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Geological Disposal

Waste Package Specification and Guidance Documentation WPS/914: Guidance on the Issues Arising from the Packaging of Non-encapsulated Wastes

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WASTE PACKAGE SPECIFICATION AND GUIDANCE DOCUMENTATION

GUIDANCE ON THE ISSUES ARISING FROM THE PACKAGING OF NON-ENCAPSULATED WASTES

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 the NDA Radioactive Waste Management Directorate. 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

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 SLCs, 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.*

In order to satisfy the various requirements of the GWPS, wastes are commonly packaged in stainless steel containers using a process that involves intimate mixing of the waste with an encapsulating material (usually cementitious). The resulting waste package thus forming one of the engineered barriers that prevents the return of radioactivity to the environment. Such an approach to packaging will, in most cases, result in waste packages which are compatible with the requirements of the GWPS and which will be suitable for storage and subsequent transport to and disposal in a geological repository.

It is acknowledged that the nature of certain wastes may mean that intimate encapsulation is not necessarily the optimum approach to achieving the required waste package performance and that an alternative approach, not involving encapsulation may be more suitable from both a safety and cost viewpoint. Indeed there exist some wastes where intimate encapsulation may have a deleterious effect of the waste and actually render it less suitable for transport and/or disposal.

The purpose of this Guidance Note is to assist SLCs in the identification of which types of waste may be suitable for packaging without intimate encapsulation, the issues that arise from such an approach and the measures that can be taken to ensure the compatibility of manufactured waste packages with the packaging standards and specifications defined by the GWPS.

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[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 Aims and Organisation of this Guidance

The objective of this document is to provide SLCs with guidance regarding the suitability of waste conditioning processes that do not involve the use of intimate encapsulation for particular types of waste. The particular aims are to discuss the issues that may arise from an approach to waste conditioning that does not involve the intimate encapsulation of the waste. This is achieved by consideration of the following aspects of such an approach:

- Identification of the potential problems that non-encapsulation of waste may create and render waste packages unsuitable for on-site storage, transport and disposal;
- Consideration of the generic characteristics of waste that may make them amenable to a conditioning process that does not involve intimate encapsulation;
- Identify specific waste types that may benefit from conditioning without intimate encapsulation;
- Consider how compliance of non-encapsulated waste packages with the requirements of the GWPS could be achieved;
- Discuss the outcome of the LoC assessment of proposals for the conditioning of actual wastes by means not involving intimate encapsulation.

This remainder of this Section provides background on the concept of geological disposal, the LoC Assessment Process[2] and the RWMD approach to setting standards and specifications for the packaging of ILW which form the basis for the LoC process.

Section 3 summarises the requirement for wasteforms, be they intimately encapsulated or non-encapsulated.

Section 4 discusses the properties of non-encapsulated wasteforms and how these may affect the ability of a waste package to be compliant with the criteria specified by the GWPS.

Section 5 identifies the nature of wastes that might be suitable for conditioning by way of a process involving non-encapsulation

Section 6 provides information from the LoC assessment of proposals to package two particular waste streams by way of a process involving non-encapsulation.

2.2 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[3]. 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;

[2] A full description of the LoC process can be found in *WPS/650*.
[3] The generic description 'ILW' is used in the remainder of this document to describe both these categories of waste.

- 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. The barrier provided by the waste package can be considered as two independent but complementary barriers, the waste container and the wasteform, each of which can play an important role in the containment of radionuclides. This two-fold nature the barrier provided by the waste package has particular relevance to the subject of this guidance.

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.

2.3 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 stages 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.

2.4 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 REQUIRED PROPERTIES OF WASTEFORMS

In general, a waste package can be considered to comprise two distinct components; a waste container and a wasteform. Together these components provide physical containment, the first of several safety barriers to the release of radionuclides from a GDF. Accordingly, the GWPS defines the requirements for the performance of waste packages in terms of those that are primarily provided by the waste container and the wasteform and those that are provided by the waste package as a whole.

In many cases the wasteform is an essential component of a waste package as it may be the primary means by which all of the hazardous components of a raw waste, both nuclear and non-nuclear, are rendered passively safe. The design and performance of the wasteform can also have a significant influence on the performance of the waste package under impact and fire accident conditions.

Currently most wastes are conditioned by either intimate mixing of the waste with an encapsulating material or, for soft wastes, by compaction of a ‘sacrificial’ steel drum containing the waste to produce a puck, which is then encapsulated within a waste container. At present this is considered best practice for the majority of UK ILW, as the waste packages so produced can be shown to be compliant with the requirements defined by the GWPS.

It should however be borne in mind that the relative importance of the wasteform in ensuring the required performance of a waste package will depend on other components of the waste package, notably the waste container and the waste itself. In some cases the use of a robust, high integrity waste container could obviate the need for many, if not all, of the wasteform performance requirements defined by the GWPS. Similarly, a waste in which the radionuclides are effectively immobilised by the physical or chemical form of the waste could satisfy many the wasteform requirements without the need for additional conditioning (i.e. intimate encapsulation).

3.1 General Requirements of all Wasteforms

The high-level specification for wasteforms in the GWPS[4] requires that:

‘During the production of the wasteform and the interim surface storage of the waste package, 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 (e.g. ullage space) is minimised.***

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

Further noting that the wasteform should contribute to the effectiveness of a waste package to retain its radioactive contents, and other hazardous materials, within given limits, during both normal and accident conditions.

In general a wasteform can satisfy these requirements if the characteristics of fluidity, dispersability and freedom of movement of radionuclides within the wasteform are eliminated. Thus potentially mobile radionuclides can be either physically trapped or chemically bound within an immobilising matrix.

Such immobilisation of radionuclides, particularly where cementitious matrices are used, will provide a number of benefits including:

- releases of radionuclides following accidents (e.g. impact and/or fire) are more likely to be low and predictable;
- rates of corrosion of waste and waste container materials will be low and predictable;
- solubility of many key radionuclides and toxic chemicals are reduced;

[4] Direct quotations from the GWPS in this Guidance are shown in ***bold blue italic type***.

- compatibility of waste packages (e.g. porosity, permeability and stability) with the environment of the backfilled vaults.

3.2 Non-encapsulated Wasteforms

Although the intimate encapsulation of waste is generally seen as best practice, the GWPS does not explicitly require such an approach to the conditioning of waste and it is recognised that waste packages containing certain wastes may meet most or all of the requirements of the GWPS, as a consequence of the physical or chemical form of the waste and/or the radionuclide inventory.

Indeed for some waste types there are a number of drivers for not adopting a conditioning approach involving intimate encapsulation and the production of a ‘non-encapsulated wasteform’, including:

- reduction in the overall conditioned waste volume by increasing the waste loadings of waste containers;
- reduction in the worker dose during conditioning;
- reduction in the costs of conditioning by the removal of the encapsulation process and the cost of conditioning materials etc.;
- elimination of undesirable interactions between the waste and conditioning materials (e.g. the corrosion of metals in cement) and the reduction of wasteform expansion, the production of particulate corrosion products and gases such as hydrogen.

Clearly the waste types for which non-encapsulation offers a viable approach are limited, but for those which could be conditioned in this way, the cost and safety benefits could be significant.

4 PROPERTIES OF NON-ENCAPSULATED WASTEFORMS

At the highest level a waste package containing a non-encapsulated wasteform must be capable of satisfying the requirements of the GWPS to an adequate degree. This compliance will be judged during the LoC assessment of the waste packages that are to be produced by a proposed process. This output of such an assessment will include an assurance that the waste packages will provide the required isolation and containment of the radioactivity associated with the waste during transport and the operational and post-closure periods of a GDF. The LoC assessment process is applied to all waste packages, whatever the proposed conditioning process(es) to ensure that this is the case and, whilst the absence of intimate encapsulation will not affect how the assessment process is applied, it will mean that certain aspects of waste package performance will receive greater attention than in the case of a proposal involving an encapsulated wasteform.

As mentioned earlier the actual performance requirement of a wasteform will depend to a large degree on the contribution to overall waste package performance provided by the waste container. The conventional approach of using relatively thin walled (i.e. a few mm) waste containers will place a greater demand on the wasteform than if a more robust waste container was used. In an extreme case a very robust waste container, capable of retaining the properties of strength and containment for an extended period (i.e. for a period comparable with the integrity target of 500 years as defined by the GWPS) could reduce or remove the need for many of the wasteform performance requirements. Accordingly the need to achieve the wasteform requirements defined in the GWPS should be considered against the waste package as a whole and should take into account the contribution made by the waste container to overall waste package performance.

In many cases, effective immobilisation of radionuclides, which will exist in a variety of physical and chemical forms, may be the fundamental requirement of a wasteform and this can have a significant influence on the performance of the waste package as a whole under both normal and accident conditions. The wasteform can also be the source of a number of other desirable waste package properties including:

- mechanical and physical properties;
- chemical containment;
- control of hazardous materials; and
- wasteform stability.

In this Section the properties of non-encapsulated wasteforms will be reviewed against the key wasteform criteria and the potential issues that could affect the ability of a waste package containing a non-encapsulated wasteform to satisfy them. The layout of this Section is such as to mirror Section 5 of Volume 1 of the GWPS which defines the general requirements for wasteforms.

The GWPS groups the wasteform criteria under six key headings:

- physical immobilisation;
- mechanical and physical properties;
- chemical containment;
- hazardous materials;
- wasteform stability;
- gas generation.

4.1 Physical Immobilisation

4.1.1 Immobilisation of Radionuclides and Particulates

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.

A non-encapsulated wasteform will clearly not have the benefit of a matrix material to immobilise radionuclides, or other materials, in particulate form, accordingly any radionuclides associated with the waste will need to be immobilised by the waste itself. The most obvious example of this type of waste would be neutron irradiated material where the radionuclides are present as an integral part of the waste rather than as a surface contamination.

The need for the immobilisation of radionuclides and particulates by a wasteform will clearly limit the range of wastes that are suitable for conditioning by way of a process not involving intimate encapsulation. Indeed it may be that the presence of significant quantities of loose contamination is the first criterion by which the possibility of using a packaging process involving non-encapsulation is discounted.

Loose particulate material is unlikely to be associated with strong, non-friable materials such as un-corroded steels or ceramics and undamaged graphite, its absence will be more difficult to demonstrate for weaker, more friable materials and those more susceptible to corrosion.

Loose particulate material may be formed during the production of the waste package (e.g. during size reduction) and techniques that minimise the generation of particulates should be used, such as cropping rather than cutting.

Account must be taken of the possible evolution of the waste following packaging, in particular during on-site storage prior to transport. The primary concern here is corrosion to produce particulate material but processes such as abrasion between larger loose items and the spallation of corrosion products may also generate particulate material.

The consequences of the presence of loose particulate material will need to be fully considered for any waste that is to be the subject of a conditioning process involving non-encapsulation. The quantity, nature and radionuclide inventory of this fraction of the waste will need to be assessed and processes identified for its separation and separate treatment. For example, the waste could be passed over a screen, vacuumed or washed and dried. The separated particles may then be conditioned and packaged separately. Alternatively it may be possible to fix the loose particulate to the surface of the waste by means of a paint or polymer coating.

4.1.2 Response to an Impact Accident.

All reasonable measures shall be taken to ensure that, in the event of an impact accident, the quantity of potentially mobile radionuclides present within the waste package, including those mobilised as a result of the impact accident, is commensurate with the waste package meeting the relevant activity release limits specified in the GWPS.

The behaviour of a non-encapsulated wasteform under impact conditions may result in the release of a greater proportion of particulate radionuclides from a waste package in response to an impact accident, when compared to an encapsulated product. The performance of the wasteform under impact accident conditions will depend on radionuclide inventory, the physical form and properties of the waste and the loading of the waste in the waste package, including distribution of materials and ability of the materials to move within the package. The selection of solid, non-friable waste types should ensure that particulate release is minimised in the event of an impact accident. Performance of the packages could be improved by the use of a more robust package design, better able to withstand impact accidents and the use of internal furniture to support and contain the waste materials.

4.1.3 Response to a Fire Accident.

All reasonable measures shall be taken to ensure that, in the event of a fire accident, the quantity of potentially mobile radionuclides present within the waste package, including those mobilised as a result of the fire accident, is commensurate with the waste package meeting the relevant activity release limits specified in the GWPS. In addition, the wasteform should not readily burn or otherwise support combustion.

The response of non-encapsulated wasteforms under fire conditions may be different from that of an encapsulated wasteform, as a result of differences in thermal properties. The absence of an encapsulating medium could also render a wasteform more liable to combustion.

The behaviour of the wasteform will be dependant on a number of factors such as waste type, radionuclide inventory, physical and chemical properties of the waste and the position of the waste in the waste package. Solid waste items composed of steels, concrete, brick and other inert inorganic solids are expected to present a low hazard and would be expected to be reasonably robust under fire conditions. Improvements to the performance of the waste package could be made by the use of enhanced waste containers with a layer of insulating material (i.e. a grout annulus) positioned between the waste and the waste container.

4.1.4 Free Liquids

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

Free liquids can be defined as those liquids that may drain from the waste package after a loss of container integrity. Examples of possible sources of free liquids include:

- Oil in gear boxes.
- Process liquors in pumps and valves.

- Containerised liquids or sludges.
- Condensation via either evaporation from damp wastes or the ingress of water vapour into the package.

The presence of free liquids is undesirable in all wasteforms as it may lead to a reduced predictability of the performance of the waste package. Free liquids may lead to internal corrosion of the waste container, increase the mobility of radionuclides in the event of loss of container integrity and a possible increase in the potential for chemical interactions between the waste components and container. The presence of free liquids in a non-encapsulated wasteform would exacerbate such problems and it would be necessary to show that particular attention would be given to their removal.

It is recognised that the demonstration of the absence of free liquids and sludges is not a simple exercise. However, the minimisation or elimination of free liquids should be regarded as best practice. All sources of free liquids and sludges relevant to the waste under consideration should be identified and the absence of free liquids argued or demonstrated practically. This will also include water that may enter the package via filters during storage.

4.2 Mechanical and Physical Properties

4.2.1 Mechanical Strength

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 mechanical strength of a waste package influences its performance under both normal (i.e. lifting and stacking) and accident conditions. The GWPS requires that both the wasteform and waste container contribute to the mechanical strength of a waste package and that neither should rely unduly on the other. This may not be the case for a non-encapsulated wasteform if the waste was not in contact with the walls of the waste container.

It will therefore be necessary to demonstrate that the waste container alone can provide the mechanical strength required of the waste package. This may involve the use of thicker waste container walls, internal stiffening members or a pre-cast grout annulus.

4.2.2 Voidage

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.

Voidage in a wasteform reduces confidence in the predictability of performance under normal and accident conditions and may undermine steps taken to engineer particular properties of the wasteform or address specific performance criteria.

Examples of the possible adverse effects of voidage include:

- local corrosion leading to the presence of mobile particles with a significant radionuclide content;
- prevention or hindrance of the chemical conditioning of key constituents of the waste;
- reduction in wasteform and waste package strength compared with expected values;
- accumulation of flammable/explosive gas;
- generation of other hazardous materials (e.g. metal hydrides);
- long-term slumping/subsidence.

The actual consequences of voidage, in particular the magnitude of any related hazards, will depend on the nature of waste, the wasteform and the container design. Accordingly, minimisation of voidage is considered to be best practice and adds confidence to packaging process control and the predictability of waste package performance.

A non-encapsulated waste by definition will have significant voidage and the consequences of this would be addressed during the LoC assessment of a packaging proposal. By consideration of the above list it may be possible to argue that the presence of such voidage does not compromise the overall performance of the waste package for a particular waste type.

If the presence of voidage is seen as an issue it may be that use of a suitable material (i.e. glass or polymer beads, dried sand etc.) as a void filler will provide adequate waste package performance. Any such use of a void filler would need to be supported by a demonstration that the proposed infilling process was effective at reducing voidage to an adequate degree.

4.2.3 Mass-transport Properties

The wasteform shall be sufficiently permeable to allow gases generated within the wasteform to be released without compromising the ability of the waste package to meet any aspect of the GWPS.

The mass transport properties of the wasteform (e.g. diffusivity and permeability) shall provide best practicable means for containment of water-soluble radionuclides within the waste package.

Two distinct issues relate to the required mass-transport properties of a wasteform and these are affected in opposite extremes by a non-encapsulated wasteform. In the first case, the presence of significant linked voidage in such a wasteform will allow for the free movement of gases without damage to the wasteform, thus satisfying the permeability requirement.

The second requirement exists to ensure, for waste packages which contain significant quantities of short lived water-soluble radionuclides (specifically Sr-90 and Cs-137), the wasteform will retain those radionuclides for a sufficiently long period to allow them to decay to insignificant levels. This is interpreted by the GWPS as requiring a retention period for these radionuclides of ~10 times their half-life (i.e. ~300 years). In general terms this degree of retention is assumed to be largely provided by the waste container for which a target for the integrity of the containment of 500 years is specified. This period is made up of a number of components of which the latter 300 years is partly justified by the requirement to provide best practicable means for the retention of short lived radionuclides. For encapsulated wasteforms, any retention provided by the encapsulating matrix would be in addition to that provided by the waste container.

For non-encapsulated wasteforms the possibility of the dissolution of water-soluble radionuclides in groundwater, and their diffusion out of the waste package, will be much greater. Accordingly the inventory of such radionuclides in waste conditioned without intimate encapsulation will have to be limited accordingly.

4.2.4 Homogeneity

Local concentrations of materials within the wasteform that may compromise the ability of the waste package to meet any aspect of the GWPS should be avoided.

Some wastes that could be considered for non-encapsulation (i.e. metal pipes etc.) would clearly result in wasteforms that would be very heterogeneous in terms of their mass distribution. However it is questionable whether such heterogeneity would *'compromise the ability of the waste packages to meet any aspect of the GWPS'*.

The GWPS justification for the need for homogeneity in a wasteform argues that a lack of it may undermine the steps taken to engineer particular properties of the wasteform to address the need for specific aspects of waste package performance and to give confidence in the predictability of that performance under normal and accident conditions.

Local concentrations of radionuclides could lead to localised heating effects and areas of unacceptably high external dose rates. Similarly concentrations of particular waste materials (i.e. reactive metals) could create chemical conditions that could accelerate waste and wastform degradation.

The actual consequences of heterogeneity, in particular any hazards arising from, or enhanced by, such heterogeneity, will depend strongly on the nature of waste and the container design and would have to be considered at an early stage in the LoC assessment of a packaging proposal involving non-encapsulation.

4.2.5 Thermal Conductivity

The thermal conductivity of the wasteform shall be sufficient to dissipate any heat generated within the waste package, when emplaced in a GDF, without unacceptable temperature rise. The minimum value of thermal conductivity should be 0.5$Wm^{-1}K^{-1}$.

The thermal conductivities of non-encapsulated wasteforms will vary greatly, due to the presence of a variable proportion of voidage containing air, which has a thermal conductivity of more than an order of magnitude less that the minimum value specified by the GWPS (i.e. 0.025$Wm^{-1}K^{-1}$ c.f. 0.5$Wm^{-1}K^{-1}$). For non-encapsulated wasteforms with low voidage (e.g. stacked graphite blocks) the overall thermal conductivity of the wasteform is likely to exceed the minimum value but this is unlikely to be the case for wastes comprising decommissioning materials (i.e. metal pipework etc) are likely to have greater voidage and proportionally lower thermal conductivity.

The minimum value for thermal conductivity given in the GWPS is prompted by two needs:

- the avoidance of ‘hot spots’ in waste packages resulting in differential thermal expansion and disruption of the wasteform, and;
- the achievement of satisfactory thermal performance by the repository vaults as a whole.

In the first case, localised heating will only result from concentrations of high heat output radionuclides, a situation that is unlikely to occur in wastes that would be considered as suitable for non-encapsulation on the basis of other characteristics (see particularly Section 4.2.4).

The attainment of satisfactory thermal performance of a GDF is achieved by, amongst other factors, an acceptable overall thermal conductivity for the backfilled vaults. The minimum value for wasteform thermal conductivity in the GWPS derives from thermal modelling of the vaults [5,6] which has shown that overall thermal conductivities in the range 0.5 - 5$Wm^{-1}K^{-1}$ would be acceptable. This has led to the lower value being considered a minimum value for wasteforms, although this value is for general guidance only. The presence of small numbers of waste packages with significantly lower thermal conductivities may not disturb the overall thermal performance of a vault containing a majority of waste package with cement based wasteforms, and backfilled with cementitious grout. The consequences of the inclusion of a large proportion of non-encapsulated and low conductivity waste packages would, however, have to be considered on a case by case basis during the LoC assessment of a packaging proposal involving a non-encapsulated wasteform.

4.2.6 Leachability

Wasteforms categorised as LSA-III material shall be sufficiently insoluble as to satisfy the requirements of Paragraph 226 (c) (iii) of the IAEA Transport Regulations.

The leachability requirement in the GWPS applies only to ‘shielded’ waste packages (i.e. 2 metre or 4 metre Box waste packages) containing the higher activity category of Low Specific Activity (LSA) material defined by the IAEA Regulations for the Transport of Radioactive

Materials[5] [7]. However, since a number of significant waste streams that may be deemed suitable for non encapsulation (i.e. decommissioning wastes including neutron activated steel and graphite), may be conditioned using such waste packages, the issue of wasteform leachability will need to be considered.

The rationale for the inclusion of Paragraph 226 (c) (iii) in the IAEA Transport Regulations is to reduce the risk of activity leaching out of waste packages as a result of rainwater percolating through waste packages during transport. In general, non-encapsulated wasteforms are liable to be more susceptible to the leaching of activity than those which are intimately encapsulated. However, for most wastes that would be considered for non-encapsulation, their resistance to the leaching of activity in the short -term (it is assumed that the transport operation will be completed in a period not exceeding 28 days) is likely to be such that the requirement can be satisfied. Demonstration of the required leachability will be required for all wasteforms categorised as LSA-III material, whether intimately encapsulated or not.

4.2.7 Shifting Loads.

Whilst not an explicit requirement of the GWPS the issue of 'shifting loads' is one that will need to be considered for non-encapsulated wasteforms.

All reasonable measures should be undertaken to avoid movement of waste items during normal handling and under impact accident conditions. This could be achieved, for example, by careful packing of the waste, heavier items should be placed in the base of the container, ensuring the centre of gravity of the package is kept low as possible and the use of internal furniture to hold the waste in position. The potential movement of loads under accident conditions should be explicitly considered as the relative acceleration of unconstrained items within a package may significantly increase the damage caused to a waste container in an accident.

4.3 Chemical Containment

The wasteform shall not be incompatible with the chemical containment of radionuclides and hazardous materials as embodied in the requirements of a GDF

Where they may inappropriately affect chemical containment, the following items should not be introduced through waste conditioning or packaging, and their presence in wastes should be minimised wherever practicable:

- ***Oxidising agents;***
- ***Acids and/or materials that degrade to generate acids;***
- ***Cellulose and other organic materials;***
- ***Complexants and chelating agents, and/or materials that degrade to generate such compounds;***
- ***Non Aqueous Phase Liquids (NAPLs) and/or materials that degrade to generate them;***
- ***Any other materials that could detrimentally affect chemical containment.***

The near-field chemical barrier of a GDF is provided by the vault backfill material, a cement-based grout which has been specially formulated to limit the migration of radionuclides over long periods of time [8]. The long-term performance of a GDF relies on the backfill fulfilling its design functions and wasteforms should be designed to avoid degrading its effectiveness. Given the materials already present in the original waste, best practice in the wasteform is

[5] Known colloquially as the 'IAEA Transport Regulations'.

wherever practicable to use only materials and processes that contribute to achieving these objectives, and do not create additional problems of their own.

The need to achieve this requirement is unaffected by whether a wasteform is intimately encapsulated or not, although the absence of an encapsulant will tend to reduce the possibility of materials that may affect the performance of the vault backfill being present, or being generated by the wasteform.

4.4 Hazardous Materials

The wasteform shall not contain hazardous[6] materials, or have the potential to generate such materials, unless the conditioning of such materials or items makes them safe. The means by which any of these materials is made safe shall be demonstrable for all relevant periods of the long-term management of the waste.

Radioactive wastes contain a wide variety of materials, some of which, because of their chemical and/or physical nature, create additional hazards during packaging, transportation and disposal. The elimination of such materials from waste packages, or their treatment to render them less hazardous, is therefore an important factor in ensuring the passive safety of waste packages.

The IAEA Transport Regulations [7] state that;

> *'…any other dangerous properties of the contents of the (transport) package, such as explosiveness, flammability, pyrophoricity, chemical toxicity and corrosiveness, shall be taken into account...'*

Hazardous materials may exist at the time of packaging, and further hazardous materials (e.g. organic molecules and gases) may be produced from the degradation of the waste or of the materials used for conditioning and packaging, and/or by reactions between them. The transport and handling of all such materials will be subject to the appropriate regulations as well as a general duty of care. Consequently, the potential presence or generation of such hazardous materials must be taken into account during the design of waste packaging.

The nature and magnitude of the hazard will depend on the nature of the raw waste, the wasteform and the conditioning process(es). As part of a packaging proposal a waste packager should demonstrate that these materials have been considered, and that they will be neutralised or removed. Hazardous materials may include pyrophoric or explosive materials, in which case it will be necessary to demonstrate that such materials have been rendered safe. More specifically, it will be necessary to demonstrate that the resulting waste package will meet the requirements of the transport and GDF operational safety cases.

The absence of an encapsulating medium as part of a conditioning process will eliminate the potential for reactions between the waste and encapsulant that could result in hazardous materials being generated. However, the potential for the waste to react with oxygen or atmospheric moisture to generate such materials will still need to be considered.

4.5 Gas Generation

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

The releases of radioactive and non-radioactive gases and vapours from waste packages are required to be consistent with the limits defined by the GWPS for the relevant waste package type. These limits are set for a variety of reasons including the needs to avoid:

- over-pressurisation of the transport container;

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[6] Including flammable, explosive, pyrophoric, chemo-toxic and oxidising materials; sealed and/or pressurised containers; and materials or objects containing stored energy.

- the creation of explosive mixtures in waste packages or transport containers;
- the release of toxic gases in dangerous quantities, and;
- the release of radioactivity in gaseous form during transport on after emplacement in a GDF.

Gases may be generated by a variety of chemical, biological and radiological processes and waste packagers are required to assess the rate of gas release expected for proposed waste packages. For non-encapsulated waste forms, the potential for some of the gas generation mechanisms will tend be reduced due to the absence of reactants (i.e. water) that will be present in the encapsulant. However the lack of an intimate encapsulant will remove the wasteforms' ability to 'hold up' gases and once generated gases would be expected to be released from the wasteform, and the waste package, almost immediately.

The rate of gas generation by a non-encapsulated wasteform can be reduced by the reduction of the quantities of reactants, particularly water, which may be entraining in some wastes. The simplest approach to this would be the drying of waste prior to packaging. This will eliminate or reduce the generation of gas by chemical processes (i.e. corrosion of metals), biological action or radiolysis.

Gas release from waste packages can be prevented by the use of an un-vented waste container although such an approach would only be suitable if the rate of gas generation is sufficiently low that the integrity of the container would not be threatened by pressurisation. The use of gas 'getters' may be a means of reducing the build up of pressure within a un-vented container.

Wastes can generate radioactive gases either by the release of previously entrained gaseous radionuclides (i.e. tritium, argon, krypton etc) or the decay of radium to produce radon. Some chemical or biological reactions can result in the release of gases labelled with radionuclides such as tritium or C-14. Control of the release of radioactive gases from non-encapsulated wasteforms would be by way of restrictions on the inventory of the relevant radionuclides or their precursors

4.6 Criticality Safety

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

- ***the waste package does not present a criticality safety hazard during transport or the operational period of a GDF; and***
- ***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 the facility.***

The criticality safety of waste packages is not strictly a wasteform issue and is generally controlled by way of limiting the quantity of fissile materials in waste packages. Specifically this generally involves the performance of a Criticality Safety Assessment (CSA) for a particular waste package design in which the risk of criticality during transport and following emplacement in a GDF, under both normal and accident conditions, is determined. CSA's tend to be conservative and, in particular, make very pessimistic assumptions regarding the ability of fissile material to become mobile and accumulate to form a critical assembly within a waste package. For a non-encapsulated wasteform the possibility of such a scenario is clearly increased over that for a wasteform where the fissile material was immobilised within an encapsulant but as this possibility is already considered as part of a CSA it will not need to be a factor when non-encapsulation is being considered.

One scenario considered in the analysis of the criticality safety of waste package is that resulting from an 'over batching' fault in which, due to an undetected failure during manufacture, the quantity of fissile material in a waste package could exceed the Safe Fissile

Mass (SFM) determined by the CSA. Where such a failure does not lead to a criticality during manufacture or on-site storage, the accumulation of loose fissile material in a non-encapsulated wasteform, due to vibrations etc. caused by transport or emplacement, could cause it to occur at a later stage.

To avoid such a scenario, extra consideration should be given to the presence of fissile material in candidate wastes for non-encapsulation, possibly by way of a package specific CSA which includes an assessment of the risk of accumulation of fissile material by such a mechanism.

4.7 Wasteform Evolution

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

Although progressive evolution and degradation of the wasteform is inevitable, wasteform stability and predictability of degradation over an extended period benefits development of safety cases for all periods of the long-term management of packaged waste.

Many aspects of wasteform performance discussed in this section could potentially be compromised by excessive degradation of the wasteform.

Degradation processes during the interim surface storage of waste packages and the operational period of a GDF may cause changes to the form of the waste and/or wasteform. Such changes may increase the potential release of radionuclides under normal and accident conditions. The nature and extent of degradation processes within non-encapsulated waste will depend on the nature of the waste and the environment within the package. Amongst the processes are:

- corrosion of metallic items, influenced by water content, and the presence of corrosion accelerators such as chloride.
- reaction between waste components or waste components and the container material; Galvanic couples may be set up in heterogeneous wastes.
- reaction after the release of aggressive agents from wastes;
- radiolysis of polymeric materials;
- physical degradation of unrestrained items due to impact and abrasion.

The environment that the waste encounters will affect the rate of degradation. Potentially, non-encapsulated waste will be more exposed to the above list of conditions than a waste that has been encapsulated. Important parameters include temperature and humidity, particularly cycling of temperature and humidity that may cause condensation within a waste package, and airborne contaminants (such as chlorides in coastal marine environments).

Potential degradation processes should be assessed in order that the evolution of the waste can be demonstrated. It is particularly important to demonstrate that the release of radionuclides is not enhanced by degradation processes.

Wastes that comprise large, robust items composed of materials such as steels, concrete, bricks and other inert inorganic solids are not expected to be susceptible to extensive chemical degradation. However, other, more reactive metals may degrade more rapidly and may not be suitable for a non-encapsulated package.

The presence of surface coatings or treatments on materials should be taken into account. This may include paints, surface treatments and polymeric coatings such as PVC. Although such coatings may be breached or not last indefinitely, it is considered to be reasonable to take credit for any resulting reduction in degradation rates at the appropriate stage.

Some polymeric materials such as PVC degrade when exposed to a radiation field of sufficient strength. A product of the radiolytic degradation of PVC is hydrogen chloride gas, which will form hydrochloric acid in contact with moisture. In the event that wastes contain quantities of PVC, due consideration should be given to the expected radiation field and the possible extent and effects of PVC degradation.

Degradation of wastes may liberate radioactive gases; for example, the corrosion of tritiated metals or the microbial degradation of organic wastes containing carbon-14. Such processes have the potential to compromise the retention of radionuclides. Exclusion of water can minimise or eliminate these processes.

Wastes that are judged to be susceptible to degradation should be segregated from the waste and be packaged separately.

5 WASTE TYPES SUITABLE FOR NON-ENCAPSULATION

In order for a waste to be deemed suitable for a conditioning process that would result in a non-encapsulated wasteform there are a number of basic criteria that will have to be satisfied. At the highest level a waste package containing a non-encapsulated wasteform must be capable of satisfying the necessary requirements of the GWPS to an adequate degree. This will include the required isolation and containment of the radioactivity associated with the waste during on-site storage, transport and during the operational and post-closure period of a GDF.

The LoC assessment process is applied to all proposals for the packaging of waste, whatever the proposed conditioning process (es), to ensure that the proposed waste packages satisfy all the criteria defined by the GWPS and, whilst the absence of intimate encapsulation will not affect how the LoC process is applied it will mean that certain aspects of waste package performance will receive greater attention than in the case of an encapsulated wasteform. As was noted at the beginning of Section 4 the nature of the waste container may play an important role in the waste package achieving the necessary performance requirements, without any significant assistance from the wasteform. The purpose of this Section is however to consider which wastes could be conditioned to produce a non-encapsulated wasteform, the performance of which would play an important role in the performance of the waste package as a whole.

If intimate encapsulation is not to be part of a conditioning process the waste will be required to have a number of characteristics which will make it more likely capable of satisfying the necessary GWPS wasteform criteria. As is the case for all wasteforms, these requirements for satisfying these criteria are not absolute and the most important consideration is that they should be satisfied to the point that they do not constitute a risk during any future stage of the long-term management of the waste.

In simple terms, wastes suitable for non-encapsulation should be:

- bulk solids without significant fine particulate material;
- relatively free of surface contamination, or capable of easy decontamination;
- dry;
- of reasonable compressive strength and not be readily fractured;
- relatively inert or resistant to corrosion by atmospheric reactant; and
- non combustible.

From these characteristics a number of generic waste types can be identified which may potentially be suitable for non encapsulation, these are shown in Table 1.

The key property for a candidate waste for non-encapsulation is that the activity associated with loose particulate material should be small, either at the time of conditioning or in the future as the waste evolves. The waste must therefore be capable of being shown to relatively free of particulate material, or a process devised the remove such material before packaging. The physical and/or chemical nature of the waste should also be such as to make the possibility of the creation of particulate material (e.g. by corrosion etc.) of negligible concern.

Loose particulate material is unlikely to be associated with strong, non-friable materials such as un-corroded steels or ceramics. This property will be more difficult to demonstrate for weaker, more friable materials, which are liable to contain loose particles.

Loose particulate may be formed during the production of the waste package, e.g. during size reduction. However, it may be possible to use techniques that minimise the generation of particulates, such as cropping rather than cutting.

Particulate material can be removed from the bulk waste for separate treatment. For example, the waste could be passed over a screen, vacuumed or washed and dried. The separated particles can then be conditioned and packaged separately using a more conventional encapsulant based process. Alternatively it may be possible to fix the loose particulate to the surface of the waste by means of a paint or polymer coating although the durability of such materials and their potential to interact with the chemical conditioning systems in a GDF will need to be assessed.

Account must be taken of the possible evolution of the waste under storage, transport and disposal conditions. Processes such as abrasion between larger loose items and the spallation of corrosion products may generate particulate material after packaging.

The arguments presented above suggest that some types of materials are likely to be unsuitable for packaging as non-encapsulated waste. This may include relatively fragile or friable materials.

In its Guidance to Inspectors [9] the Health and Safety Executive (HSE) points out the risks of waste dispersion and how they can be reduced through the concept of passive safety. The guidance states:

> *'Passive safety requires the radioactivity to be immobilised and packaged in a form that is physically and chemically stable…….. In many cases, the raw radioactive material or radioactive waste will require conditioning to place it into a passively safe form to immobilise the radioactivity. Typical waste forms[7] that fall into this category are gases, liquids, wet solids, slurries, sludges, powders, particulate material, bulk material and radioactive materials including spent fuel.'*

The IAEA also provides guidance on the conditioning of radioactive wastes. In its guide on the requirements and methods for low and intermediate level waste package acceptability [10] it states that:

> '…*waste forms that promote dispersion in the event of a release (respirable particles)….should be prohibited in the waste package.*'

Specifically, it states that particles with diameters less than 200μm must be 'stabilised' or immobilised.

During on-site storage, transport and handling, waste packages are designed to provide containment and isolation of their radionuclide and other hazardous inventory in order to protect workers and members of the public from the damaging effects of inhalation, ingestion

[7] In this quotation and the IAEA quotation that follows, 'waste forms' (two words) refers to various types of original/raw waste. It does not refer to conditioned wasteforms (one word) as used in this and other RWMD publications.

or skin contamination by such materials. After disposal the wasteform continues to provide barriers to the release of such materials.

To ensure the passive safety of the waste packages produced it is important to ensure that there are no materials or processes that may cause the dispersal of radionuclides or present a hazard themselves. In this context solid items composed of steels, concrete, brick and other inert inorganic solids would not be expected to present a hazard due to their robust physical nature, general low toxicity and resistance to corrosion etc.

Wastes that are dispersible, chemically reactive, explosive or combustible cannot be considered inherently safe, even when packaged within sealed containers, primarily because of the consequences of loss of containment under accident conditions. It is not possible to provide a definitive list of hazardous materials that may be present in wastes. Instead, waste packagers are advised that the composition of the waste should be carefully reviewed and reassurance provided that hazardous materials are not present. Examples of hazardous materials are reactive metals such as sodium and finely-divided uranium, combustible materials and pressurised containers. This will include degradation products of materials contained in the wasteform. Any significant degradation processes must be considered and the safe performance of the waste demonstrated.

To comply with the requirements of the appropriate wasteform specifications, identified hazardous materials must be made safe. In the case of non-encapsulated waste this is most likely to be achieved by segregation of the hazardous materials from the waste or treatment prior to packaging to render them safe.

The above list is not exhaustive and serves as an example of potential wastes types which may be suitable for non encapsulation. It may be possible to show that some polymeric materials are suitable for non-encapsulation but they do have potential issues associated with fire and impact accidents and the production of breakdown products from radiolysis.

Table 1 Possible waste types which may be suitable for non-encapsulation

Waste Type		Desirable Characteristic of Waste					
		Bulk Solid (No particulate)	Low Surface Contamination	Dry	Strong and non-brittle	Inert	Non-combustible
Stainless steel	Chemical plant etc.	✓	(✓)	✓	✓	✓	✓
	Neutron irradiated	✓	✓	✓	✓	✓	✓
Other metals e.g. aluminium, lead		✓	✓	✓	✓	(✓)	✓
Building rubble (concrete etc)		×	×	✓	×	✓	✓
Glass		✓	✓	✓	×	✓	✓
Ceramics		✓	✓	✓	×	✓	✓
Graphite	AGR Sleeves etc	×	✓	✓	×	✓	✓
	Reactor Core	✓	✓	✓	✓	✓	✓

Key:
- ✓ Waste types which would normally be expected to possess the required characteristic.
- (✓) Waste types which would possess the required characteristic in some cases.
- × Waste types which would generally not be expected to possess the required characteristic.

6 EXAMPLES OF PACKAGING PROPOSALS INVOLVING NON-ENCAPSULATION

To date there have been only a limited number of submissions by SLCs for the LoC endorsement of proposals to package waste which involve a non-encapsulated wasteform. The most advanced applications are for ILW arising from the decommissioning of the Joint European Torus (JET) at Culham and graphite wastes from the dismantling of the Windscale Piles. These two very different waste types have been considered by way of a Conceptual stage[8] LoC assessment.

6.1 JET wastes

The ILW anticipated to arise from the decommissioning of the JET facility comprises of bulk metals (i.e. steel and copper) contaminated with tritium which has diffused into the structure of the metal. Due to their irradiation with neutrons the metals also contain small quantities of other radionuclides in the form of activation products (e.g. isotopes of Fe, Ni, Co etc.), also implanted in their structure.

During the development of the LoC submission it was realised that encapsulation of these materials with conventional grouts would lead to corrosion which would result in the release of tritium in gaseous form at rates significantly greater than that which would be expected from natural diffusion out of the metal structure. For activation products corrosion could result in the generation of particulate material contaminated with these radionuclides.

The packaging proposal involved the use of standard 2 metre Boxes (see *Specification for 2 metre Box Waste Package, WPS/350* and the GWPS [1] for further information on this waste container). Waste packages manufactured using this type of container are transported without overpacking as transport packages in their own right. It was felt that the accelerated release of tritium due to corrosion of the waste, and its release from the vented waste packages, could compromise their ability to be compliant with routine activity releases during transport and the operational period of a GDF. This was particularly exacerbated by the highly mobile nature of tritium in gaseous form.

In view of the relative short half life of tritium (i.e. 12.35y) it was felt that the best option for the packaging of metal waste containing it would be the use of a non-encapsulated wasteform which would allow the bulk of tritium to remain inside the structure of the metal for a long enough period to allow it to decay to insignificant levels (this would require a period of ~100 years). The proposed method involved the loading of dry waste into un-vented 2 metre Boxes, backfilling with an inert void filler (e.g. glass micro-spheres) and sealing with a welded inner lid. The area above the inner lid would then be capped with a 20mm thick layer of polymeric material and the container lidded in the normal manner. To avoid pressurisation of the sealed container by tritium enhance tritium containment, hydrogen ‘getters’ would be included.

At the time of the production of this Guidance, the proposal to package JET wastes had not progressed beyond the Conceptual stage and, as a result, no significant development work to investigate the viability of the proposed method of conditioning has been undertaken. In particular this would be required to show that the use of a sealed inner container and of void fillers would result in waste packages that would be suitable for all stages of long-term management of the waste, including disposal in a GDF.

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[8] The Conceptual stage assessment is the first stage of the 3 stage LoC process (see *Guidance on the Preparation of Letter of Compliance Submissions, WPS/908*) and is normally limited to an initial consideration of a proposed packaging concept and ensuring that the proposed waste packages would be compliant with the basic requirements for the long-term management of the waste, including disposal in a GDF.

Whilst the JET waste are not typical of other ILW in the UK inventory the principle of not encapsulating metal wastes, particular those where the majority of radionuclides are in the form of activation products already ‘intimately encapsulated’ by the waste itself, can be applied to many waste arising from, for example, the decommissioning of reactors. The activity associated with such wastes (e.g. Co-60 with a half life of 5.27y) can decay within the structure of the waste whereas the use of a cementitious encapsulant could accelerate corrosion of the waste and result in the generation of activity in particulate form which could be released from the package under normal or accident conditions. This point is particularly relevant if the wastes are to be packaged using large ‘shielded’ waste containers such as the 2 metre and 4 metre Boxes which are transported without protective overpacking.

6.2 Windscale Pile Graphite

The Windscale Piles comprise two graphite moderated air-cooled reactors which were used for the production of plutonium in the 1950’s. Following a fire in Pile 1 in 1957 both reactors were shut down pending full decommissioning and dismantling, and conditioning of waste for disposal at a later date.

The cores of the two Piles comprise a large quantity (i.e. ~2000t each) of graphite in a variety of shapes and sizes but much of it in the form of blocks with sizes of up to ~0.8 x 0.2 x 0.2m and masses of up to ~50kg each. Whilst some of the graphite in Pile 1 was damaged by the fire much remains undamaged, as does all of the graphite in Pile 2. Some of the graphite is classed as ILW by virtue of activation products resulting from neutron irradiation and surface contamination by uranium, plutonium and fission products from leaking fuel cartridges.

The proposed method of packaging of the undamaged graphite involves the use of 4 metre Boxes into which the graphite, held in waste baskets, will be loaded. The waste will be placed into the 4 metre Boxes in such a way as to allow it to be intimately grouted but, in order to allow the possibility of reworking the graphite before disposal (e.g. annealing to removed stored energy), this will not take place immediately after loading. Based largely on the inert nature of the waste, and the compliance of a non-encapsulated wasteform with the requirements of the GWPS, the possibility of not grouting the waste at all has also been considered.

The Conceptual stage LoC assessment of this proposal considered the possible non-encapsulation of the waste and few issues were identified. Whilst the assessment did not result in endorsement of the packaging proposal this was mainly due to issues not associated with those arising from non-encapsulation, with the exception of the accident performance of the proposed waste packages, specifically the possible presence of activity in particulate form.

Graphite waste arsing from the decommissioning of commercial powers stations (e.g. Magnox and AGR stations) will make up a large fraction of the total UK ILW inventory. Whilst some characteristics of this material will be different to that of the Windscale Pile graphite (e.g. total neutron irradiation, operational lifetime etc.) the physical and chemical characteristics would be expected to be very similar. Accordingly It would be expected that a conditioning process involving a non-encapsulated wasteform would be suitable for this significant waste.

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