Nuclear Decommissioning Authority

WASTE PACKAGE SPECIFICATION AND GUIDANCE DOCUMENTATION

WPS/730: 4 metre Box Waste Package Specification: Explanatory Material and Design Guidelines

March 2008
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WASTE PACKAGE SPECIFICATION AND GUIDANCE DOCUMENTATION

4 METRE BOX WASTE PACKAGE SPECIFICATION: EXPLANATORY MATERIAL AND DESIGN GUIDELINES

This document forms part of a suite of documents prepared and issued by the Radioactive Waste Management Directorate (RWMD) of the Nuclear Decommissioning Authority (NDA).

The Waste Package Specification and Guidance Documentation (WPSGD) provide specifications and guidance for waste packages, containing Intermediate Level Waste and certain Low Level Wastes, which meet the transport and disposability requirements of geological disposal in the UK. They are based on, and are compatible with, the Generic Waste Package Specification (GWPS).

The WPSGD are intended to provide a 'user-level' interpretation of the GWPS to assist Site License Companies (SLCs) in the early development of plans and strategies for the management of radioactive wastes. To aid in the interpretation of the criteria defined by the WPSGD, and in their application to proposals for the packaging of wastes, SLCs are advised to contact RWMD at an early stage.

The WPSGD will be subject to periodic enhancement and revision. SLCs are therefore advised to contact RWMD to confirm that they are in possession of the latest version of any documentation used.

WPSGD DOCUMENT NUMBER WPS/730 - VERSION HISTORY		
VERSION	**DATE**	**COMMENTS**
WPS/730/01	October 2005	Aligns with GWPS (Nirex Report N/104) as published June 2005
WPS/730/02	March 2008	Responsibility for the WPSGD passed to RWMD. Aligns with Issue 2 of GWPS (Nirex Report N/104) as published March 2007. Changes comprise: Changes to NII SAPs and modelling of DBAs

This document has been compiled on the basis of information obtained by Nirex and latterly by the NDA. The document was verified in accordance with arrangements established by the NDA that meet the requirements of ISO 9001. The document has been fully verified and approved for publication by the NDA.

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1 INTRODUCTION

The Radioactive Waste Management Directorate (RWMD) of the Nuclear Decommissioning Authority (NDA) has been established with the remit to implement the geological disposal option for the UK's higher activity radioactive wastes. The NDA is currently working with Government and stakeholders through the *Managing Radioactive Waste Safely* (MRWS) consultation process to plan the development of a Geological Disposal Facility (GDF).

As the ultimate receiver of wastes, RWMD, acting as GDF implementer and future operator, has established waste packaging standards and defined package specifications to enable the industry to condition radioactive wastes in a form that will be compatible with future transport and disposal. In this respect RWMD is taking forward waste packaging standards and specifications which were originally developed by United Kingdom Nirex Ltd, which ceased trading on 1st April 2007 and whose work has been integrated into the NDA.

The primary document which defines the packaging standards and specifications for Intermediate Level Waste (ILW), and certain Low Level Wastes (LLW) not suitable for disposal in other LLW facilities is the Generic Waste Package Specification (GWPS) [1]. The GWPS is supported by the Waste Package Specification and Guidance Documentation (WPSGD) which comprises a suite of documentation primarily aimed at waste packagers, its intention being to present the generic packaging standards and specifications at the user level. The WPSGD also includes explanatory material and guidance that users will find helpful when it comes to application of the specification to practical packaging projects. For further information on the extent and the role of the WPSGD, reference should be made to the *Introduction to the Waste Package Specification and Guidance Documentation, WPS/100*[1].

RWMD has defined a range of standard containers that can be used to produce waste packages, and has issued a specification for each waste package. To assist waste packagers in applying these specifications to their waste packaging proposals, each waste package specification is accompanied by a document containing explanatory material and design guidelines. This document contains the explanatory material and design guidelines that accompany *Specification for 4 metre Box Waste Package, WPS/330*.

[1] Specific references to individual documents within the WPSGD are made in this document in *italic script,* followed by the relevant WPS number.

2 BACKGROUND

2.1 The Concept of Geological Disposal

A key aspect in the production of standard and specifications for packaged waste is the definition of a disposal system which encompasses all stages of the long-term management of waste from retrieval through to final disposal.

In line with the MRWS consultation process, RWMD are continuing to develop concepts for the geological disposal for higher activity wastes which include ILW, and certain LLW not suitable for disposal in other LLW facilities[2]. It is envisaged that the geological disposal of such wastes would comprise a number of distinct stages including:

- the retrieval and conditioning of the waste to create disposable waste packages, usually at the site of waste arising;
- a period of interim surface storage, also at the site of arising;
- transport of the waste packages to a GDF;
- transfer of waste packages underground and emplacement in disposal vaults;
- a period of monitored storage underground, during which retrieval by relatively simple means would be feasible;
- back-filling of the disposal vaults, followed by eventual sealing and closure.

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

The Phased Geological Repository Concept (PGRC) [2], has been developed as one manifestation of geological disposal and has been adopted as the reference concept for the purposes of establishing packaging standards. The PGRC is supported by a suite of safety, security and environmental assessments intended to demonstrate that this concept will provide safety to workers and the public and provide the necessary level of environmental protection.

The safety philosophy adopted in the PGRC is one of containment of radionuclides by multiple barriers, of which that provided by the waste package is a key component. Included in these barriers are those provided by the waste package, which itself can be considered as two independent but complimentary barriers, the waste container and the wasteform, each of which plays an important role in the containment of radionuclides.

As the MRWS consultation process continues it is anticipated that the siting process, based on expressions of interest from volunteer communities, may lead to the identification of sites for investigation as to suitability to host a GDF. The disposal concept

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[2] The generic description 'ILW' is used in the remainder of this document to describe both these categories of waste.

design and safety case will be developed to suit the specific characteristics of the site and packaging standards will be updated to reflect the new circumstances as appropriate.

2.2 The Generic Waste Package Specification

A major area of the RWMD's work is the provision of advice to the packagers of radioactive waste in the UK, by way of the definition of packaging standards and the assessment of individual waste packaging proposals against those standards.

The primary document that defines packaging standards for ILW is the GWPS [1]. Derived from the PGRC and its associated generic documentation, which comprise the system specifications and safety assessments that define the PGRC, the GWPS provides the basis for assessing the suitability of waste packages containing ILW for disposal in a GDF.

The packaging standards defined by the GWPS are generic in two respects in that they are:

- derived from a full consideration of all future stage of long-term waste management; and
- independent of the location of the site of a GDF, which could be implemented at a range of different sites within the UK, representing a range of geological environments.

The format of the GWPS is to define:

- general requirements that are applicable to all waste packages;
- a range of standard waste containers;
- specific requirements for the standard waste package design that are created using the standard waste containers;
- requirements for the conditioned wasteforms that are placed into containers;
- requirements for quality management and for the creation and maintenance of records about each individual waste package.

The GWPS therefore defines the performance requirements for the two barriers to the release of radionuclides provided by the waste package, the waste container and the wasteform, against which the overall performance of waste packages can be assessed.

2.3 The Assessment of Packaging Proposals

Since the mid-1980s, waste producers in the UK have made significant investment in waste retrieval and packaging plant as a means of ensuring that such wastes are rendered passively safe and suitable for disposal. Historically Nirex was responsible for the assessment and endorsement of the suitability of packaging processes for this latter need, originally by way of the 'Letter of Comfort' assessment process. Over the ensuing two decades the Letter of Comfort process has developed and matured to a point that the assessments undertaken were established on a more structured footing with detailed advice being issued to waste producers highlighting further information needs, or need for further development and/or research before a Letter of Comfort could be issued. The assessment process was also modified to integrate better with the implementation of packaging plant projects, with staged interactions occurring at a number of stages before active operation of a packaging plant commenced. The status of the assessment process was strengthened in January 2004, when support was provided by UK nuclear regulators, and it was recognised within improved regulatory arrangements for nuclear licensed sites [3]. This was accompanied by significant changes to the assessment process which was renamed the 'Letter of Compliance' assessment process, a full description of which can be found in *Guide to the Letter of Compliance Assessment Process, WPS/650*.

In April 2007 Nirex was dissolved and its responsibilities assumed by RWMD. This included the role of assessing and endorsing nuclear site operators' waste packaging proposals through the LoC assessment process.

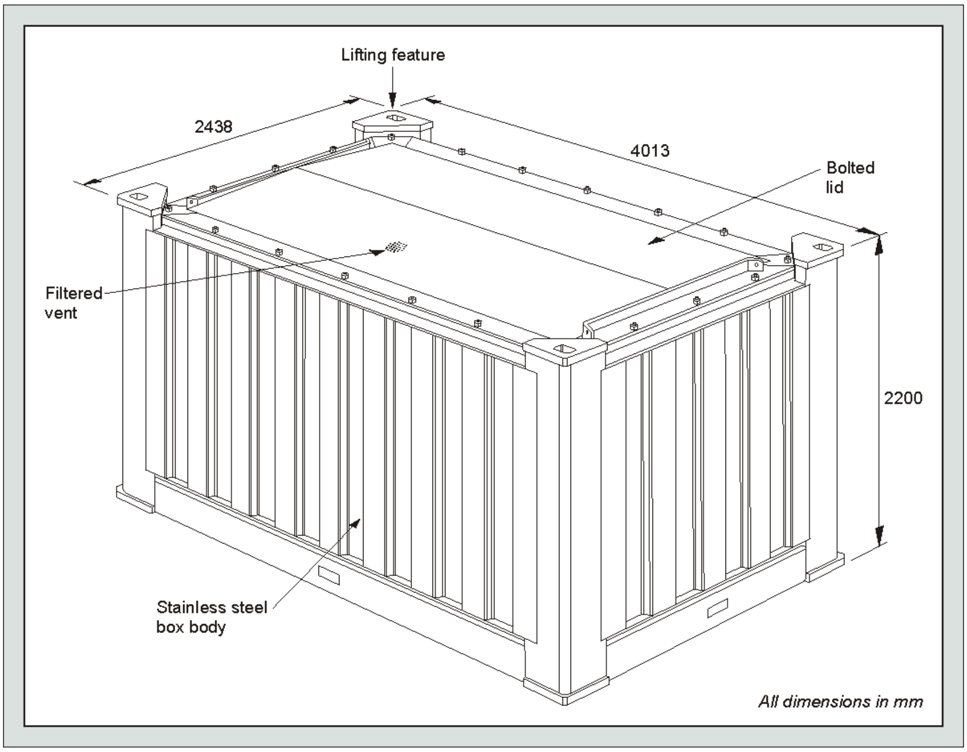
In undertaking LoC assessments RWMD determines whether wastes, when packaged, will have characteristics compliant with plans for transport to, and operations at a GDF, and ultimately whether the wastes could be accommodated within a GDF long-term post-closure safety case. The main output of a LoC assessment is an Assessment Report which may be accompanied by the issue of a LoC endorsing the packaging proposal. In line with the recently updated regulatory guidance [4] such endorsement is now seen by the regulators as an important component of the operator's Radioactive Waste Management Case.

This specification is intended to provide waste packagers with a reference point against which waste packaging proposals can be progressed to the point at which a submission for assessment by way of the LoC process can be made. Waste packagers will find *Guidance on the Preparation of Letter of Compliance Submissions, WPS/908,* of assistance in this matter.

3 THE 4 METRE BOX WASTE PACKAGE

The 4 metre Box waste package (Figure 1) is one of a limited range of standard waste packages defined by the GWPS. It is essentially a freight container than can incorporate its own shielding in the form of a concrete liner. The 4 metre Box waste package is intended to be sued predominantly for ILW arising from the decommissioning of redundant nuclear facilities.

Figure 1 4 metre Box Waste Package



The 4 metre Box waste package is a 'shielded waste package' in that, where necessary, it will have built-in shielding and/or contain low activity materials, such that they do not need remote handling techniques. In view of the wide range of activities of the wastes that could be conditioned using 4 metre Box waste packages it is anticipated that four different shielding thicknesses could be used; 0mm, 100mm, 200mm and 300mm.

As well as being suitable for disposal in a GDF, 4 metre Box waste packages are specified in such a manner as to qualify as transport packages in their own right and capable of being transported through the public domain without the need for an overpack to provide additional radiation shielding and/or containment.

The 4 metre Box waste package is classed as an Industrial Package Type 2 (Type IP-2) under the IAEA Transport Regulations [5] and as such, the allowable contents are limited to materials that qualify as Low Specific Activity (LSA) material and/or Surface Contaminated Objects (SCO).

4 CRITERIA

This specification defines the key features and sets minimum standards of performance for 4 metre Box waste packages, taking into account all of the requirements for long-term management. They are therefore appropriate for all stages of long-term management but shall be applied to waste packages at the time of transport from the waste packager's site unless otherwise stated.

It should be noted that, where the words *shall* and *should* are used in criteria within this specification, their use is consistent with the recommendations of BS 7373:1998 [6] and that they have the following meaning:

- *shall* denotes a criterion which is derived from consideration of a regulatory requirement and/or which forms the basis for package standardisation;
- *should* denotes a criterion which is considered as a target, and for which variations may be possible following discussion with RWMD.

4.1 Activity Content

The waste package shall contain conditioned ILW or LLW and the waste package activity contents shall be restricted to meet the other aspects of this specification (i.e. heat output, dose rate, criticality safety and normal operational and accident release criteria).

The contents of the waste package shall be solid LSA material or SCO. The quantity of LSA material or SCO in the waste package shall be so restricted that the external radiation level at 3 metres from the unshielded material does not exceed 10mSvh^{-1}.

The contents of the waste package shall be capable of being excepted from the IAEA Transport Regulations requirements for packages containing fissile material.

The 4 metre Box waste package is primarily intended for the conditioning, transport and long-term management of ILW arising from operations to decommission nuclear facilities, although it is equally suitable for use with LLW from similar sources.

The 4 metre Box waste package has been designed to satisfy the requirements of ISO-1496 [7] for freight containers defined as IP-2 packages by the IAEA Transport Regulations. Therefore, the waste to be transported must comply with the activity limits and all other requirements for LSA material or for SCO.

Under the IAEA Transport Regulations IP-2 packages are permitted to carry all classes of solid LSA and SCO, although LSA-III material can only be carried under the conditions of 'exclusive use'[3].

Among the restrictions regarding the physical and chemical nature of LSA and SCO (Paragraphs 226 and 241) are the following restrictions on activity content:

LSA-II: *'….material in which the activity is distributed throughout and the estimated average specific activity does not exceed $10^{-4}A_2/g$…'* [4]

LSA-III: *'The estimated average specific activity of the solid, excluding any shielding material, does not exceed $2 \times 10^{-3}A_2/g$.'*

The total amount of LSA or SCO in an IP-2 package must also be limited (Paragraph 521) such that:

> '…*the external radiation level at 3m from the unshielded material…….does not exceed $10mSvh^{-1}$.'*

with a further restriction of $100A_2$ on the total activity of LSA/SCO in the form of 'combustible solids' carried on a single vehicle (Paragraph 525).

RWMD have produced *Guidance on the Application of the IAEA criteria for Low Specific Activity Material to Shielded Waste Packages, WPS/910* to assist waste packagers in the interpretation of this aspect of the IAEA Transport Regulations and with their application to 4 metre Box waste packages.

The limit on the total activity content of an individual waste package is generic with respect to the site of a future GDF. However, when a specific site is identified, the authorised limits for certain radionuclides may be particularly sensitive to site-specific factors in the post-closure safety case. Work has been carried out to determine the specific impact of individual radionuclides on a GDF [8] and has derived Guidance Quantities (GQ) for each of the 112 'relevant radionuclides' that could, potentially, impact on the safe long-term management of packaged waste. Waste producers intending to package significant quantities of these radionuclides, before Waste Acceptance Criteria specific to a specific GDF become available, are advised to maintain close contact with RWMD.

The quantity of activity that can be packaged in a 4 metre Box waste package may also be limited by other criteria, such as external dose rate (Section 4.2), heat output (Section 4.3), the requirement for limiting the quantity of fissile material (Section 4.12) and the requirements of the impact and fire performance of the waste package (Sections 4.13 and 4.14).

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[3] Exclusive use' is defined by the IAEA Transport Regulations as meaning *'the sole use, by a single consignor, of a conveyance or large freight container, in respect of which all initial, intermediate and final loading and unloading is carried out in accordance with the consignor or consignee'.* If all of these conditions cannot be met, transport is deemed to take place under 'non-exclusive use'.

[4] A_2 is a measure of activity linked to possible exposure pathways and defined in the IAEA Transport Regulations.

4.2 Dose Rate

The dose rate at 1 metre from the surface of the waste package shall not exceed 0.1mSvh^{-1} and the dose rate on its external surface shall not exceed 2mSvh^{-1}. These requirements are in addition to the dose rate restriction resulting from controls on activity content, as specified in Section 4.1.

The 4 metre Box waste package is designed to be a transport package and, accordingly must comply with the external dose rate limits for radioactive waste packages transported through the public domain, as set by the IAEA Transport Regulations [5]. The actual limits depend on the operational procedures applied during transport and, in line with a conservative approach, RWMD has adopted the more stringent of the two transport regimes from the point of view of external dose rate, those pertaining to transport carried out under the conditions of 'non-exclusive use'. For packages transported under these conditions:

- the dose rate at 1m from the surface of a transport package shall not exceed 0.1mSvh^{-1} and;
- the dose rate on its external surface shall not exceed 2mSvh^{-1}.

Waste packages with higher radiation levels may be permitted, but this would be dependent on the approval certificate for the package, the operational procedures applied during transport and the operational period of a GDF. The ultimate upper limits for the dose rate from transport packages are those defined for 'exclusive use' and are:

- the dose rate at 2m from the surface of a transport package shall not exceed 0.1mSvh^{-1} and;
- the dose rate on its external surface shall not exceed 10mSvh^{-1}.

4.3 Heat Output

The total heat output from the waste package should not exceed 200 watts.

Waste packages generate heat as a result of the radioactive decay of their contents (radiogenic heat), as well as from other sources such as biodegradation, cement hydration, corrosion and other chemical reactions. Typically, the radiogenic heat output of ILW is of the order of 1Wm^{-3} although variations of up to two orders of magnitude either side of this value are not unusual.

The radiogenic heat output from a waste package can be calculated from the radionuclide content and the effective radioactive decay energy per disintegration for each radionuclide (typically a few W/TBq).

Heat generation by non-radiogenic mechanisms can also be significant and could amount to an additional 3Wm^{-3} at times depending on the physical and chemical composition of the waste and conditioning materials. In extreme cases this additional heat could affect thermal performance, particularly following backfilling. Non-radiogenic sources of heat should therefore be included in heat calculations if they are likely to exceed 0.1Wm^{-3}. The anticipated timescales of such additional heat generation may also need to be considered.

Heat generation by waste packages affects all of the stages of their long-term management and limits have to be set accordingly. During transport, assurance is required that internal heat generation will not alter the physical state of the package or its contents. Additionally, the IAEA Transport Regulations [5] place limits on the external temperature and surface heat flux of transport packages.

For the operational period of a GDF, the Generic Disposal System Specification (GDSS) [9] defines the following temperature targets:

'A long-term temperature target of up to 50°C shall be applied to all waste packages.

During the operational phase, short-term excursions above the 50°C target will be tolerable: e.g. experimental data are available to justify increases in waste package temperatures of up to 80°C as acceptable for a period of 5 years. For shorter durations, higher temperatures would probably be acceptable but experimental data are not currently available to demonstrate this.'

Studies of the effect of heat generated by 4 metre Box waste packages during the operational period of a GDF [10] have shown that heat outputs well in excess of the limit set by transport would be required to challenge the maximum temperature targets.

Following vault backfilling, when the same temperature targets will apply, considerable quantities of additional heat are generated by the hydration of the cementitious backfill and studies have been carried out [11] to determine the maximum heat output that could be allowed from 4 metre Box waste packages without challenging either the short or long-term temperature targets.

Consideration of the restraints discussed above has led to a limit of 200W on the heat output from 4 metre Box waste packages.

4.4 Surface Contamination

The non-fixed surface contamination of the waste package should be as low as reasonably achievable and, when averaged over an area of 300cm^2 of any part of the surface of the waste package, shall not exceed:

- ***4.0Bqcm^{-2} for beta, gamma and low toxicity[5] alpha emitters and;***
- ***0.4Bqcm^{-2} for all other alpha emitters.***

Limits on non-fixed surface contamination are specified as a means of ensuring that the contamination of transport systems and waste package handling areas in a GDF are maintained below acceptable levels. The routine handling of contaminated waste packages could lead to a gradual build-up of contamination of transport and GDF equipment with an associated increase in the doses to workers during normal operations and maintenance. This would require decontamination operations which themselves produce liquid and airborne effluents that will require treatment and handling. To ensure that doses to workers and the public are ALARP, and in accordance with good industry practice, limits on surface contamination of waste packages are therefore necessary and those specified above should be considered absolute upper limits.

The 4 metre Box waste package is designed to be capable of being transported to a GDF without overpacking, as a Type IP-2 transport package. Accordingly the non-fixed surface contamination limits specified by Paragraph 508 of IAEA Transport Regulations [5] apply directly to such waste package in order that they can be transported through the public domain.

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[5] Defined 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.

The limits specified are intended to control surface contamination to realistic and achievable levels and will reduce any potential requirement for the decontamination of waste package handling areas.

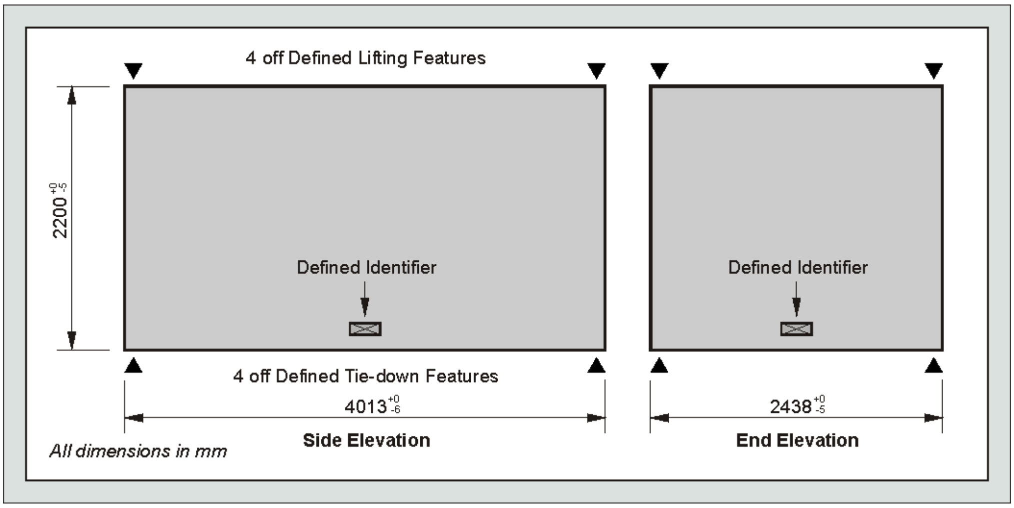
In recognition of the need to minimise the surface contamination of waste packages RWMD has produced specific design guidance on the requirements and the methods for the control of the surface finish of waste containers [12].

4.5 Dimensions

The overall dimensional envelope of the waste package shall be

- ***Length:*** ***4013mm +0mm/-6mm***
- ***Width:*** ***2438mm +0mm/-5mm***
- ***Height:*** ***2200mm +0mm/-5mm.***

Figure 2 Standard features of the 4 metre Box waste package



It is essential that all 4 metre Box waste packages fit within a maximum dimensional envelope that is compatible with the transport and GDF handling systems, and that also allows for the optimum utilisation of vault space.

To allow handling and restraint during transport, the key dimensions are those relating to the location of the handling features as discussed in Section 4.6 below. Dimensions must also be standardised for transport on standard vehicles within the regulations for road and rail transport. The cross-sectional limits of the UK rail ‘loading gauge’ are the chief constraint; the specified dimensions give a minimum clearance of 155mm within the W6A rail gauge, at the top corner of the waste package. This clearance will allow the option of an overpack if this becomes necessary at any time in the future.

Most importantly, dimensions must be standardised for disposal, where the boxes are to be placed in the disposal vault with an accuracy of better than 100mm.

Tolerance bands are specified to allow reasonable manufacturing tolerances and are in accordance with current practice for freight container construction, they also include an allowance for any change of the container shape due to the effects of the packaging process.

4.6 Handling Features

To allow lifting, handling and restraint during transport, corner fittings suitable for the waste package mass, and based on the British and International Standards for Freight Containers, shall be provided, in the form of twistlock apertures of dimensions and geometry as defined in Figure 3, located as shown in Figure 4.

The waste package shall be capable of being lifted using any three of the twistlock apertures, without exhibiting any permanent deformation, with a force equivalent to twice the maximum gross mass specified for the waste package.

Figure 3 Twistlock Dimensions and Geometry

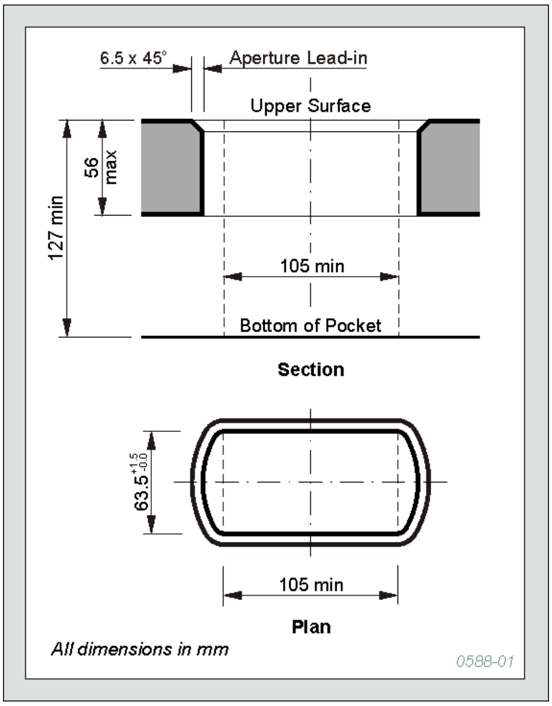
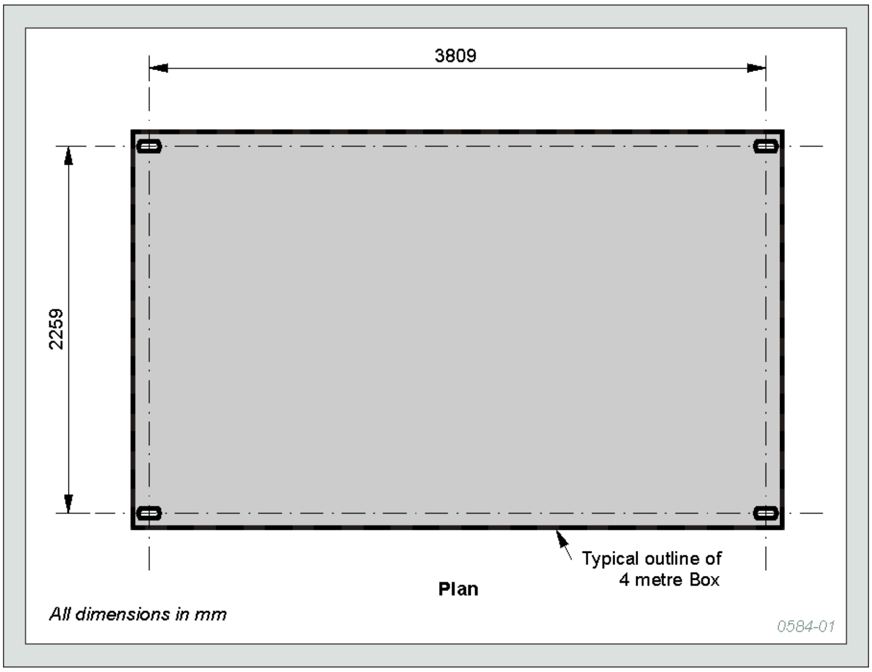


Figure 4 Layout of Lifting Feature for 4 metre Box



The 4 metre Box waste package will be handled using a top-lift spreader fitted with lifting twistlocks as described in *Lifting frame for 4 metre Box. Description and Design Guidelines, WPS/602*. Each waste package must therefore be provided with four corner fittings on the top face for lifting, and a further set of four fittings at the corners of the base for restraint during transport. Examples of methods for securing freight containers for transport are also given in Part 1: Section 1.5:1989 of BS 3951 [13].

The corner fittings should be rated for the maximum package mass[6] and should incorporate standard twistlock fittings in accordance with Part 1: Section 1.2: 1985 of BS 3951 [14]. It should be noted that the corner fittings only require apertures on horizontal surfaces and there is no requirement for side or end apertures.

The philosophy of ISO 1496/1 is that the tolerances specified on dimensions, as shown in Appendix A, are satisfied following manufacture. A prototype design will be subjected to a series of regulatory tests, as discussed in Section 4.17, these tests being 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 [5] and the accelerations experienced by the restraints during normal conditions of transport (NCT) must also be considered.

To comply with the requirements for lifting at a GDF, each twistlock point must be designed to withstand the weight of the box in a three-point lift, multiplied by a 'snatch factor' of 2, without any permanent deformation. Snatch factor being an equivalent term to that described as 'impact factor' in BS 2573 [15].

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

4.7 Mass

The gross mass of a waste package should not exceed 64,000kg.

The maximum allowable mass of waste packages is set by a combination of constraints imposed by the transport system and a GDF handling systems.

Waste packages can be transported by road or rail[7]. Most of the UK rail system limits axle loading to 22.5t per axle, which leads to a maximum loaded rail wagon mass of 90t for a four-axle wagon. The current design of rail wagon has an unladen mass of 26t which limits the maximum transport package mass to 64t. However, for packages transported by road, the maximum mass that can be transported on an ordinary heavy goods vehicle is 30t. Packages with masses greater than this will require special transport arrangements, so if road transport is required there may be operational benefits in maintaining package masses below 30t.

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6 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.

7 The possibility for transport by sea also exists, although no specific constraints would arise from that mode of transport.

A further imitation on the maximum mass for packages to be transported by road arises from an interpretation of legislation regarding 'abnormal and indivisible loads' [16]. Packages with masses exceeding 30t can only be transported by road if they are deemed to be 'indivisible', this being defined as:

> *'...a load that cannot without undue expense or risk of damage be divided into two or more loads for the purpose of being carried on a road...'*

RWMD is currently seeking clarification on how this affects the transport of waste packages on the public highway. Until this matter has been resolved, waste packagers should be aware of this potential further constraint on the maximum allowable mass for 4 metre Box waste packages transported by road.

Once delivered to a GDF, transport packages have to be unloaded and transported on site for emplacement. It is currently assumed that handling equipment at a GDF would be designed to handle transport packages with masses of up to 65t.

4.8 Gas Generation

The total radioactive gas release rate from the waste package should not exceed 10^{-6} A_2 per hour.

Radioactive gases are generated by wasteforms by three principal mechanisms:

- release of tritium and entrained noble gases (Ar, Kr, Xe) by diffusion or corrosion;
- radioactive decay of radium and the release of radon;
- chemical production of bulk gases containing radioisotopes (e.g. $^{14}CH_4$, $^{14}CO_2$).

Releases of all activity, including radioactive gases, during transport through the public domain are subject to limits defined by the IAEA Transport Regulations [5]. As Type IP-2 transport packages, 4 metre Box waste packages are not subject to specific numerical limits on the release of activity under normal conditions of transport (NCT) although such transport packages must be designed in such a way as to '*prevent loss or dispersal of the radioactive contents'.* This requirement is not quantified and RWMD has chosen to apply the same activity release limit to the 4 metre Box waste package as that which is required of Type B transport packages under NCT (i.e. $10^{-6}A_2$/hr). On this basis, Appendix B lists the allowable activity release rates (in TBq day^{-1}) for a range of radioactive gases for the 4 metre Box waste package.

In the particular case of Rn-222, control of the rate of gas generation is primarily by control of the quantity of the parent radionuclide Ra-226 in the waste package. A study of the effects of radium in waste packages, *Guidance Note on the Packaging of Radon-generating Wastes*, *WPS/902* has derived maximum waste package inventories, above which measures will need to be taken to limit the release of Rn-222 from the wasteform.

The specified limits for the release of radioactive gases are very conservative as they give no credit for number of beneficial factors such as the low pressure drive resulting from the small pressure difference across the waste package lid seal and vent and the radioactive decay of short-lived gaseous radionuclides within the wasteform. These factors may be taken into account during the assessment of packages whose predicted releases of radioactive gases are in excess of the values given in Appendix B.

For waste packages that have the potential to exceed the specified limits the potential exists for the sealing of waste package vents for the duration of the period of transport, provided that the possibility of excessive pressurisation of the waste package can be eliminated.

4.9 Venting

Waste packages that, by virtue of the nature of their container and/or contents, could be susceptible to pressurisation due to gas generation at any time, should incorporate an engineered vent designed to retain significant particulate activity.

Gases may be generated in wasteforms by a variety of processes including:

- chemical processes, such as corrosion;
- microbial degradation of organic materials;
- radiolysis of water and organic materials;
- radioactive decay producing gaseous products (e.g. Rn);
- release of entrained radioactive gases (e.g. H-3, Ar, Kr).

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

- pressurisation and damage of the wasteform, leading to increased release of radionuclides under normal and accident conditions;
- pressurisation of unvented waste packages leading to distortion and/or damage to the waste container;
- releases of radioactive/toxic/flammable gases from packages;
- alteration of the chemical characteristics of the backfill;
- pressurisation and damage to the surrounding geology;
- generation of additional groundwater flow pathways and modification of flow patterns;
- modification to the rate of re-saturation of the disposal vault.

Waste packages that have the potential to generate significant quantities of gas, by any of the mechanisms identified above, will need to be assessed to determine the magnitude of potential releases and their consequences, and such packages may require filtered venting to be provided.

The generation of gas within a sealed waste package under normal or accident conditions (in particular, fire) could lead to pressurisation of the waste container and the wasteform, unless steps are taken to avoid it. Pressurisation can lead to swelling, damage to the structure of the wasteform and eventual failure of the container. This could compromise the integrity of the barriers provided by the waste package against the release of activity.

The requirement to reduce the possibility of package pressurisation is an important requirement of geological disposal, along with the requirement to minimise the release of particulate activity. This leads to the requirement for the vent to be filtered, which could for example be achieved by using a proprietary high efficiency particulate in air (HEPA) or sintered filters.

The requirement for venting does potentially conflict with a requirement to limit the release of radioactive gases from 4 metre Box waste packages during transport (Section 4.8) and waste packagers may have to include a facility for sealing vents during transport for waste packages with the potential to exceed the specified gaseous activity release limit. Such an option would need to be taken into account during the design of the vents for those packages, and could only be used if the possibility of excessive pressurisation of the waste package during transport can be eliminated.

The provision of vents also would potentially conflict with the 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 container.
- 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 both NCT and specified impact and fire accident conditions (Sections 4.13 and 4.14).
- When considering designs of venting systems, waste packagers should take into account the long-term integrity requirements for the waste package (Section 4.10). This should include the longevity of the filter medium under the anticipated conditions of waste package storage.
- The cross-sectional area of the vent should be as small as possible while still satisfying the required performance criteria.
- The position of the vent(s) should be such as to prevent the ingress of water into the waste package during transport.
- The lid 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.
- 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 of up to 80°C.

4.10 Integrity

The integrity of the waste package shall be such that it is capable of retaining its contents and of being moved and handled safely and efficiently, as required, during all stages of long-term management.

The waste packages should be designed so that:

- ***following a period of interim surface storage, currently assumed to be up to 150 years, the waste package shall meet the requirements for handling and for transport to a GDF;***
- ***following emplacement in a GDF, the waste package should be capable of maintaining its integrity for the operational period, currently assumed to be 50 years;***

- ***upon cessation of the operational period, the waste package should retain integrity during a period of care and maintenance, during which time the waste package must be capable of being retrieved and safely handled. This period could extend to a few hundred years;***
- ***following the period of care and maintenance, a GDF may be backfilled. The waste package should continue to retain its integrity for a period consistent with the containment of short-lived soluble radionuclides.***

A period of 500 years should be considered a target for the integrity of the waste container.

Integrity is defined, in this context, as the ability of a waste package to maintain the containment of its contents, and to maintain the surety of its physical handling features (i.e. lifting locations). The timescale for this requirement is discussed in Section 4.10.1, and is set by the need for waste packages to enter the post-closure period in good condition, and it therefore needs to encompass the stages of interim surface storage, transport, GDF operations and vault backfilling.

Although containment is provided by both components of a waste package – the waste container and the wasteform – the barrier provided by the waste container is particularly important in limiting operational discharges, i.e. liquid and airborne effluents, during the earlier stages of long-term management. The integrity of the waste container must be maintained over the required timescale by:

- appropriate design;
- selection of suitable materials;
- appropriate manufacturing processes;
- provision of appropriate storage environments.

The major threats to integrity are discussed in Section 4.10.2, which identifies corrosion in particular.

4.10.1 Integrity Timescale

Initially, waste packages will need to remain in interim surface storage for the period until a GDF becomes available. Previously it had been recommended that this storage period be assumed to be 50 years. However, in the light of delays to a GDF programme, a longer period should be assumed as a precautionary measure. In the report on a joint study by the Radioactive Waste Management Advisory Committee (RWMAC) and the Nuclear Safety Advisory Committee (NuSAC) [17] it was noted that:

> *'The main waste producers, the regulators and Nirex all now broadly accept that it would be prudent to plan for a period of interim storage of the order of 100 to 150 years'*

Designing for an interim storage period of 150 years is therefore consistent with such a belief. During this period, waste package physical and structural integrity should be maintained to ensure that it retains its contents and is suitable for subsequent stages of long-term management. Advice on the appropriate control of the storage environment during this period can be found in *Guidance on Environmental Conditions during Storage of Waste Packages, WPS/630*.

It is currently assumed that the operational period of a GDF would be approximately 50 years, whilst waste packages are emplaced in the vaults. During this time the vault environment will be controlled in accordance with the requirements specified for the vaults in the GDSS [9].

After all of the waste packages have been emplaced in a GDF, future generations will have the option to keep the facility 'open' for a further period of underground storage involving care, maintenance and monitoring, and potential retrieval of waste packages. During that period, the environmental controls maintained during the operational period would be continued until it was decided to backfill the vaults. Waste packages would be required to continue to retain their integrity during that period so that, if required, they could still be retrieved safely for inspection, using the waste package handling feature and standard equipment.

Concepts for geological disposal based on multiple overlapping barriers do not explicitly rely on waste containers continuing to maintain their integrity in the post-backfilling period and the establishment of the chemical barrier provided by the backfill material. However the physical barrier provided by the waste container would still be considered the best practical means of preventing the release of such soluble short-lived radionuclides as Sr-90 and Cs-137 ($T_{½}$ ~30 years) from the engineered system. A period of approximately ten half-lives (i.e. ~300 years) following backfilling is considered sufficient [18] for this purpose. Such a timescale would also provide a more extended period during which future generations would be able to retrieve packages safely for inspection.

Considering the possible durations of all the stages discussed above, a requirement for integrity to be maintained for 500 years should be the target for all waste containers.

4.10.2 Threats to Container Integrity

Corrosion is the major potential threat to waste container integrity. In response to this, and to the timescale requirement identified above, the commonly adopted (although not universal) solution is to manufacture containers from austenitic stainless steel to grade 316L (EN 1.4404 [19]) 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 [20]. '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 container will also play a fundamental role in maintaining the integrity of the waste container.

A high pH environment is considered to be beneficial in reducing corrosion. A waste conditioning matrix that does not produce high pH conditions could accelerate corrosion.

Stainless steel has various corrosion mechanisms, dominated by:

- general corrosion;
- pitting/crevice corrosion;
- stress corrosion cracking.

The general atmospheric corrosion performance of stainless steel is widely reported [21] and corrosion rates from <0.2μmy^{-1} (>5,000ymm^{-1}) to 3μmy^{-1} (300ymm^{-1}) have been observed in industrial/urban and marine environments. Initial measurements from longer-term testing suggest corrosion rates of ~0.01μmy^{-1} (100,000ymm^{-1}) which can be extrapolated to container lives well in excess of the longest integrity requirements imagined for a GDF.

Pitting or crevice corrosion, although regarded as localised corrosion mechanisms, are considered a greater threat to stainless steel waste packages than general corrosion. Crevices can be formed between container components, between the wasteform and the inside of the container, between packages when stacked, and/or in the container lid area.

Container and package designers should therefore bear in mind the requirement to minimise the creation of such crevices.

Nevertheless, data extrapolated from tests [22, 23] have shown that the time for a pit to penetrate 1mm into 316L stainless steel is 730-1000 years. Localised corrosion mechanisms are 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 [12]. Since the molybdenum content of stainless steel is instrumental in preventing the onset and propagation of pitting corrosion, 304 grade stainless steel, which has a lower molybdenum content than 316L grade, is not recommended for the package primary containment. However, the general corrosion performance of 304 grade stainless steel is good, so it is regarded as suitable for structural features of the container such as the lifting/stacking feature, internal package furniture etc whereas 316L grade is more suitable for thinner sections such as the container walls, base and lid.

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 [21]. Such corrosion of stainless steel can be accelerated at temperatures above 60°C and may also be significant at lower temperatures. The chloride content therefore should 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, e.g. by the radiolysis or thermal breakdown of chlorine-containing plastics.

Stress corrosion cracking during interim surface storage is not regarded as a significant threat to package integrity, because control of the environmental conditions the stores (as specified in *Guidance on Environmental Conditions During Storage of Waste Packages, WPS/630)* will help to eliminate the conditions under which stress corrosion cracking could occur.

Another pre-requisite for this type of localised corrosion is access by oxygen to the surface of the container material. The elimination or reduction of internal voidage, ullage or gaps between the waste matrix and the container skin can help reduce oxygen access, and also reduce the possibility of water condensation on internal surfaces.

Backfilling will also limit access by oxygen and other contaminants to the external surfaces of the container. In the subsequent period following re-saturation by groundwater, access by oxygen will be further hindered because incoming groundwaters are likely to have a low oxygen concentration due to chemical reduction in the surrounding rock (although oxygen may still be generated locally by radiolysis). The high pH of the porewater in the surrounding backfill will also tend to inhibit corrosion, because the higher the pH, the higher are the chloride levels needed to initiate localised 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.

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 material containing carbon or nitrogen.

4.10.3 Summary

When compared with thickness of the containment typically used for 4 metre Box containers (i.e. ~10mm) the corrosion rates quoted for the processes identified above do not appear to threaten an integrity target of 500 years. Such a conclusion assumes that container material selection, construction techniques and storage conditions after manufacture are in line with best practice. To assist waste packagers in these areas, guidance has been produced on the general corrosion properties of stainless steel [20], the requirements for surface finish [12] and on welding techniques used during the manufacture of stainless steel containers [24].

4.11 Properties of the Wasteform

All reasonable measures shall be taken during the production of the wasteform, and the interim surface storage of the waste package, to ensure that:

- ***radionuclides in the waste are immobilised;***
- ***loose particulate material is minimised;***
- ***free liquids are excluded;***
- ***hazardous materials are excluded or made safe;***
- ***toxic materials are minimised;***
- ***any gases generated do not result in pressurisation of the wasteform;***
- ***the presence and volume of voids (e.g. ullage, holes etc) is minimised.***

The measures taken to achieve these objectives should include an anticipation of the effects of ageing on the performance of the wasteform.

Specification of Wasteform for 4 metre and 2 metre Box Waste Packages, WPS/520 and *4 metre and 2 metre Box Wasteform Specification: Explanatory Material and Guidance, WPS/820* contain a full specification and supporting guidance in this area. This section is therefore limited to guidance on the higher-level requirements given in the *4 metre Box Waste Package Specification, WPS/330.*

4.11.1 Immobilisation of Activity

The main function of the wasteform is to ensure that the waste is rendered passively safe which includes ensuring that activity is not present in a mobile form (gaseous, liquid or fine particulate) which would be more readily released during normal or accident conditions. This can be achieved in the case of liquid or sludge waste by mixing with a suitable binder material and allowing the product to set into a solid mass. Special measures may have to be taken to reduce the mobility of gases, depending on the chemical nature of the gas. Guidance on the need for and means of achieving immobilisation can be found in *Guidance on the Immobilisation of Radionuclides in Wasteforms, WPS/903.*

After emplacement the wasteform provides a diffusive barrier to the escape of radioactivity from the package. To ensure the effectiveness of this barrier, the waste packager should seek to manufacture a wasteform which is, as far as possible, monolithic and of low permeability to gas and water.

4.11.2 Mechanical Strength

The performance of a package under accident conditions, particularly those involving impacts, is dependent on the mechanical properties of the wasteform. The waste packager should also design the wasteform to ensure that it responds to the challenges of impact or fire accidents in a progressive and predictable manner. In practice, this can be achieved by ensuring that all activity is well dispersed throughout the solid matrix, and that there are no weak areas in the package or areas where activity is present in potentially dispersible form.

It is envisaged that, in a GDF, 4 metre Box waste packages will be stacked five-high directly on top of one another, and the corner posts are designed to provide the necessary support. Also the walls and floor of the waste package are strengthened by internal members and the reinforced concrete liner and, as a result, the strength of the wasteform does not normally affect the stackability of 4 metre Boxes, although waste packagers should confirm this for the specific wasteform involved.

The performance of a package under accident conditions, particularly those involving impacts, is also dependent on the mechanical properties of the wasteform. The waste packager should also design the wasteform to ensure that it responds to the challenges of impact or fire accidents in a progressive and predictable manner. In practice, this can be achieved by ensuring that all activity is well dispersed throughout the solid matrix, and that there are no weak areas in the package where activity is present in potentially dispersible form. Static compressive strengths in the range 4 to 40MPa are deemed satisfactory in this context.

4.11.3 Voidage

Voidage can occur as residual volumes within the waste or wasteform that have been incompletely filled by the encapsulating material, either within the conditioned wasteform, or between the container skin and wasteform. Other examples of voidage include ullage (empty space beneath the lid), enclosed volumes within waste items, and spaces between waste items, waste package furniture etc. that have been poorly infilled with grout. In a different sense, the natural porosity of the cementitious grout can also be considered to be 'voidage'.

Excessive voidage within a waste package has a number of disadvantages which include:

- the potential to make the package weaker and so more susceptible to damage and break-up in the event of impact;
- the possibility of locally accelerated corrosion of the container material, particularly when the material is stressed and when condensation may form in the void;
- the creation of pockets where flammable mixtures might collect;
- the creation of weak areas that might lead to deformation of the package under hydrostatic pressure, which could result once the vault has become re-saturated by groundwater;
- the possibility of interconnected voidage in the vault, which could lead to increased groundwater flow.

It is therefore desirable that voidage be eliminated from waste packages. However, it is also recognised that it will be impractical to achieve zero voidage, and that some limited voidage will be acceptable the tolerable extent of which will be dependent on the nature of the package contents and other features of waste package design. The waste packager must however demonstrate, in the packaging submission, that any voidage within a waste package has been minimised, and that any unavoidable residual voidage does not prejudice the ability of the package to meet the other requirements of the GWPS.

4.11.4 Leachability

The IAEA Transport Regulations [5] (Paragraph 601) give specific leachability requirements for LSA-III material:

> *'The radioactive material is relatively insoluble, or it is intrinsically contained in a relatively insoluble matrix, so that, even under loss of packaging, the loss of*

radioactive material per package by leaching when placed in water for seven days would not exceed 0.1A_2'

The purpose of this requirement is to justify allowing a higher specific activity for this category of LSA, and specifically to demonstrate that the material would be sufficiently insoluble if it became exposed to rainfall following an accident.

Paragraphs 710 and 711 set out a suggested testing regime that could provide evidence regarding the expected leaching performance of wasteforms.

4.11.5 Other Restrictions

Attention must be given to non-radiological hazards that could affect the long-term integrity of waste packages. Possible sources of non-radiological hazards include: inherently pyrophoric or explosive material; highly corrosive material; waste containing or capable of generating flammable or toxic gases, vapours or fumes through corrosion or degradation; putrescible or fermentable waste; or waste containing hazardous biological, pathogenic or infectious material.

Hazardous materials should be excluded from the waste as far as possible or else measures should be taken to make them safe. This could in some cases be achieved by mixing with chemically stable materials such as cement, concrete or glass, or by a neutralising chemical process.

Paragraph 507 of the IAEA Transport Regulations [5] requires that, in addition to the radioactive properties, any other dangerous properties of the contents be taken into account in packing, labelling, marking, placarding, storage and transport, in order to be in compliance with the relevant regulations for dangerous goods. These would include: UN Recommendations on the Transport of Dangerous Goods [25]; the UK Classification, Packaging and Labelling of Dangerous Goods Regulations [26]; international agreements covering particular transport modes, such as the ADR for road [27] and the RID for rail [28]; and conditions set by individual transport operators, such as the British Rail List of Dangerous Goods [29].

In the longer term, waste that contains chemical complexing agents might accelerate the migration of radionuclides away from a GDF. Complexing agents should therefore be excluded from waste, or their effects neutralised by an appropriate conditioning process.

4.12 Criticality Safety

The presence of fissile materials[8], neutron moderators and reflectors in the waste package shall be controlled to ensure that they do not present a criticality safety hazard during any of the active stages of their long-term management.

It shall also be ensured that, following closure of a GDF, the possibility of local accumulation of fissile material such as to produce a neutron chain reaction is not a significant concern to the long-term performance of a GDF.

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8 Defined as U-233, U-235, Pu-239 and Pu-241 but excepting unirradiated natural or depleted uranium and natural or depleted uranium that has been irradiated in a thermal reactor.

In addition, the waste package shall be capable of being excepted from the IAEA Transport Regulations requirements for packages containing fissile material.

Waste packages must not represent an unacceptable criticality safety hazard, either individually or in arrays, during any stage of their long-term management. A criticality incident involving waste packages during transport or operational period of a GDF would result in substantially increased heat output, changes to the radionuclide inventory and elevated dose rates. Such an event would therefore present an immediate hazard to the public or workers. During the post-closure period of a GDF, the increased generation of heat could compromise the effectiveness of the barriers to radionuclide release from individual packages and from a GDF.

The RWMD approach to criticality safety is outlined in [30] and is based upon the production of 'benign packages' containing insufficient fissile material for criticality to occur, even in worst-case conditions. This is achieved by controlling the package design, including the quantities of both fissile and moderating materials, to help eliminate the potential for criticality either in individual packages or in assemblies of packages, during routine transport and GDF operations. In accident conditions, the physical robustness of waste packages is such none of the credible accidents considered would result in criticality. This process has resulted in the derivation of a conservative generic screening level of 50g Pu-239 or equivalent for waste packages.

For 4 metre Box waste packages, the approach outlined above tends to be less restrictive than the limits imposed by the need for 4 metre Box waste packages to be capable of being excepted from the IAEA Transport Regulations [5] requirements for packages containing fissile material (Section 4.1). The requirement is interpreted as a requirement for the contents of the waste package to satisfy at least one of the exceptions listed in Paragraph 672 of the Regulations. In summary, a waste package can be excepted from the requirements for packages containing fissile material if:

a) It satisfies a mass limit such that:

$$\frac{\text{mass of U-235 (g)}}{180} + \frac{\text{mass of other fissile material (g)}}{290} < 1$$

provided that either:

(i) there is no more than 15g of fissile material in the package, or

(ii) the fissile material is in a homogenous hydrogenous mixture where the ratio of fissile nuclides to hydrogen is less than 5% by mass, or

(iii) there is not more than 5g of fissile material in any 10 litre volume of packaged material.

b) Neither beryllium nor deuterium shall be present in quantities exceeding 0.1% of the fissile material mass.

c) It contains uranium enriched in U-235 to a maximum of 1% by mass, and with a total Pu and U-233 content not exceeding 1% of the mass of U-235, provided that the fissile material is distributed essentially homogeneously throughout the material. In addition, if U-235 is present in metallic, oxide or carbide forms, it shall not form a lattice arrangement.

d) It contains a total plutonium mass of not more than 1kg, of which not more than 20% by mass may consist of Pu-239, Pu-239 or any combination of those radionuclides.

RWMD have produced *Guidance on the Application of the IAEA Transport Regulations 'fissile exceptions', WPS/912* to assist waste packagers in the interpretation of this aspect of the Transport Regulations and with their application to 4 metre Box waste packages.

4.13 Impact Performance

The waste package should be designed such that, in the event of an impact accident:

- ***releases of radionuclides and other hazardous materials are low and predictable, exhibit progressive release behaviour with increasing impact severity and do not exhibit significant cliff-edge performance characteristics within the anticipated range of impact conditions;***
- ***both barriers to radionuclide release from the waste package (i.e. the waste container and the wasteform) should play an effective role in minimising those releases.***

The waste package shall be capable of being dropped, in any credible attitude, from a height of 0.3 metres onto a flat unyielding surface, whilst retaining its radioactive contents, without loss of shielding integrity that would result in more than a 20% increase in radiation level at any external surface of the package and remaining suitable for safe handling during all subsequent stages of long-term management.

The release of radioactive contents from the waste package, as a result of credible impact accidents during transport and the operational period of a GDF, shall not result in the relevant regulatory dose limits to workers and to members of the public being exceeded.

Impact accidents can affect waste packages at a number of stages of their long-term management and are a mechanism by which the radioactive contents of a package could be released into the environment in an uncontrolled manner. Accordingly, waste packages must be capable of withstanding a number of specified impact conditions without excessive loss of contents in order that they will comply with regulatory requirements and with the assumptions which underpin the safety assessments for transport and operations at a GDF.

RWMD has defined three types of impact accident to which waste packages could be exposed:

- Minor impacts resulting from normal handling;
- Impacts resulting from transport accidents;
- Impacts resulting from accidents in a GDF.

4.13.1 Impacts resulting from normal handling

Waste packages may be subject to knocks, collisions and rough handling in the course of normal handling operations at any stage of the PGRC. It is expected that all waste packages should be sufficiently robust to withstand such impacts and, following external examination, should be capable of onward management without repair or rework. According, following such impacts, waste packages must continue to be capable of retaining their radioactive contents, and must remain compatible with the transport and GDF systems (although it is accepted that non-standard handling arrangements may have to be used).

In this context, as Type IP-2 transport packages, 4 metre Box waste packages are directly subject to Paragraph 622 of the IAEA Transport Regulations [5]. This requires that the design of such packages shall be such that, if they were submitted to a ‘free drop test’ (as defined in Paragraph 722), it would prevent:

- loss or dispersal of the radioactive contents; and

- loss of shielding integrity which would result in more than a 20% increase in the radiation level at any external surface of the package.

For packages with masses of greater than 15t, the height for the free drop test is specified as 0.3m.

The attitude of the waste package for such a drop test is discussed in the Advisory Material for the IAEA Transport Regulations [31] where it is acknowledged (Paragraph 722.6) that, within the drop height available, transport packages with 'large dimensions' can only rotate into a limited range of impact attitudes. In such cases the Regulations allow drop testing to be limited to 'credible' attitudes, provided that documented justification is produced by the package designer.

The objective of this requirement is to ensure that following a minor impact in the course of normal handling, the radioactive contents of the waste package cannot escape in sufficient quantities to create a radiological hazard or unacceptable contamination. For Type IP-2 transport packages, this objective is achieved jointly by the limitations on the allowable contents (Section 4.1) and by the specifications for mechanical robustness.

The interpretation of preventing 'loss or dispersal of the radioactive contents' is not quantified by the Transport Regulations and RWMD has chosen to apply the same regulatory activity release limit that applies to Type B transport packages under NCT (i.e. 10^{-6} A_2/hr) to the 4 metre Box waste package in this context. This value is also deemed to satisfy the ongoing requirements for safe handling and continued storage identified by the Generic Operational Safety Assessment (GOSA) [32].

4.13.2 Impacts resulting from transport accidents

No explicit performance requirement is specified for the 4 metre Box waste package for transport impact accidents. This is in line with the IAEA Transport Regulations, which restrict the consequences of such an accident involving Type IP-2 transport packages by placing restrictions on allowable activity contents and the physical form of the waste contained in such packages.

4.13.3 Impacts resulting from accidents in a GDF

Following receipt at the disposal facility, waste packages will be subject to a series of lifting and handling operations, leading to their emplacement in the vaults. During this period the possibility exists for accidents which could result in waste packages being subject to a range of mechanical impacts. These include:

- the dropping of waste packages during handling;
- the dropping of equipment (including other waste packages) on to waste packages;
- more extreme facility mechanical failures, such as vault roof collapses, etc.

Such accidents could result in damage to waste packages, the release of their radioactive contents and radiation dose to both workers on-site and members of the public off-site. The regulatory control of radiation exposure as a result of operations on nuclear licensed sites are by way of criteria defined by the NII SAPs [33]. In the case of Design Basis Accidents (DBAs) the SAPs define Basic Safety Levels (BSLs) for on- and off-site dose consequences, on the basis of the expected frequency of the fault that would result in such an accident. The BSL doses are listed in Table 1.

RWMD have adopted a conservative approach to the treatment of DBAs by assuming that all such events will have a fault frequency of $>10^{-3}$ pa unless it can be shown otherwise. For most faults involving waste package impacts this will mean that the lowest of the BSLs from Table 1 will be adopted (i.e. Post-accident dose limit of 20mSv for workers and 1mSv for members of the public). However the opportunity exists for specific extreme faults to be assigned a lower frequency and corresponding higher BSLs should this prove necessary.

Table 1 Basic Safety Level doses for DBAs

DBA Fault Frequency	BSL for on-site dose	BSL for off-site dose
$>1x10^{-3}$ pa	20mSv	1mSv
Between $1x10^{-3}$ and $1x10^{-4}$ pa	200mSv	10mSv
$<1x10^{-4}$ pa	500mSv	100mSv

As part of the Generic Operational Safety Assessment (GOSA) [34], a HazOp study has been carried out to identify the nature of DBAs that could occur during the operational period. This has identified a number of impact faults for which the highest frequency of occurrence in Table 1 has been assumed. For shielded waste packages such as the 4 metre Box, a range of faults, including the dropping of a waste package during lifting or from the top of a stack of waste packages, equivalent to a drop from a height of approximately15m[9],are used to define waste package impact performance criteria.

All such faults are assumed to involve the impact of a waste package on to an unyielding surface (i.e. the vault floor) or on to an unyielding 'aggressive feature' such as the corner stacking post of another waste package.

Other, more extreme faults have also been identified by the HazOp study, including the collapse of a vault roof 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 one equivalent to that resulting from a 15m drop and, in some cases, could affect many waste packages. It is assumed that sufficient safety features would be incorporated in the design of relevant systems to ensure that such events would have a lower frequency that 10^{-3} pa and that the higher values of BSL from Table 1 would be applied to their consequences. Historically it had been assumed that such faults would result in an impact to a waste package equivalent that resulting from a fall from 25m and this value was previously used as the basis for defining waste package impact performance. It is now believed that the requirement for the impact performance of waste packages to be '*low and predictable' and to 'exhibit progressive release behaviour with increasing impact severity……..within the anticipated range of impact conditions',* backed up by computer modelling and/or impact testing of waste packages, will provide sufficient confidence regarding the performance of waste packages for the full range of anticipated impact faults.

As part of the GOSA [34], RWMD has developed a standardised methodology that allows the radiological consequences of the release of activity from a waste package to be determined [35]. The methodology is applied by way of the GOSA Toolkit, a code that

[9] This being a conservative figure for the maximum height to which waste packages would be lifted in a GDF in which shielded waste packages are stacked five high.

calculates the dose consequences of the full range of potential accidents identified by the HazOp analysis. The Toolkit incorporates assumptions made regarding the availability and efficiency of protective equipment within a GDF and the ventilation system, 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.

To produce quantified release limits for waste packages the GOSA Toolkit has been used to determine the size of release of individual radionuclides that would result in on- and off-site doses equal to the lowest BSL doses in Table 1. Table 2 lists the results of this process for radionuclides with the highest inventories in UK ILW[10]. Values are given for each of the two impact scenarios identified above, these values being different due to the different levels of protection currently assumed for workers and members of the public for impact accidents occurring in the respective areas of a GDF.

Table 2 shows that, in all cases, the on-site dose is the bounding situation, in some cases by up to four orders of magnitude. This reflects the protection provided to off-site releases of activity by the ventilation system, dispersion of activity by winds following release and the assumptions regarding the manner by which members of the public would be exposed to any released activity.

The values given in Table 2 are not direct specifications for waste package impact performance but provide guidance as to whether a proposed waste package would be capable of demonstrating compliance with relevant regulatory requirements following an impact accident. It should first be noted that the values are for individual radionuclides and that the dose resulting form the release of activity following an impact accident in a GDF would be the combination of contributions from all of the radionuclides present in the waste package and released during an accident. The GOSA Toolkit is used to perform an assessment of the dose consequences of impact accident for each proposed waste package type proposed by Site License Companies. Such an assessment takes into account the actual radionuclide inventory of the proposed waste packages together with the release fraction[11] (RF) for waste packages subjected to representative impact challenges. Using generic values for RF [i.e. 36] and expected maximum waste package inventories, the values from Table 2 can be used to judge the potential acceptability of a packaging proposal in advance of a full LoC assessment which would include the use of the GOSA Toolkit to assess the impact accident performance of the proposed waste packages.

In the case of accidents in a GDF the maximum size of particles considered to contribute to dose has been historically considered to be 100μm. Although these larger particles are not considered respirable, they are considered to be 'suspendable' in air, and thus

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[10] Equivalent data on the full range of radionuclides considered by the GOSA Toolkit can be found in Appendix B.

[11] RF is defined as the activity released in and accident as the fraction of the total activity within a waste package. The value of RF for a particular waste package type will depend on the waste container and waste conditioning process(es) used, together with the nature and form of the radionuclides present in the waste. Typically RF's lie in the range 10^{-3} to 10^{-5} for standard waste packages containing wastes conditioned using cementitious grouts.

capable of contributing to the dose to both workers and the public by external radiation (i.e. 'shine') from deposited activity. Particles larger than 100μm have been deemed too large to be dispersed following an impact accident, and are not considered to contribute to the post-accident dose. 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 and RWMD acknowledge that this value may be over-conservative, especially when the conclusions of the ICRP study [37] are considered. However, in the absence of convincing arguments for a relaxation of this conservatism, these values are to be retained although RWMD will be conducting work in the future with a view to reducing them.

Table 2 Allowable activity releases following impact accidents

Nuclide	Waste package activity release resulting in BSL for impact faults with frequency $>10^{-3}$ pa	
	Off-Site (1mSv)	On-Site (20mSv)
	TBq	TBq
Am-241	4.90E-05	7.60E-07
C-14	8.33E+00	5.13E-02
Co-58	3.18E-02	1.49E-02
Co-60	1.04E-03	1.03E-03
Cs-137	1.13E-03	4.43E-03
Fe-55	1.81E-02	3.23E-02
H-3	2.00E+03	7.25E-01
Ni-59	1.94E+01	3.58E-02
Ni-63	2.70E-01	1.48E-02
Pu-238	9.01E-05	6.92E-07
Pu-239	8.62E-05	6.33E-07
Pu-240	8.62E-05	6.33E-07
Pu-241	6.29E-03	3.50E-05
Sm-151	5.18E-01	8.03E-03
Sr-90	3.42E-04	1.98E-04
Y-91	2.16E-02	3.54E-03

The values given in Table 2 are not direct specifications for waste package impact performance but provide guidance as to whether a proposed waste package would be capable of demonstrating compliance with relevant regulatory requirements following an impact accident. It should first be noted that the values are for individual radionuclides and that the dose resulting form the release of activity following an impact accident in a GDF would be the combination of contributions from all of the radionuclides present in the waste package and released during an accident. The GOSA Toolkit is used to perform an assessment of the dose consequences of impact accident for each proposed waste package type proposed by Site License Companies. Such an assessment takes into account the actual radionuclide inventory of the proposed waste packages together with the release fraction[12] (RF) for waste packages subjected to representative impact challenges. Using generic values for RF [i.e. 38] and expected maximum waste package inventories, the values from Table 2 can be used to judge the potential acceptability of a packaging proposal in advance of a full LoC assessment which would include the use of the GOSA Toolkit to assess the impact accident performance of the proposed waste packages.

4.13.4 Influence of Waste Package Design on Impact Performance

The impact performance of waste packages is strongly dependent on package design, and careful attention should be paid to this from an early stage in the development of a packaging proposal. In particular, the benefits provided by the waste container and the wasteform under impact conditions should both be considered, to ensure that these two components are seen as independent and complementary barriers against the release of package contents following an impact accident.

A programme of analytical studies and physical test work has been performed to assess the impact performance of waste packages and their detailed design features, (including work on unshielded packages which has relevance to shielded waste packages such as the 4 metre Box [39, 40]). This work has generated substantial information, improved the understanding of waste package impact performance and aided in the development of design guidelines. Guidance has also been produced on waste container design [41] which includes specific guidance on how container design can maximise waste package impact performance.

The following points outline some basic principles that should be considered in waste package design, but it is recommended that waste packagers consult RWMD in order to gain full benefit from the available information:

- An area that requires particular attention is the waste container lid, failure of which can lead to a major breach and loss of contents.
- Welds positioned at or near to the top or bottom edge of the waste container are vulnerable to failure on impact. These welds, particularly at the base of the container, should be located as far as possible from the edges.
- All butt welds should be full penetration, and fillet welds should be continuous and as strong as the parent material.
- Ductile material behaviour during deformation is highly desirable. This should be a consideration in the selection of waste container material and in determining any requirement for stress relieving following manufacture.

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[12] RF is defined as the activity released in and accident as the fraction of the total activity within a waste package. The value of RF for a particular waste package type will depend on the waste container and waste conditioning process(es) used, together with the nature and form of the radionuclides present in the waste. Typically RF's lie in the range 10^{-3} to 10^{-5} for standard waste packages containing wastes conditioned using cementitious grouts.

- Designs that involve sudden and large changes in the waste container wall thickness, or include notches and other stress raisers, should be avoided. Such features can lead to stress concentration, and can promote brittle (rather than ductile) material behaviour, particularly at high strain rates.
- Account should be taken of any reduction in impact performance capabilities as a result of corrosion of the waste container material, either internally or externally.
- Under certain circumstances, internal features of the waste package could cause the waste container to rupture during an impact. To reduce this potential, these features should be kept as far away from the sidewalls of the container as possible. Features near or attached to the sidewalls should preferably be rounded and non-aggressive, not sharp, and should not create severe localised reductions in ductility that could be prejudicial to impact performance.
- In general, problems are likely to occur with stiff unyielding features, which may protrude from the container surfaces, or may be present inside the package alongside soft yielding features. These could lead to rupture by punching, or to concentrations of shear strain. This effect is more likely when the contents are relatively strong (unconfined compressive strength >20MPa).
- A wasteform that is too weak can result in inadequate impact performance. However, in certain circumstances, a wasteform that is too strong could also result in inadequate performance by over-stressing the container. The assessment work performed to date by RWMD demonstrates that static compressive strengths in the range 4 to 40MPa will be satisfactory, provided that the design details and material properties of the container are also appropriate. Wasteforms and matrix strengths outside this range may be acceptable, but would require consideration on a case-by case basis.
- Special consideration should be given to heterogeneous wasteforms, e.g. encapsulated hard wastes, because of the potential for waste items to penetrate the container wall under impact conditions. If the waste has sharp edges, the potential for piercing of the container skin in an impact accident should be guarded against when loading the waste into the container.

4.14 Fire Performance

The waste package should be designed such that in the event of a fire accident:

- ***releases of radionuclides and other hazardous materials are low and predictable, exhibit progressive release behaviour with increasing fire severity and do not exhibit significant cliff-edge performance characteristics within the anticipated range of impact conditions;***
- ***both of the barriers to radionuclide release from the waste package (i.e. the waste container and the wasteform) should play an effective role in minimising those releases.***

The release of radioactive contents from the waste package, as a result of credible fire accidents during transport and the operational period of a GDF, shall not result in the relevant regulatory radiation dose limits to workers or to members of the public being exceeded.

The effects of fire accidents can potentially affect waste packages at all stages of their long-term management, up to vault backfilling, in a similar manner to impact accidents as discussed in Section 4.13. Accordingly, waste packages must be capable of withstanding specified fire conditions without excessive loss of contents. For the purposes of this document, the stages at which the effects of a fire accident are considered are limited to transport and subsequent handling and emplacement in a GDF (although the latter will have many similarities to operations during storage by the waste packager prior to transport).

4.14.1 Fire Severity

In developing the criteria for the required fire performance of waste packages it is necessary to define appropriate fire accident conditions (i.e. temperature and duration). The thermal test specified for transport packages[13] (by the IAEA Transport Regulations [5] requires such packages to be exposed for 30 minutes to a hydrocarbon fuel/air fire with an average temperature of 800°C, fully engulfing the package. The potential for more challenging thermal transients, when unprotected waste packages could be directly exposed to fires during the operational period of a GDF and this has been considered to allow bounding conditions for such fires to be determined [42]. This work has concluded that, although a fire duration of 30 minutes encompasses 85% of road transport fire accidents, the complicating factors of restricted access and fire fighting capabilities in an underground disposal facility mean that a longer duration (i.e. 1 hour) should be adopted as the fire challenge for waste packages.

With regard to flame temperature, experience from transport accidents suggests that although 800°C would be appropriate to transport accidents, it does not take into account the particular conditions that could pertain to an underground fire. Recent fires in similar circumstances, albeit with large fuel inventories, have yielded evidence of flame temperature transients in excess of 1000°C. Accordingly a more conservative temperature than would be required for transport fires alone has been adopted and 1000°C has been specified as the average flame temperature for the fire challenge.

4.14.2 Fires resulting from transport accidents

As with transport impact accidents (Section 4.13.3), no performance requirement is specified for the 4 metre Box waste package in a transport fire accident. This is in line with the IAEA Transport Regulations, which restrict the consequences of such an accident involving Type IP-2 transport packages by placing restrictions on allowable activity contents and the physical form of the waste contained in such packages.

4.14.3 Fires resulting from accidents in a GDF

The approach to setting allowable waste package activity releases following a fire accident in a GDF once again reflects that adopted for impact accidents (Section 4.13.3). A fire accident is considered a DBA; and in accordance with NII SAPs [33], it should not result in on- or off-site doses in excess of the relevant BSLs. For the purposes of this guidance, the most restrictive BSLs are conservatively assumed, for accidents with a frequency of greater than 10^{-3} pa. The GOSA Toolkit has been used to determine the size of release of individual radionuclides that would result in on- and off-site doses of

[13] Note that such a test is not required for Type IP-2 transport packages excepted from the requirements for packages containing fissile material.

20mSv and 1mSv respectively. Table 3 lists the results of this process for radionuclides with the highest inventories in UK ILW[14].

It is assumed that releases from waste packages as a result of a fire accident will, in the first instance, be predominantly in the form of gases and vapours. Accordingly no maximum particle size is specified for activity releases following a fire accident and the values given in Table 3 are for total activity release during and following a fire.

Table 3 Allowable activity releases following fire accident

Nuclide	Waste package activity release resulting in BSL for fire faults with frequency >10^{-3} pa	
	Off-Site (1mSv)	On-Site (20mSv)
	TBq	TBq
Am-241	4.90E-05	3.05E-06
C-14	8.33E+00	2.05E-01
Co-58	3.18E-02	5.93E-02
Co-60	1.04E-03	4.10E-03
Cs-137	1.13E-03	1.77E-02
Fe-55	1.81E-02	1.29E-01
H-3	2.00E+03	2.90E+00
Ni-59	1.94E+01	1.43E-01
Ni-63	2.70E-01	5.93E-02
Pu-238	9.01E-05	2.76E-06
Pu-239	8.62E-05	2.53E-06
Pu-240	8.62E-05	2.53E-06
Pu-241	6.29E-03	1.40E-04
Sm-151	5.18E-01	3.21E-02
Sr-90	3.42E-04	7.94E-04
Y-91	2.16E-02	1.42E-02

[14] Equivalent data on the full range of radionuclides considered by the GOSA Toolkit can be found in Appendix C.

The values given in Table 3 are not direct specifications for waste package fire performance but provide guidance as to whether a proposed waste package would be capable of demonstrating compliance with relevant regulatory requirements following a fire accident. It should first be noted that the values are for individual radionuclides and that the dose resulting form the release of activity following a fire accident would be the combination of contributions from all of the radionuclides present in the waste package and released during such an accident. The GOSA Toolkit is used to perform an assessment of the dose consequences of a fire accident for each waste package type proposed by Site License Companies. Such an assessment takes into account the actual radionuclide inventory of the proposed waste packages together with the RF for waste packages subjected to representative thermal challenges. Using generic values for RF [i.e. 38] and expected maximum waste package inventories, the values from Table 3 can be used to judge the potential acceptability of a packaging proposal in advance of a full LoC assessment, which would include the use of the GOSA Toolkit to assess the fire accident performance of the proposed waste packages.

4.14.4 Influence of Waste Package Design on Thermal Performance

The thermal performance of waste packages is dependent on package design, and careful attention should be paid to this from an early stage in the development of a packaging proposal.

The exposure of a waste package to an external fire provides a driving force that may lead to a release of radioactive material in the form of volatile or gaseous species, contaminated steam or particles entrained in steam or gas. The extent of this hazard should be minimised, and made predictable through application of the principles of wasteform design outlined in Section 4.11. In particular, the presence of free liquids, voidage or excessive heterogeneity of the wasteform could have significant mechanical effects on a wasteform heated during a fire. These effects include uneven expansion and excessive cracking with the consequential loss of radionuclide containment.

If a wasteform could support combustion, that could have a significant effect on the release of activity during and following a fire accident. Modelling and experimental work indicates that the interior of a typical non-combustible wasteform does not suffer a significant temperature rise during an external fire, and this effect makes a major contribution to the limitation of releases; but combustion of the wasteform would lead to higher temperatures, particularly if it took place in the interior of the wasteform. That in turn would lead to physical and chemical changes in the wasteform, resulting in the release of a larger fraction of the radionuclide inventory. Therefore combustion of the wasteform is an unacceptable hazard; wasteforms should be designed neither to burn nor to support combustion.

A programme of analytical studies, experimental work and modelling work has been undertaken to assess the thermal performance of waste packages and the release of radionuclides under fire conditions [43, 44]. This work has generated substantial information, improved the understanding of waste package fire performance and aided in the development of design guidelines. Modelling data on the behaviour of a package in a fire is available to waste package designers, and waste packagers are recommended to consult RWMD in order to gain full benefit from the available information.

The following guidance indicates desirable or undesirable features, and to identifies those aspects that require particular attention:

- The analysis of the effects of a fire should continue for some time after the end of the fire, because the interior temperature of the package will initially continue to increase as temperatures equilibrate throughout the wasteform.
- The emissivity of the flames can be taken to be 0.9. The waste package emissivity must be justified by analysis.

- Designs that involve sudden and large changes in wall thickness should be avoided since these could lead to localised heating of the wasteform, or to local thermally-induced stress concentrations which may not be desirable.
- Any modelling of the performance of the package and its wasteform under fire accident conditions should take account of any internal structures (e.g. internal stiffening of the container or mixing paddles in the wasteform) since the latter in particular may provide significant heat transfer paths to the interior of the wasteform. As noted above, any demonstration of acceptable performance as a function of time should be continued to the point where falling temperatures, or improving parameters are achieved throughout the package.
- The wasteform should normally be considered homogeneous, with the same release mechanisms applying throughout, and the releases depending only on the maximum local temperatures reached. However, if the design or nature of the package is such that the distribution of activity is non-uniform, this also should be considered. In this context, the benefits of the use of an annular grouted wasteform should be considered for challenging wastes.

For non-homogeneous wasteforms (e.g. metal components or compacted drums of soft waste, in-filled with grout) the possibilities of inward transfer paths for heat and outward transfer paths for gases and vapours, and associated radioactivity, must be considered.

4.15 Stackability

The waste package shall be capable of withstanding a stacking load due to a six high stack of similar waste packages, each with a gross mass of 65,000kg. This shall be the equivalent of a compressive load of 325,000kg applied along the vertical axis of the waste package. Under these load conditions, the waste package should not exhibit any permanent deformation or abnormality that would render it incompatible with any of the requirements defined in WPS/330.

It is currently envisaged that 4 metre Box waste packages would be emplaced in a GDF in stacks up to five high, they must therefore be capable of withstanding the loads associated with this... These loads are less than that specified in the IAEA Transport Regulations [5] (Paragraph 723) for a 'stacking test' for transport packages. The stacking test requires the package to be able to withstand a compressive load equal to the equivalent of five times the package mass (i.e. a six high stack) for a period of 24 hours, following which the package must be able to satisfy the same requirements to prevent loss or dispersal of contents or loss of shielding integrity as were given in Section 4.13.1.

Waste packagers may choose stack 4 metre Box waste packages higher than this during interim surface storage, but must ensure that after having been stacked for up to 150 years (Section 4.10.1) the packages will still meet the specifications for the dimensional envelope (Section 4.5) and the lifting features (Section 4.6) and are capable of being handled safely.

4.16 Identification

The waste package shall be marked with an unique alpha-numeric identifier as defined in Specification of Waste Package Identification System, WPS/410. The identifier shall be marked on the four sides of the waste package, midway along the bottom of the waste package walls. The characters shall be 6-10mm high and shall be capable of being read during all active stages of long-term management.

The waste package shall also comply with the placarding requirements of the IAEA Transport Regulations.

The application of a unique identification marking on each waste package enables the identification and tracking of waste packages throughout all stages of their long-term management and permits assignment of the appropriate data record. Making the identification '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. The use of OCR-A characters [45] also allows for checking by the operator, either by direct sight or through the use of automated reading equipment.

The identifier will consist of ten alpha-numeric characters, the form of which is specified in *Specification for Waste Package Identification System, WPS/410,* supported by *Waste Package Identification System: Explanatory Material and Guidance, WPS/860.*

The identifier is required to be a permanent feature of the waste package that, as a minimum, will be readable accurately by machine and by eye upon receipt of the waste package at a GDF and remain readable by some means during at least the first 50 years of the operational period. As a design basis, a maximum period of interim surface storage of 150 years prior to transport should be assumed, leading to a minimum identifier longevity of 200 years.

For automatic reading systems to operate effectively, it is important to establish standard locations for the identifiers. Four such positions are specified to provide redundancy and minimise the risk of a package becoming unidentifiable. The positions specified, at the mid-sides on each of the bottom longitudinal and transverse rails of the waste package feature (Figure 1), have been selected partly because marking in these positions is unlikely to affect the corrosion performance and associated containment integrity of the waste package.

The recommended method of inscribing the identifier is to laser-etch the characters which, in the case of austenitic stainless steel packages, is also expected to satisfy the above requirements for the longevity of the marking.

In addition to the identifier markings required by RWMD, each waste package must be marked, labelled and placarded in accordance with the requirements of the IAEA Transport Regulations [5] for Type IP-2 packages (Paragraphs 534 and onwards).

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. However, any additional identification, whether temporary or permanent, must not compromise the integrity containment of the package. This should include a consideration of the materials used for such markings, guidance on which can be found in [46].

4.17 Transport Regulations

The waste package is intended to be a transport package and, as such, shall comply with the IAEA Transport Regulations for an Industrial Package Type 2, and shall be designed to conform to the British and International Standards for Freight Containers, excluding dimensions and ratings.

The 4 metre Box waste package is designed to be both a transport package and disposal package and must therefore comply with the relevant requirements of the IAEA Transport Regulations [5]. It must also comply with the requirements for carriage of radioactive substances by road [27] and by rail [28]; both of the latter being based on the IAEA Transport Regulations and differ only in a few additional detailed requirements.

It should be noted that the IAEA Transport Regulations are under a two-year revision cycle and, over a long period of interim storage, the Regulations may well change before the packages are transported.

Currently, under the IAEA Transport Regulations, two routes for Regulatory Approval exist and these are outlined in the following subsections. During development of packaging designs consideration should be given to the chosen approach, and in particular the implications for the package design and Regulatory Approval that may arise as a result of transporting waste packages after prolonged periods of storage.

4.17.1 Approval using free drop testing

The 4 metre Box waste package is specifically designed as an Industrial Package Type 2 (IP-2) as defined by the IAEA Transport Regulations. As such, its design must meet the general requirements of Paragraphs 606 to 616 and the particular requirements of Paragraph 622 of the IAEA Transport Regulations. The latter requires that if the package is subjected to the specified tests for an IP-2 package; a free drop test (Section 4.13.1) and a stacking test (Section 4.15), it should be designed so as to prevent:

- loss or dispersal of the radioactive contents[15]; and
- loss of shielding integrity that would result in more than a 20% increase in the radiation level at any external surface of the package.

4.17.2 Approval using ISO 1496 specification and testing

Paragraph 627 of the IAEA Transport Regulations permits the use of freight containers for IP-2 packages, the rationale being that the combined tests for an approved freight container are equivalent to the tests specified for IP containers. This approach requires that the container is designed and tested in accordance with the requirements specified in ISO 1496/1 [7] (excluding dimensions and ratings).

As part of the ISO 1496 test programme, additional tests must also be undertaken to demonstrate compliance with the IAEA Transport Regulations requirement to prevent loss and dispersal of the contents and maintain shielding integrity. The container design must also meet the Industrial Package Type 1 (IP-1) requirements specified in Paragraph 621 of the IAEA Transport Regulations.

The tests in ISO 1496/1 are intended to demonstrate that a container design is safe for use and assumes that, in any normal mode of transport, the actual loads applied either externally or due to the contents will not exceed those specified. These include lifting (from top or bottom corner fittings) loads, stacking loads, restraint loads, floor and roof loads, transverse and longitudinal racking, end wall loads and side wall loads. After all of the specified tests, a container should sustain no permanent deformation or abnormality that would render it incapable of being used for its designed purpose. In the context of IP-2 packages, the criteria are that the package still meets the specifications and tolerances for overall dimensions and handling features (Sections 0 and 4.6) and also maintains its containment and shielding as required by Paragraph 622 of the IAEA Transport Regulations [5].

The waste package should be shown to meet the regulatory requirements at the design stage (including prototype testing), during production (e.g. by sampling of representative production packages) and immediately before transport (by operational procedures and controls). It will therefore be necessary to consider how pre-transport checks can be carried out to confirm package performance after extended interim storage.

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[15] Interpreted by RWMD as not more than$10^{-6}A_2$ per hour.

4.18 Physical Protection Nuclear Security

The quantity of Nuclear Material contained within the waste package shall be such that the waste package can be transported subject to standards of physical protection no higher than Category III.

The Nuclear Industries Security Regulations (NISR) 2003 lay down the approvals required for the physical protection of 'Nuclear Material' (NM)[16] in transit between licensed sites, against the risk of theft or sabotage. They are administered and enforced by the OCNS acting on behalf of the Secretary of State for Trade and Industry.

It is RWMD's intention that the NM content of all waste packages destined for emplacement in a GDF will be such that they will require standards of physical protection no higher than those defined for Category III material under the NISR. This intention forms part of the GDF Security Plan.

The assessment of the suitability of waste packages containing NM for transport to Category III standards of physical protection will take account of the following:

- the estimated maximum mass of NM in a single waste package, including the reliability of the estimate;
- the quantity, and activity, of other (non-fissile) radioactive material present;
- the method of conditioning of the waste, including any Safeguards issues raised by the possibility of recovery;
- the potential impact on the physical protection categorisation of a GDF of the proposed waste packages.

Table 4 lists the mass limits applicable to a number of types of NM typically found in ILW that would allow them to be transported with Category III standards of physical protection. A full listing of all NM can be found in [47]. It should be noted that these limits apply to NM in any physical or chemical form and that less restrictive limits may apply to the same material in conditioned wasteforms packaged in a manner that makes their recovery difficult.

During the assessment of a packaging proposal, a physical protection assessment will be carried out to consider the nature and quantity of any NM intended for transport and disposal, in particular, its attractiveness for theft and its dispersability from an act of sabotage. The assessment will conclude with a statement regarding compliance with the current Security Plan. Any issues identified in the assessment that do not comply with the provisions and conditions of the Security Plan will be referred to the OCNS for information, and, if necessary, for direction.

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[16] Defined by OCNS as plutonium, uranium, neptunium, americium and other irradiated materials

Table 4 Limits on quantities of NM for waste packages transported with Category III levels of physical protection

Type(s) of Material	Maximum quantity categorised as Category III
Pu, U-233	0.5 kg
Enriched uranium containing >20% U-235	1.0 kg
Enriched uranium containing <20% but >10% U-235	10 kg
Enriched uranium containing <10% U-235	Any quantity

4.19 Nuclear Materials Safeguards

The Safeguards status of any fissile or source materials (i.e. isotopes of uranium, plutonium and thorium) contained within a waste package shall be ascertained.

To prevent the potential for the diversion of civil nuclear materials to military use, packaged wastes that contain isotopes of uranium, plutonium or thorium derived from the UK civil nuclear programme may be subject to national and international controls known as 'Safeguards'. In principle, where these materials are subject to Safeguards, it is likely that they will be subject to those controls during all stages of their long-term management and a Safeguards assessment will be required. Such an assessment will review the proposed management processes for the packaged waste and consider whether they are likely to be adequate to meet the requirements of the Safeguards authorities.

In order that implications of accepting waste packages that contains safeguarded materials can be fully assessed and, in particular, the likely impact on GDF operations, the waste packager will be required to provide sufficient information on the quantity, nature and status of all Safeguarded material that will be incorporated into proposed waste packages.

5 QUALITY MANAGEMENT

Quality management arrangements shall be applied to all aspects of the packaging of radioactive wastes that affect product quality. These arrangements shall be agreed with RWMD prior to the start of the activities to which they relate.

All activities relevant to licensing of a GDF will be conducted in accordance with appropriate quality management arrangements. The objective in establishing and operating a quality management system is to provide an integral framework of procedures which will ensure that the work is adequately controlled, documented and recorded. It is the responsibility of the waste packager to develop, operate and maintain appropriate quality management arrangements which meet all RWMD requirements. These arrangements will be the subject of a separate approval by RWMD, as specified in *Waste Package Quality Management Specification, WPS/200*. Guidance on the quality management requirements can be found in *Waste Package Quality Management Specification. Guidance Material, WPS/210.*

6 WASTE PACKAGE DATA AND INFORMATION RECORDING

Information shall be recorded on all relevant details of the manufacture of each waste package. That information shall be sufficient to enable assessment of the waste package characteristics and performance against the requirements of all stages of their long-term management.

Waste Package Data and Information Recording Specification, WPS/400, describes the information to be supplied by waste packagers on the nature and contents of each waste package. Supporting guidance can be found in *Waste Package Data and Information Recording Specification: Explanatory Material and Guidance, WPS/850*. Most of this data will of necessity have to be recorded at the time the waste is packaged. It will eventually be transferred and stored on a GDF database maintained by RWMD, where it will be enhanced with additional information including the location of each waste package within a GDF. The data will comprise a permanent record of the waste that has been disposed of in a GDF and will be used to ensure that operations are carried out within the limits of the relevant authorisations.

7 REFERENCES

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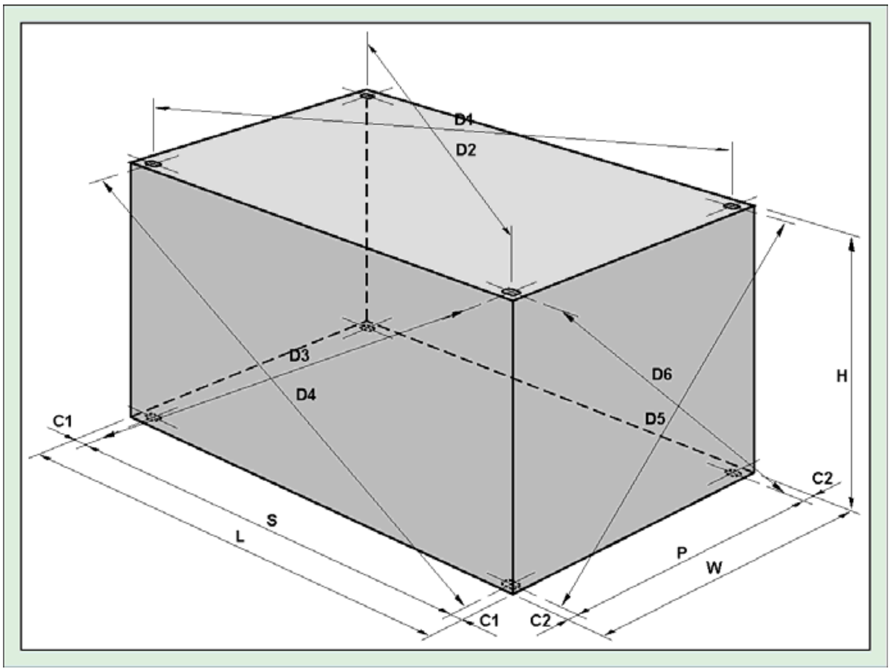
APPENDIX A LOCATION OF CORNER FITTINGS FOR 4 METRE BOX WASTE PACKAGE



KEY

Label	Description	Dimension (mm)	Tolerance (mm)
L	Overall Box Length	4013	+0/-6
W	Overall Box External Width	2438	+0/-5
H	Overall Box External Height	2200	+0/-5
S	Length between Corner Fitting Aperture Centres	3809	ref.
P	Width between Corner Fitting Aperture Centres	2259	ref.
K1	Difference between D1 & D2 or D3 & D4 i.e. │D1-D2│ or │D3-D4│	11	max.
K2	Difference between D5 & D6 i.e. │D5-D6│	11	max.
C1	Corner Fitting Measurement[17]	101.5	+0/-1.5
C2	Corner Fitting Measurement	89.0	+0/-1.5

[17] from BS3951: Pt. 1: Section 1.2: 1985

APPENDIX B RADIOACTIVE GAS GENERATION LIMITS

Nuclide	Allowable activity release (TBq/day)
Ar^{-}-39	2.0×10^{-5}
Ar-41	3.0×10^{-7}
C-14	3.0×10^{-6}
H-3	4.0×10^{-7}
Kr-81	4.0×10^{-5}
Kr-85	1.0×10^{-5}
Kr-85m	3.0×10^{-6}
Kr-87	2.0×10^{-7}
Rn-222	4.0×10^{-9}
Xe-122	4.0×10^{-7}
Xe-123	7.0×10^{-7}
Xe-127	2.0×10^{-6}
Xe-131m	4.0×10^{-5}
Xe-133	1.0×10^{-5}
Xe-135	2.0×10^{-6}

APPENDIX C ACTIVITY RELEASE LIMITS FOR DBAs

Radionuclide	Waste package activity release resulting in BSL for faults with frequency >10^{-3} pa			
	Impact Accidents		Fire Accidents	
	Off-Site (1mSv)	On-Site (20mSv)	Off-Site (1mSv)	On-Site (20mSv)
	TBq	TBq	TBq	TBq
Ag-108m	1.74E-04	8.47E-04	5.49E-04	3.40E-03
Am-241	2.38E-05	7.60E-07	4.90E-05	3.05E-06
Am-242m	2.64E-05	8.47E-07	5.46E-05	3.40E-06
Am-243	2.38E-05	7.60E-07	4.90E-05	3.05E-06
Ba-137m	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Be-10	4.88E-03	9.30E-04	1.45E-02	3.71E-03
C-14	3.62E+00	5.13E-02	8.33E+00	2.05E-01
Ca-41	8.93E-03	1.10E-02	2.77E-02	4.41E-02
Ca-45	8.93E-03	1.10E-02	2.77E-02	4.41E-02
Ce-144	2.79E-03	6.06E-04	8.62E-03	2.42E-03
Cl-36	6.33E-04	4.30E-03	2.02E-03	1.72E-02
Cm-242	2.74E-04	6.19E-06	4.72E-04	2.48E-05
Cm-243	3.56E-05	1.03E-06	6.21E-05	4.10E-06
Cm-244	2.94E-05	1.19E-06	6.02E-05	4.75E-06
Cm-245	2.51E-05	7.43E-07	4.39E-05	2.97E-06
Cm-246	2.53E-05	7.43E-07	4.42E-05	2.97E-06
Co-58	1.01E-02	1.48E-02	3.18E-02	5.93E-02
Co-60	3.27E-04	1.03E-03	1.04E-03	4.10E-03
Cr-51	5.99E-01	8.26E-01	1.89E+00	3.30E+00
Cs-134	3.70E-04	3.10E-03	1.18E-03	1.23E-02
Cs-135	3.37E-04	3.00E-02	7.87E-04	1.20E-01
Cs-137	3.55E-04	4.43E-03	1.13E-03	1.77E-02
Eu-152	8.13E-04	7.60E-04	2.55E-03	3.05E-03
Eu-154	9.26E-04	5.93E-04	2.89E-03	2.38E-03
Eu-155	1.95E-02	4.57E-03	4.33E-02	1.83E-02
Fe-55	5.65E-03	3.23E-02	1.81E-02	1.29E-01
H-3	8.62E+02	7.25E-01	2.00E+03	2.90E+00
I-129	3.37E-05	3.10E-04	7.87E-05	1.23E-03
I-131	3.05E-03	1.48E-03	7.19E-03	5.93E-03
Mn-54	2.79E-03	1.98E-02	8.70E-03	7.94E-02

Radionuclide	Waste package activity release resulting in BSL for faults with frequency >10^{-3} pa			
	Impact Accidents		Fire Accidents	
	Off-Site (1mSv)	On-Site (20mSv)	Off-Site (1mSv)	On-Site (20mSv)
	TBq	TBq	TBq	TBq
Mo-93	2.14E-04	1.35E-02	6.80E-04	5.41E-02
Nb-93m	1.33E-01	1.85E-02	3.76E-01	7.43E-02
Nb-94	2.10E-04	6.60E-04	6.67E-04	2.64E-03
Nb-95	2.23E+00	1.85E-02	5.81E+00	7.43E-02
Ni-59	1.13E+01	3.58E-02	1.94E+01	1.43E-01
Ni-63	8.62E-02	1.48E-02	2.70E-01	5.93E-02
Np-237	6.33E-05	1.42E-06	1.12E-04	5.67E-06
Pa-231	3.56E-05	2.29E-07	8.62E-05	9.13E-07
Pb-210	7.87E-06	2.70E-05	2.48E-05	1.08E-04
Pd-107	1.12E-03	5.41E-02	2.62E-03	2.16E-01
Pm-147	3.00E-01	6.33E-03	5.18E-01	2.53E-02
Po-210	7.87E-06	9.90E-06	2.48E-05	3.96E-05
Pr-144	0.00E+00	9.90E-01	0.00E+00	3.96E+00
Pu-238	3.79E-05	6.92E-07	9.01E-05	2.76E-06
Pu-239	3.56E-05	6.33E-07	8.62E-05	2.53E-06
Pu-240	3.56E-05	6.33E-07	8.62E-05	2.53E-06
Pu-241	2.43E-03	3.50E-05	6.29E-03	1.40E-04
Pu-242	3.77E-05	6.76E-07	9.17E-05	2.70E-06
Ra-226	6.49E-05	9.30E-06	1.26E-04	3.71E-05
Rh-106m	0.00E+00	1.56E-01	0.00E+00	6.25E-01
Ru-103	7.41E-02	1.06E-02	2.01E-01	4.25E-02
Ru-106	1.95E-03	4.80E-04	5.78E-03	1.92E-03
S-35	6.76E-04	2.29E-02	1.57E-03	9.13E-02
Se-79	3.37E-04	9.57E-03	7.87E-04	3.83E-02
Sm-151	3.00E-01	8.03E-03	5.18E-01	3.21E-02
Sn-121m	3.60E-03	7.07E-03	1.14E-02	2.83E-02
Sn-126	3.27E-04	1.10E-03	1.04E-03	4.41E-03
Sr-89	8.93E-03	3.96E-03	2.77E-02	1.59E-02
Sr-90	1.08E-04	1.98E-04	3.42E-04	7.94E-04
Ta-182	9.62E-03	3.06E-03	2.15E-02	1.23E-02
Tc-99	6.33E-04	3.06E-03	2.02E-03	1.23E-02
Th-229	3.56E-05	3.00E-07	8.62E-05	1.20E-06

Radionuclide	Waste package activity release resulting in BSL for faults with frequency >10^{-3} pa			
	Impact Accidents		Fire Accidents	
	Off-Site (1mSv)	On-Site (20mSv)	Off-Site (1mSv)	On-Site (20mSv)
	TBq	TBq	TBq	TBq
Th-230	3.56E-05	7.43E-07	8.62E-05	2.97E-06
Th-232	3.56E-05	7.07E-07	8.62E-05	2.83E-06
U-233	1.58E-04	3.41E-06	2.75E-04	1.37E-05
U-234	1.58E-04	3.50E-06	2.75E-04	1.40E-05
U-235	1.63E-04	3.86E-06	2.94E-04	1.54E-05
U-236	1.58E-04	3.76E-06	2.75E-04	1.50E-05
U-238	1.09E-04	4.07E-06	2.33E-04	1.63E-05
Y-90	3.37E+00	1.75E-02	5.85E+00	6.99E-02
Y-91	9.71E-03	3.54E-03	2.16E-02	1.42E-02
Zn-65	2.10E-04	1.03E-02	6.67E-04	4.10E-02
Zr-93	1.46E-01	1.03E-03	2.54E-01	4.10E-03
Zr-95	9.71E-03	5.41E-03	4.27E-02	2.16E-02

APPENDIX D ABBREVIATIONS AND ACRONYMS

ACT	Accident Conditions of Transport
Bq, GBq, TBq	becquerel, gigabecquerel (10^9 Bq), terabecquerel (10^{12}Bq)
DBA	Design Basis Accident
GDF	Geological Disposal Facility
GDSS	Generic Disposal System Specification
GOSA	Generic Operational Safety Assessment
GRD	Generic Repository Design
GWPS	Generic Waste Package Specification
HEPA	High Efficiency Particulate in Air (filter)
HEU	High Enriched Uranium
HPA	Health Protection Agency
HSE	Health and Safety Executive
IAEA	International Atomic Energy Agency
ILW	Intermediate Level Waste
LLW	Low Level Waste
LoC	Letter of Compliance
LSL	Lower Screening Level
MNOP	Maximum Normal Operating Pressure
NCT	Normal Conditions of Transport
OCNS	Office for Civil Nuclear Security
PGRC	Phased Geological Repository Concept
RF	Release Fraction
SAPs	NII Safety Assessment Principles
SFM	Safe Fissile Mass
Sv, mSv	sievert, millisievert
t	metric tonne (1000kg)
USL	Upper Screening Level
W, kW	watt, kilowatt
WPSGD	Waste Package Specification and Guidance Documentation

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