

Geological Disposal

Waste Package Specification and Guidance Documentation WPS/915: Guidance on the Use of Grout Caps in Waste Packages

February 2009

**Geological Disposal
Waste Package Specification and
Guidance Documentation
WPS/915: Guidance on the Use of
Grout Caps in Waste Packages**

February 2009

CONDITIONS OF PUBLICATION

This report is made available under the NDA Transparency Policy. In line with this policy, the NDA is seeking to make information on its activities readily available, and to enable interested parties to have access to and influence on its future programmes. The report may be freely used for non-commercial purposes. However, all commercial uses, including copying and re-publication, require permission from the NDA. All copyright, database rights and other intellectual property rights reside with the NDA. Applications for permission to use the report commercially should be made to the NDA Information Manager.

Although great care has been taken to ensure the accuracy and completeness of the information contained in this publication, the NDA can not assume any responsibility for consequences that may arise from its use by other parties.

© Nuclear Decommissioning Authority 2009. All rights reserved.

BIBLIOGRAPHY

If you would like to see other reports available from NDA, a complete listing can be viewed at our website www.nda.gov.uk, or please write to the Library at the address below.

FEEDBACK

Readers are invited to provide feedback to the NDA on the contents, clarity and presentation of this report and on the means of improving the range of NDA reports published. Feedback should be addressed to:

John Dalton,
Head of Communications,
Nuclear Decommissioning Authority (Radioactive Waste Management Directorate),
Curie Avenue,
Harwell Campus,
Didcot,
Oxon,
OX11 0RH
UK

WASTE PACKAGE SPECIFICATION AND GUIDANCE DOCUMENTATION
GUIDANCE ON THE USE OF GROUT CAPS IN WASTE PACKAGES

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.

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.

CONTENTS

1	INTRODUCTION	1
2	BACKGROUND	1
2.1	The Concept of Geological Disposal	1
2.2	The Generic Waste Package Specification	2
2.3	The Assessment of Packaging Proposals	3
3	BACKGROUND FOR OBJECTIVE OF THIS GUIDANCE	4
4	THE ROLE OF A GROUT CAP	5
4.1	Physical Immobilisation	6
4.2	Free Liquids	6
4.3	Wasteform Evolution	7
4.4	Mechanical Strength	8
4.5	Voidage	8
4.6	Gas Generation	9
4.7	Accident Performance	9
4.8	Benefits of a grout cap to waste container performance	9
4.9	Summary	10
5	ASSESSING WHETHER A GROUT CAP IS REQUIRED	10
6	DEFINITION OF THE REQUIREMENTS OF A GROUT CAP	13
6.1	Requirements common to all grout caps	14
6.2	Wasteform specific requirements	14
6.3	Waste packages incorporating annular grouted wasteforms	15
6.4	Materials used for grout caps	16
7	SUMMARY	17
8	CONCLUSIONS	19
	REFERENCES	20
	APPENDIX A IDENTIFICATION OF THE ROLES OF A GROUT CAP IN THE PERFORMANCE OF A WASTE PACKAGE	21

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.

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.

The diverse physical, chemical and radiological nature of ILW in the UK means that particular challenges arise in the packaging of certain wastes. To assist waste packagers with the preparation of proposals for the packaging of such challenging wastes, the RWMD has produced, and continues to add to, a suite of thematic Guidance Notes. A full list of the Guidance Notes produced by the NDA, together with an abstract of each, can be found in *Introduction to the NDA Waste Packaging Guidance Notes, WPS/900*.

Historically it has been the practise to 'cap' the contents of waste packages (i.e. the conditioned wasteform) with a layer of inactive cement. The inclusion of such a 'grout cap' is not a requirement of the GWPS although it is generally believed to improve the overall performance of the wasteform and waste package. The purpose of this guidance is to provide waste packagers with background information that can be used to inform decisions regarding the applicability of a grout cap to the packaging of specific waste types.

2 BACKGROUND

2.1 The Concept of Geological Disposal

A key aspect in the production of standards 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.

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

WPS/915

February 2009

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. 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. 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 wastefrom, 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 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

An important aspect 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.

3 BACKGROUND FOR OBJECTIVE OF THIS GUIDANCE

For many categories of ILW the most common, although not universal, method of conditioning has been the intimate encapsulation of the waste with a cementitious (or occasionally polymer based) grout within a stainless steel waste container. Historically such an approach has resulted in waste packages that are compatible with the needs for interim storage, transport and disposal in a GDF. It has also been the general practice for the primary matrix of waste and encapsulating material (i.e. the wasteform) to be supplemented by the addition of an additional layer of inactive cementitious material to provide a 'grout cap' (Figure 1).

Figure 1 Typical 500 litre Drum Waste Package showing grout cap



Whilst the inclusion of a grout cap is not explicitly specified in the GWPS, it is generally believed that a number of advantages to overall waste package performance will result if one is included. However, these advantages are not universal and it may be that, for certain waste and wasteform types, no such advantage would result and the cost of including a grout cap would not be justified. Furthermore there may be cases where the presence of a grout cap may be deleterious to the overall performance of a waste package.

The objective of this guidance is to assist waste packagers in identifying the various benefits and drawbacks associated with the inclusion of a grout cap in the design of a waste package, such that reasoned arguments for inclusion or omission can be made as part of a LoC submission.

Specifically this guidance is intended to identify the benefits of the use of a grout cap in assisting a waste package to be compliant with the various requirements defined by the GWPS, as well as the potential drawbacks associated with the provision of such a cap. This includes advice on:

- whether a particular waste package design for a specific type of waste should include a grout cap;

- what performance requirements such a grout cap should possess;
- how a grout cap could be specified (in terms of material, thickness etc) to achieve those performance requirements.
- how issues related to the inclusion, or otherwise, of a grout cap can be addressed in a LoC submission.

4 THE ROLE OF A GROUT CAP

A fundamental requirement of a waste package is to provide adequate containment of the radionuclides and other hazardous materials associated with the enclosed waste. This containment needs to be provided for a period commensurate with that anticipated for the long-term management of the wastes and to a degree that underpins the assumptions made in the various safety assessments associated with that management.

Currently most ILW is either intimately mixed with an appropriate encapsulant, or compacted within mild steel drums that are subsequently encased in an encapsulant. In both cases the resulting wasteform is enclosed within a waste container, the combination of wasteform and container providing a suitably robust, multi-barrier waste package that satisfies the requirements for interim storage, transport and disposal, as defined by the GWPS.

With regard to wasteforms The GWPS requires that, during their production and their interim surface storage, all reasonable measures shall be taken 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; and
- the presence and volume of voids is minimised.

The effects of evolution of the wasteform, particularly during interim storage have also to be considered. The wasteform must also be sufficiently robust that its performance during certain prescribed accidental impact and fire events can be assured within given limits.

In general it is believed that a grout cap placed on top of a wasteform will assist it in meeting these requirements. However, for some wasteforms, the nature of the waste or of the conditioned wasteform may mean that the GWPS requirements can be satisfied without the use of a grout cap and that the inclusion of such a feature may be of limited overall benefit to overall waste package performance. Indeed it is possible that a grout cap may have a deleterious effect on some aspect of the overall performance of the waste package or on some aspect of the long-term management of the waste (e.g. by adding cost to the packaging process).

The role of a grout cap in generally assisting a waste package to achieve these key wasteform criteria, and potential issues that will affect wasteform performance are discussed in the following section, grouped under six key headings:

- Physical immobilisation.

WPS/915
February 2009

- Free liquids.
- Wasteform evolution.
- Mechanical strength.
- Voidage.
- Gas generation.
- Accident performance.

4.1 Physical Immobilisation

The GWPS requires that:

'All reasonable measures shall be taken to ensure that radionuclides and toxic materials in the waste are immobilised and that loose particulate material is minimised'.

The upper surface of the primary encapsulant/waste matrix may have the potential for the presence of un-encapsulated particulate material that has floated to the surface during the curing period. For cemented wasteforms this could include materials that have been carried to the surface by the free water in the grout ('bleed water') and then reabsorbed during the curing period, leaving a potentially friable layer on the top of the matrix surface. Such material represents a source of activity that could be released from the waste package under normal or accident conditions

In such cases a grout cap can provide a simple and reliable method of containing this potential source of loose material by adhering it to the matrix surface or by incorporating it into the lower surface of the grout cap.

Settling and shrinkage of the matrix during curing (or for certain cemented wastes following production of excessive bleed water) could result in material intended to be encapsulated in the primary matrix remaining uncovered. The provision of a grout cap can ensure such items are encapsulated completely without the need for small batch top-ups of matrix encapsulant, which may not be suitable, would delay processing and likely produce a significant wastage of matrix material.

Following disposal and the backfilling of a GDF it is currently assumed that the disposal vaults will become re-saturated by groundwater. As many waste packages incorporate filtered vents (to permit the escape of gases but retain particulate activity) water will be able to enter and similarly saturate the wasteform. Whilst it is expected that the waste container will at least initially provide a barrier against the release of soluble radionuclides, the possibility will exist for their diffusion through the vent. A suitably designed and formulated grout cap can slow the escape of such materials from the wasteform.

4.2 Free Liquids

The GWPS requires that:

'All reasonable measures shall be taken to exclude free liquids from the wasteform.'

The presence of free liquids within a wasteform is undesirable as they may reduce performance in a number of areas and can also tend to promote corrosion of the waste,

thereby increasing the mobility of radionuclides, and of the internal surface of the waste container. The potential for activity to escape from waste packages during interim storage may be substantially increased if there are free liquids present.

Application of a suitably formulated grout cap can provide a method for absorbing any residual free liquids that remain on the surface of the wasteform encapsulant following curing. This can particularly be the case where unavoidable variations in the waste composition may lead to waste of different water content being encapsulated. This may give a situation where water must be removed from the wasteform surface following matrix curing, generating a secondary effluent stream. A grout cap that can absorb this excess water would therefore prevent the requirement to remove and treat this secondary effluent.

A further difficulty can arise from the nature of the matrix encapsulant upper surface. If the surface is uneven then removal of any water remaining on the surface could be difficult since it may not be possible to deploy a water removal device to all areas of the surface thereby leaving pockets of free liquid. A grout cap that can absorb or displace this liquid so that it can be removed would therefore be of significant advantage.

If a grout cap is to be used for the specific purpose of absorbing excess liquid, care should be taken with its formulation, quantity etc. to ensure that the cap is capable of absorbing the maximum anticipated quantity of free liquid anticipated from the waste.

4.3 Wasteform Evolution

The GWPS requires that:

'Changes in the characteristics of the wasteform as it evolves shall not result in degradation that will compromise the ability of the waste package to meet any aspect of the GWPS'

During interim surface storage and prior to the backfilling of a GDF wasteforms are to a limited degree exposed to atmospheric gasses and conditions, and may undergo a range of aging processes, such as gradual drying, carbonation or oxidisation, any of which could be detrimental to their performance. A grout cap can protect the primary encapsulant by sealing it completely from the atmosphere and thereby provide additional confidence in predictions of wasteform and waste package longevity. Such sealing of a wasteform need not be performed during initial production of the wasteform and some advantages may be gained from delaying the addition of a grout cap. This could be particularly the case for wasteforms that contain reactive metals which may corrode at a greater rate during the earliest period of interim storage before achieving a chronic rate. Addition of a grout cap could therefore be part of a 'rework' strategy to ensure such waste packages are suitable for transport and disposal.

However, it should be noted a delayed capping strategy would impose additional engineering challenges, and could result in increased dose to workers, associated with removal of the complete lid or opening an access port, implementing cap addition and then re-lidding of the waste package.

4.4 Mechanical Strength

The GWPS requires that:

'The wasteform shall provide sufficient mechanical strength to allow the waste package to be transported and handled without compromising the ability of the waste package to meet any aspect of the GWPS.'

The presence of significant voidage above the active wasteform could affect the overall compressive strength of the waste package. Completely filling the waste container by the use of a grout cap can therefore significantly contribute to the overall strength and stability of the waste package and therefore to its ability to withstand static stacking forces and dynamic forces resulting from both normal handling and more extreme impacts during accidents.

Waste packages will be stacked during both interim surface storage and following emplacement in a GDF and, for those waste packages that are not handled and stacked using stillages; there is the requirement for waste packages to bear the weight of those packages stacked on top of them for extended periods of time (i.e. hundreds of years). This is a particular consideration for those waste packages where the wasteform contributes to stacking performance, such as in the case of the 3 cubic metre Drum waste package.

4.5 Voidage

The GWPS requires that:

'All reasonable measures shall be taken to ensure that the volume of voidage within the waste package (such as ullage space and other holes or spaces) is minimised.'

During metering of waste and encapsulating materials into waste containers it is necessary that an ullage space is incorporated above the wasteform in order to reduce spillage and contamination and thereby the arising of secondary wastes from decontamination operations. The subsequent addition of capping material can assist in reducing the volume of this ullage space since it can be brought to a level closer to the top edge of the container without a risk of contamination should it overflow. Grout caps can also be formulated to be more fluid² and 'self-levelling' such that it is possible to routinely fill to a more precise level within the container. Reducing this ullage space provides less volume for the collection of potentially combustible gasses such as hydrogen and reduces the volume associated with breathing effects caused by changes in atmospheric conditions (such as humidity, temperature and air pressure) during storage.

In the case of stainless steel waste containers with cementitious based encapsulated wastes, exposed metal in the ullage space is more prone to corrosion since it is not in direct contact with the cement matrix, which by nature of its alkalinity is passivating.

A further potential advantage is that in the case of an explosive event caused by combustible gasses held within an ullage space, the surface of the wasteform exposed to such an event is that of the non-active grout cap.

² Care should be taken that this does not conflict with other requirements of the grout cap, such as the absorbing of free liquid (Section 4.2)

4.6 Gas Generation

The GWPS requires that:

'Gases generated by the wasteform shall not compromise the ability of the waste package to meet any aspect of the GWPS'.

Many wasteforms have the potential to produce a variety of gases through a number of mechanisms including corrosion, radiolysis and microbial activity. In general gas generation rates are low but for wasteforms containing reactive metals, such as magnesium, aluminium or uranium) this can be significant, particularly during the period that the waste encapsulant is curing. This can result in a series of gas channels extending from the body of the matrix to the upper surface which could remain after curing. A grout cap can seal these pathways and thereby reduce the number of potential weak points within the matrix making the wasteform more robust, as well as reducing voidage.

4.7 Accident Performance

For the impact and fire accident performance of waste packages the GWPS requires that:

'The waste package shall be designed such that in the event of an impact/fire accident:

- releases of radionuclides and other hazardous materials are low and predictable, exhibit progressive behaviour with increasing fire severity and do not exhibit significant 'cliff-edge' performance characteristics within the anticipated range of impact/fire 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 weakest point of the waste package during an impact accident is likely to be the waste container lid which can become detached during a fall and permit the release of particulates resulting from any break up of the wasteform caused by the impact. The provision of a grout cap beneath the lid adds confidence in the performance of the waste package under such conditions since the top region of the wasteform is the most likely to be damaged during an impact and, were this to comprise material from the grout cap this would be nominally free of radionuclides. This would significantly reduce the amount of particulate activity released during an impact accident.

During a fire accident activity can be released from the wasteform in the form of gases and vapours created during heating of the wasteform. A grout cap free of radionuclides would not produce such activity and would act as a filter to those released from the underlying wasteform.

4.8 Benefits of a grout cap to waste container performance

Whilst much of the benefit that can be claimed from the presence of a grout cap is related to improvements in wasteform performance, a grout cap can also benefit waste container performance. These benefits are mainly in the area of waste container corrosion where, for example, the elimination of free liquids (Section 4.2) can reduce the potential for corrosion of the inner surface of the waste container, as would the reduction of ullage by reducing the area of the inner surface exposed to the atmosphere.

The grout cap can also act as a filter for activity in fine particulate form that could be mobilised by the flow of gas from a wasteform. Waste packages with the potential to generate gas are required to be fitted with a filtered vent and a lidding arrangement that ensures that such gases pass through the vent. Whilst this arrangement would be expected to be effective in the prevention of the escape of particulate activity in the early periods of the management of waste packages (when gas generation would be expected to be at its greatest), deterioration of the lid seal may reduce the effectiveness of the filter in the longer term. A grout cap that is permeable to the gas produced in the matrix can reduce the particulate challenge to the filter during the earlier periods and reduce the presence of loose particulates on the top surface of the waste during all periods.

4.9 Summary

In summary the provision of a grout cap can assist a waste package in meeting the requirements of the GWPS, mainly by enhancing the performance of the wasteform. There are also some benefits that the presence of a grout cap will have for waste container performance.

5 summarises these benefits and separates them into those that apply to the wasteform and those that affect the waste container.

5 ASSESSING WHETHER A GROUT CAP IS REQUIRED

The decision as to whether the design of a waste package for a particular waste type should incorporate a grout cap should not be purely based on the requirements of the GWPS, but also on process requirements that must be considered in order that the decision is taken holistically.

The variable nature of the physical and chemical form of ILW is such that a range of approaches to conditioning and packaging is required, including novel solutions, in response to the challenges presented. This means that it is not possible to provide a universal ranking of the importance of each potential advantage offered by a grout cap for all waste packages. Instead general guidance on a hierarchy of the benefits associated with capping is offered.

In general the benefits associated with a grout cap can be considered to either promote performance of the wasteform, the waste container or both, as discussed in Section 4. The relative strength of arguments presented by a waste packager in support of a particular waste package design will therefore have a strong bearing on whether a grout cap is required, since if a cogent case can be made for the suitability of a waste package design without such a feature, then the additional benefits may be judged not substantial enough to warrant inclusion. Conversely, for a waste package that includes unavoidable uncertainty, particularly for accident performance, the extra confidence gained by provision of a grout cap may be essential to the overall judgement of the suitability of the waste package for transport and disposal.

The process implications of a grout cap are of substantial importance since they can fundamentally determine the plant approach to certain aspects of safety, quality and process design. These can then, themselves, have a significant impact on the decision to include a grout cap irrespective of any other associated benefits relating to all subsequent stages of the long-term management of the waste package.

Table 1 Benefits of a grout cap to wasteforms and waste containers

GWPS Requirement	Potential benefit provided by grout cap	
	To Wasteform	To Waste Container
Physical immobilisation	Prevention of loose particulate. Ensuring complete encapsulation of waste Provides a barrier to the diffusion of radionuclides following saturation in post-closure period	
Free liquids	Absorption of free liquids, reduction of mobility of radionuclides.	Reduction of free liquids can reduce the potential for corrosion of inner surface of waste container.
Wasteform Evolution	Protection of primary encapsulant from external environment.	
Mechanical Strength	Fills waste container to provide stronger wasteform Fills cracks etc in primary encapsulant	
Voidage.	Reduces volume of ullage In-fills connected voids created by gases during curing of primary encapsulant.	Complete filling of waste package ullage may reduce potential for container corrosion.
Gas Generation.	Reduces volume available for collection of flammable gasses.	Acts as a filter and reduces burden on engineered waste container filters and seals.
Accident Performance.	Reduces activity associated with loose particulates released following accident.	

Potential process advantages resulting from the inclusion of a grout cap include:

- Enabling the matrix encapsulation system to be simplified since there is no requirement to minimise ullage in the waste package at that point in the process. The upper matrix surface can therefore be targeted at a level in the waste container that will prevent secondary contamination of the surrounding area due to splashing etc. This not only enables the plant to be kept cleaner but reduces the burden on the container decontamination system and the generation of associated secondary wastes. Ullage is then reduced to an acceptable level at the more precisely controlled capping stage.
- Allowing use of a lower upper matrix surface which reduces risk of splashing material when transporting products containing non-set matrix encapsulant. For plants with a constrained footprint, this can benefit throughput since a single

WPS/915
February 2009

matrix addition station can then be used to fill many waste containers with each being transferred to a common curing area. This method of operating can provide potential savings to the design and running cost of a facility from fewer matrix delivery stations without compromising throughput.

- Reducing the requirement to precisely fill a waste container to a given point at the primary matrix stage. The precision of level control becomes less critical and the waste package more robust to slight changes in the volume of waste if a grout cap of variable thickness is to be added subsequently. This can simplify the matrix encapsulant delivery.

In order to judge if a grout cap is required for a particular waste package the roles of such a feature in that particular waste package should be identified. For example, if the grout cap was intended to fix loose activity or providing a control for the presence of free liquids then its inclusion in the waste package is likely to be considered essential. Conversely 'adventitious benefits' to the wasteform, such as potential increases in package longevity, may be considered desirable, but unless they can be shown to be important to the overall performance of the waste package, and can be substantiated, they are unlikely on their own to justify the inclusion of a grout cap.

Whilst the inclusion of a grout cap will provide benefits to most waste packages these must be considered alongside the potential disadvantages to the process and the waste package. These disadvantages include:

- Increasing the overall volume of a conditioned waste stream. Although not explicitly stated in the GWPS there is an expectation that the total conditioned volume of a waste stream, as represented by the total number of waste packages produced, should be minimised. This will have the effect of reducing the total capacity of interim storage facilities and a GDF, and reducing the use of associated facilities particularly those used for transport (with an associated reduction in the number of transport operations, risk and cost). Unless a grout cap is needed to ensure that a waste package satisfies the requirements of the GWPS, its addition could be seen as occupying volume that could better be used to accommodate more waste. For a 500 litre Drum waste package with a 50mm thick grout cap this 'dead' volume would be $\sim 0.03\text{m}^3$ or $\sim 6\%$ of the useful capacity of the waste container.
- The provision of the ability to add a grout cap to a wasteform represents an area of additional cost to the wasteform packager since it may require additional research and development to underpin the design and formulation of the specified grout cap. This may also unacceptably delay treating a waste with particular risks associated with its current storage into a more acceptable (i.e. passive) state. Once the design is implemented there are also the additional costs of plant, ongoing maintenance and operation.
- Whilst the manufacture of a grout cap is unlikely to produce any active secondary wastes there will be a certain amount of unavoidable non-active waste materials, the nature of which will depend upon the choice of cap material.

Application of a grout cap could have detrimental effects on the wasteform and these are potential implications which should be considered during the development of a package design for a particular waste. Specifically (but not limited to) early in the waste package lifetime if the wasteform ages unexpectedly and unacceptably there would be an increased volume of material requiring remediation. The grout cap itself may become a barrier to what could otherwise have been a less onerous method of remediation or may have adversely contributed to the unexpected degradation. For example the grout cap may occupy volume the wasteform might otherwise have expanded to occupy without

detriment. Grout caps could also generate secondary heat effects in the wasteform resulting from any exotherm generated as they cure. This could increase or prolong exotherm effects in the wasteform leading to additional waste corrosion and gas generation.

The relationship between advantages and disadvantages of providing a grout cap to a wasteform will be particular to each waste package. If some detrimental effect on the wasteform or waste package was identified then this would likely determine that addition of a grout cap was inappropriate in that case, although this could be age dependant. For some wastestreams it could be that the number of waste packages produced for disposal is of increased importance. For example addition of a grout cap to a small waste stream could increase the number of packages, costs, etc without significantly reducing the risk presented by that waste during interim storage or disposal. There may be more appropriate engineered solutions that would provide many of the benefits associated with a grout cap for small volume waste streams, which would be too costly to deploy on a large volume waste stream.

Clearly, as can be seen from the preceding discussion, there are many factors to be considered by the waste packager in determining whether a cap needs to be applied to a wasteform. These factors are not always resolved in terms of simple yes/no questions or are not immediately quantifiable; thus relative benefits of adding a permanent cap need to be considered alongside the extra process complexity, cost implications and alternative solutions such as the use of engineered barriers.

Such a decision, which involves multiple and often conflicting criteria lends itself to the use of techniques, such as Multiple Attribute Decision Analysis (MADA), which aim to help decision makers learn about the decision situation and facilitate the identification of an appropriate course of action, and justify why it should be taken.

The discipline imposed by processes such as MADA helps to clarify the importance of various factors that need to be taken into account in arriving at a decision and hence the techniques complement intuitive judgement. Moreover, an obvious advantage of such methods is that the underlying assumptions can be stated explicitly, and therefore can be documented, criticised, defended and revised more easily than the bases of a purely judgmental decision. Unspoken biases can thus be avoided. Furthermore, once agreement has been reached on the important factors then such methods can pinpoint what information is needed in the decision, thus minimising data gathering costs.

The first stage of such a process is to identify the performance requirements of a waste package and determine which elements of the waste package contribute to the performance. This identifies the key role of the grout cap and can then form the basis for subsequently defining the properties of the grout cap or engineered barrier, if one is required. An example of this process is presented in Appendix A.

6 DEFINITION OF THE REQUIREMENTS OF A GROUT CAP

Having described the potential role of grout cap and general advantages that such a feature can offer to a waste package, the properties of the grout cap necessary in order to achieve these benefits can be defined in more detail.

Not all grout caps will need to meet all the requirements outlined below as it will depend upon the defined roles and advantages that the grout cap is providing to each particular waste package. However, there are some general requirements that are common to all grout caps irrespective of the benefits they are providing.

6.1 Requirements common to all grout caps

The grout cap must be compatible with the primary encapsulant such that neither the performance of the grout cap nor the primary encapsulant is compromised. This applies to the period during which the grout cap is curing and during the longer period of storage and disposal where evolution of the matrix should not have a significant effect on the performance of the grout cap. The effect of any heat generated during curing of the grout cap material on the encapsulated wastes should also be considered.

The capping material must be stable and not undergo chemical or physical changes (such as carbonation or oxidation) that would unacceptably enhance the risk of releasing radioactive particulates particularly during interim storage and transport, or otherwise affect performance of the grout cap. However, it should also be understood that the addition of a grout cap is intended to enhance the performance of the wasteform (and the waste package as a whole) and minor degradation or imperfections may not be significant, providing its function is not impaired. For example, 'sacrificial' aging of a grout cap to protect the matrix would be acceptable providing it did not then affect wasteform stability. For instance, if the grout cap aged to the extent that it could no longer fulfil its intended function but in doing so did not cause any detrimental effect on the wasteform beneath it.

The grout cap must possess radiation and thermal stability no worse than the primary encapsulant to prevent it having a detrimental influence on wasteform stability.

One desirable characteristic of a grout cap is that its upper surface would not be contaminated with radionuclides. To prevent radioactive material floating through the grout cap during curing it is beneficial if the capping material has a lower density than that of the waste that may already have floated to the top of the primary wasteform.

The quantity (i.e. minimum thickness) of the grout cap required to achieve the identified performance criteria must be determined. In addition, for cement based grout caps, the minimum thickness required to prevent cracking due to shrinkage and cracking during curing will need to be determined. The effect of drum furniture such as anti-floatation plates should be taken into account since their proximity to the grout cap surface is likely to have an effect.

The gas permeability of the grout cap must be at least equal to that of the primary wasteform. This is to ensure that the grout cap will not hinder the passage of gas generated by the wasteform from its upper surface in order to prevent pressurisation of the wasteform and the potential for damage. An impermeable grout cap could result in it becoming detached from the primary wasteform and therefore losing some of the benefits for which it was intended.

A grout cap should be sufficiently fluid that it can penetrate all unwanted voids within the waste container. Special consideration should be given to filling around any internal furniture, such as anti-floatation plates and inner lids, and to fill any gas channels produced during curing. A fluid self-levelling capping material will allow the final level of the grout cap to be controlled more precisely and therefore reduce the volume of any remaining ullage to a minimum.

6.2 Wasteform specific requirements

Grout caps that are required to encapsulate waste that may be protruding from the primary encapsulant, must have a compatibility with this waste no worse than that of the primary encapsulant otherwise they may be considered to present a potential route for

escape of activity from the wasteform. The ability of the grout cap to infill any un-encapsulated waste materials should also be considered. It may not be possible to enhance the ability of the grout cap to infiltrate waste by the same techniques as those used during matrix encapsulation (e.g. by vibration) due to the requirement to fill closer to the container maximum volume. Also, in such cases the inability of the matrix grout to fully encapsulate the waste may indicate a waste related problem that will have to be addressed during the design and formulation of the capping material.

Wasteforms that produce substantial quantities of gas during processing and curing of the primary encapsulant may have difficulty meeting the requirements of the GWPS for low voidage, if, in an extreme case, they become fissured or contain many pathways extending into the wasteform where gas has escaped during curing. A carefully formulated grout cap may assist such products by providing a method of repairing this damage and thereby substantially increasing mechanical strength and confidence in the longevity of the waste package as a whole. In such products, the ability of the grout cap to fulfil this role will require demonstration.

For wasteforms that contain significant activity the grout cap provides a nominally non-active surface at the top of the wasteform which can reduce the risks associated with release of particulate materials if the waste package is subjected to an accidental impact. The performance of the grout cap during such events should be investigated since a highly brittle grout cap may not offer any advantage in this respect. For wasteforms that have a low activity content in the encapsulant, the provision of a grout cap may offer little or no increase in performance in such scenarios.

6.3 Waste packages incorporating annular grouted wasteforms

The treatment of waste packages where the radionuclides in the waste are immobilised by a method such as encapsulation or compaction, and then further immobilised by a grout annulus is a particular case that requires further consideration. For such waste packages the grout cap can effectively be an integral part of the inactive grout annulus (Figure 2) or, if the waste has the potential to contaminate the grout annulus during manufacture, a separate grout cap can be used (Figure 3).

Figure 2 Examples of 500 litre Drum waste packages with annular grouted wasteforms and integral grout cap

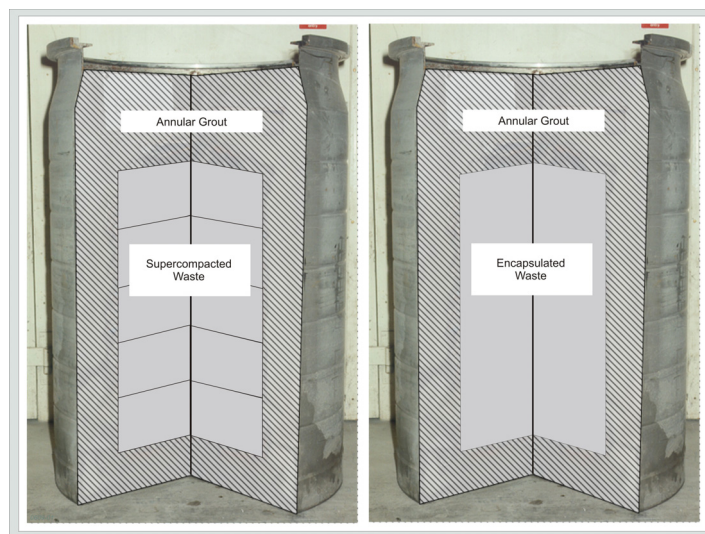
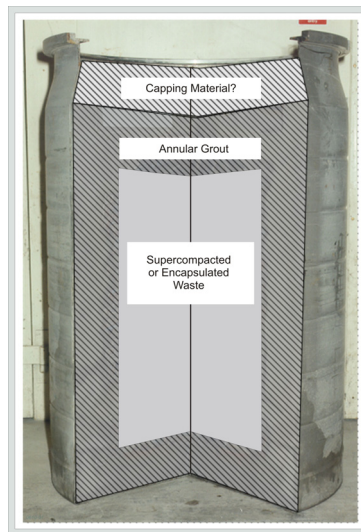


Figure 3 Waste package with annular grouted wasteform and separate grout cap



When deciding whether a separate grout cap is required it should first be considered why the decision to use an annular grouted wasteform was made. The reasons for the use of such wasteforms are several, and may be quite distinct, and include the provision of:

- additional radiation shielding for higher activity wastes;
- additional physical protection for wastes containing significant particulate activity which has not been intimately encapsulated (e.g. super compacted waste);
- additional protection of the waste container from corrosion promoting materials in the waste, or that may be created during evolution of the wasteform; or
- enhanced criticality safety by reducing the neutronic interaction between fissile material in adjacent waste packages.

The decision as to whether to use a separate grout cap will then be driven by the same considerations as for other wasteform types, as discussed in Sections 4 and 5.

For relatively low activity wastes or intimately encapsulated wasteforms that are not expected to degrade, it may be the case that the grout annulus is providing little other benefit than as a void filler or additional confidence during transport. In these cases it could be appropriate to consider delaying the addition of the annular cap such that any unexpected changes in the wasteform can be addressed prior to transport to a GDF. Such an approach would reduce the risk of deleterious aging of the grout cap during unexpected, enforced prolonged interim storage. However, this risk would need to be balanced against the risks associated with interim storage of a waste package with substantial container ullage space.

6.4 Materials used for grout caps

Once a decision has been made to incorporate a grout cap in a waste package design the matter of the material selection must be considered on the basis of the specific need that has been identified for the grout cap, together with a requirement for long term compatibility with the primary matrix.

The use of cementitious materials for capping is that the materials are readily available, relatively cheap and not onerous to handle. Materials, such as Ordinary Portland Cement (OPC) combined with either ground granulated Blast Furnace Slag (BFS) or Pulverised Fly Ash (PFA) are routinely used to provide suitable fluid capping grouts.

Where a similar formulation of cementitious grout is used as the primary encapsulant there are advantages to the development of the waste package due to synergies. For example, a grout cap could be formed by a delayed second pour of matrix grout, or a slightly modified matrix grout. However, obtaining the necessary fluidity of the grout is a balance between the effects of additional water on providing fluidity and otherwise adversely affecting grout properties i.e. propensity to bleed, corrosion of encapsulated metals. A potential method of achieving fluidity without excess water is to use super-plasticisers, although some super-plasticisers tend to reduce permeability of the cured grout, which may present challenges with maintaining permeability equal to or greater than the matrix. It should also be remembered that such additives may have the potential to affect the post-closure performance of a GDF, and their use will require endorsement by way of the LoC process.

In general the low permeability of polymeric materials prevents their use for grout caps with cement based wasteforms. However there may be the opportunity to use polymers after prolonged periods of interim storage if the gas generation rate of a package has reduced to sufficiently low levels. Alternatively, wasteforms with low gas generation may meet this requirement much earlier. The use of polymer based grout caps may offer substantial advantages due to the potential for very low viscosity materials prior to curing, that will allow them to infiltrate the waste package ullage and give additional benefits in terms of waste package remediation to repair fissured or cracked wasteforms.

If the grout cap is not required to provide any function in the immobilisation of the waste then some of the advantages of a cap may be obtained using inert 'void fillers' rather than a material that forms a monolithic layer. However it would be required to demonstrate the acceptable performance of waste packages that contain mobile fillers during a mishandling event such as an accidental impact to a waste package. Overall it is probably likely that using a non-curing void filler would reduce confidence in the waste package performance and therefore undermine the key benefit of providing a grout cap.

It may be possible to provide some of the benefits of a grout cap by other engineered solutions such as a double skinned waste container, inner lids etc. The appropriateness of this approach will depend upon the specific role(s) required of the grout cap. Designing a waste container that features an engineered inner lid can provide a waste package that achieves many of the benefits associated with a capped wasteform but not all. For example a wasteform with loose activity will still contain loose activity but if this were contained beneath an inner lid this could still enhance the accident performance etc. of the waste package.

For waste packages where the overall cost of inner lids and other engineered solutions would not be prohibitive they could offer an appropriate method of increasing confidence in the wasteform particularly where all the advantages of a grout cap are not required.

7 SUMMARY

A grout cap can assist a waste package in meeting the requirements of the GWPS, therefore the provision of a grout cap to any wasteform must be considered at an early stage during development of the tailored solution for that waste. The first stage in this process should be to consider the requirements of the GWPS and identify any shortcomings in the waste package where a grout cap would enhance performance.

WPS/915
February 2009

These performance criteria should then be considered in terms of the overall waste package performance since it may be possible to provide engineered features within the waste container (such as an inner lid) that could provide the advantages offered by a grout cap. Conversely it could be possible to simplify the waste container design by increasing the challenge placed on a grout cap.

This could also be the case for the process design of the proposed packaging plant, where some process constraints could be reduced by careful formulation of a suitable grout cap. A grout cap may therefore offer a waste packager the opportunity to reduce the costs associated with producing an acceptable waste package, whilst increasing the confidence of regulators in the long term performance of the wasteform and associated waste package.

Whilst it is not feasible to provide a detailed ranking of all of the benefits and drawbacks associated with grout caps, the application of a hierarchy for advantages and disadvantages will provide guidance on the potential overall benefits of providing such a feature. This will allow decisions to be made on the importance of a grout cap for any particular wasteform on a holistic basis. This could be undertaken using a formalised decision process such as MADA or similar.

The largest potential benefit of a grout cap to the performance of a waste package arises in the case where such a feature contributes to the physical immobilisation of radionuclides within the waste package, either by reducing the mobility of loose particulate or reducing the presence of free liquids. Thus in cases where high levels of mobile activity are expected (for example sludge wastes) then it is highly likely that a grout cap should be considered essential to demonstrating the suitability of the waste package for interim storage, transport and eventual disposal.

The most substantial disadvantage to providing a grout cap is in the case of deleterious effects on the waste package such as occupying volume required for wasteform expansion or causing secondary exotherm effects. However, in these cases it may be that judicious consideration of the time a grout cap is added to the waste package removes the disadvantage. The remaining disadvantages are associated with the environmental and financial cost arising from increasing the total volume of material to be included for final disposal and the potential for increased safety challenges and costs associated with additional waste treatment. However, these potential disadvantages need to be carefully considered against any identified advantages since for a waste package where the grout cap is providing a substantial component of the immobilisation these disadvantages may be considered to be of lesser importance.

Wasteforms least likely to benefit from capping are those that contain a very limited amount of activity, such that the accident performance, process and transport requirements can be demonstrably achieved without a cap.

Clearly, in line with the advantages and disadvantages that have been discussed in the preceding sections there are cases where the case for a grout cap is compelling, although for many wastes, the decision can be more ambiguous. In basic terms this can be summarised thus:

Strong case: Highly mobile activity content (e.g. sludge and slurry wastes) that will leave activity at the surface of the matrix or on internal container walls above the settled matrix following mixing.

Waste contains chemically reactive material that needs to be kept isolated.

Debateable case: Mixed waste, activity largely confined to dense material that binds well to matrix and little activity rises to surface. Gas generation rates are low to moderate.

No case: Negligible contamination risk, activity contained (e.g. irradiated steels)

Drying out of wasteform not considered likely.

In the particular case of annular grouted wasteforms it is a matter of debate as to whether the grout annulus is considered to be a capping material or part of the primary encapsulant. This is likely to be case dependant since, if the grout annulus is considered to be a primary encapsulant then the decision to provide an additional grout cap is no different to any other product, but if it is considered to be a capping material then more care must be taken to ensure that the performance criteria of the grout cap are fully understood.

Once the overall role of a grout cap in assisting a particular waste package to meet the requirements of the GWPS is understood, then the specific performance criteria of such a feature should be identified. The material used for the grout cap is likely to be similar to that of the primary encapsulant due to the requirement for compatibility and similar long term performance but the remaining performance criteria will be dependant upon the identified role of the grout cap in the specific waste package.

It is possible that for some waste packages it may be appropriate to delay when a cap or annular cap is manufactured to maximise the effective potential benefit of the grout cap, particularly if the primary advantage of the grout cap has been identified to be during transport of the waste package from interim storage to final disposal or there are disadvantages identified with early/immediate capping.

8 CONCLUSIONS

In general terms the inclusion of a grout cap in a waste package is considered to be beneficial since it can assist the waste package to meet the requirements of the GWPS. There are further potential benefits to the waste producer if the provision of a grout cap is considered early in the development of a waste package including potential process advantages.

The relative importance of the advantages and disadvantages associated with providing a cap to any particular wasteform are dependant upon the specific properties of the wasteform but in general the most important considerations are likely to be:

- In the case of a grout cap that contributes to the physical immobilisation of radionuclides either by reducing the mobility of loose particulate or reducing the presence of free liquids it is highly likely that a grout cap would be considered essential to demonstrating the suitability of the waste package for interim storage, transport and eventual disposal.
- Wasteforms that contain a very limited amount of activity, such that the accident performance and transport requirements can be readily achieved without further encapsulation are least likely to benefit from provision of a cap.
- The most substantial disadvantage to providing a grout cap is in the case of deleterious effects on the waste package such as the grout cap occupying volume required for wasteform expansion or causing secondary exotherm effects.

However, in these cases it may be that judicious consideration of the time a cap is added to the waste package removes the disadvantage.

- Waste packages that feature an annular encapsulant are a special case where consideration must be made as to whether the annular material is an extended cap or the primary encapsulant. In the case that they are considered to be an extended cap then the performance criteria of the grout cap must be carefully considered as they are likely to be different to those of a more traditional grout cap placed on top of a wasteform.
- Grout caps may occupy volume within the waste container that could otherwise be used for incorporating more waste although this may not be the case depending upon the encapsulation process requirements for free volume above the primary encapsulant, fissile limits or other constraints on matrix volume.

The benefits associated with capping a wasteform can be realised at different points within the waste package lifecycle depending upon the encapsulation process. The benefits to immobilisation of radionuclides and free liquids may arguably apply to the entire lifecycle, whereas mechanical strength, wasteform evolution and voidage reduction are of more importance during long term storage. Depending upon the handling requirements of the plant process the advantages associated with accident performance may only be of significance during transport from interim storage to the disposal site. Accordingly for waste packages that only substantially benefit from the advantages of capping after interim storage, capping the wasteform at that time may be of more benefit.

REFERENCES

- 1 Nirex, *Generic Waste Package Specification*, Nirex Report N/104 Issue 2, 2007.
- 2 Nirex, *The Nirex Phased Disposal Concept*, Nirex Report N/074, 2003.
- 3 HSE/EA/SEPA, *Improved Regulatory Arrangements for the Conditioning of ILW on Nuclear Licensed Sites, Regulators' Position Statement*, 2003.
- 4 HSE/EA/SEPA, *The Management of Higher Activity Radioactive Waste on Nuclear Licensed Sites, Part 1 The Regulatory Process. Guidance from the HSE, EA and SEPA to Nuclear Licensees*, 2007.

APPENDIX A IDENTIFICATION OF THE ROLES OF A GROUT CAP IN THE PERFORMANCE OF A WASTE PACKAGE

Note that cells shaded **green** indicate 'primary roles' and those shaded **yellow** are 'secondary roles'

Waste Package Performance Criterion	Requirement	Role(s) Played by Waste Package Components						Conclusion	
		Waste	Primary Matrix	Grout Cap	Waste Container		Lid Seal		Filtered Vent
					Walls	Lid			
External Fire 1000°C for 1 Hour <i>Acceptable loss of radionuclides e.g. ¹³⁷Cs, ¹³⁴Cs, ³H from waste package.</i>	Reactive waste is insulated from fire resulting in temperature < 100°C.	Bounding case reactivity is graphite oxidation which has been shown to be negligible below 100°C	Further insulation	Good insulation properties. Retains performance if container fails. Must minimise heat short circuit.	Additional barrier to fire	Additional barrier to fire			Performance delivered by 2-3 with waste temperature rises being very low. Additional barriers present.
<i>Package retains overall integrity after fire</i>	Robust physical support of outer annulus & matrix				Must retain function of holding rest of package together after 1000°C fire for 1 hr.	Must retain function of holding rest of package together after 1000°C fire for 1 hr.	Not required to function under fire conditions. Seal integrity may be compromised after a fire.		Performance delivered by 4 and 5.

Waste Package Performance Criterion	Requirement	Role(s) Played by Waste Package Components						Conclusion	
		Waste	Primary Matrix	Grout Cap	Waste Container		Lid Seal		Filtered Vent
					Walls	Lid			
<i>Gases escape without pressurisation of package during fire</i>	Pressure relief mechanism incorporated into box design. <i>Acceptable permeability of matrix.</i>		Acceptable gas permeability under fire conditions	Acceptable gas permeability under fire conditions			Directs gases through filter. Seal integrity may be compromised after a fire.	Under fire conditions must retain integrity of lid and allow gases to escape – no pressure build-up.	Performance delivered by 7.
Internal Fire <i>Waste will not self ignite and should not support propagation</i>	Limited oxygen ingress. Few ignition sources. Limited propagation.	Limited number of credible ignition sources present. Very limited propagation of fire.	Limits oxygen ingress. Prevents propagation.	Limits oxygen ingress. Barrier to fire.	Limits oxygen ingress. Barrier to fire.			Limits oxygen ingress	Performance delivered by 1-4.
Impact onto unyielding surface from 25m <i>Acceptable loss of material from waste package</i>	Energy absorption by grout & ductility of outer skin. Material retention by outer skin.	Non-dispersible (>100µm). Strong agglomeration.	Physically stabilises waste. Some energy absorption.	Energy absorption. Additional barrier between waste and likely impact point.	Energy absorption (ductile). Material retention. Retains lid.	Energy absorption (ductile). Material retention. Lid remains attached		Energy absorption (ductile). Material retention. Stays in place	Energy absorption delivered by 3-5 and 7. Containment delivered by 4, 5 and 7.

Waste Package Performance Criterion	Requirement	Role(s) Played by Waste Package Components						Conclusion	
		Waste	Primary Matrix	Grout Cap	Waste Container		Lid Seal		Filtered Vent
					Walls	Lid			
Immobilisation <i>Waste in immobile form with minimum loose particulate.</i>			Immobilises activity. Diffusive barrier, high pH and chemical barrier preventing migration of radioactive species.	Seals loose activity on matrix surface. Diffusive barrier.					Performance delivered by 2 and 3.
Containment <i>Minimum activity migration from package</i>	Multiple diffusive barriers.		O/S items must be contained	Seals loose activity on matrix surface. Diffusive barrier.	Diffusive barrier.	Diffusive barrier.	Completes containment.	Retains particulate. May allow some aerial activity egress.	Performance delivered by 2-6.
Free Liquids <i>Minimisation of free liquids in waste package to avoid mobilisation of activity and degradation of barriers</i>	Absorption by grout matrix. Further impermeable barriers.	Variable water content is handled by design of process.	Incorporates any liquids during process. Bleed self-regulates water content.	Absorbs, adsorbs or consumes any liquids during storage.	Impermeable barrier. Will contain free liquids.	Impermeable barrier. Will contain free liquids.	Impermeable barrier. Will contain free liquids.		Absorption and self-regulation by 2. Additional barriers provided by 3-6.

Waste Package Performance Criterion	Requirement	Role(s) Played by Waste Package Components							Conclusion
		Waste	Primary Matrix	Grout Cap	Waste Container		Lid Seal	Filtered Vent	
					Walls	Lid			
Gas release <i>Allows gases to be released to avoid undue pressurisation, activity release and disruption of package</i>	Gas permeability greater than generation rate.	Low rate of gas generation.	Sufficiently permeable to release gas without degradation.	Sufficiently permeable to release gas without degradation.	Directs gas to filter.		Directs gas to filter.	Must maintain gas release without pressurisation (challenge greatest in early years).	Matrix and cap (2 and 3) allow diffusion, allowing gas release through filter (7).
Criticality <i>Avoidance of criticality</i>	Maintain safe package inventory & geometry	Fissile limit maintained.	Help maintain safe geometry. Could benefit fissile limit if required.						Performance delivered by fissile limit (1). Safe geometry by liner dimensions.
Compatibility with disposal concept.	Chemical (pH, Eh etc.) compatibility with disposal facility materials and chemistry.		Grout high pH provides buffer against acid environments e.g. from degradation of plastics etc.						Performance delivered by 2.

Waste Package Performance Criterion	Requirement	Role(s) Played by Waste Package Components						Conclusion	
		Waste	Primary Matrix	Grout Cap	Waste Container		Lid Seal		Filtered Vent
					Walls	Lid			
Physical Stability <i>Package retains overall dimensions for future handling</i>	Rigidity of steel components supported by solid grout. Compatibility of all materials of container construction with waste.	Waste does not degrade outer package features	Solid waste/grout matrix		Rigid. Maintains outer dimensions within acceptable limits. Able to take stacking loads without plastic deformation. Corrosion resistant.	Will contribute to strength of overall package.			Performance delivered by 4 with support from 1,2 and 5.



Certificate No 4002929



Certificate No 4002929

Nuclear Decommissioning Authority
Radioactive Waste Management Directorate
Curie Avenue
Harwell Science and Innovation Campus
Didcot
Oxfordshire OX11 0RH

t +44 (0)1925 802825

f +44 (0)1925 802932

w www.nda.gov.uk

© Nuclear Decommissioning Authority 2009