TECHNICAL NOTE

Waste Package Performance Data for the Analysis of Fire and Impact Hazards within Safety Assessments of the Phased Disposal Concept

October 2003
Number: 411270
TECHNICAL NOTE

Waste Package Performance Data for the Analysis of Fire and Impact Hazards within Safety Assessments of the Phased Disposal Concept

October 2003
Number: 411270
Conditions of Publication

This technical note is made available under Nirex’s Transparency Policy. In line with this policy, Nirex 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. This document may be freely used for non-commercial purposes. However, all commercial uses, including copying and re-publication, require Nirex’s permission. All copyright, database rights and other intellectual property rights reside with Nirex. Applications for permission to use this technical note commercially should be made to the Nirex Business Development Manager.

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

©United Kingdom Nirex Limited 2003. All rights reserved

Bibliography

If you would like to see other publications available from Nirex, a complete listing can be viewed at our website www.nirex.co.uk, or please write to Corporate Communications at the address below, or email info@nirex.co.uk.

Feedback

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

Corporate Communications Administrator
United Kingdom Nirex Limited
Curie Avenue
Harwell
Didcot
Oxfordshire
OX11 0RH
UK
Or by e-mail to: info@nirex.co.uk
Technical Note

Waste Package Performance Data for the Analysis of Fire and Impact Hazards Within Safety Assessments of the Phased Disposal Concept

Executive Summary

The validity of the Waste Package performance data for use in the Safety Assessment of the Phased Disposal Concept has been confirmed following a review of existing data and more recent research results on fire and impact performance. The data presented provide recommended values for use in safety assessment of standard Nirex packages subject to either fire or impact hazards during transport and handling operations within the Nirex Phased Disposal Concept.

The data from which the values were derived were produced by experimentation on full scale and small scale packages and wasteforms over a number of years. In addition, detailed computer models of package behaviour are under development and their results were utilised where appropriate.

Data are presented for the six standard Nirex packages and two non-standard packages designed for ILW and LLW, namely:

- 500 litre ILW Drum
- 3 m$^3$ ILW Box
- 3 m$^3$ ILW Drum
- 4 metre ILW Box
- 2 metre LLW Box
- 4 metre LLW Box
- Miscellaneous Beta Gamma Waste Store (MBGWS) Box
- Windscale Advanced Cooled Reactor (WAGR) Box

New modelling data has been provided for the thermal performance of the 4 metre ILW Box. This has been also applied to the derivation of fire release fraction data for the WAGR Box non-standard waste package.
# TECHNICAL NOTE

## TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Executive Summary</td>
<td>iii</td>
</tr>
<tr>
<td>1 INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>1.1 Background</td>
<td>1</td>
</tr>
<tr>
<td>1.2 Definitions of Release Fraction</td>
<td>2</td>
</tr>
<tr>
<td>1.3 Package Types</td>
<td>4</td>
</tr>
<tr>
<td>2 REVIEW OF DATA - GENERAL</td>
<td>5</td>
</tr>
<tr>
<td>2.1 Overview of the Fire and Impact Release Data</td>
<td>5</td>
</tr>
<tr>
<td>2.2 Interpretation of General Data</td>
<td>5</td>
</tr>
<tr>
<td>3 RELEASE FRACTION DATA: FIRE HAZARD</td>
<td>7</td>
</tr>
<tr>
<td>3.1 Scope of Applicability of Release Fraction Data</td>
<td>7</td>
</tr>
<tr>
<td>3.2 Element Groupings</td>
<td>8</td>
</tr>
<tr>
<td>3.3 ILW Release Fractions</td>
<td>8</td>
</tr>
<tr>
<td>3.4 LLW Release Fractions</td>
<td>9</td>
</tr>
<tr>
<td>4 RELEASE FRACTION DATA: IMPACT HAZARD</td>
<td>9</td>
</tr>
<tr>
<td>4.1 Scope of Applicability of Release Fraction Data</td>
<td>9</td>
</tr>
<tr>
<td>4.2 Summary of Impact Release Fractions</td>
<td>10</td>
</tr>
<tr>
<td>5 SUMMARY</td>
<td>12</td>
</tr>
<tr>
<td>6 REFERENCES</td>
<td>12</td>
</tr>
<tr>
<td>Appendix A Rational behind Recommended Release Fraction Values</td>
<td>Appendix A-1</td>
</tr>
<tr>
<td>REFERENCES</td>
<td>Appendix A-6</td>
</tr>
</tbody>
</table>
TECHNICAL NOTE

1 INTRODUCTION

The mission of Nirex is to provide the UK with safe, environmentally sound and publicly acceptable options for the long-term management of radioactive materials. The aim is to develop coherent concepts, which include a range of options for the long-term management of the UK’s intermediate level and certain low-level radioactive wastes. Therefore one of the key aims is to ensure that when waste is packaged by waste producers it is in a form which is suitable for safe storage, transport, handling and long-term management.

In 2000 Mott MacDonald produced a report on impact and fire release fractions for use in safety case assessments. The approach was to identify bounding release fractions that could be applied to the range of waste package types identified for potential disposal.

In developing the Generic Documents 2003, there is a requirement to review the release fraction data to ensure that it is still current and valid for use in the safety cases.

The main areas where these release fractions have been updated is to use improved fire performance data for the 4 metre Box, and to increase the range to include additional non-standard waste packages. These release fractions are identified both in the text and by footnotes in Tables 3.3 and 4.2.

1.1 Background

This report describes work undertaken by Nirex in support of waste packaging advice to the industry on waste package performance subject to accident faults representative of fire and impact conditions. This work has led to the quantification of activity releases from waste packages expressed in the form of Release Fractions (RF). Such RF values, relating to standard Nirex Intermediate Level Waste (ILW) and Low Level Waste (LLW) packages, are required as input data to assessments of transport and operational safety of the Phased Disposal Concept.

The Nirex concept envisages:

- immobilisation and packaging of wastes (physical containment);
- transport to a repository;
- emplacement in vaults excavated deep underground within a suitable geological environment (geological isolation);
- a period of monitoring during which wastes would be retrievable;
- backfilling of the repository at a time determined by future generations (chemical conditioning);
- sealing of the repository (geological containment).

Data presented is considered to be conservative and includes margins which make due allowance for the variation in wastes and for wasteform degradation that may occur during all the phases that safety needs to be demonstrated for handling packaged waste.

Nirex has issued the Waste Package Specification for Intermediate Level Waste [1] to provide a sound foundation upon which advice to the UK nuclear industry can be based.
TECHNICAL NOTE

The Nirex Phased Disposal Concept plays a central role in the development of practical packaging standards and advice to waste producers, as illustrated in Figure 1. By assessing waste packaging proposals against the generic requirements of the Phased Disposal Concept, Nirex can provide the best possible assurance that the waste packages will indeed be suitable for disposal.

Figure 1   Central role of the Nirex Phased Disposal Concept

| Safety regulations for storage, transport & long-term environmental protection | Set by society through parliament and the regulators |
| Phased disposal concept | Developed to meet all safety standards and ensure long-term environmental protection and underpinned by ongoing research |
| Waste packaging specifications and advice process | Give practical guidance to waste producers to ensure wastes are packaged consistent with the concept and long-term environmental protection |

The severity and range of the fire and impact hazards under consideration are defined by the current assumptions in the Phased Disposal Concept safety assessments and are as presented in the specifications for waste packages [1].

1.2 Definitions of Release Fraction

In order to quantify the performance of waste packages it is possible to define a Release Fraction (RF) that can be used to quantify the proportion of the original radionuclide inventory that will be released as a consequence of fire or impact accidents in any of the sequence of phases leading to closure of the Phased Disposal Concept as described in section 1.1.

(a) Fire Hazard Release Fraction

In the case of releases due to the fire hazard there are a number of different mechanisms active in the release process depending on the chemical form of the various radionuclides present. Hence it is possible to associate an RF with each radionuclide present:

\[
\text{Release Fraction (Fire)} = \frac{\text{Activity in material released from the waste package}}{\text{Activity present in waste package}}
\]

The extent of releases resulting from fires and hence the associated RFs are temperature dependent. The recommended RFs presented in section 3 assume a very severe fully engulfing fire of 1000°C and of 1-hour duration. For a more onerous set of parameters (i.e. a fire of higher temperature or extended duration) the recommended values may not be appropriate.
Although RFs have been measured for only a limited number of radionuclides, a method has been proposed to extend these data to the full range of potential radionuclides that may exist within the UK inventory of radioactive wastes (see Section 2.2.1).

For most of the ILW packages, the detailed thermal profiles within the wasteforms are not taken into account in the RF values recommended, but are based on measurements conducted at 1000°C. Clearly, reductions could be made to the recommended values if volume weighted peak wasteform temperatures were utilised. This would require a knowledge of the temperature distribution within the waste package. Such an approach would be feasible based on Nirex's thermal modelling capability. However, the approach adopted is simpler and represents a conservative approach.

For the 4 metre ILW Box consideration is taken for the thermal protection that is afforded by the concrete shielding. This concrete shielding is well-defined. Modelling studies in 2003 demonstrated that the 4 metre Box concrete shielding (grade C50) provides a very effective thermal barrier such that the inner surface of a typical 200 mm thick layer of concrete shielding does not experience temperatures above about 90°C. This modelling is conservative as the inner surface of the concrete was considered as an adiabatic surface (i.e. no heat was considered to be lost from the concrete to the wasteform). Even when the thermal properties were varied by a factor of 0.3 to 3.0 in a comprehensive sensitivity study the inner surface temperature did not exceed 150°C [2]. Based on the results of this work, the temperatures at which the release fractions were taken, was reduced from 300°C to 150°C.

In the case of LLW, however, temperature distributions within packages were taken into account since the results of thermal models were readily available. These gave predicted internal temperatures and radionuclide releases from LLW packages.

(b) Impact Hazard Release Fractions

In the case of the impact hazard, the release is due to mechanical breaching of the container combined with physical disintegration of the immobilised contents. In many cases it is not possible to differentiate between particles from the break up of encapsulating grout and particles from the wastes. It is therefore assumed in calculating release fractions, that all debris released contains activity in the same proportion as in the wasteform, thus,

\[
\text{Release Fraction (Impact)} = \frac{\text{Mass of material released from the waste package}}{\text{Mass of wasteform}}
\]

The numerator of this expression can be refined to relate it to the mass of material released which comprises only particles less than a given size (typically < 100μm or < 40μm). The details of these limits are discussed in Section 2.2.2.

(c) Comparison of Releases due to Fire and Impact

Implicit in the above definitions is a marked difference between releases due to the two hazardous events under consideration. The release due to impact is a direct proportion of the total activity content of the package, the amount varying with the degree of mechanical damage. This differs from the fire release case which is a function of the physical and chemical properties of the radionuclides and the immobilising grout. The release process is dictated by changes of state of the materials in the wasteform as local temperatures increase and therefore there is an extra level of complexity in the relationship between radionuclide content and release.
(d) Scope of Applicability of Recommended RFs

The RF values recommended will be utilised in generic safety assessments of operations involving both the transport and handling of waste packages at the Phased Disposal Concept. The RFs should therefore be reflective of the prolonged periods now expected and take into account any degradation processes that the package may have experienced during that period.

Waste package RFs have been generated following a review of available information in the literature and that resulting from experimental investigations carried out by Nirex. It is recognised that ageing processes could lead to an increase of RF over time as a result of wasteform or package degradation, however the extent of any degradation is not expected to be significant, given that the assessment process undertaken by Nirex before the endorsement of a particular waste package does address the stability and evolution of wasteforms and packages. Notwithstanding the above, a cautious approach has been adopted and the recommended RFs are based on conservative performance data.

It should be noted that engineered features will be added to provide a more predictable interim storage environment: it is assumed that the wastes will be stored in controlled environments thus avoiding accelerated corrosion and ageing processes. It is also assumed that good practice will be applied to the design of the storage area so that the potential for mechanical damage is minimised and the leakage of fluids into the area is avoided.

Further research and development on the issue of waste package ageing and on the effects this may have on package performance and RFs continues.

1.3 Package Types

Release fraction data are provided for each of the Nirex standard waste packages [3]. The standard packages will be used to package the vast majority of radioactive wastes that are to be considered by the suite of generic safety assessments. Consistent with the range of standard waste packages and the reference waste volume [4] RF data are reported for a range of wasteform types. Thus, the waste package types for which data are presented are:

a) Standard ILW Packages
   - 500 litre Drum for Homogeneous Wastes
   - 500 litre Drum for Heterogeneous Wastes
   - 500 litre Annular Grouted Drum for Compacted Wastes
   - 3m³ Box for Heterogeneous Wastes
   - 3m³ Drum for Homogeneous Wastes
   - 4 metre Box for Heterogeneous Wastes

b) Standard LLW Packages
   - 2 metre Box for Heterogeneous Wastes
   - 4 metre Box for Heterogeneous Wastes
c) Non-Standard ILW Packages

MBGWS Box for Heterogeneous Wastes
WAGR Box for Heterogeneous Wastes

The 500 litre Drum, 3m$^3$ Box and 3m$^3$ Drum are manufactured from relatively thin walled steel. During transport they are 'overpacked' within a re-usable shielded transport container which will carry either up to four 500 litre Drums, or one 3m$^3$ Drum or one 3m$^3$ Box. The transport container provides a barrier against the heat from an external fire and provides a further level of containment such that the transport container and contents together constitute a Type B transport package meeting the requirements of the IAEA Transport Regulations [5].

The 4 metre ILW Box and 2 metre and 4 metre LLW Boxes are described as transport packages as defined by IAEA Transport Regulations in their own right. Releases are controlled by restricting their contents to solid non-fissile Low Specific Activity material (LSA I, II or III) or Surface Contaminated Objects (SCO I or II).

The MBGWS Box and WAGR Box are non-standard waste containers. Similar to the 4 metre ILW Box, these waste packages are designed to qualify as transport packages in their own right.

Table 1 identifies the waste package, wasteform type and typical wastes considered in the studies.

2 REVIEW OF DATA - GENERAL

2.1 Overview of the Fire and Impact Release Data

The release fraction data presented in section 3 for use in impact and fire safety assessments is derived from studies which can be categorised as follows:

i) Full scale testing of waste packages utilising inactive wasteform simulants;
ii) Small scale testing of wasteforms, active and inactive, from which detailed data is derived;
iii) Calculations to either extend the data derived from small scale tests to the full scale position or to model the response of waste packages to fires and impacts;
iv) Generic work on the behaviour of wasteforms and released material.

2.2 Interpretation of General Data

2.2.1 Theoretical Extensions to Measured Fire Release Fraction Data

The fire hazard presents a particular problem with respect to extrapolating the limited experimental data to the wide range of radionuclides and the chemical state in which they can be found in the various wasteforms. In an attempt to deal with this issue Nirex has developed a method which attempts to provide a systematic approach to identifying appropriate RFs for all radionuclides [6]. This approach is as follows:

Release mechanisms initiated by a fire can be defined by two main processes, namely entrainment of soluble radioactive materials in the emitted steam or the production of radioactive gases from volatile substances in the wasteform. The steam arises from the release of pore water held in the cementitious grouts used to stabilise the wastes. Measurements of release fractions take account
of these processes and therefore release fractions for specific nuclides can be derived. The test samples used to date contain less than ten radionuclides but an approach has been proposed to extend these limited measurements to all potential nuclides by consideration of their solubilities and volatilities.

The approach represents a significant advance in the derivation of a justified range of release fractions, however it cannot be applied wholly without caveats. A limitation of the method is that the calculated solubilities and volatilities relate only to the elemental form of the radionuclides. They do not take account of the chemical form in which each radionuclide may be present in the wasteforms. However with this proviso, the recommendation of reference [6] is that the groupings of radionuclides based on their volatilities should be used across the range of waste temperatures from 150°C to 1000°C.

2.2.2 Categorisation of Particle Size Resulting from Impacts

Release fractions for the impact hazard are quoted for particles (total mass fraction) of geometric diameter less than either 100μm or 40μm. These data are pessimistic with respect to values required for use in safety assessments where it is the Aerodynamic Equivalent Diameter (AED) of the particles which is of significance since this can be related to dispersion and uptake mechanisms.

AED is defined as the diameter of a sphere which would be subjected to the same drag force as a particle of interest in an air flow of a specified rate. The 100μm is appropriate for defining a size limit for 'suspended particles' and was derived from consideration of air flow rates consistent with the repository design. The 40μm value relates to the size of particles that can be mobile in the quiescent conditions within a Transport Container. Hence 40μm represents an upper bound on the size of particles which are available for dispersion in that case. It is also a pessimistic bound on the AED values associated with 'respirable particles'.

2.2.3 Degradation of the Stored Waste Packages

It is most probable that wastes will be stored for several decades at the sites where they are packaged prior to their transport to the Phased Disposal Concept. There are ageing processes that can affect properties of the wasteform and hence which could affect package performance in subsequent accidents. It is important to ensure therefore that release fraction data utilised in safety assessments are robust to uncertainties in degradation processes.

Initial experiments carried out to determine release fractions resulting from a fire suggest that releases reduce with age, as a result of pore water progressively reacting with the cement paste to form a stable gel, thereby trapping more of the soluble radionuclides. This phenomenon has not been subject to detailed investigation, however the approach adopted for the identification of recommended release fraction data is considered to be pessimistic and includes margins to cover the possibility of the release increasing with age.

The position with respect to the impact hazard is similar; initial experimental evidence indicates that break-up reduces with ageing of the wasteform. The significant change in property of the grout in this case is the increase in compressive strength during the curing period. Some doubt on the general conclusion remains however as the potential for cracks to develop in the wasteform cannot be discounted and this would lead to a reduction in its overall strength. It should however be possible to minimise the effects of wasteform instability by the development of an appropriate envelope for the various wasteform constituents. As with fire data, the approach adopted for the identification of
recommended impact release fraction is pessimistic and includes margins to cover uncertainties in the effect of ageing.

The overall conclusion from the initial studies therefore is that the recommended release fraction values for both the fire and impact hazards are conservative with respect to any degradation of the stored waste packages prior to their disposal. As noted previously it will be necessary for Nirex to confirm on a case by case basis that the performance of individual waste package types is consistent with the recommended release fractions before endorsing particular waste packaging proposals.

2.2.4 Migration of Nuclides within Grout

A series of calculations has been performed to estimate the extent to which radionuclides may migrate from a monolithic wasteform matrix into the initially inactive capping grout layer over a 50 year period. This has been used to give some indication as to the migration that may be expected during the interim storage period. The migration process is a function of (a) the solubilities of the radionuclides and their daughter products in the pore water of the cementitious grout which encourages their diffusion and (b) of their propensity to sorb onto the cementitious materials which acts to prevent further diffusion.

The calculated increase in activity level within the capping grout has been shown to be extremely low compared with the initial package inventories. This effect is accounted for in the recommended performance data as any release (which may be via the capping grout) is assumed to have ‘average’ activity of the waste package as a whole. The migration levels calculated are considered to be very much a second order effect, with a maximum of 1% of the original drum inventory migrating into the capping grout in the case of Cs-137. Hence, for breaches in which capping grout dominates the amount of material released the actual release fraction could be up to 2 orders of magnitude lower than if the release had been from the immobilised wasteform.

3 Release Fraction Data: Fire Hazard

Recommended release fractions for the fire hazard are presented in this section. The rationale behind the derivation of the values is presented in Appendix A, sections A.1 and A.2 for ILW packages and LLW packages respectively.

3.1 Scope of Applicability of Release Fraction Data

The scope of applicability of the data presented in Sections 3.2 and 3.3 is:

- Safety assessments since the values presented are conservative.
- Bare standard waste packages as listed in Section 1.3 i.e. no protection is assumed such as might be afforded by a Transport Container.
- All wasteform types within each waste container.
- Wasteforms of any appropriate degree of degradation1.
- Engulfing fires with average flame temperatures up to 1000°C and one hour duration.

1 Backfilling of the vaults is considered to be the end time point at which impact and fire faults are no longer applicable.
**TECHNICAL NOTE**

- All radionuclides within the element groups defined in the table in section 3.2

### 3.2 Element Groupings

The groupings of radionuclides are as follows, with Group I containing the elements with highest volatilities (can form gaseous compounds e.g. \( \text{CO}_2 \)) and Group VI the lowest (can form very stable compounds e.g. \( \text{ThO}_2 \)):[7]:

<table>
<thead>
<tr>
<th>Element Group</th>
<th>Chemical Elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>I H, C, S, Cl, Se, I</td>
<td></td>
</tr>
<tr>
<td>II Sn, Sb, Te, Cs, Po</td>
<td></td>
</tr>
<tr>
<td>III Be, Zn, Mo, Ru, Ag, Ba, Eu, Pb, Ra</td>
<td></td>
</tr>
<tr>
<td>IV Ca, Cr, Mn, Fe, Co, Ni, Sr, Pd, U</td>
<td></td>
</tr>
<tr>
<td>V Y, Zr, Ce, Np, Pu, Am, Cm</td>
<td></td>
</tr>
<tr>
<td>VI Nb, Tc, Pm, Sm, Ta, Th, Pa</td>
<td></td>
</tr>
</tbody>
</table>

These element groupings are to be used in conjunction with the tables presented in sections 3.3 and 3.4, below.

### 3.3 ILW Release Fractions

Release Fractions in the following table are to be used for all ILW waste packages:

<table>
<thead>
<tr>
<th>Element Group</th>
<th>Package Type</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>500 litre Drum</td>
</tr>
<tr>
<td></td>
<td>Homogenous</td>
</tr>
<tr>
<td>I</td>
<td>1.0</td>
</tr>
<tr>
<td>II</td>
<td>2.5x10(^{-1})</td>
</tr>
<tr>
<td>III</td>
<td>1.3x10(^{-2})</td>
</tr>
<tr>
<td>IV</td>
<td>1.3x10(^{-2})</td>
</tr>
<tr>
<td>V</td>
<td>3.4x10(^{-3})</td>
</tr>
<tr>
<td>VI</td>
<td>3.4x10(^{-3})</td>
</tr>
</tbody>
</table>

---

\(^1\) Following extensive modelling of the 4 metre Box, the predicted wasteform maximum temperature has been reduced from 300°C to 150°C. This results in the release fraction for Groups V and VI reducing from 6.5 x 10\(^{-6}\) to 4.3 x 10\(^{-6}\).

\(^2\) In the previous report release fraction data was not extended to these non-standard waste packages.
3.4 LLW Release Fractions

Release Fractions in the following table are to be used for 2 metre LLW and 4 metre LLW Boxes:

<table>
<thead>
<tr>
<th>Element Group</th>
<th>Release Fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>1.0</td>
</tr>
<tr>
<td>II</td>
<td>4.3 x 10^-3</td>
</tr>
<tr>
<td>III</td>
<td>4.3 x 10^-3</td>
</tr>
<tr>
<td>IV</td>
<td>3.8 x 10^-5</td>
</tr>
<tr>
<td>V</td>
<td>2.4 x 10^-6</td>
</tr>
<tr>
<td>VI</td>
<td>2.4 x 10^-6</td>
</tr>
</tbody>
</table>

4 RELEASE FRACTION DATA: IMPACT HAZARD

Recommended release fractions for the impact hazard are presented in this section. The rationale behind the derivation of the values is presented in Appendix A, sections A.3 and A.4 for ILW packages and LLW packages respectively.

4.1 Scope of Applicability of Release Fraction Data

The scope of applicability of the data presented in Sections 4.2 is:

- Safety assessments since the values presented are conservative.
- Bare standard waste packages as listed in Section 1.3, i.e. no protection is assumed such as might be afforded by a Transport Container. It should however be noted that a Transport Container could protect its contents from impacts with aggressive targets.
- All wasteform types within each waste container, unless otherwise stated. The 4 metre ILW boxes will contain grouted wastes and the 2 metre and 4 metre LLW boxes will contain supercompacted pucks.
- Wasteforms of any age, from the time at which the grout has cured to the time when the vaults are backfilled.
- Impacts from drops heights between 0.3m and 25m, unless otherwise stated.
- Impacts of the waste package at any orientation.
- Impacts onto either flat unyielding targets or punch (aggressive) targets as indicated below.
## 4.2 Summary of Impact Release Fractions

<table>
<thead>
<tr>
<th>PACKAGE TYPE</th>
<th>TARGET TYPE¹</th>
<th>DROP HEIGHT RANGE</th>
<th>RELEASE FRACTION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>PARTICLES &lt; 40μm</td>
</tr>
<tr>
<td>ILW</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>500 litre Standard Drum for Homogeneous Wastes</td>
<td>Flat</td>
<td>Up to 25m</td>
<td>2.7 x 10⁻⁵</td>
</tr>
<tr>
<td></td>
<td>Aggressive</td>
<td>Up to 25m</td>
<td>2.7 x 10⁻⁵</td>
</tr>
<tr>
<td>500 litre Standard Drum for Heterogeneous Wastes</td>
<td>Flat</td>
<td>Up to 25m</td>
<td>1.5 x 10⁻³</td>
</tr>
<tr>
<td></td>
<td>Aggressive</td>
<td>Up to 25m</td>
<td>1.5 x 10⁻³</td>
</tr>
<tr>
<td>500 litre Annular Grouted Drum for Compacted Wastes</td>
<td>Flat</td>
<td>Up to 25m</td>
<td>1.6 x 10⁻⁵</td>
</tr>
<tr>
<td></td>
<td>Aggressive</td>
<td>Up to 25m</td>
<td>4 x 10⁻⁴</td>
</tr>
<tr>
<td>3m³ Box for Heterogeneous Wastes</td>
<td>Flat</td>
<td>Up to 25m</td>
<td>4.0 x 10⁻⁶</td>
</tr>
<tr>
<td>3m³ Drum for Homogeneous Wastes</td>
<td>Flat</td>
<td>Up to 25m</td>
<td>4.0 x 10⁻⁶</td>
</tr>
<tr>
<td>4 metre Box for Heterogeneous Wastes</td>
<td>Flat</td>
<td>Up to 10m</td>
<td>1.3 x 10⁻⁴</td>
</tr>
<tr>
<td>MBGWS Box² for Heterogeneous Wastes</td>
<td>Flat</td>
<td>Up to 25m</td>
<td>4.0 x 10⁻⁶</td>
</tr>
<tr>
<td>WAGR Box² for Heterogeneous Wastes</td>
<td>Flat</td>
<td>Up to 10m</td>
<td>1.3 x 10⁻⁴</td>
</tr>
<tr>
<td>LLW</td>
<td>Flat &amp; Aggressive</td>
<td>Up to 10m</td>
<td>FINE PARTICULATE</td>
</tr>
</tbody>
</table>

¹ Waste packages have been drop tested onto two types of targets: a flat unyielding target, and an aggressive target similar to features in an interim storage facility or the Phased Disposal Concept.

² In the previous report release fraction data was not extended to these non-standard waste packages.
<table>
<thead>
<tr>
<th>PACKAGE TYPE</th>
<th>TARGET TYPE</th>
<th>DROP HEIGHT RANGE</th>
<th>RELEASE FRACTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 metre LLW Box for Heterogeneous Wastes</td>
<td>Flat &amp; Aggressive</td>
<td>Up to 10m</td>
<td>FINE PARTICULATE</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$1.0 \times 10^{-3}$</td>
</tr>
</tbody>
</table>
TECHNICAL NOTE

5 Summary

This Technical Note provides the recommended impact and fire release fractions for use in the Generic Documents 2003.

The 2000 Mott MacDonald report on impact and fire release fractions for use in safety case assessments has been reviewed and revised to reflect the availability of improved data. The two areas where the recommended release fractions have been revised are:

- Detailed thermal modelling of the 4 metre Box waste container has demonstrated that the waste temperatures are lower than had been assumed such that lower release fraction data at 150°C can be applied.

- Non-standard waste packages (MBGWS Box and WAGR Box) were considered separately. The performance of these container types is now considered and included in this Technical Note.

6 REFERENCES


2 United Kingdom Nirex Limited, Thermal modelling of the 4 metre Box waste container, Nirex Technical Note #411085v5, 21 January 2003.

3 United Kingdom Nirex Limited, Data Sheets for Standard and Non-Standard Radioactive Waste Packages, Nirex Report N/012

4 Mott MacDonald Limited, Recommended Release Fractions for Standard Nirex Packages: Input data for the Analysis of Fire and Impact Hazards within Transport and Repository Safety Assessments, 51994/02/C, December 2000, PC Docs #358449


7 AEA Technology, Categorisation of Radionuclides in to Volatility Groups for Release Calculations, MA Mignanelli, December 2000, AEAT/R/NT/0306, PC Docs #356902
**Table 1 Waste Package Characteristics**

<table>
<thead>
<tr>
<th>Waste Container</th>
<th>Wasteform Type</th>
<th>Examples of Raw Wastes Materials</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Standard ILW</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>500 litre Drum</td>
<td>Homogeneous</td>
<td>Floccs, liquors</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ion exchange resins</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sludges</td>
</tr>
<tr>
<td>500 litre Drum</td>
<td>Heterogeneous</td>
<td>Solid beta-gamma wastes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Magnox swarf</td>
</tr>
<tr>
<td></td>
<td></td>
<td>THORP Fuel Hulls</td>
</tr>
<tr>
<td>500 litre Annular Grouted Drum</td>
<td>Compacted/annular grouted</td>
<td>Supercompacted Plutonium Contaminated Material (PCM), dried sludge</td>
</tr>
<tr>
<td>3m³ Box</td>
<td>Heterogeneous</td>
<td>Solid beta-gamma wastes, Pond furniture and Fuel element debris</td>
</tr>
<tr>
<td>3m³ Drum</td>
<td>Homogeneous</td>
<td>Sludge and Resins</td>
</tr>
<tr>
<td>4 metre Box</td>
<td>Heterogeneous</td>
<td>Miscellaneous activated components and Graphite</td>
</tr>
<tr>
<td><strong>Standard LLW</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 metre Box</td>
<td>LLW Supercompacted</td>
<td>Laboratory/ operational waste</td>
</tr>
<tr>
<td>4 metre Box</td>
<td>LLW Supercompacted</td>
<td>Laboratory/ operational waste</td>
</tr>
<tr>
<td><strong>Non-Standard ILW</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MBGWS Box</td>
<td>Heterogeneous</td>
<td>Miscellaneous large items</td>
</tr>
<tr>
<td>WAGR Box</td>
<td>Heterogeneous</td>
<td>Miscellaneous large items from WAGR decommissioning</td>
</tr>
</tbody>
</table>
Appendix A  Rational behind Recommended Release Fraction Values

A.1 Fire Hazard - ILW

The objective of this document is to provide data that can be considered conservative and which is appropriate for use in safety assessments. In support of this objective the following simplifying assumptions have been adopted to arrive at the data recommended:

i) No account is taken of detailed temperature distributions within the waste packages. Thus if a package, or the package and its transport container (e.g. a TC) was subjected to a 1000°C fire, it has been assumed that data appropriate to a wasteform at that temperature should be used. There is considerable variability in the average waste stream thermal properties as well as those derived for the extremes of the matrix formulation envelope. Benefit could be derived by making use of the growing dataset available from detailed thermal models which are developed in response to waste package submissions.

ii) The container and wasteform types as detailed in Reference 2 have been adopted for data presentation. Typical wasteforms for 500 litre Drums (homogenous, heterogeneous and annular grouted) have been tested extensively. Data for 3m³ Boxes, 3m³ Drums and MGBWS Boxes have been deduced from these data by using similarities in the major characteristics of the designs, namely:

   a) The 500 litre Drums, 3m³ Boxes and Drums are all of a relatively thin steel construction.

   b) The 500 litre Drum (homogenous) and 3m³ Drum both contain homogeneous wastes and therefore the release mechanisms from the wasteforms will be similar. Also, the surface area to volume ratio for the 3m³ Drum container is less than for 500 litre Drum (homogenous), hence the effect of fire on the wasteform will be less. In the absence of direct 3m³ Drum data, that for 500 litre Drum (homogenous) will be adopted.

   c) 500 litre Drums (heterogeneous), 3m³ Boxes and MGBWS Boxes contain heterogeneous wastes and therefore the release mechanisms from the wasteforms will be similar. Again, the surface area to volume ratio for the 3m³ Box and MGBWS Box containers are less than for 500 litre Drums (heterogeneous), hence the effect of fire on the wasteform will be less. In the absence of direct 500 litre Drum (heterogeneous) and MGBWS Box data, that for 500 litre Drums (heterogeneous) will be adopted.

iii) The 4 metre ILW Box release mechanisms are based on grouted metallic wastes at 150°C because of its type of construction and contents. The waste container is designed for packaging of decommissioning wastes and the nominal thickness of concrete shielding anticipated for the package is judged adequate to prevent the wasteform temperature from exceeding this figure, following exposure to a 1000°C pool fire.

The WAGR Box is a reinforced concrete waste container. Similar to the 4 metre ILW Box the thickness of concrete shielding is expected to provide a good thermal barrier to the external heating source. The intended wastes are also from decommissioning activities. Therefore the 4 metre ILW Box release fractions are applied to the WAGR Box based on the overall similarities of package properties.

iv) The proposed groupings of radionuclides from Reference 5 has been adopted in presentation of the data. That review incorporates the latest results from two extensive
research programmes conducted by Nirex into the performance of wasteforms and grouts at elevated temperatures. These are termed the ARFAC and ILW Fire Programme.

v) The RF data in Reference 2 is for a range of temperatures (usually up to 1000°C). The date used in this work assumes that all the waste is at the highest temperature. This in general represents a conservatism, particularly where data for 1000°C is available since most of the wasteform would not be expected to reach that temperature. 500 litre Drums (annular grouted) data is available only to 450°C. This temperature is appropriate in this case since the 500 litre Drum (annular grouted) container is a 500 litre Drum which incorporates a grout annulus which will provide thermal insulation to the wasteform and prevent excessively high temperatures being reached.

A2 Fire Hazard - LLW

The data presented for the 2 metre and 4 metre LLW boxes was derived using calculated waste temperatures applied to measured releases from pucks. Because the surface area to volume ratio is higher for the 2 metre LLW Box than for the 4 metre LLW Box releases are systematically higher in the case of the former and therefore data for the 2 metre LLW Box will be used to characterise releases from both waste packages. The difference is not large, typically 20%.

As in the case of ILW, a number of assumptions have been made in order that the data can be presented simply:

i) The groupings of elements are the same as for ILW

ii) The temperature range to which the waste packages are subjected is the same for ILW as it is for LLW wasteforms. The release mechanisms for radionuclides in different chemical forms could be different for LLW compared with ILW, but the groupings are a relatively coarse measure and some differences at the RF levels under consideration are not considered significant.

iii) The data presented is for test conditions researched, i.e. one hour duration, 1000°C fully engulfing fire [A1].

A3 Impact Hazard – ILW

A3.1 Released Particulate Sizes for which Data Values are Presented

Source RF data presented in test result summaries relate to particles which are smaller than either 100μm or 28μm, limits which are described as defining suspendible and respirable particles, respectively. The data presented here, however, relates to particles smaller than 40μm and 100μm, the former value being related to the size of particles available for release from TCs, which will be used to transport 500 litre Drums, and 3m³ Drums/Boxes and the latter to particles which can be transported in air flow rates likely to be found in the Phased Disposal Concept. With respect to the other packages considered, namely the 4 metre Box and the 2 metre and 4 metre LLW Boxes, the 40μm values are clearly a conservative bound to the particle referred to previously quoted as respirable.

Since some data were obtained from small scale tests to derive estimates, extrapolation of the results from small scale tests to full scale is still subject to considerable uncertainty, but it is judged that a measure can be made of the ratio of particles smaller than 40μm to those smaller than 100μm. A review of the literature showed that a ratio of around 0.5 applies. Thus, where direct measurements are not available the 100μm (106μm) values.
have been reduced by a factor of 2 to provide values of Release Fractions for the particles smaller than 40\(\mu\)m.

Release data is presented for 25m drop height. Test results indicate that linear factoring to lesser drop heights based on data provided for the 25m drop cases would be pessimistic.

A3.2 500 litre Standard Drums

A3.2.1 500 litre Standard Drum – Homogeneous Wasteform

The recommendations for drops up to 25m onto aggressive targets, such as a wedge, are derived from data for full scale tests in which particle size distributions of the material released were measured. Wasteforms tested were ion exchange resin wastes and centrifuge cake simulants, both of which are typical homogeneous wasteforms.

Data for drops from similar heights onto flat targets were also available from earlier tests. Releases from the drum were rare because the containment boundary was not breached. However, subsequent examination of the behaviour of the contents of the dropped drums confirmed that particulate material had been generated internally. It has therefore been recommended that the release fraction value for aggressive targets is also used for the flat target impacts, it being a conservative compromise between the amount of material available for release and that actually released from a drum which is expected to remain essentially intact.

The same RF value for particles smaller than 40\(\mu\)m is also recommended for both flat and aggressive targets. The RF values corresponding to particles smaller than 40\(\mu\)m are derived using the times 2 reduction factor discussed above.

A3.2.2 500 litre Standard Drum – Heterogeneous Wasteform

The recommendations for drops up to 25m onto flat and aggressive targets are derived from full scale tests of wasteforms containing wastes such as fuel hulls and miscellaneous \(\beta\gamma\) wastes, both of which are representative of the heterogeneous wastes allocated to the 500 litre Drum (heterogeneous) waste package. Tests involved the dropping of drums in various orientations onto both flat and aggressive targets. The effects of the impacts varied considerably, but for conservatism the recommended results are based on a case in which the drum split. This result is to be applied to impacts on both flat and aggressive targets.

The RF values corresponding to particles smaller than 40\(\mu\)m are derived from the 100\(\mu\)m values, using the times 2 reduction factor discussed above.

A3.2.3 500 litre Annular Grouted Drum - Compacted wasteform

500 litre drums with a grout annulus are to be used with a number of pre-treated waste streams. In the main the wastes will be subject to high-force compaction, to form pucks, before encapsulation in the drums. There are two main types of wastes which are currently proposed for this type of package, Plutonium Contaminated Material (PCM) which can be either hard (metallic) or soft (paper, polythene), and dried process materials such as sludges, sands and clinoptilolite.

Testing of full scale packages has shown that releases from those containing dried compacted process wastes give rise to slightly greater releases than those containing PCM pucks. For conservatism, therefore, the process waste results were used as the basis for the recommended values. Also, results from full scale tests are available for impacts on both flat and aggressive targets and therefore release fractions appropriate to each are recommended.
A value of half of these values is again recommended for particles smaller than 40\(\mu\)m. This is a pessimistic bound based on the information presented in Section A3.1 above.

Additional information derived from the full scale tests, comprising drops from 10m, 25m and 31.25m onto flat targets, were that (a) the material ejected was restricted to capping grout and (b) no pucks were ejected. There is no indication from the reported test results that the pucks were themselves damaged to the point where their contents could be released. It is judged that the masses of pucks in the tests would encompass those of pucks with any other potential contents and hence these package tests can be considered to be representative of any drum impacts on flat targets.

**A3.3 3m\(^3\) Box**

Release fractions were derived directly from full scale testing of the 3m\(^3\) Box dropped from 25m. Particles released were analysed for size distribution. A linear scaling up of the measurements was carried out to estimate releases from 3m\(^3\) Boxes with the maximum mass permitted by the specification; the test 3m\(^3\) Boxes were somewhat lighter.

The understanding of how 3m\(^3\) Boxes perform under impact conditions has been investigated using finite element (FE) analyses, correlated with the results of drop tests.

**A3.4 3m\(^3\) Drum**

Testing of 3m\(^3\) Drums has been carried out for drops in various orientations from up to 10m. No breaches of the containment resulted in any of the tests, with the exception that in one test one of the suspension chains which fell with the drum caused a local breach, and therefore this result have been discounted. In the tests the masses of the drum and contents were less than the maximum allowed within the specification. However, the tests are still considered to be representative since the waste incorporated in the tests was typical of that which would be packed into 3m\(^3\) Drums in practice. Hence, for drop heights up to 10m an RF of zero should be adopted.

For drop heights beyond 10m (and up to 25m), the RFs for the 3m\(^3\) ILW Box should be adopted.

The recommendation for drops greater than 10m is based on:

- a) the mass of the 3m\(^3\) Drum being similar to that of the 3m\(^3\) Box and hence the impact energies being similar.
- b) the information gained from the 4 metre ILW Box RF data review, where it has been shown that releases are not strongly dependent on wasteform content, nor on its compressive strength. Hence, it is reasonable to assume that for these large containers this finding about the effects of the physical details of the contents is generally applicable.

**A3.5 4 metre Box**

There has been no specific testing of 4 metre Boxes, but finite element calculations of the amount of energy absorbed in the wasteforms for drops from 2, 5 and 10m have been carried out. The energy calculated to be absorbed in the wasteform has then been used in conjunction with release data obtained from small scale tests of 1/8 scale models of 500 litre drum wasteforms to derive the recommended release fractions.

Extrapolation to drops from 25m is not a simple matter, since data is not available for the energy absorbed in the wasteform for such impacts. It is not clear that extrapolation from the 10m energy data to the 25m case would be conservative, since experience from other waste package tests demonstrates that the extent of damage increases more rapidly than
linearly with total impact energy. Therefore, no recommendation is made for drops beyond 10m.

A3.6 MBGWS Box

There has been no specific testing of MBGWS Boxes. Of the other waste packages for which impact data is available, the 3m³ Box is considered to have the most similar waste container and wasteform contents to the MBGWS Box. In the absence of direct MBGWS Box data that for the 3m³ Box will be applied.

A3.7 WAGR Box

There has been some testing of WAGR Boxes which confirmed that at low heights, the shielding provided good protection to the wasteform. Of the other waste packages for which impact data is available or has been derived, the 4 metre Box for ILW is considered to have the most similar waste container and wasteform contents to the WAGR Box. In the absence of direct WAGR Box data at 10 m and 25 m that for the 4 metre Box will be applied.

A4 Impact Hazard LLW (2 metre and 4 metre LLW Boxes)

There is no explicit test or calculation information on the impact performance of 2 metre and 4 metre LLW Boxes. However, the following approach has been developed from puck drop tests as the basis for guidance on release fractions:

All wastes will be in solid form. If any of the contents of the 2 metre and 4 metre LLW Boxes were in the form of fine powders or particulate then these will have been immobilised. Supercompacted pucks will be the normal means utilised for the packaging within LLW Boxes. Drop testing of individual supercompacted pucks containing either hard or soft ILW has been carried out. The soft waste simulants comprised cotton, PVC, polythene, rubber and paper and the hard wastes comprised mild steel, stainless steel, aluminium and lead.

The results for soft wastes showed virtually no variation with impact energy (i.e. drop height). The hard wastes led to no release for drops below 5m, while a linear relationship between the 5m results and 25m provided an upper bound to results from intermediate heights.

Since a 10m drop height is likely to be typical of stacking heights for this type of package in the Phased Disposal Concept a release fraction was derived for 10m from the hard waste results. This was found to exceed the essentially constant soft waste release fraction.

Hence, for conservatism it will be assumed that the contents of LLW Boxes behave like pucks of hard waste only.

The effect of a localised aggressive feature is not considered to be likely to give rise to an additional release since in the above analysis the overall containment is already taken to be breached and all internal containers are assumed to have been damaged.
A1  AEA Technology, Radionuclide Release Fractions for Low Level Waste Packages under Fire Accident Conditions, P J Stopford, February 1997, AEAT-0599, PC Docs #413554)