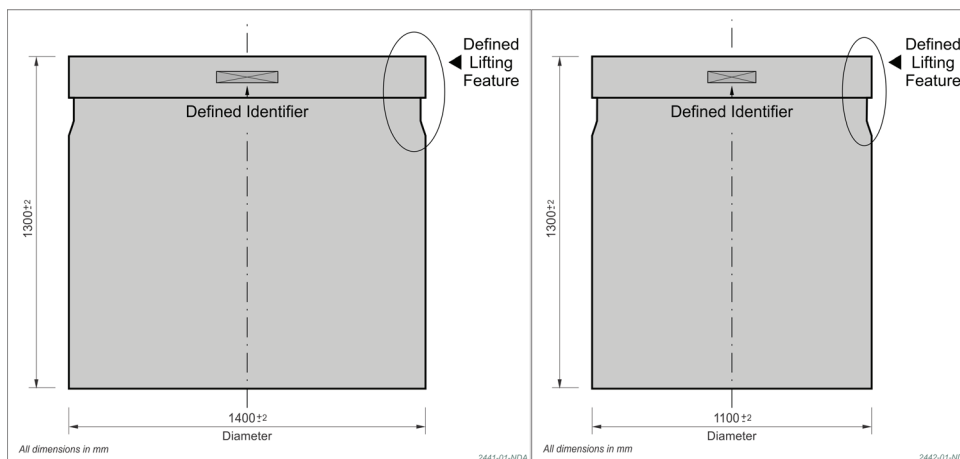


Figure 10 Standard features of the Type 1 and Type 4 drums



The fabrication of a waste container with the required dimensions, shape and containment properties will place demands on a number of properties of the materials selected. For example the fabrication of waste containers from metal may involve forming (e.g. bending, spinning), joining (e.g. welding) and machining (e.g. tapping and threading of bolt holes). Fabrication from concrete will need to address such as adequate fluidity during casting, shrinkage during curing and the use of metal reinforcement may provide sufficient tensile strength, such as would be required for lifting operations and stacking.

The dimensions and shape of a waste container must also be maintained within a defined envelope during and following waste package manufacture. It is therefore important that material properties such as yield strength, creep resistance and shrinkage will have to be suitable to ensure the long-term dimensional stability of waste packages. Degradation of the wasteform, particularly as a result of the corrosion of 'reactive' metals such as uranium, can lead to wasteform expansion and the waste container should be sufficiently rigid to allow it to resist this and ensure that the waste package dimensions remain within the defined envelope.

Austenitic stainless steel, typically Type 316L, has been extensively used for the fabrication of waste containers. The choice of this material is largely historic, but is supported by a number of properties it offers including:

- It benefits from extremely low general corrosion rates [22]: in atmospheric and controlled stored environments, and possesses good corrosion resistance to wastes that will be placed in the containers.
- A low corrosion rate results in a reduced need for a 'corrosion allowance' in the design of waste containers, there reducing material usage and waste container mass.
- It is strong, yet ductile and so is readily fabricated. It can be used in relatively thin sections.
- It can be cut, formed, machined and welded by standard methods.
- There is no need for pre or post-weld heat treatment.
- Experienced commercial fabrication shops are available.
- Common grades of stainless steel are widely used in other industries and so they are readily available in a range of product forms.
- It has a good long-term track record in analogous industrial applications.

Other stainless steels (notably Type 304L) have also been used in the fabrication of waste containers but this has tended to be restricted to thicker sections, such as lifting features and lid flanges. Duplex stainless steels have also been identified as being suitable for the fabrication of waste containers as they offer higher strength and corrosion resistance, and hence can be used with lesser thicknesses than austenitics. Duplex steels are however potentially more difficult to form and weld and may not be suitable in all cases.

To date, only limited use has been made of concrete for the manufacture of waste containers in the UK. However the material has many properties that make it suitable for such use and a number of overseas organisations (e.g. in France, Germany and Sweden) have made extensive use of concrete waste containers for the packaging ILW. Concrete is very suitable for casting in well-defined shapes and much experience is available from the civil engineering sector. In order to confer suitable mechanical properties, such as compressive and tensile strength, to concrete, reinforcement is often required. This can involve the use of conventional carbon steel reinforcement bars (rebars) or metal or polymer fibres.

4.1.1 External dimensions

The overall dimensions of a transport package should not exceed 6.058m x 2.438m plan x 2.591m high.

The dimensions of a transport package carried by rail shall not exceed 2.67m wide or 2.40m high.

The external dimensions of waste packages must be such that will permit them to be safely and efficiently handled using the systems defined for transport to and emplacement in a GDF.

Waste packages could be transported to a GDF by road, rail, sea or inland waterway, or by a combination of these means. Transport by rail is, in general, the most restrictive from the point of view of package external dimensions whereas road transport tends to be the most restrictive for waste package mass.

The maximum overall dimensions of a transport package to be carried by rail, including any covers, is set by a requirement to be compliant with the relevant 'rail gauge'. To permit the use of a large proportion of the UK rail network the GTSD uses the Standard W6A Rail Gauge [23] as the basis for defining a maximum overall envelope for a transport package (including protective covers) of 2.67m wide by 2.40m high. Restrictions will also exist for the length of transport packages although these will be less onerous than those on width. Less restrictive rail gauges exist although this could limit which parts of the network could be used. Larger waste packages could also be transported by road; although the transport of larger waste packages in this manner may ultimately be limited by weight restrictions (see Section 4.3.2).

The current generic designs for a GDF [24] assume a maximum transport package dimensional envelope of 6.058m x 2.438m plan x 2.591m high, the limiting factor being the capability of the drift access to transfer transport packages underground. Transport by rail therefore places the bounding limit on the height of transport packages.

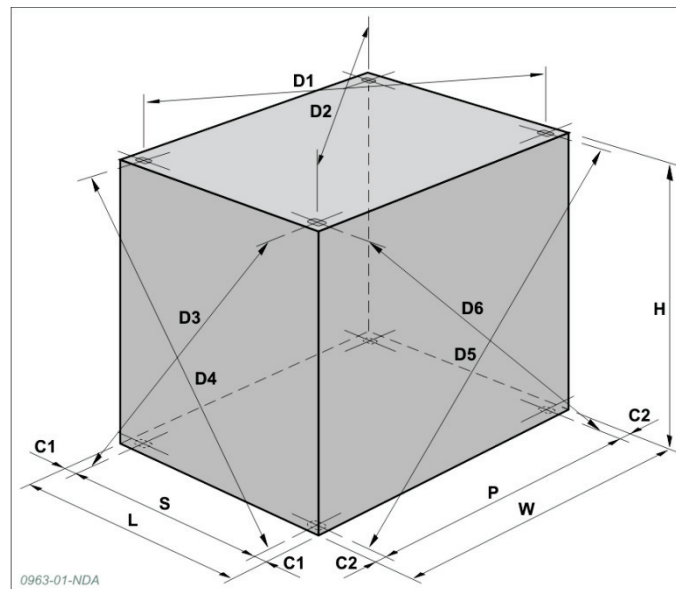
As shielded waste packages will be transported as transport packages in their own right, the bounding values for transport defined above will apply directly to the waste packages. RWM has placed additional dimensional constraints on the existing designs of waste containers used for the manufacture of shielded waste packages and these are discussed below.

The key external dimensions of the three designs of cylindrical waste containers (Figure 11) are primarily based on the principles established for Series 1 International Organisation for Standardisation (ISO) freight containers [25]. The width dimensions¹⁴ of the three boxes correspond to the ISO standard (i.e. 2.438m) and the lengths of the 4 metre box and 2 metre box correspond to 2/3rds and 1/3rd of the standard 6m ISO container. The length of the 6 cubic metre box was defined to suit the needs of the original use of the container (i.e. for the packaging of WAGR decommissioning waste for sea disposal). The heights of the three containers are the same (i.e. 2.200m) this value being chosen to ensure maximum flexibility for transport whilst maximising the payload volume of the containers. Table 1 lists the maximum external dimensions of the two cylindrical shielded waste containers.

The payload volumes of the current range of shielded waste containers (Table 2) will depend on the shielding provided although, in the case of the 6 cubic metre box and the Type 1 and Type 4 drums, these values are currently fixed by design. It should be noted that no payload volume for a 2 metre box with 300mm shielding is stated as RWM does not believe that the use of such a variant would constitute an optimal use of the capacity of a GDF.

¹⁴ This actually being the 'length' of the 6 cubic metre box due to the orientation of the twistlock apertures.

Figure 11 Key dimensions of standardised cuboidal shielded waste containers



Label	Description	Dimension (mm)			Tolerance (mm)
		4 metre box	2 metre box	6 cubic metre box	
L	Overall Box Length	4013	1969	2438	+0/-5
W	Overall Box External Width	2438	2438	2210	+0/-5
H	Overall Box External Height	2200	2200	2200	+0/-5
S	Length between Corner Fitting Aperture Centres	3809	1765	2108	± 2.5
P	Width between Corner Fitting Aperture Centres	2259	2259	1960	± 2.5
K1	Difference between D1 & D2 or D3 & D4 i.e. $ D1-D2 $ or $ D3-D4 $	11	9	9	max.
K2	Difference between D5 & D6 i.e. $ D5-D6 $	11	11	11	max.
C1	Corner Fitting Measurement ¹⁵	101.5	101.5	163.5	+0/-1.5
C2	Corner Fitting Measurement ¹⁵	89.0	89.0	123.5	+0/-1.5

¹⁵ From BS3951: Pt. 1: Section 1.2: 1985

Table 1 External dimensions of Type 1 and Type 4 drums

Container type	Maximum external dimensions (mm)	
	Diameter	Height
Type 1 drum	1402	1302
Type 4 drum	1102	1302

Table 2 Payload volumes of shielded waste containers

Shielding thickness (mm)	Payload volume (m ³)				
	4 metre box	2 metre box	6 cubic metre box	Type 1 drum	Type 4 drum
0	18.9	9.5	-	-	-
100	14.3	6.9	-	-	-
160	-	-	-	0.9	0.5
200	10.9	5.0	-	-	-
240	-	-	5.8	-	-
300	8.1	-	-	-	-

4.1.2 Handling feature

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 the Level 2 Specification.

The waste container shall incorporate tie-down features suitable for the maximum gross mass specified for the waste package.

The design of the waste package should enable remote handling

To permit the safe and efficient handling of waste packages, all waste containers are required to incorporate handling features designed in such a manner to be compatible with the handling systems that are currently assumed in the generic transport and GDF designs [24, 26].

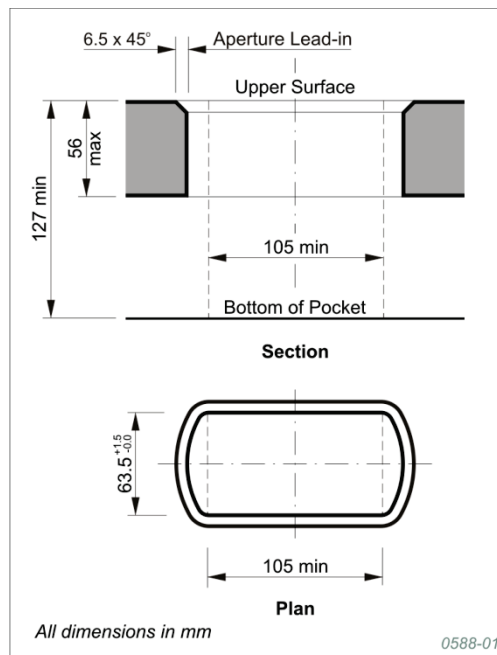
The handling features defined for these waste packages must be able to withstand the full range of forces which could be applied during normal waste package lifting operations. This includes a requirement for them to be able to withstand the loads that would result from the lifting of a waste package of twice the specified maximum gross mass, in an equi-spaced three-point lift, to take into account the so-called 'snatch factor' [27].

The Generic Disposal Facility Designs (GDFD) report [24] assumes that all shielded waste packages will be 'contact handled' insomuch as they will be unloaded on receipt at the GDF, and emplaced in the disposal vaults, using manually driven stacker trucks. However the designs of the lifting features should be such to enable automated systems to be used for engaging the twistlock pockets, as a means of minimising direct contact by transport

and GDF workers as a means of ensuring that radiation doses are as low as reasonably practicable (ALARP).

To enhance safety during the GDF operational period it is desirable that the number of different designs of waste package handling features should be minimised and that different designs of waste container should incorporate a common design of handling feature where practicable. To promote such an approach, RWM has defined a standardised handling feature in the form of 'twistlock' aperture [28] as shown in Figure 12.

Figure 12 Twistlock dimensions and geometry



All of the existing designs of shielded box waste package will be handled via corner fittings which should be rated for the maximum package mass¹⁶ and should incorporate standard twistlock fittings as defined in the WPS and described in [28]. Four corner fittings are required on the top face for lifting, and a further four on the base for restraint during transport. Examples of methods for securing freight containers for transport are given in [29]. It should be noted that the corner fittings only require apertures on horizontal surfaces and there is no requirement for side or end apertures.

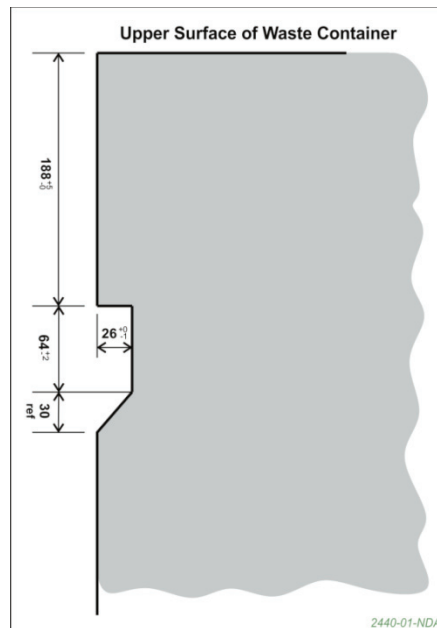
To comply with the requirements for ISO freight containers, the three shielded box waste package designs incorporate tie down features to ensure safety during transport. The layouts for the locations of the lifting and tie-down features on the three designs of shielded box waste package are shown in Figure 11.

During the GDF operational period, shielded box waste packages will be handled using a top-lift spreader. To comply with requirements at a GDF, each twistlock point must be designed to withstand the loads that would result from the lifting of a waste package of twice the specified maximum gross mass.

The two shielded drum waste containers are fitted with an integral handling feature of the form shown in Figure 13.

¹⁶ The 4 metre box waste package will be rated at 65t for the ISO 1496/1 stacking tests irrespective of the actual mass when filled with waste.

Figure 13 Lifting feature for Type 1 and Type 4 drums



As all shielded waste packages will be transported as Type IP transport packages, it is necessary that they are designed and tested in accordance with the requirements specified in ISO 1496/1 [30]. The aim of ISO 1496/1 is to ensure that the tolerances specified on dimensions are satisfied following manufacture. A prototype design will be subjected to a series of regulatory tests which are intended to represent the forces experienced by the container during transport and handling. However, users of the waste packages must ensure they are not subjected to greater loads during normal use. The requirements for restraint and tie-down are given in the IAEA Transport Regulations and the accelerations experienced by the restraints during normal conditions of transport (NCT) must also be considered.

Each waste packager will also need to consider the lifting requirements at its own site, but must comply with the RWM specification as a minimum.

For some of the standardised designs of shielded waste package the lifting feature will also play a significant role in their stacking (Section 4.1.3) and that the design of the feature will need to take this into account.

4.1.3 Stackability

Waste packages which rely on their design to withstand stacking loads should be capable of being stacked to a height of 11m with other waste packages of the same design, each with their maximum specified gross mass. This loading shall not result in any effect that could render the waste package non-compliant with any of the requirements defined in the relevant WPS.

Waste packages which are transport packages in their own right shall comply with the stacking requirements defined by the IAEA Transport Regulations

Waste packages containing LHGW will need to be capable of being stacked, as would be required by the design of the GDF, without suffering any deleterious effects that could threaten their safe onward long-term management.

Waste packages will be stacked in the disposal vaults to a maximum height governed by the ability to excavate vaults in a specific geological environment, whilst leaving sufficient clearance for any emplacement equipment (e.g. overhead cranes). The GDF Report [24] identifies achievable heights for disposal vaults in different geological environments and these lead to the maximum waste package stack heights for shielded waste packages

shown in Table 3. This shows that the maximum stack height for shielded waste packages in a GDF constructed in a higher strength rock environment would be approximately 11m.

Table 3 Shielded waste package stack heights for GDF vaults constructed in different geological environments

Geological environment	Estimated maximum height of disposal vault	Estimated maximum stack height for shielded waste packages
Higher strength rock	15.0m	11m
Lower strength sedimentary rock	11.5m	6.7m
Evaporite rock	5.5m	4.4m

The maximum stack height of 11m for shielded waste packages would result in 5-high stacking for the three shielded box waste packages, and 7-high stacking for the Type 1 and Type 4 drums. The maximum loads that would result from such stacking (i.e. that suffered by the waste package located at the bottom of a stack of waste packages, each with the maximum specified gross mass) are listed in Table 4. Under these conditions, the waste packages should not exhibit any permanent deformation or abnormality that would render it incompatible with any of the requirements defined in the relevant WPS.

Table 4 Maximum stacking heights and loads for shielded waste packages

	Maximum stack height	Maximum stacking load
4 metre box	5	2.6MN
2 metre box	5	1.6MN
6 cubic metre box	5	2.0MN
Type 1 drum	7	480kN
Type 4 drum	7	360kN

As Type IP transport packages all shielded waste packages will be required to satisfy the requirements of Paragraph 723 of IAEA Transport Regulations and withstand a stacking load equal to five times the weight of the package whilst remaining capable of preventing the loss or dispersal of contents or of shielding integrity. In the context of this requirement the stacking load will be five times the actual weight of the package, which may in some cases be less than the requirement defined above. The demonstration of compliance with this requirement will form part of the certification process for the waste package as a Type IP transport package.

Although the ability to be safely stacked without deformation is considered a necessary characteristic of waste packages, it is considered good practise to allocate this requirement, where feasible, to the waste container and to claim no benefit from support

provided by the wasteform [31]. This is on the basis that a waste container can be designed and manufactured to provide the required load bearing performance for the required period of time whereas the longer-term strength of a wasteform, not primarily designed for load bearing, cannot be assured with the same degree of confidence.

As noted in Section 4.3.2, shielded waste packages with gross masses of up to 65t would be compatible with the GDF handlings and emplacement equipment. However the gross mass limits of both the 2 metre box and the 6 cubic metre box waste packages are less than this (i.e. 40t and 50t respectively). Part of the basis for this is to avoid the need for these designs of waste package to be 'over-designed' in order to withstand excessive stacking loads which would be unlikely to occur in practise.

The stacking elements of a waste package design must take into account timescale and ageing of the waste package, especially the components of the waste package that will take the stacking load. Yield strength, stiffness and creep resistance are material properties expected to control the stacking performance of a container material and the thinning of the container material due to corrosion will also have to be taken into account.

A method for assessing the suitability of a candidate material for the fabrication of waste containers, from the point of view of waste package stacking, can be found in [32].

Waste packagers may choose to stack waste packages higher than the GDF stack heights during interim surface storage, but must ensure that after having been stacked in such a manner for an extended period¹⁷ the waste packages will still meet the requirements of the relevant WPS for dimensional envelope and the handling features.

4.1.4 Identification

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

The waste package shall remain identifiable by automated systems for a minimum period of 150 years following manufacture.

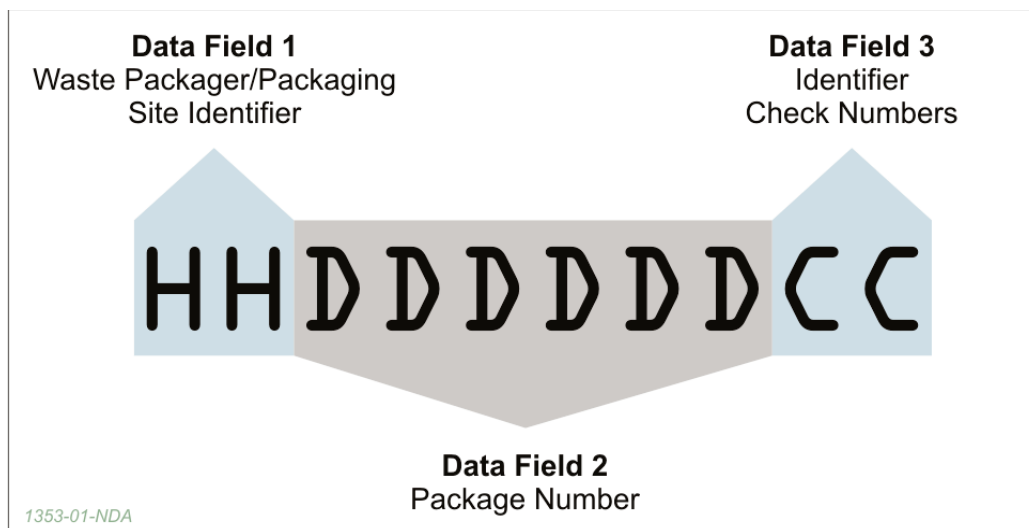
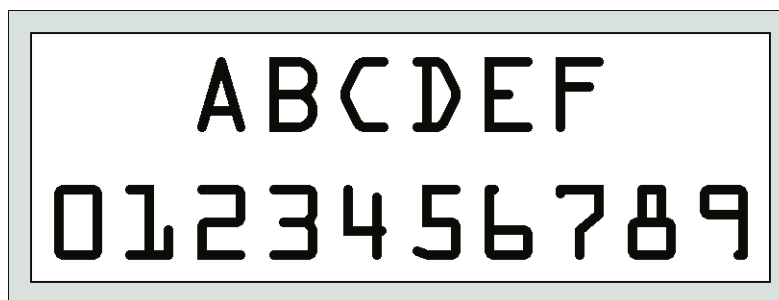
The identifiers shall comprise ten digit OCR-A characters each 6-10mm.

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 permits the permanent assignment of the appropriate data record to that waste package.

RWM has defined an identifier format consisting of ten alpha-numeric characters (Figure 14), which includes 'check numbers', to help minimise the possibility of loss of waste package identification over the required period [33]. The use of the specified standard character set (i.e. OCR-A characters, Figure 15 [34]), of a specified size (i.e. 6-10mm high) will permit either direct visual checking by human operators or the use of automated reading equipment. Making the identifier machine-readable and the use of a format containing check digits allows the waste package to be identified remotely and its number verified by an automatic computer check.

Waste package identifiers will need to remain machine readable for a period that permits identification of the waste package at least until the time at which it is surrounded by the backfill material. In defining a durability timescale for identifiers RWM applies the same arguments as those used to justify the required durability of waste container integrity (see Section 4.1.5). These lead to a minimum period of 150 years following manufacture during which the waste package shall remain capable of being identified.

¹⁷ For consistency with the identification and durability of integrity requirements for waste packages (see Sections 4.1.4 and 4.1.5) a period of 150 years should be assumed.

Figure 14 Form of waste package identifier**Figure 15 Character set for identifiers**

For automated reading systems to operate effectively, standard locations must be specified for identifiers. Multiple locations will aid in the ease of reading by reducing the need for the waste package to be moved during identification as well as providing redundancy in the event of damage (for example that caused by corrosion) and will reduce the risk of waste packages becoming unidentifiable. The specified locations for identifiers on the three unshielded waste package designs are shown in Figure 7 to 10.

The locations specified for identifiers on shielded waste packages have been selected in such a manner as to reduce the need for the waste package to be moved in order for it to be identified and also minimise the possibility of the identifier being obscured by handling equipment.

The recommended method of inscribing an identifier on a metal surface is laser-etching which, in the case of a stainless steel surface, would be expected to satisfy the requirement specified for the longevity of the marking. For waste containers fabricated from concrete it may be necessary to attach stainless steel plates to the external surface of the container to permit adequately durable identifiers to be inscribed in the specified locations.

In-house markings and additional labels may be applied by the waste packager if required for its own purposes, provided that they do not affect package performance. In particular, any additional identification, whether temporary or permanent, must not compromise the integrity or containment of the package. This should include a consideration of the materials used for such markings, guidance on which can be found in [35].

In addition to the identifier markings required by RWM, each waste package must be marked, labelled and placarded in accordance with the requirements of the IAEA Transport Regulations for Type IP-2 packages (Paragraphs 534 and onwards).

4.1.5 Durability of waste container integrity

The integrity of the waste container should be maintained for a period of 500 years following manufacture of the waste package.

In Section 2.2 the safety functions that are required of waste packages, and that are identified in the GWPS [2], were discussed in the context of waste packages containing LHGW. For most designs of waste package those safety functions will be provided by a combination of contributions from both the waste container and the wasteform, the degree of contribution made by each being dependent on the particular design of the waste package (Figure 1).

Two of the operational safety functions (i.e. for containment and safe handling) rely heavily on the maintenance of the integrity of the waste container for a given period. Other safety functions, such as the ability of the waste package to withstand 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 all anticipated external loads, notably those resulting from stacking.

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'* [36]. Such a period broadly aligns with current planning assumptions regarding when a GDF would be available to receive waste packages for disposal (i.e. 2040) and the anticipated length of the GDF operational period (assumed in the GDFD to be ~100 years [24]).

The potential for the retrieval of waste packages from the disposal vaults also needs to be considered when defining the period over which the integrity of the waste container is required to be maintained. RWM's current position on retrievability is that activities concerned with the development and implementation of a GDF will be carried out in such a way that the option of retrievability is not excluded [37]. The UK Government's policy regarding retrievability is outlined in the 2014 White Paper [1] which states that waste packages could be retrieved during the GDF operational period *'if there was a compelling reason to do so'*, whilst acknowledging that a GDF *'could be open for construction and waste placement for around one hundred years, to accommodate the current volume of legacy waste'*. The White Paper also notes that retrieving emplaced waste packages *'would tend to become more difficult with time, particularly after the end of its operational stage (that is, once a GDF has been closed permanently)'*.

The DSTS defines a number of safety functions that the waste container will be required to provide for waste packages in the post-closure period. These include restricting the access of groundwater to the wasteform, as a means of delaying the release of radionuclides into the other components of the EBS. In the case of waste packages containing ILW this refers notably to the retention of relatively short-lived water soluble radionuclides (e.g. strontium-90 and caesium-137, each with half-lives of ~30 years). Whilst indefinite retention of such radionuclides is not the aim, the waste container should provide an effective barrier for a period that would permit them to decay to relatively insignificant levels before their release.

In order to satisfy the potential requirements of both the operational and early post-closure periods, the need to maintain waste container integrity for 500 years, as specified in the 2007 GWPS¹⁸ [38], has been retained. RWM has carried out work which shows that current designs of waste container, designed to meet the durability requirement identified by regulatory guidance (i.e. 150 years), would also be expected to maintain an appropriate level of integrity for at least 500 years [39]. Notwithstanding this, RWM acknowledge that

¹⁸ This document has since been replaced by the Generic Specification for waste packages containing LHGW [3]

after 150 years waste packages may need to be handled by means which do not involve the use of the integral handling feature.

The ability of a specific design of waste container to meet this durability requirement will be assessed by way of the Disposability Assessment Process which, as well as considering the design of the waste container itself, will also take into account the potential consequences of the contents of the waste package for the durability of waste container integrity.

The ability of a waste container to maintain its integrity over a specified period is controlled by a number of key factors:

- the design of the waste container, including the materials and manufacturing processes;
- the nature of container material degradation mechanisms;
- the nature of any interactions between the waste container and the wasteform; and
- the environment of storage and disposal facilities.

Corrosion is the major potential threat to the ability of a waste container to maintain an adequate level of integrity for the required timescale. Other mechanisms of degradation can include the effects of heat, biodegradation, abrasion, radiolysis and chemical reactions between waste container components.

When selecting a material for the fabrication of waste containers, waste packagers will need to understand both the internal and external environments that a container will be subjected to, and determine which degradation mechanisms can take place in those environments.

The two materials that have been used to date for the manufacture of waste containers for unshielded waste packages have been stainless steel and reinforced concrete.

Stainless steel waste containers

The response of waste packagers to this requirement has generally been to manufacture waste containers from austenitic stainless steel to grade 316L (EN 1.4404 [40]) or its equivalent. The corrosion performance and mechanical properties of this material are generally regarded as optimum for the packaging of radioactive waste, and this performance has been demonstrated by experience and research [22]. 'Duplex' stainless steel (notably grade EN 1.4462) has been identified as an alternative material that has the necessary corrosion performance to make it suitable for the manufacture of waste containers. Whichever material is selected it should be noted that quality control of the material, the container manufacturing process and the control of surface finish of the material will also play key roles in maintaining the integrity of the waste container.

A variety of corrosion mechanisms can threaten the integrity of waste containers manufactured from stainless steel, the most significant of which are; general atmospheric corrosion, pitting or crevice corrosion and stress corrosion cracking.

The rate of general atmospheric corrosion performance of stainless steel are widely reported [41] and corrosion rates from $<0.2\mu\text{my}^{-1}$ ($>5,000\text{y}\text{mm}^{-1}$) to $3\mu\text{my}^{-1}$ ($300\text{y}\text{mm}^{-1}$) have been observed in industrial/urban and marine environments. Initial measurements from longer-term testing suggest corrosion rates of $\sim 0.01\mu\text{my}^{-1}$ ($100,000\text{y}\text{mm}^{-1}$) are more typical in a GDF environment which, when applied to waste container sections of a few mm, would suggest that such a mechanism is not a significant threat to integrity.

Localised corrosion mechanisms such as pitting or crevice corrosion, tend to be considered a greater threat to stainless steel waste containers than general corrosion. Nevertheless, data extrapolated from tests [42, 43] have shown that the time for a pit to penetrate 1mm into 316L stainless steel is many centuries. Crevices formed between waste container components, in the container lid area and in between the wasteform and the inside of the

container should be avoided during waste container and waste package design. Localised corrosion mechanisms are also dependent upon the presence of surface contaminants, in particular, chlorides. Work has been carried out to investigate these effects and to specify requirements for, amongst other factors, the surface finish of stainless steel used for waste containers [44].

The incidence of atmospheric stress corrosion cracking is dependent on the presence and concentration of soluble chloride deposits, the chemical form of the chloride, temperature, relative humidity and the metallurgical state of the stainless steel [41]. Such corrosion of stainless steel can be accelerated at temperatures above 60°C but may also be significant at lower temperatures. The chloride content of wasteforms should therefore be kept to a minimum and careful consideration given to possible corrosion mechanisms if it exceeds 100ppm. Consideration should be given to mechanisms for the generation of chloride ions by the wasteform, for example by the radiolysis or thermal breakdown of chlorine-containing plastics. A pre-requisite for this type of localised corrosion is access by oxygen to the surface of the container material. Accordingly the elimination or reduction of internal voidage, ullage or gaps between the wasteform and the waste container inner surface, to reduce oxygen access, is of benefit, and will also reduce the possibility of water condensation on internal surfaces.

Intergranular corrosion or 'weld decay' can occur in austenitic stainless steel that has been 'sensitised' by the high temperatures experienced during welding. The risk of sensitisation is minimised by use of low carbon or stabilised grades of stainless steel. Nevertheless, excessively high heat inputs should be avoided, as should contamination of the weld by materials containing carbon or nitrogen.

The following matters should be taken into account during the design of a waste container, and the wasteform it contains:

- A high pH environment is generally considered to be beneficial in reducing corrosion rates; accordingly a wasteform that does not promote such conditions could accelerate corrosion.
- Corrosion inside the waste container can also be accelerated by electrolytic action with dissimilar materials, or with other aggressive components that may be present in the package. Particular consideration should be given to preventing the possibility of metal items in the wasteform from contacting the container walls directly.
- The presence of microbes, together with the right conditions of nutrient and water supply on a waste container surface, could also lead to the microbially induced corrosive degradation of the material.
- Stored waste packages will emit and be exposed to gamma radiation from within and from surrounding packages. A consequence of such exposure is to produce nitric acid from atmospheric nitrogen, oxygen and water. Minimisation of the presence of free water, or water readily available in the vapour phase, will reduce the quantity of nitric acid that could be produced.
- Radiolysis of waste package contents can result in the production of aggressive chemicals (e.g. hydrochloric acid from the radiolysis of polyvinyl chloride) that accelerate degradation processes.

To assist waste packagers in these areas, guidance has been produced on the general corrosion properties of stainless steel [22], the requirements for surface finish [44] and on welding techniques used during the manufacture of stainless steel containers [45].

Reinforced concrete waste containers

The degradation mechanisms for reinforced concrete can be significantly different than for stainless steel although many of the reactants are common (i.e. water, oxygen and chloride).

Corrosion of the steel reinforcement bars in concrete waste packages is accelerated by the presence of aggressive ions, such as chloride or sulphide [46], and such contaminants may be deposited on waste packages in stores [47]. Deposition of chloride on packages, coupled with the presence of moisture may lead to diffusive penetration of package walls leading to chloride-induced localised corrosion. Such localised corrosion is more than an order of magnitude more rapid than uniform corrosion and may weaken the reinforcing steel and cause spalling of the concrete cover. It is critical to maintain chloride concentrations at less than the 400ppm concentration in pore fluids, considered to be a threshold for the onset of localised corrosion [48]. The high alkaline content of concrete passivates and protects the steel reinforcement bars from corrosion, it is therefore important that the bar is the defined depth beneath the surface of the concrete to mitigate the risk of corrosion, resulting in spalling of the concrete cover to the reinforcement..

Actions to minimise the risk of corrosion occurring include ensuring the box is not subjected to condensation, high temperature variations and ensuring chloride depositions are kept as low as possible during interim storage. Additionally the use of a protective surface coating (such as that used in the manufacture of the WAGR box waste packages) may be of benefit. The greatest risk of chloride contamination and/or deposition of such containers is during transport of waste packages; this can be reduced by temporarily overwrapping waste packages with an impervious material.

One of the most common forms of degradation of reinforced concrete structures is concrete carbonation. This occurs when atmospheric carbon dioxide reacts with the alkalis in the cured concrete, thereby reducing the alkalinity of the concrete [49]. If the carbonation front reaches the steel it can lead to the breakdown of the passivation layer on steel reinforcement, expansive corrosion of the reinforcement and spalling of the concrete cover. Proprietary anti-carbonation coatings can be used to prevent the ingress of carbon dioxide, re-alkalising the concrete and preventing the ingress of chloride ions and water. The use of such materials may have consequences for the post-closure performance of a GDF, as indeed could the use of other forms of protective coatings and super-plasticisers (to increase the fluidity of the concrete during waste container manufacture) and their use would need to be carefully considered in this context. The much better solution is to ensure the structure is manufactured using a good quality concrete with adequate cover of the rebars. The concrete cover must have a minimum thickness to provide a highly resilient barrier to carbonation and chloride ingress and thereby minimises the risk of rebar degradation and to provide thermal insulation to protect them from the effect of fires. The relevant BS advises that such cover should be no less than 25mm, although a minimum of 40mm is recommended [50].

4.2 Requirements for wasteforms

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.***

Evolution of the wasteform shall ensure maintenance of the waste package properties that are necessary for safe transport and operations at a GDF.

Evolution of the wasteform shall ensure maintenance of the required safety functions for post-closure performance as set out in the ESC.

As discussed in Section 2.2 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. For a shielded waste package, with built-in shielding and the restrictions on the activity of their contents (Section 4.3.1), the waste container is likely to play a significant role in the

achievement of passive safety of the waste package as a whole. However, the role played by the wasteform should also be considered. Wastes should therefore be conditioned to minimise chemical reactivity and to satisfy some basic requirements as to their physical and biological properties. This should extend to ensuring the compatibility of the wasteform and the material from which the waste container is fabricated.

These general requirements for wasteforms can be achieved by sorting, segregation and/or a range of pre-treatment processes to ensure the appropriate control of the quantities of some types of material, or of wasteform properties, that could affect the overall performance of the waste package or the other barriers that make up the geological disposal system. Typically this could include controls on the presence of:

- free liquids;
- activity or hazardous materials in particulate form;
- voidage;
- in-homogeneity;
- reactive materials;
- other hazardous materials¹⁹; and
- materials that could have a deleterious effect on the other barriers that make up the EBS.

The extent of such controls will be very dependent 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. This would normally be assessed as part of the disposability assessment of a proposed waste package design.

The wasteform will play a key role in the immobilisation of the radionuclides associated with the waste it contains. Immobilisation is defined as the adequate elimination of the freedom of movement of radionuclides within a wasteform and can be achieved by rendering waste into a solid monolithic form, typically by the use of a cementitious or polymeric encapsulating medium. Encapsulation of the wasteform allows it to be classified as LSA-III material as long as the average specific activity does not exceed $2 \times 10^{-3} \text{A}_2\text{g}^{-1}$. If the wasteform is not encapsulated, it may only be capable of being classed as LSA-II material for which the allowable average specific activity is a factor of 20 times less than that for LSA-III material. This is further discussed in see Section 4.3.1.

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 the GDF operational period.

In the post-closure period the wasteform may continue to play a role in the overall safety of a GDF. The DSTS defines a single post-closure 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.

The role of the wasteform in helping to ensure adequate waste package performance, and the manner in which wasteform performance can be achieved, is discussed in detail in the wasteform guidance that complements this Guidance (i.e. [6, 7]).

¹⁹ Hazardous materials include flammable, explosive, pyrophoric, chemo-toxic and oxidising materials, sealed containers and objects containing stored energy.

4.3 Requirements for waste packages

4.3.1 Activity content

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

The contents of waste packages transported as Type IP transport packages in their own right, shall be capable of being categorised as LSA material or as SCOs.

The IAEA Transport Regulations require that the contents of Type IP transport packages comply with activity limits and other requirements defined for LSA material (Paragraph 409) or for SCOs (Paragraph 413), and a limit on the 'unshielded dose rate' for the contents of such transport packages (Paragraph 517). In many cases this is likely to be the most bounding limit on the activity content of shielded waste packages although the total activity content of a waste package may be limited by one or more of a number of radionuclide related parameters which are dealt with separately in the packaging specifications. These comprise:

- External dose rate (Section 4.3.3)
- Heat output (Section 4.3.4)
- Criticality safety (Section 4.3.7)
- Accident performance (Section 4.3.8)

Paragraph 409 defines three categories of LSA that can be carried in Type IP transport packages of which two²⁰ are of relevance to the contents of shielded waste packages:

LSA-II: Material in which the activity is distributed throughout and the estimated average specific activity does not exceed $10^{-4}A_2g^{-1}$; and

LSA-III: Material which is relatively insoluble, in which the activity is throughout a solid, or a collection of solid objects, or is essentially uniformly distributed in a solid compact binding agent and the estimated average specific activity of the solid does not exceed $2 \times 10^{-3}A_2g^{-1}$.

In some cases a non-encapsulated wastefrom would not qualify as LSA-III material unless it comprised of a 'collection of solid objects' in which the activity was effectively an integral part of the structure of the material. Wastes such as irradiated metal or graphite with little or no loose surface contamination could therefore be capable of being classed as LSA-III material without the need to encapsulate them.

There is a requirement for a greater degree of uniformity in the distribution of the activity within wastefroms classed as LSA-III material and a requirement for such material to be '*relatively insoluble*'. The Transport Regulations define a leaching test (Paragraph 703) to allow the required degree of insolubility to be demonstrated for wastefroms defined as LSA-III material. Additionally the transport of packages containing LSA-III material must take place under the conditions of exclusive use.

SCOs are solid objects which are not intrinsically radioactive but which have radioactive material distributed on their surfaces (i.e. surface contamination). This description

²⁰ LSA material with the lowest specific activity (i.e. LSA-I) is likely to be more suitable for surface disposal in facilities such as the Low Level Waste Repository in Cumbria.

excludes bulk radioactive material (e.g. uranium metal) and materials such as metals and graphite which have become radioactive as a result of neutron irradiation²¹.

Paragraph 413 defines two groups of SCOs on the basis of the degree of fixed and/or non-fixed surface contamination. The surface contamination limits for SCOs with the highest level of surface contamination (i.e. SCO-II) are listed in Table 5.

Table 5 Activity limits for SCO-II

Nature of contamination	Contamination on surfaces of object averaged over 300cm ² (Bqcm ⁻²)	
	β- and γ-emitters and low toxicity α-emitters	All other α-emitters
Non-fixed contamination on accessible surfaces	400	40
Fixed contamination on accessible surfaces	8x10 ⁵	8x10 ⁴
Non-fixed plus fixed contamination on inaccessible surfaces		

The total quantity of LSA material or SCOs that can be carried in a Type IP-2 transport package is limited by the 'unshielded' dose rate from the material itself, Paragraph 517 requires that:

'the external radiation level at 3m from the unshielded material or object or collection of objects does not exceed 10mSv⁻¹.'

In the context of packaged waste the term 'unshielded' here refers to the contents of the waste package (i.e. the wasteform), with no benefit being claimed for any shielding provided by the waste container. The benefits on any self-shielding by the waste itself, or that provided by any encapsulating materials, can however be taken into account when assessing the unshielded dose rate.

For waste containing combustible solids a further restriction of 100A₂ is placed on the total activity of LSA material or SCOs carried on a single vehicle (Paragraph 522/Table 6). The Advisory Material [51] that supports the IAEA Transport Regulations define combustible solids as '*materials in solid form which are capable of sustaining combustion either on their own or in a fire*'. Such a definition could therefore encompass some forms of graphite.

4.3.2 Gross mass

The bounding values which apply to the maximum gross mass are limited by the transport system as set out in the GTSD.

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

The 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).

²¹ These materials could be carried in Type IP-2 transport packages if they could be shown to be LSA material by virtue of their average specific activity.

The GDFD currently includes a number of assumptions regarding the safe working loads (SWL) for the 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 80t. For shielded waste packages which are transport packages in their own right, emplacement is currently assumed to be by the use of stacker truck with a SWL of 65t.

For transport by road, the maximum permitted laden mass of an ordinary HGV is 44t which, when an allowance is made for the mass of the vehicle itself, sets a limit of ~30t for the load. Transport packages with gross masses of greater than 30t will require special transport arrangements and there may therefore be operational benefits in maintaining transport package masses below this value.

For transport by rail, the GTSD [26] currently assumes the use of a four-axle wagon, which would allow transport packages with gross masses of up to ~64t to be carried on a large proportion of the UK rail network. The possibility does exist for the use of eight-axle rail wagons capable of carrying greater loads but these may only be suitable for use on a reduced proportion of the rail network.

As transport packages in their own right shielded waste packages are directly subject to one or more of the three gross mass limits set by the transport and GDF systems, i.e.:

- 30t for transport by road by use of an ordinary HGV (i.e. without the need for special arrangements);
- 64t for transport by rail; and
- 65t for handling and emplacement at a GDF.

These limits are applied to each of the three shielded waste package designs in the cases of the 2 metre box and 6 cubic metre box maximum gross masses of 65t are specified (i.e. 40t and 50t respectively) on the basis that such limits are not to be exceeded in practice and the specification of a 65t limit could result in waste being 'overdesigned' to withstand stacking loads to which they would not be subjected.

Table 6 combines the gross masses specified for the three designs of shielded box waste package with the payload volumes in Table 1 to produce maximum wasteform densities for the waste packages. This shows that the option does not exist to transport 4 metre box waste packages by road without special arrangements, except for very low density wasteforms (or un-encapsulated waste).

The maximum gross masses specified for Type 1 and Type 4 drum waste packages (i.e. 8t and 6t respectively) are such that they are suitable for either rail or road transport without special arrangements.

Table 6 Maximum wastefrom densities for shielded waste packages

Container	Shielding thickness	Typical mass of empty container (t)	Maximum wastefrom density (tm^{-3})			
			Limit for road transport	WPS limit		
				30t	40t	50t
2 metre box	0mm	3	2.8	3.9	-	-
	100mm	10	2.9	4.3	-	-
	200mm	15	3.0	5.0	-	-
4 metre box	0mm	5	1.3	-	-	3.2
	100mm	18	<1	-	-	3.3
	200mm	23	<1	-	-	3.9
	300mm	31	N/A	-	-	4.2
6 cubic metre box ²²		17	2.0	-	5.0	-
		26	<1	-	3.6	-

4.3.3 External dose rate

The external dose rate from the waste packages 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 at 1 metre from any external surface of a transport package, under normal conditions of transport, not exceeding 0.1mSvh^{-1} and the dose rate on its external surface not exceeding 2mSvh^{-1} .

Limits on waste package external dose rates are specified to ensure that routine radiation doses to transport and GDF workers, as well as to members of the public, are ALARP and less than the relevant regulatory limits.

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 (i.e. whether under the conditions of 'exclusive use' or 'non-exclusive use'). The more stringent of the limits, those for non-exclusive use, have been adopted as the limiting values for all transport packages in the GTSD [26] and the Transport Safety Case (TSC) [52];

²² The values given are for WAGR Boxes manufactured using 'normal density' and 'high density' concrete.

they are therefore also adopted in this Guidance. These limits require that transport package dose rates are no more than:

- 2mSvh^{-1} on the external surface; and
- 0.1mSvh^{-1} at 1m from the external surface.

As the existing designs of shielded waste packages are assumed to be transported without additional protection²³, these limits are applied directly to the external surfaces of the waste package.

As noted above the GTSD and the TSC assume that all transport packages will be carried under the conditions of non-exclusive use and the external dose rates quoted above are adopted as the limiting values in the TSC. However this does not preclude the transport of shielded waste packages with higher radiation levels, if they were carried under the conditions defined for exclusive use. Under such conditions the external dose rate limits are:

- 10mSvh^{-1} on the external surface; and
- 0.1mSvh^{-1} at 2m from the external surface.

It should be noted that shielded waste packages with external dose rates in excess of those defined for the conditions of non-exclusive use could have consequences for worker dose during interim storage at the site of arising, transport and during the GDF operational period, and for the respective safety cases. The waste packager will need to consider the former to ensure that the dose consequences of the packaging of the waste and the interim storage of the waste packages are ALARP, whilst those of the latter two periods (i.e. transport and GDF operations) would be considered as part of the disposability assessment of the proposed waste packages.

The thickness and density of the shielding provided by a shielded waste container should be selected to ensure that the overall dose consequences of the packaging of the waste are ALARP. The use of thicker shielding is not always the optimum approach as this can have significant consequences for the payload volume of the waste container and result in a greater number of waste packages, transport operations etc. The possibility exists to use high density concrete for container walls and liners and high density grouts for waste encapsulation. When used for the packaging of WAGR decommissioning wastes the 6 cubic metre box was used with two different grouts to permit the optimal packaging of wastes with different activities. A 'normal density' grout ($2,350\text{kgm}^{-3}$) was used for the packaging lower activity wastes, such as irradiated graphite, and a 'high-density' grout ($3,800\text{kgm}^{-3}$) containing haematite was used for the packaging of higher activity wastes such as irradiated steel.

The dose consequences, and the ease by which shielding can be provided for the different types of radiation has a great effect on the allowable radionuclide inventories of shielded waste packages. In general radionuclides which emit only either alpha or beta radiation will not contribute significantly to the external radiation of a waste package whereas those which produce gamma or neutron radiation will make up most of the external dose. The Contents Specifications for the 2 metre box [53] and 4 metre box [54] waste packages list specific radionuclide limits on the basis of ensuring compliance with the external radiation limits for the conditions of non-exclusive use. These values are provided to give waste packagers guidance on the acceptable contents of such waste packages and it should be noted that they are given for individual radionuclides only and assume that no other radionuclides are present in the waste package. During a disposability assessment, the

²³ Shielded waste package may be protected from weather by simple devices but these are not assumed to provide any significant radiation shielding.

external radiation dose rates for the proposed waste packages will be determined taking account of the whole radionuclide inventory of the waste package.

4.3.4 Heat output

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

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

The heat output of the waste package at the time of disposal vault closure should not exceed 6 watts per cubic metre of conditioned waste.

The most significant source of heat generation in LHW is radiogenic heat which is typically of the order of 1Wm^{-3} for conditioned waste [55]. Variations of up to two orders of magnitude either side of this mean value are not unusual and the in-homogeneity of activity in some waste streams could lead to values of greater than 100Wm^{-3} (although such wastes are very unlikely to be suitable for conditioning as shielded waste packages).

In general the radiogenic heat output of the wastes that are expected to be conditioned to form shielded waste packages is low and would rarely be the bounding factor for waste package contents. The wastes which are anticipated to be packaged in shielded waste packages [55] have an average heat output of $\sim 1\text{Wm}^{-3}$ in 2040, declining to $\sim 0.05\text{Wm}^{-3}$ by 2090.

It should be noted that radionuclides are not the only source of heat generation in some types of waste. Heat generation by non-radiogenic mechanisms can also be significant for some ILW and could amount up to 3Wm^{-3} due to the corrosion of metals in wastes, and up to 2Wm^{-3} from the microbial degradation of materials such as cellulose [56].

In order to define limits for the heat output of waste packages, it is necessary to consider the consequences of heat on all periods of their long-term management, notably transport and the operational and post-backfilling periods of a GDF.

Transport

The IAEA Transport Regulations define only qualitative controls on the heat generated by the contents of Type IP transport packages. These transport packages are limited to ensuring that *'the design of the package shall take into account ambient temperatures that are likely to be encountered during routine conditions of transport'* (Paragraph 616) whilst ensuring that the design is capable of preventing *'loss or dispersal of contents'* and limiting any loss of shielding under such conditions (Paragraph 624).

Thermal modelling of a typical Type IP-2A transport package²⁴ has shown that a total heat output of 200W would not result in surface temperature in excess of 50°C ²⁵ as stated above being exceeded [57].

GDF operational and post-closure periods

The DSTS specifies a limit of 50°C on air temperature in the disposal vaults to limit the deterioration of the waste package, to protect GDF systems such as electrical equipment and HEPA filters, and to permit human access to relevant areas.

²⁴ In this case a 4 metre box waste package

²⁵ This being the maximum temperature specified for Type B transport packages under conditions of non-exclusive use, a value RWM has opted to use for shielded waste packages transported as Type IP transport packages.

RWM has commissioned thermal modelling of various designs of disposal vault to investigate the thermal performance of waste packages during the operational period [58, 59]. This has shown that, for disposal vaults containing large arrays of waste packages with an average waste package heat output of 6Wm^{-3} , a maximum package temperature of 35°C would occur. Further modelling work of large waste packages (i.e. with a volume of $\sim 20\text{m}^3$) has shown internal heating of $\sim 60\text{Wm}^{-3}$ would be needed to elevate the waste package temperature to 50°C from an ambient temperature of 35°C [57].

The DSTS also specifies temperature targets for the GDF disposal vaults in the post-backfilling period specifically to reduce the consequences of heat on the GDF engineered barrier system. This could result from accelerated evolution of the waste packages or chemical changes in any disposal vault backfill material. The curing of such material may be accompanied by the release of significant quantities of chemical energy which will result in the temporary (i.e. for a few years) increase in the temperature of the disposal vaults. In addition radiogenic heat will continue to be generated by the contents of the waste packages, albeit at a progressively decreasing rate. As a means of minimising the likelihood and consequences of such effects, the DSTS defines a short-term target of 80°C , applicable to a period of a few years, and a longer-term target of 50°C which should be attained a few decades after backfilling of the disposal vaults. Thermal modelling of the backfilled vaults has shown that an average waste package heat output of 6Wm^{-3} at the time of back-filling would result in the 50°C target being exceeded for a period of ~ 20 years but that the short term target of 80°C would not be exceeded [60].

In defining a screening level for the heat output of waste packages following emplacement in the GDF, the value of 6Wm^{-3} is used, although it is expected that other restrictions on the activity of the contents of shielded waste packages (notably the requirement for them to be LSA material or SCOs) will mean that this limit on heat output is unlikely to be challenged in practise. Table 7 lists the heat output limits for the five existing designs of shielded waste package.

Table 7 Heat output limits for shielded waste packages

	Maximum heat output (W)	
	At time of transport	At time of disposal vault backfilling
4 metre box	200	60
2 metre box	60	35
6 cubic metre box	60	30
Type 1 drum	12	12
Type 4 drum	7	7

4.3.5 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.

For waste packages which are transport packages in their own right the non-fixed surface contamination, when averaged over an area of 300cm² of any part of the surface of the waste package, shall not exceed:

- ***4.0Bqcm⁻² for beta, gamma and low toxicity alpha emitters²⁶; and***
- ***0.4Bqcm⁻² for all other alpha emitters.***

Limits on the non-fixed²⁷ surface contamination of 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 is maintained below acceptable levels and ALARA; and
- Routine doses to workers and the members of the public are ALARP and in accordance with good industry practice.

The limits specified are those defined in Paragraph 508 of the IAEA Transport Regulations for the non-fixed surface contamination of transport packages. As transport containers in their own right the existing designs of shielded waste package are subject directly to these limits.

It should be noted that these targets 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 cause dose by such mechanisms. It can however contribute to the external radiation from the waste packages and is covered by the limits discussed above. It should also 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.

In most instances where packages are slightly contaminated on the outer surfaces, the contamination is almost entirely removable or non-fixed. However, some contaminants may strongly adhere to, or penetrate into, the external surfaces of waste containers. Contamination may become ingrained in pores, fine cracks and crevices, particularly in the vicinity of lid seals. Subsequent weathering, exposure to rain or even exposure to moist air conditions may cause some fixed contamination to be released or to become non-fixed.

Care is necessary prior to dispatch of the waste package to utilize appropriate decontamination methods to reduce the level of contamination such that the limits on non-fixed contamination will not be exceeded at any time during transport. It should be recognized that on some occasions the non-fixed contamination limits may be exceeded over the period of a transport operation. However, this situation generally presents no significant hazard because of the pessimistic assumptions used in calculating the derived limits for non-fixed contaminations.

²⁶ Low toxicity alpha emitters are defined by the IAEA Transport Regulations (Paragraph 227) as '...natural uranium; depleted uranium; natural thorium; uranium-235 or uranium-238; thorium-232; thorium 228 and thorium-230 when contained in ores or physical and chemical concentrates; or alpha emitters with a half-life of less than 10 days'.

²⁷ 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.'

The key means of minimising the risk of the non-fixed surface contamination of a waste package is by good practise during manufacture, storage, handling etc. and by effective decontamination in the event that activity becomes attached to the external surfaces of the waste package. In the case of waste packages containing conditioned LHGW, decontamination is normally achieved by the use of water jetting and/or swabbing to mechanically remove loosely attached particulate activity.

The surface finish of the waste container is key in this respect [44]. In general, a material with a smooth, hard, corrosion resistant surface will reduce the possibility of contamination and make any necessary decontamination more effective. The effectiveness of a decontamination method for a material with a specific surface finish can be evaluated using the 'decontamination factor' (DF), the ratio of the initial contamination of the surface to that after decontamination. 'Ease of decontamination' (ED) is a qualitative term (e.g. excellent, good, fair or poor) that is related to the DF value as shown in Table 8. The main criterion affecting the ability of a waste container material to be amenable to effective decontamination is the surface texture than can be readily achieved during the manufacture of the material. The 'smoother' a material finish, the less number of locations that can harbour contamination and resist simple decontamination methods, and the lower the qualitative definition of ED. Guidance on surface texture and its measurement are given in [61,62].

Table 8 The relationship between decontamination factor and ease of decontamination

Measured DF	Corresponding ED
> 1000	Excellent
100 - 1000	Good
10-100	Fair
<10	Poor

The hardness of a material is an important property that should be considered when selecting a material for container fabrication. Harder surfaces have more resistance to abrasive damage thereby reducing the potential for surface scratching affecting the surface topography of a material, and the potential for ground-in contamination to occur during a waste treatment process. Additional chemical and mechanical treatment can be applied to a material particularly after completion of the container fabrication, to achieve a satisfactory decontamination performance.

A definitive finish for a material to achieve the surface contamination requirement specified by the WPS cannot be given. However, it has been recommended [44] that decontamination tests are carried out in accordance with BS4247-1 [63], to ensure that the selected material, following any additional surface finish processes, is fit for purpose in terms of its decontamination performance. The decontamination tests should be carried out on the selected material surface finish with the type of contamination likely to be encountered, in order to demonstrate that the non-fixed surface contamination is below the required level.

4.3.6 Gas generation and release

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

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

Gases generated by waste packages transported as part of a Type IP transport package, or as Type IP transport packages in their own right, should not:

- cause the internal pressure of the transport package to exceed a gauge pressure of 700kPa under normal conditions of transport; or
- result in the release of radionuclides, in gaseous or particulate form, from the transport package under normal conditions of transport exceeding $10^{-6}A_2$ per hour.

The release of activity, in gaseous or particulate form, from the waste package during the GDF operational period should not exceed:

- 8kBq/hour per cubic metre of conditioned waste for hydrogen-3;
- 180Bq/hour per cubic metre of conditioned waste for carbon-14; or
- 150Bq/hour per cubic metre of conditioned waste for radon-222.

Many of the wastes in the UK ILW inventory have the potential to generate gases by a number of different mechanisms (see below), and at different times during their long-term management. Gas generation by waste packages can have consequences for their transport and for the GDF operational and post-closure periods.

The physical, chemical, biological and radiological properties of the wastes covered by the Generic Specification for LHGW are such that the potential exists for the generation of a wide range of gases [64]. These include:

- the corrosion of metals to produce hydrogen and the release carbon-14 in gaseous form;
- microbial degradation of organic materials, including the prior hydrolysis of cellulose to smaller organic compounds;
- the radiolysis of water, both groundwater and that entrained in the wasteform, and to a lesser extent, some organic materials;
- the release of tritium and noble gases by diffusion from metals;
- radioactive decay of radium, leading to the generation and release of radon-222; and
- the release of gases labelled with tritium and/or carbon-14 from irradiated graphite.

These different processes tend to occur over significantly different timescales and this needs to be considered when the consequences of gas generation by waste packages are being considered. For example, processes requiring water (e.g. corrosion, radiolysis) tend to be relatively short-lived and will cease when the available water is consumed whereas the generation of radioactive gases by long-lived radionuclides can persist for many millennia.

The most significant 'bulk' gases generated by ILW are H₂, CO₂ and CH₄, each of which can be generated by a number of processes. These gases may include the radionuclides tritium and/or carbon-14 and they can also entrain other radioactive gases such as

radioisotopes of argon, krypton and radon which may be present in, or be generated by, waste.

Gases give rise to a range of potential effects that may have an influence on all periods of the long-term management of waste packages. These include:

- pressurisation, distortion and/or damage to sealed waste containers;
- pressurisation and damage to the wastefrom leading to the production of activity in particulate form;
- releases of radioactive/toxic/flammable gases from waste packages;
- pressurisation and damage to the GDF backfill and host rocks leading to:
 - generation of additional groundwater flow pathways and modification of flow patterns;
 - modification to the rate of re-saturation of disposal vaults; or
 - mineralogical changes leading to changes to the chemical characteristics of the backfill material.

Transport

The IAEA Transport Regulations place no explicit limits on the generation of gas or for the release of activity in gaseous form by Type IP transport packages. There are, however, requirements to restrict the contents of Type IP transport packages to low activity materials (i.e. LSA materials and/or SCO) and to *prevent loss or dispersal of the radioactive contents* from such transport packages under defined conditions (Paragraph 624). In order to quantify a target for the gas generation and release by shielded waste packages the WPS for shielded waste packages specify a target of 800kPa for the maximum internal pressure of the waste container, and a limit of 10^{-6} A₂ per hour is applied to the loss of the radioactive contents under NCT²⁸. These values are those specified for Type B transport packages under NCT and are applied in the Generic Specification to shielded waste packages which are to be transported as Type IP transport packages.

GDF operational and post-closure periods

During the GDF operational period the ventilation system will be designed such as to prevent the accumulation of toxic, asphyxiating, radioactive, flammable or explosive gases within the disposal vaults and associated facilities by diluting them to safe concentrations and/or removing them. In the case of radioactive gases the ventilation system for a specific GDF design will include an assessment of the overall dose and risk to workers, members of the public and the environment (including non-human biota), to show that these doses are ALARP and do not exceed regulatory limits.

In the post-closure period the migration of gases from the disposal vaults is one of the main potential pathways by which radionuclides might be released to the accessible environment. Gases produced by waste packages in this period could thus have a significant effect on post-closure safety, if not managed appropriately at the packaging stage. These issues will be assessed and addressed during the disposability assessment of proposed waste packages.

The release of activity in gaseous form from waste packages has the potential to cause on- and off-site dose during both the GDF operational and post-closure periods. The ESC [21] identifies hydrogen-3, carbon-14 and radon-222 as the three most significant radionuclides that could be released from waste packages in gaseous form and that could lead to off-site

²⁸ This includes both radioactive gases and activity in particulate form which may be entrained in non-radioactive gases

dose. The generic Operational Environmental Safety Assessment [65] uses a value of 0.01mSv/year (derived from the 2009 Statutory Guidance to the Environment Agency [66]) as a target for the maximum dose to the most exposed group of members of the public due to routine discharges from a GDF. This value is used to define screening levels for the release of gaseous radionuclides from waste packages on the basis that if these levels were exceeded by the entire ILW inventory (i.e. ~360,000m³) the 0.01mSv/year target would be exceeded. Table 9 lists screening levels for the release of activity in gaseous form during the GDF operational period.

Table 9 Radioactive gas release screening levels for shielded waste packages during the GDF operational period

Waste package type	Activity release rate (Bq/hour)		
	Tritium	Carbon-14	Radon-222
4 metre box	80,000	1,800	1,500
2 metre box	40,000	900	750
6 cubic metre box	40,000	1,000	800
Type 1 drum	16,000	360	300
Type 4 drum	10,000	220	180

Guidance on the amelioration of the effects of gas generation by waste packages

A number of generic approaches can be adopted to ameliorate the effects of gas generation by the contents of waste packages:

- The incorporation of an engineered vent²⁹ into the waste container (provided that this does not cause worker dose to exceed regulatory limits during the operational period);
- The use of a gas permeable waste container material (e.g. concrete);
- The use of a sufficiently robust waste container to resist the forces produced by the anticipated maximum internal pressure³⁰; or
- The creation of a chemically inert wasteform to significantly reduce or eliminate the potential for gas generation. This could involve:
 - the drying of waste to remove water, a major component of many gas generation reactions;
 - the mixing of the waste with a suitable encapsulant such as a polymeric material; or

²⁹ If such a device is used, its effectiveness over the long term (i.e. up to the time of disposal vault backfilling) will need to be assured.

³⁰ Waste packages manufactured using such waste containers are beyond the scope of this document and will be the subject of future guidance.

- the use of a high temperature process (e.g. vitrification) to produce a relatively inert wasteform.

In the particular case of radon-222, control of the quantity of this gaseous decay product generated by waste packages is primarily by control of the quantity of its parent, radium-226, or by design of the waste package to encourage retention of radon within the wasteform³¹. A consideration of the issues arising from the packaging of radium bearing wastes has resulted in the definition of a methodology for the derivation of limiting waste package inventories for radium-226, above which appropriate measures will need to be taken to limit the release of the gas from the wasteform [67].

For waste containers which include a stainless steel outer shell, such as the 2 and 4 metre box, venting is the recommended approach to dealing with the potential for waste package pressurisation. Reinforced concrete waste containers, such as the 6 cubic metre box and the Type 1 and Type 4 drums, are generally considered to be adequately permeable to gas such that excessive pressurisation is not considered a risk during the long-term management of waste packages.

Venting of waste packages to manage the possible consequences of gas generation is the approach recommended by the IAEA guidance on the requirements for waste containers containing ILW [68]. However the presence of a vent leads to the possibility of the release of activity in gaseous and/or particulate form and could be viewed as possibly conflicting with the requirement to ensure adequate containment by the waste container. This leads to the requirement for the vent to be filtered, which could for example be achieved by the use of a proprietary high efficiency particulate in air (HEPA) or sintered filter as part of the vent, or by using a lidding arrangement that incorporates a device such as a labyrinth seal.

The requirement for venting does, however, potentially conflict with a requirement to minimise ingress of water into waste packages in the post-closure period of a GDF. This requirement should be taken into account in vent and filter design and the effective area of the vent minimised.

Precautions should be taken in the waste container design to ensure that there is no alternative gas pathway that could bypass the filtering feature (e.g. through an ineffective body/lid seal), particularly during the earlier, more reactive phases of wasteform evolution.

The following are guidelines on the need for the venting of waste packages and the general requirements of such a system, if it needs to be included in a waste package design:

- Waste packages should be vented if gas production by the wasteform, over the period during which the waste package will need to be handled, is considered capable of causing pressurisation of the waste container.
- Un-vented waste packages should be sufficiently leak-tight such that they are capable of satisfying the requirements for retention of activity under normal handling conditions or under specified impact and fire accident conditions (Section 4.3.8).
- The design of a venting (and filtration) system should not compromise the ability of the waste package to satisfy the requirements for retention of activity under normal handling conditions or under specified impact and fire accident conditions (Section 4.3.8).
- When considering designs of venting systems, waste packagers should take into account the long-term integrity requirements for the waste package (Section 4.1.5). This should include the longevity of the filter medium under the anticipated conditions of waste package storage.

³¹ The short half-life of radon-222 (i.e. 3.8 days) means that if retained for a relatively short period, it will decay to insignificant quantities before it can be released.

- The cross-sectional area of the vent should be as small as possible while still satisfying the required performance criteria.
- The use of a 'cap' of inactive grout placed on top of the active wasteform will significantly reduce the activity associated with particulates released from the upper surface of the wasteform.
- The sealing of waste packages with a filtered vent should be sufficiently leak-tight to ensure that the filter performance is not compromised by alternative gas pathways (e.g. through an ineffective body/lid seal), particularly during the earlier, more reactive phases of wasteform evolution.
- The filter should be able to cope with the maximum gas production rate anticipated under normal conditions.
- The dust-holding capacity of the filter should be such that it would be capable of operating with optimum performance over the envisaged storage period and with the potential levels of particulates.
- The filter should be able to satisfy the required performance criteria at temperatures up to 80°C.

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

The total quantity of fissile material in the waste package should not exceed 47g³².

The quantities of fissile material, neutron moderators and reflectors in shielded waste packages should be controlled to ensure that the transport package can be excepted from the requirements of the IAEA Transport Regulations for packages containing fissile material.

The GWPS defines distinct requirements for the criticality safety of waste packages during the three main periods of their long term management. It is expected that shielded waste packages will typically be used for the conditioning of waste containing relative small quantities of fissile material such that the resulting waste packages would not present a criticality risk at any point during their long-term management.

Furthermore, the TSSA [19] assumes that all shielded waste will be capable of being 'excepted' from the IAEA Transport Regulations requirements for transport packages containing fissile material, and this will generally place such restrictions on the contents of their contents such as they would satisfy all of the requirement for criticality safety.

RWM's approach to achieving the three distinct aspects of criticality safety defined by the GWPS is based on the production of waste packages, which are passively safe in this respect. This is generally achieved by controlling the quantities of fissile material and of

³² This limit is the mass of plutonium-239 or the total mass of all fissile nuclides which would produce the equivalent reactivity of 47g of plutonium-239 with optimal shape and neutron moderation and reflection.

neutron moderating and reflecting materials³³ within waste packages such that criticality cannot occur under all credible conditions during each period. This approach generally involves determining the limiting quantities of fissile materials that will satisfy each of the three requirements stated above and using the most bounding value as the safe fissile mass (SFM) for the proposed waste packages, and the definition of manufacturing controls to ensure that the SFM is not exceeded during waste package manufacture.

The different conditions experienced by waste packages during the three distinct periods of their long-term management (i.e. transport and the GDF operational and post-closure periods) has led RWM to carry out extensive work to develop fissile materials limits for waste packages. This has included, in cooperation with waste producers and industry regulators, the development of methodologies for ensuring criticality safety without placing over onerous demands on the packaging of waste.

Transport

The IAEA Transport Regulations lay down a number of conditions under which transport packages can be exempted from the requirements for packages containing fissile material. This 'fissile exception' of transport packages can be achieved in four ways:

- (i) By virtue of their contents not being classed as 'fissile material', as defined by Paragraph 222;
- (ii) By limiting the quantities of fissile radionuclides in the package such that one or more of the exceptions defined in Paragraph 417 applies;
- (iii) By showing that the package can comply with the requirements of Paragraphs 674 and 675, thereby permitting exception without Competent Authority approval; or
- (iv) By demonstrating that the contents of the package will remain sub-critical under normal and accident conditions of transport, this being subject to Competent Authority approval

The first option is the easiest to apply in that Paragraph 222 defines 'fissile material' as material containing any of the four fissile radionuclides uranium-233, uranium-235, plutonium-239 or plutonium-241 but specifically excludes:

- (a) Natural uranium or depleted uranium which is unirradiated; and
- (b) Natural uranium or depleted uranium which has been irradiated in thermal reactors only.

This second exclusion will encompass a significant proportion of the UK ILW inventory, including most³⁴ of the uranium bearing wastes arising from the operation and decommissioning of Magnox power stations, and of the fuel cycle activities associated with them (notably fuel reprocessing). Care should be taken in the application of this exclusion since some fuel processing operations can result in nominally excluded materials becoming 'fissile material' (e.g. such as those which could result in the accumulation of the outer layers of fuel where the 'skin effect' may have resulted in a higher plutonium content). Waste packagers will also have to be able to rule out the possibility of a waste stream being contaminated with fissile material from another source.

³³ The three most significant materials of interest are graphite, compounds containing deuterium (hydrogen-2) and beryllium.

³⁴ Whilst Magnox power stations primarily used natural uranium fuel there are some instances where fuel with uranium-235 concentrations of greater than that of natural uranium was used.

For materials that cannot be excluded under the definition given by Paragraph 222, fissile exception can be achieved by limiting the quantities of fissile material³⁵ and other relevant materials (i.e. neutron moderators and reflectors), such that the waste package can be 'fissile excepted' in accordance with Paragraphs 417 or 673. Paragraph 417 defines limits for a number of categories of fissile material that can be so excepted, these include waste packages containing:

- (i) uranium with a maximum enrichment of 1% U-235 and containing limited quantities of plutonium and U-233, provided that the fissile nuclides are distributed essentially homogeneously throughout the bulk of the materials in the package;
- (ii) up to 70g of uranium with a maximum enrichment of 5% U-235 and containing limited quantities of plutonium and U-233;
- (iii) up to 2g of fissile nuclides;
- (iv) up to 45g of fissile nuclides, if the waste package is transported under the conditions of exclusive use.

Shielded waste packages containing larger quantities of fissile material than that would permit exception under paragraph 417, can be still be excepted if they can satisfy the high level requirements of Paragraph 673; to '*maintain subcriticality during routine, normal and accident conditions of transport*'. Paragraph 675 outlines how transport packages containing up to 220g of uranium-235, or up to 28g of other fissile nuclides (i.e. uranium-233, plutonium-239 and plutonium-241) can be excepted, without recourse to explicit Competent Authority approval.

It may be possible to transport shielded waste packages fissile material which are not capable of being 'fissile excepted' as Type IF transport packages. This would require the performance of a critical safety assessment to show that the requirements of Paragraph 673 could be maintained under normal and accident conditions of transport, and would be subject to Competent Authority approval.

Guidance has been produced to assist waste packagers in the application of this aspect of the IAEA Transport Regulations for shielded waste packages [69].

GDF operational and post-closure periods

Notwithstanding their ability to be excepted from the IAEA Transport Regulations requirements for packages containing fissile material, all shielded waste packages will also need to be shown to be capable of satisfying the other criticality safety requirements that apply to the GDF operational and post-closure periods. In this context, the RWM *Radiological Protection Policy Manual* (RPPM) [70] applies the Health and Safety Executive's (HSE) *Safety Assessment Principles for Nuclear Facilities* (SAPs) [71] to the treatment of accidents during the GDF operational period. The SAPs requirement ECV.2 states that any containment design (such as that provided by a waste package) should:

'.....incorporate measures to minimise the likelihood of unplanned criticality wherever significant amount of fissile materials may be present.'

This includes a requirement to demonstrate that the risk of criticality during the GDF operational period is ALARP.

RWM has determined a 'general screening level' (GSL) of 47g of fissile material³² for unshielded waste packages to ensure criticality safety during the GDF operational and post-closure periods [72]. In general terms this value will also apply to each of the current designs of shielded waste package.

For waste packages containing larger quantities of fissile material than the GSL, RWM has developed a methodology for the determination of safe fissile masses for a range of

³⁵ Together with other relevant materials, such as neutron moderators and reflectors.

generic fissile materials types when packaged using standardised designs of waste container³⁶.

During the development of proposals to package wastes containing fissile materials, waste packagers will need to take into account all of the aspects of criticality safety discussed above as a means of defining a SFM for the proposed waste packages. The value of SFM will be such as to ensure that manufactured waste packages will be capable of demonstrating compliance with both the regulatory requirements for their transport and the safety cases for disposal. The waste packager will also be required to show that steps will be taken during the actual packaging of the waste to ensure that the SFM cannot be exceeded under all credible circumstances. To this end, as part of a submission for the disposability assessment of proposed waste packages, waste packagers will be required to produce *Criticality Compliance Assurance Documentation* (CCAD). The CCAD will consider the quantity and form of the fissile materials in a waste stream and define the procedural controls which will be put in place to ensure that a defined SFM will not be exceeded during waste package manufacture. RWM has produced guidance on the preferred format of CCAD, and the means by which such documentation can be produced [73].

4.3.8 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 the GDF operational period.

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

Waste packages may be subject to a range of accident conditions during their long-term management, up until the end of the GDF operational period. Specifically these include minor impacts during normal handling and more severe accidents involving impacts and/or fires during transport and the GDF operational period. All such accidents are a potential mechanism for the release of radionuclides from waste packages into the environment in an uncontrolled manner.

The safety cases for transport and the GDF operational period consider the consequences of such accidents, which may involve impact and/or fires, and make assumptions regarding the performance of waste packages under such conditions. Waste packages must therefore be capable of being compliant with assumptions regarding their performance in response to specified impact and fire challenges, which is assessed during the disposability assessment. Additionally all waste packages must be capable of limiting the release of radionuclides following such challenges such that radiation doses to workers and members of the public are ALARP and less than the relevant regulatory limits.

Transport

No explicit accident performance requirements are specified for shielded waste packages for accidents during transport. This accords with the IAEA Transport Regulations which limit

³⁶ To date this methodology has only been applied to unshielded waste packages.

the consequences of accidents involving Type IP transport packages by placing restrictions on their allowable activity (Section 4.3.1) and the physical form of their contents (Section 4.2).

However the Transport Regulations do specify a range of requirements for Type IP transport packages which are aimed at demonstrating their ability to withstand the 'minor' impacts that could occur under NCT. Paragraph 624 requires that Type IP-2 transport packages should be capable of withstanding a 'free drop test' such that it '*...would not suffer any:*

- (a) *loss or dispersal of the radioactive contents; and*
- (b) *loss of shielding integrity which would result in more than a 20% increase in the radiation level at any external surface of the package.'*

The conditions for the free drop test are defined in Paragraph 722 which specifies a height for the test; which depends on the gross mass of the transport package as shown in Table 10.

Table 10 Drop heights to simulate NCT for transport packages'

Transport package mass	Drop height
<5t	1.2m
≥5t but <10t	0.9m
≥10t but <15t	0.6m
≥15t	0.3m

Whilst 'loss or dispersal of radioactive contents' is not quantified, for assessment purposes the maximum activity 'leak rate' of $10^{-6} \text{A}_2\text{hr}^{-1}$ for Type B transport packages under NCT (Paragraph 659 (a)) is used for shielded waste packages transported as Type IP-2 transport packages.

GDF operational period

During the GDF operational period the potential exists for shielded waste packages to be exposed to accidents involving impacts and/or fire which would result in them being subject to a range of mechanical and thermal challenges [74]. Such challenges could result in damage to waste packages, the release of radionuclides within the GDF and to radiation dose to workers on-site and/or members of the public off-site.

The regulatory control of radiation exposure as a result of operations on nuclear licensed sites is by way of criteria defined by the HSE SAPs [71]. In the case of Design Basis Accidents (DBAs), the SAPs define Basic Safety Levels (BSLs) as targets for maximum on- and off-site dose, on the basis of the expected frequency of the initiating fault that would result in such an accident.

The analyses of the consequences of accidents during transport and the GDF operational period form part of the relevant generic safety cases (i.e. [52, 75]). These safety cases summarise why RWM has confidence that the systems for the transport and disposal of waste packages would be safe, under both normal and credible fault conditions, provided that waste packages can perform in an adequate manner. They also provide preliminary assessments of the risk during transport and GDF operations (including GDF construction risk), against regulatory limits and targets. Included in these safety cases are a number of assumptions about waste package properties (e.g. external dose rate, surface

contamination) and performance (e.g. impact and fire accident performance, criticality safety) which are captured in the packaging specifications.

RWM has identified a range of accidents that could affect waste packages during the GDF operational period, and that could result in the release of radionuclides and radiation dose to workers on-site and/or members of the public off-site. These accidents include:

- The dropping of waste packages on to floors or equipment within the GDF;
- The dropping of equipment (including other waste packages) on to waste packages;
- The collapse of single or multiple stacks of waste packages;
- Extreme facility mechanical failures; and
- Fires caused by a variety of faults.

As well as requiring that the doses resulting from accidents in which radionuclides are released are ALARP the HSE Safety Assessment Principles (SAPs) [76] define Basic Safety Objectives (BSOs) for the cumulative annual on- and off-site doses due to accidents on nuclear sites. The SAPs also define Basic Safety Levels (BSLs) as targets for the maximum on- and off-site dose that could result from release of radionuclides as a result of design basis accidents (DBAs), on the basis of the expected frequency of the initiating event that would result in such an accident (Table 11). The highest of these BSLs, for accidents with an expected initiating event frequency of less than 10^{-4} per annum, are therefore used as upper bounds for the dose consequences of GDF accidents. However, for accidents for which a higher fault frequency cannot be discounted, the lower BSLs will apply.

Table 11 Basic Safety Level doses following DBAs

DBA fault frequency	BSL for on-site dose	BSL for off-site dose
$>1 \times 10^{-3}$ pa	20mSv	1mSv
Between 1×10^{-3} and 1×10^{-4} pa	200mSv	10mSv
$<1 \times 10^{-4}$ pa	500mSv	100mSv

It should be noted although the BSLs are targets for the maximum on- and off-site dose that would result from DBAs it is HSE policy that new facilities should at least meet the relevant values. This is on the basis that simply meeting the BSL values may not be ALARP for the facility. In practice, the design of a GDF, and the waste packages that will be disposed there, should be such as to ensure that the doses resulting from DBAs are ALARP and meet targets that reflect modern nuclear safety standards and expectations. To this end, the aim of RWM is to reduce such doses to those defined in the RPPM [70] as BSOs for the cumulative annual on- and off-site doses (i.e. 0.1mSv and 0.01mSv respectively) for accidents involving the release of activity from waste packages occurring at a GDF.

GDF impact accidents

All impact accidents are assumed to subject a waste package to an impact equivalent to that which would result from a free drop from a height at the location at which the fault occurs. Such faults are assumed to involve the impact of a waste package on to an 'unyielding flat surface' such as the floor of a disposal vault, or on to an 'unyielding aggressive feature' such as the edge of another waste package. The mechanical

challenge for a shielded waste package during the GDF operational period is currently defined as a drop of 15m on to either an unyielding surface or aggressive feature.

Other, more extreme faults have also been identified, including the collapse of a vault roof or a handling crane on to waste packages, or the consequences of a 'runaway' transporter in the drift access to the underground facilities. Such faults could result in more severe impacts than that resulting from a 15m drop and could affect groups of waste packages rather than individuals. However, it is also assumed that sufficient safety features would be incorporated in the design of relevant GDF systems to ensure that such events would occur with an initiating event frequency of less 10^{-3} pa.

The definition of the size of particles that will contribute to dose following an impact accident has significance in the definition of waste package impact performance. Historically it had been assumed that all particles with sizes of up to $100\mu\text{m}$ would be taken into account during the assessment of the consequences of GDF impact accidents. It was however acknowledged that this value may be over conservative, especially when the conclusions of an International Commission on Radiological Protection study into the matter are considered [77]. As a means of justifying a reduction in this conservatism RWM has recently commissioned work to determine what constitutes a 'respirable particle' in the context of a GDF [78, 79] and this has led to a reduction in the maximum size of particles that need to be considered in GDF accidents to $10\mu\text{m}$.

GDF fire accidents

A range of accidents has been identified that could result in fires during the operational period and that could result in the release of radionuclides from waste packages and the potential to cause radiation dose to both workers on-site and members of the public off-site [74].

Whilst the design of a GDF would be such as to minimise the possibility of faults that could lead to fire accidents, work has been commissioned to determine the potential severity of the fires that could result from such faults. Historically this had led to the conclusion that a DBA fire accident should be defined as a fully engulfing 60 minutes hydrocarbon pool fire with an average flame temperature of 1000°C [80]. These values are significantly more severe than those specified by the IAEA Transport Regulations for transport accidents (i.e. 30 minutes/ 800°C) and this deliberate conservatism was based on a consideration of complicating factors such as restricted access and firefighting capabilities in a GDF, including a review of the outcomes of investigations of a number of fires in similar circumstances [81].

More recent work has shown that the fire duration for unshielded waste packages in a GDF constricted in the most bounding geology can be reduced to 30 minutes [82]. Additional work is underway to determine whether similar reductions can be made for shielded waste packages.

Assessing the consequences of GDF impact and fire accidents

In order to determine the potential consequences of proposed waste packages for the operational safety of a GDF RWM has developed a methodology that allows the radiological consequences of a wide range of accidents involving the waste packages to be determined [83]. The methodology is applied to specific designs of waste package by way of the *Repository Operational Safety Assessment* (ROSA) 'toolkit' [84]. In calculating the dose consequences of accidents, the toolkit considers a number of factors for specific waste package designs including:

- The radionuclide inventory of the proposed waste packages;

- The release fractions³⁷ (RFs) for the challenges presented by the accidents;
- The availability and efficiency of protective equipment and the ventilation system within a GDF;
- The anticipated proximity, exposure times and breathing rates etc. of on-site workers to radionuclides released during accidents; and
- The exposure routes to members of the public following an off-site release.

For the purposes of guidance, the ROSA toolkit has been used to determine the releases of activity that would lead to the lowest BSLs being equalled for the impact and fire accidents with the greatest on- and off-site dose consequences. These are listed in Table 12 for a range of the most significant radionuclides³⁸ that are found in the wastes that would typically be packaged in shielded waste packages.

The values given Table 12 can be used by waste packagers as a means of identifying issues that may exist regarding the impact and/or fire accident performance of proposed shielded waste packages.

During the evaluation of operational safety that takes place as part of the disposability assessment of proposals to package waste, a full evaluation of the dose consequences of impact and fire accidents involving the proposed waste packages is carried out. The inputs to such an evaluation will include the maximum radionuclide inventory derived as part the disposability assessment and representative RF values for the waste package type. The RFs for different designs of shielded waste packages will depend on both the waste container type and the nature of the wastefrom (i.e. encapsulated or non-encapsulated waste etc.). A limited amount of RF data is available for the current designs of shielded waste package, derived from a combination of finite element modelling and small scale and full size testing [85]. Table 13 lists impact RFs for the three existing designs of shielded box waste package³⁹, standardised for the impact resulting from a drop from a height of 15m on to a 'flat unyielding' surface, and for a wastefrom comprising of cemented heterogeneous metallic waste. Indicative RFs for other drop heights can be determined by simple scaling (i.e. $RF \propto \text{drop height}$).

As noted above, impact accidents can involve waste packages impacting a range of different target types; flat or aggressive, yielding or unyielding, and the magnitude of the RF can depend significantly on the nature of such a target. The consequences of impacts against more aggressive targets such as the corner pillar of another waste package, a stillage or other GDF equipment may also need to be considered in an analysis of the impact accident performance of a proposed waste package design. In this context the RF values given in Table 13 can be used to produce conservative values for the expected releases resulting from the impact of waste packages on to the unyielding floor of a disposal vault. RWM is currently considering the consequences of impacts on to yielding surfaces and representative aggressive features, either of which could result in different RF values.

³⁷ Release fraction is defined as the fraction of the total contents of a waste package (in terms of the mass of material or the activity associated with that material) released as a consequence of a defined accident.

³⁸ The corresponding information on the full range of radionuclides considered by the ROSA toolkit is available from RWM on request.

³⁹ No impact or fire RF values have yet been defined for Type 1 and Type 4 drum waste packages. In the interim it is recommended that the RF values recommended for use with the 2 metre box are used.

Table 12 Unshielded waste package activity release resulting in BSL for faults with frequency $>10^{-3}$ pa

Nuclide	Impact Accidents		Fire Accidents	
	Off-Site (1mSv)	On-Site (20mSv)	Off-Site (1mSv)	On-Site (20mSv)
	TBq	TBq	TBq	TBq
Am-241	4.90E-04	2.90E-06	4.90E-05	5.18E-06
C-14	8.33E 01	1.96E-01	3.62E 00	3.48E-01
Cl-36	2.02E-02	1.64E-02	6.33E-04	2.93E-02
Co-60	1.04E-02	3.91E-03	1.04E-03	6.97E-03
Cs-137	1.13E-02	1.69E-02	1.13E-03	3.02E-02
H-3	2.00E 04	2.76E 00	8.62E 02	4.93E 00
I-129	7.87E-04	1.18E-03	3.37E-05	2.11E-03
Ni-63	2.70E 00	5.67E-02	2.70E-01	1.01E-01
Pu-239	8.62E-04	2.41E-06	8.62E-05	4.30E-06
Pu-240	8.62E-04	2.41E-06	8.62E-05	4.30E-06
Pu-241	6.29E-02	1.33E-04	6.29E-03	2.38E-04
Se-79	7.87E-03	3.65E-02	3.37E-04	6.51E-02
Sr-90	3.42E-03	7.55E-04	3.42E-04	1.34E-03
Tc-99	2.02E-02	2.90E-02	2.02E-03	5.18E-02
U-235	2.94E-03	1.47E-05	2.94E-04	2.62E-05
U-238	2.33E-03	1.55E-05	2.33E-04	2.77E-05

Table 13 Recommended impact RFs for shielded box waste packages dropped from 15m

Waste package type	RF
2 metre box	7.5E-04
4 metre box	3.0E-04
6 cubic metre box	4.5E-04

Fire RFs are a function of waste package type (i.e. container and wasteform), fire severity (i.e. temperature and duration) and the volatility of the radionuclides of interest. To simplify the treatment of the latter aspect RWM has grouped all of the elements that could be present in ILW into six 'volatility groups' and defined a RF for each group. Table 14 lists recommended fire RFs for all three designs of shielded box waste package³⁹ containing a cemented heterogeneous metallic wasteform. The RFs are relevant to a 1000°C/1 hour fire⁴⁰ and, concrete shielding thicknesses of 200mm and 240mm assumed for the 2 and 4 metre boxes and the 6 cubic metre box respectively.

Table 14 Recommended fire RFs for shielded waste packages (1 hour, 1000°C fire)

Volatility group	Elements	RF
I	Ar, As, At, Br, C, Cl, F, H, He, Hg, I, Kr, N, Ne, O, P, Rn, S, Se, Xe	1
II	B, Bi, Cd, Cs, Fr, Ge, In, K, Li, Na, Os, Po, Rb, Re, Sb, Sn, Tc, Te, Tl	7.0E-04
III	Ag, Ba, Be, Ga, Mo, Pb, Ra, Ru, W, Zn	7.0E-04
IV	Al, Au, Ca, Co, Cr, Cu, Eu, Fe, La, Mg, Mn, Ni, Pd, Sr, U, V	6.0E-05
V	Ac, Am, Bk, Ce, Cf, Cm, Es, Fm, Lr, Md, Nd, No, Np, Pu, Rh, Si, Y, Zr	3.0E-05
VI	Db, Dy, Er, Gd, Hf, Ho, Ir, Lu, Nb, Pa, Pm, Pr, Pt, Rf, Sc, Sm, Ta, Tb, Th, Ti, Tm, Yb	3.0E-05

It should be noted that significant variations from the RFs quoted in Table 13 and 14 may occur for different waste packages with different wasteform types. For example a non-encapsulated wasteform could well result in a higher impact RF, whereas a wasteform produced by a high temperature process would be expected to result in a lower impact RF. For wasteforms with significantly different properties to those assumed here, additional modelling and/or testing may be required in order to derive more representative RF values.

Designing waste packages for optimum impact and fire accident performance

When designing a waste package for optimum impact performance the main aims are to achieve low and predictable damage (and the associated release of activity) which is

⁴⁰ No RFs have been defined for a 30 minute fire, the values in Table 14 should be used in the interim.

progressive with increasing impact severity. The impact performance of a waste package is controlled by the properties of both the wasteform and the waste container and both components should ideally play effective and independent roles in minimising the release of activity.

The two key mechanical properties of a waste container material, namely brittle fracture and ductility, have been identified as controlling the impact performance of a container material [68]. Design features of the waste container such as the lid/body connection and container design specifications such as weld locations and type will have the potential to significantly affect impact performance. In general waste container design should avoid stiff, unyielding features juxtaposed to soft yielding features. In this configuration there is the possibility of waste container rupture by punching and shear strain concentration [86]. Such a scenario can occur when heavy non-deformable objects are encapsulated within a wasteform. Under impact conditions the object may dislodge encapsulation grout that in turn, may strike the container walls or the lid, or the object itself may strike the container walls or lid [31].

The fire performance of a waste package is controlled by the properties of both the wasteform and waste container. The waste container forms the primary barrier to an external heating source, protecting the wasteform from direct contact with the fire. It will also restrict the supply of oxygen to the wasteform thereby reducing the possibility of wasteform combustion. The waste container also plays an important role in the overall containment of activity within the waste package during a fire accident. Experimental work with waste packages containing cementitious wasteforms [87] has shown that steam and gases generated within the wasteform provide a major driving force for the escape of activity. The presence of an intact waste container would have a significant effect in reducing such releases.

Modelling and experimental work [87, 88] has shown that higher temperatures, at which the fraction of radionuclides liable to be released from the wasteform may be significant, tends to be restricted to a thin layer around the outside of the wasteform. Accordingly, the thermal properties of the waste container could have a significant effect on the overall performance of the waste package during fire accidents.

The pathway between the waste container and the wasteform is considered to have a significant role in allowing steam and gases generated in the wasteform to be released from the package vent. Failure of such pathways may cause pressurisation of the waste package.

In view of the above, the particular properties of the material used for waste containers which would give benefits during a fire accident would be:

- high melting temperature (i.e. $>1000^{\circ}\text{C}$) – to ensure that overall containment is maintained;
- lack of phase transitions at temperatures below 1000°C – as above;
- non-combustibility;
- low thermal expansion – to limit the possibility of waste container failure due to uneven expansion;
- low thermal conductivity – to limit the conduction of heat to the wasteform.

The role played by the wasteform in achieving the required waste package performance during impact and/or fire accidents is dealt with in detail in the wasteform guidance that complements this Guidance (i.e. [6, 7]).

5 Summary

The Generic Specification for waste packages containing LHGW [3] defines the requirements for all such waste packages, irrespective of the design and nature of the waste container or the wasteform they contain. The DSTS [5] identifies a limited range of standardised designs of waste container which incorporate integral radiation shielding and which are suitable for the packaging of LHGW in a form suitable for transport to and disposal in a GDF.

This document explains the manner by which the requirements of the Generic Specification are applied to shielded waste packages and provides guidance on the means by which those requirements could be achieved for actual waste packages.

Whilst this guidance is primarily aimed at waste packages manufactured using the existing standardised designs of waste container, much of the information it contains is relevant to other approaches to the packaging of waste that would result in the manufacture of waste packages that could be described as 'shielded'. Users are encouraged to contact RWM at an early stage in the development of such approaches.

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Appendix A Constraints placed on Type IP transport packages by the IAEA Transport Regulations

Transport package property	Limits or constraints on Type IP transport packages
Total activity content	<p>Contents must be LSA material (Paragraphs 226 and 409) or SCOs (Paragraphs 241 and 413).</p> <p>Paragraph 517: Total quantity of LSA material or SCOs must be limited to ensure that the external radiation level at 3m from the unshielded material does not exceed 10mSv h^{-1}.</p> <p>Paragraph 522: The total quantity of LSA or SCO in the form of combustible solids, liquids or gases not to exceed 100A_2 (10A_2 if transported by inland waterway)</p>
Non-fixed surface contamination	<p>Paragraph 508: When averaged over any area of 300cm^2, non-fixed surface contamination shall not exceed 4Bq cm^{-2} for beta and gamma emitters and low-toxicity alpha emitters, and 0.4Bq cm^{-2} for other alpha emitters.</p>
External dose rate	<p>Paragraph 569: Under conditions of exclusive use; not more than 10mSv h^{-1} at the surface and 0.1mSv h^{-1} at 2m from the surface.</p> <p>Paragraph 563: Under conditions of non-exclusive use; not more than 2mSv h^{-1} at the surface and 0.1mSv h^{-1} at 1m from the surface.</p>
Release of activity during normal transport operations	<p>Paragraph 624: When submitted to specified mechanical challenges (Paragraphs 719 to 724) the package should be capable of preventing:</p> <ul style="list-style-type: none"> • loss or dispersal of radioactive contents; and • more than a 20% increase in the maximum external dose rate.
Control of fissile material	<p>Paragraph 673: Packages containing fissile material (as defined by Paragraph 222) must be able to be shown to be capable of remaining subcritical, singly and in arrays, under all normal and credible accident conditions.</p> <p>Packages containing fissile material can be excepted from the requirements for packages containing fissile material if they can satisfy the provisions of Paragraphs 417 or 674.</p>
Stacking	<p>Paragraph 723: Packages should be capable of resisting a compressive load equal to 5 times their maximum weight for a period of 24 hours, following which they must be capable of satisfying the requirements of Paragraph 622 (i.e. to prevent the loss or dispersal of contents or loss of shielding integrity).</p>
Heat output	<p>Paragraph 562: Packages with an average surface heat flux exceeding 15W m^{-2} may require special stowage provisions.</p>
<p>No requirements for: External surface temperature, gas generation or the release of activity under accident conditions of transport.</p>	

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 [18].

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.

conditioning

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

container

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

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.

disposal vault

Underground opening where ILW or LLW waste packages are emplaced.

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 (Sv h^{-1}), millisieverts/hour (mSv h^{-1}) and sievert/year (Sv y^{-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.

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 Office for Nuclear Regulation (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.

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.

Industrial Package (Type-IP)

A category of transport package, defined by the IAEA Transport Regulations for the transport of radioactive materials with low specific activities.

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.

low specific activity (LSA) material

A material classification defined by the IAEA Transport Regulations as 'Radioactive material which by its nature has a limited specific activity (i.e. activity per unit mass of material), or radioactive material for which limits of estimated average specific activity apply.'

Managing Radioactive Waste Safely (MRWS)

A phrase covering the whole process of public consultation, work by CoRWM, and subsequent actions by Government, to identify and implement the option, or combination of options, for the long term management of the UK's higher activity radioactive waste.

Nuclear Decommissioning Authority (NDA)

The NDA is the implementing organisation, responsible for planning and delivering the 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.

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.

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 Limited (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, RWM will evolve under the NDA into the organisation responsible for the delivery of the 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.

safety function

A specific purpose that must be accomplished for safety.

shielded waste package

A shielded waste package is one that either has in-built shielding or contains low activity materials, and thus may be handled by conventional techniques.

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 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.

stack (of waste packages)

A stack of waste packages placed vertically one on top of each other.

surface contaminated object (SCO)

A solid object which is not itself radioactive but which has radioactive material distributed on its surfaces.

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 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.

unshielded waste package

A waste package which, owing either to radiation levels or containment requirements, requires remote handling and must be transported in a reusable transport container.

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. The categories generally used are:

- depleted uranium: <0.71% uranium-235;
- natural uranium: ~0.71% uranium-235;
- low enriched uranium: Up to ~5% uranium-235; and
- highly enriched uranium: >5% uranium-235.

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

Any vessel used to contain a wasteform for disposal.

wasteform

The waste in the physical and chemical form in which it will be disposed of, including any conditioning media and container furniture (i.e. in-drum mixing devices, dewatering tubes etc) but not including the waste container itself or any added inactive capping material.

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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