Radioactive Waste Management

WPS/911/03

# Waste Package Specification and Guidance Documentation:

## Guidance on Application of the Criticality Safety Requirements of the IAEA Transport Regulations for Waste Packages that Contain Small Quantities or Concentrations of Fissile Material

May 2020

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# Executive Summary

This document forms part of the Waste Package Specification and Guidance Documentation (WPSGD) suite, which is intended to assist waste packagers in the development of plans for the packaging of higher activity waste in a manner suitable for geological disposal. The WPSGD is subject to periodic enhancement and revision. Therefore, users are advised to contact RWM or refer to the RWM website (**www.gov.uk/guidance/generic-waste-package-specification**) to ensure that they are in possession of the latest version of any documentation used.

The main purpose of this guidance document is to assist waste packagers with the interpretation of different exception criteria set out in the IAEA Transport Regulations. This guidance:

- outlines the criticality safety requirements of the IAEA Transport Regulations;
- provides a systematic guide to a process of determining whether waste packages can be excepted from the requirement for competent authority approval to be transported when they contain fissile material; and
- provides advice to waste packagers on the interpretations of the relevant sections of the IAEA Transport Regulations and identifies potential issues when considering the application of exception criteria.

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| **WPS/911** | January 2009 | Aligns with 2007 Generic Waste Package Specification (Nirex Report No. N/104), and the 2005 Edition of the IAEA Transport Regulations (TS-R-1) |
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| **WPS/911/03** | October 2019 | Aligns with the Specification for Waste Packages Containing Low Heat Generating Waste: Part C – Fundamental Requirements (RWM report no. WPS/220/01). |

# List of Contents

# Abbreviations and acronyms used in this document

| | |
|---|---|
| **CCAD** | Criticality Compliance Assurance Documentation |
| **CSA** | Criticality Safety Assessment |
| **CSI** | Criticality Safety Index |
| **DSSC** | Disposal System Safety Case |
| **GDF** | Geological Disposal Facility |
| **HSE** | Health and Safety Executive |
| **IAEA** | International Atomic Energy Agency |
| **ILW** | Intermediate Level Waste |
| **IF** | Industrial Fissile package |
| **IP** | Industrial Package |
| **LLW** | Low Level Waste |
| **LSA** | Low Specific Activity |
| **NDA** | Nuclear Decommissioning Authority |
| **ONR** | Office for Nuclear Regulation |
| **PDSR** | Package Design Safety Report |
| **RWM** | Radioactive Waste Management Ltd |
| **WPS** | Waste Package Specification |
| **WPSGD** | Waste Package Specification and Guidance Documentation |

# 1. Introduction

Radioactive Waste Management Ltd (RWM) has been established as the delivery organisation responsible for the implementation of a safe, sustainable and publicly acceptable programme for geological disposal of the UK's higher activity radioactive waste. Much of the waste destined for geological disposal is generated in a form that is not immediately suitable for such disposal and it must be treated and packaged in such a way as to render it [**1** , §2]:

- passively safe, such that it can be stored safely with the minimum need for actively managed safety systems, monitoring or prompt human intervention;
- safely handleable during interim storage;
- 'disposable', in that it can be shown that it can be transported to and disposed of in a geological disposal facility (GDF) safely and in a way that is compliant with the relevant regulations and safety cases for a GDF.

Some wastes include fissile radionuclides (predominantly U-235 and Pu-239) and the development of waste packaging solutions for such wastes must address criticality safety requirements associated with each phase of waste management.

## 1.1 Demonstrating criticality safety in waste packaging

A criticality safety demonstration for a proposed waste package needs to provide arguments and evidence that show how [2] ***'[t]he presence of fissile material, neutron moderators and reflectors in the waste package shall be controlled to ensure that:***

- ***criticality during transport is prevented***
- ***the risk of criticality during the GDF operational period is tolerable and as low as reasonably practicable***
- ***in the GDF post-closure period both the likelihood and consequences of criticality are low.'***

These criticality safety requirements are met by controlling how the wastes are packaged as well as controlling the waste package transport and disposal processes.

RWM produces packaging specifications in the form of *Waste Package Specification and Guidance Documentation* (WPSGD) as a means of providing a baseline against which the suitability of plans to package radioactive waste for geological disposal can be assessed, as well as guidance on the implementation of associated waste packaging requirements. The WPSGD includes waste package requirements relating to criticality safety and guidance on how those requirements can be met.

The WPSGD is available to waste producers and other stakeholders. In particular:

- Waste Package Specification (WPS) Part C sets out Fundamental Requirements on the packaging of low heat generating wastes such that they are suitable for transport and disposal [3].
- WPS Part D provides Container-specific Requirements for a standard range of containers used to package low heat generating waste [4].

Requirements on demonstrating the criticality safety of waste packages are included in Part C, with reference to the following supporting guidance:

- WPS/916, which provides guidance on the preparation of (i) criticality safety assessments (CSAs) to derive the constraints on waste packaging needed to ensure that criticality safety requirements are met, and (ii) Criticality Compliance Assurance Documentation (CCAD) to provide evidence that the constraints derived in the CSAs will be met when the wastes are packaged [5];
- WPS/911 (i.e. this document), which provides guidance on application of the 'fissile exception' criteria of the International Atomic Energy Agency (IAEA) *Regulations for the Safe Transport of Radioactive Material*[1] [6].

## 1.2 Scope of guidance

The transport of radioactive material through the public domain in the UK is subject to regulations that effectively require conformance with the IAEA Transport Regulations [6]. These regulations place controls on the design and contents of transport packages that contain fissile material in order to ensure that sub-criticality is maintained during routine, normal and accident conditions of transport.

The IAEA Transport Regulations include specifications of conditions under which the contents of transport packages that contain relatively small quantities of fissile nuclides or fissile material that is subcritical in any quantity can be defined as 'non-fissile' material or classified as 'fissile-excepted' material. Transport packages containing non-fissile or fissile-excepted material are excepted from the requirements of the IAEA Transport Regulations for packages that contain fissile material. The IAEA Transport Regulations also specify criteria that permit transport packages containing specified quantities of fissile nuclides and moderating materials that meet certain performance requirements to be excepted from the requirement for competent authority approval for the transport of fissile material.

The main purpose of this guidance document is to assist waste packagers with the interpretation of the different exception criteria of the IAEA Transport Regulations. With this aim, the guidance:

- outlines the criticality safety requirements of the IAEA Transport Regulations;
- provides a systematic guide to a process of determining whether waste packages that contain fissile material can be excepted from the requirement for competent authority approval to be transported; and
- provides advice to waste packagers on the interpretations of the relevant sections of the IAEA Transport Regulations and identifies potential issues when considering the application of exception criteria.

[1] *Referred to hereafter as the 'IAEA Transport Regulations'.*

## 1.3 Guidance structure

The guidance is structured as follows:

- Section 2 provides background information on the requirements for the safe transport of radioactive waste, information on the different categories of container for packaging low heat generating waste, focusing on those used to transport fissile material, and RWM's process for assessing the disposability of proposed waste packages.
- Section 3 provides RWM's interpretation of the criticality safety requirements specified by the IAEA Transport Regulations, with particular attention to the manner by which transport packages can be 'excepted' from those requirements.
- Section 4 discusses the potential problems that can arise regarding fissile exception for the packaging of typical UK intermediate level waste (ILW) for transport to a GDF.
- Section 5 summarises key paragraphs from the IAEA Transport Regulations.
- A glossary of key terms and phrases is presented at the end of the document.

# 2. Background

## 2.1 Requirements for the safe transport of radioactive waste

The Government is implementing a consent-based approach to identifying potentially suitable GDF locations based on working with interested communities that are willing to participate in the siting process [**7**]. Although potential locations for a GDF have not yet been identified, it is acknowledged that some or all of the waste packages manufactured in the UK will have to be transported through the public domain from their site of arising to the GDF. These transport operations will be subject to national and international regulations, the most significant of these being the IAEA Transport Regulations. The regulations that implement the requirement to comply with IAEA Transport Regulations are discussed in RWM's Generic Disposal System Specification (Part A) [**8**, §3.4.2] and Generic Transport Safety Case [**9**, §2]. Regulation of the transport of radioactive material in the UK depends on the location and mode of transport, and is divided between the Office for Nuclear Regulation (ONR), the Department of the Environment in Northern Ireland, the Health and Safety Executive (HSE), the Health and Safety Executive for Northern Ireland, the Office of Rail and Road and the Maritime and Coastguard Agency.

The IAEA Transport Regulations apply to the transport of all categories of radioactive material including wastes with a wide range of specific activities. To enable a proportionate approach to ensuring the safety of such materials, a number of categories of 'transport package'[2] are defined, including:

- **Type A** - for the transport of radioactive material in quantities that represent a limited radiological hazard;
- **Type B** - for the transport of radioactive materials in quantities that represent a hazard greater than that permitted for Type A transport packages;
- **Industrial Packages** - Type IP - for the transport of materials with low specific activity or low levels of surface contamination; and
- **Industrial Fissile**[3] - Type IF - for the transport of fissile material bearing materials with low specific activity or low levels of surface contamination.

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[2] *The distinction between a 'waste package' and a 'transport package' is important because it influences the manner by which the requirements of the IAEA Transport Regulations are applied. A waste package will, in general, comprise a container in which waste is placed and which is suitable for disposal without further treatment. Some waste packages may require additional physical and/or thermal protection for transport (e.g. they will need to be placed in a transport container), in which case the transport package comprises the waste packages and any protective devices. Some waste packages will be transportable without additional protection, and are described as transport packages in their own right.*

[3] *Referred to in the Transport Regulations as 'Industrial package design for fissile material' (Paragraph 832(c)).*

It is assumed that only Type B and Type IP transport packages will be used for the transport of waste packages containing ILW, although it is possible that Type A or Type IF transport packages could be used in certain circumstances [**4**, §3].

The IAEA Transport Regulations establish requirements for the safe transport of radioactive materials on the basis of a need to contain the radioactive contents, control external radiation levels, prevent criticality and prevent damage caused by heat. These requirements are met by applying a graded approach to the contents limits for packages and to performance standards applied to the package design depending on the hazard presented by the radioactive contents.

The transport package has to be designed such that it demonstrably meets the regulatory constraints for the package type with regards to containment, shielding, criticality and heat. The design will lead to limits on waste package contents and standards for waste package performance that, in some cases, will be bounding for all stages of the long-term management of the waste packages.

The demonstration of compliance of a transport package with the requirements of the IAEA Transport Regulations is provided by analyses presented in the Package Design Safety Report (PDSR). A PDSR for a Type IP or Type A transport package is approved by a competent body and a PDSR for a Type B, Type IF or other transport package containing fissile material is approved by the competent authority (i.e. the ONR in the UK) and must include a criticality safety analysis that demonstrates that the package maintains sub-criticality during routine, normal and accident conditions of transport.

## 2.2 Types of waste package

A variety of waste container designs have been proposed for the packaging of UK low heat generating waste for geological disposal. These designs can be grouped into three basic types on the basis of the general nature of the wastes that they would contain and how they would be transported [**10**]:

- Waste containers with integral radiation shielding[4] can be used to produce *shielded waste packages* for ILW and low level waste (LLW) with low specific activity (LSA) that would not generally require the extensive use of remote handling techniques. Such waste packages would generally be expected to be transportable through the public domain without additional protection and would qualify as Type IP transport packages in their own right.
- Relatively thin-walled (i.e. a few mm) metal containers can be used to produce *unshielded waste packages* for higher activity ILW that would generally require the use of remote handling techniques. Because of their high external radiation dose rate or requirements for the containment of their contents, such waste packages would be expected to be transported through the public domain in reusable shielded transport containers as Type B transport packages.
- Thick-walled (i.e. many 10's of mm thick) waste containers can be used to produce *robust shielded waste packages* that provide both radiation shielding and physical containment for all types of ILW. Such waste packages may be stored, transported and disposed of without the need for remote handling techniques or additional shielding or containment. Depending on their individual designs and radionuclide contents, robust shielded waste packages could be transported as either Type IP or Type B transport packages.

[4] *If needed, to ensure that external radiation dose rates do not exceed the regulatory limits for transport.*

The containment philosophy that underpins the safety of the Type B and Type IP transport packages anticipated for ILW is fundamentally different in the manner by which workers and members of the public are protected from the consequences of the release of radionuclides from each type of transport package. For Type B transport packages, protection is vested in the design of the containment system, whereas for Type IP transport packages it is achieved by controls on the physical form of the contents. To this end the contents of Type IP transport packages are limited to LSA material and surface contaminated objects, each of which have defined radionuclide limits. By contrast, no such limits are placed on the contents of Type B transport packages. Instead, the IAEA Transport Regulations specify a containment criterion for Type B transport packages when subjected to tests representing accident conditions of transport[5].

With regard to criticality safety, controls typically involve limiting the fissile material content of the waste package, but they may also include requirements on the arrangement or distribution of fissile material in the waste package and controls on the presence of neutron moderating, absorbing and reflecting materials, as well as requirements on the type and properties of the container.

Much of the ILW that is planned to be packaged in shielded waste packages (i.e. Type IP transport packages) contains some fissile material, albeit generally only in relatively small quantities (i.e. up to a few 10's of grams per waste package). Such quantities of fissile material would not normally be considered as presenting a criticality safety concern at any point during the long-term management of the waste, including its geological disposal. The main aim of this document is to provide guidance on how shielded waste packages[6] could be excepted from the requirements of the IAEA Transport Regulations relating to packages that contain fissile material. The guidance is also relevant to other types of waste packages (i.e. unshielded and robust shielded waste packages) if they contain sufficiently small quantities of fissile material.

Note that, even though a waste package meets the fissile exception requirements of the IAEA Transport Regulations, and is thus consistent with RWM's requirement that criticality during transport is prevented [**2**], it does not necessarily mean that the waste package will be compliant with the requirements for criticality safety during the GDF operational and post-closure periods. In general, it would be expected that such a waste package would meet GDF operational and post-closure criticality safety requirements, but this would need to be demonstrated during the development of a proposal to package the waste for geological disposal.

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*[5] The tests for demonstrating whether a Type B package can withstand accident conditions of transport include a 9 m free drop onto an unyielding surface and exposure to heat flux at least equivalent to a 30 minute duration fire with an average flame temperature of 800°C. These tests apply to:*

- *the Type B accident conditions of transport containment requirement for which the pass criterion is that in the week following the tests the release of radioactivity from the transport package is restricted to less than 10 $A_2$ for krypton-85 or 1 $A_2$ for all other radionuclides; and*
- *competent authority approved fissile packages for which the pass criterion is that the package maintains sub-criticality.*

*[6] RWM has identified three standardised designs of waste container that could be used for the manufacture of shielded waste packages: the 2 metre box, 4 metre box and 6 cubic metre concrete box [10, §4.2].*

## 2.3 The assessment of waste packaging proposals

RWM has established the Disposability Assessment Process [**1**] to support waste producers in the development of plans to package higher activity wastes. Specifically, the Disposability Assessment process is used to demonstrate that proposals to package waste would, if implemented, result in 'disposable' waste packages. In this context, a disposable waste package is one that is compliant with all of the relevant regulations and safety cases for transport to and disposal in a GDF, and in line with regulatory expectations for the long-term management of the waste [**11**]. RWM has provided guidance to waste packagers on the preparation of submissions for the disposability assessment of packaging proposals [**12**].

The Disposability Assessment process plays an important role in underpinning the generic Disposal System Safety Case (DSSC) [**13**] by providing confidence that the safety cases, which are based on generic assumptions regarding the wastes that are anticipated to be accommodated by a GDF, are compatible with the 'real' waste packages that are being manufactured. Waste package disposability assessments thus provide a process for confirming that the disposal concepts considered in the generic DSSC are appropriate for the wastes that they are intended to cover, as well as identifying waste packages that could challenge current disposal concepts and facilitating early consideration of the changes that may be required to accommodate such waste packages.

# 3. Interpretation of the exception criteria relating to fissile material in the IAEA Transport Regulations

The IAEA Transport Regulations include three paragraphs of particular relevance to the fissile exception of transport packages containing low heat generating wastes:

- Paragraph 222, which provides a definition of fissile material, including defining conditions under which the contents of a transport package can be excluded from definition as fissile material;
- Paragraph 417, which defines the conditions under which the contents of transport packages can be excepted from classification as fissile material; and
- Paragraph 674, which defines the conditions under which limited quantities of fissile material may be transported using a package design not requiring competent authority approval to contain fissile material.

If a waste package does not meet any of the fissile exception criteria, then requirements set out in Paragraph 673 relating to the transport of packages containing fissile material will need to be met. The Part C WPSGD includes the following requirement [3]:

**C133. A criticality safety demonstration *shall* be made for waste package transport that satisfies the IAEA Transport Regulations in one of the following ways [4]:**

**a) A non-fissile case *shall* be made under Para 222.**

**b) A fissile exception case *shall* be made under Para 417, or Para 674.**

**c) For fissile waste material a criticality safety case *shall* be provided according to Para 673.**

The IAEA has provided Advisory Material [14] that includes guidance on the application of the criticality safety requirements of the IAEA Transport Regulations. Furthermore, the IAEA has produced guidance on how to identify if fissile material can be transported in packages where the design does not require competent authority approval for the inclusion of fissile material, including example applications of the fissile exception criteria [15].

This guidance focuses on interpretation of the exclusion criteria presented in Paragraphs 222, 417 and 674 of the IAEA Transport Regulations in order to facilitate their application to waste packaging proposals in the UK. Note that Paragraph 673 (on the transport of packages containing fissile material) is also presented because it provides the context for application of Paragraphs 417 and 674, but guidance on application of Paragraph 673 is not included. Paragraph 675, which relates to the transport of Pu-238, is also discussed for completeness, but it is unlikely to be applicable to the transport of low heat generating waste.

The guidance includes flowcharts with YES/NO decision points relating to whether the contents of a particular transport package would be defined as fissile or whether the material can satisfy any of the exception criteria referred to in Paragraphs 222, 417 and 674 of the IAEA Transport Regulations. The flowcharts are intended for use in relation to a particular waste consignment, where a 'consignment' is defined as (Paragraph 211 of the IAEA Transport Regulations) '*... any package or packages, or load of radioactive material presented by a consignor for transport.*' Note that more than one route may be available to meet an exception criterion for a particular transport package and all possibilities need to be considered to ascertain the most appropriate (i.e. least onerous) waste packaging option.

## 3.1 Paragraph 222: Definition of fissile nuclides and fissile material

Section 2 of the IAEA Transport Regulations provides definitions of terms that are applicable to the regulations. Fissile nuclides and fissile material are defined in Paragraph 222:

> *Fissile nuclides shall mean uranium-233, uranium-235, plutonium-239 and plutonium-241. Fissile material shall mean a material containing any of the fissile nuclides. Excluded from the definition of fissile material are any of the following:*
>
> *(a) Natural uranium or depleted uranium which is unirradiated;*
>
> *(b) Natural uranium or depleted uranium which has been irradiated in thermal reactors only;*
>
> *(c) Material with fissile nuclides less than a total of 0.25 g;*
>
> *(d) Any combination of (a), (b) and/or (c).*
>
> *These exclusions are only valid if there is no other material with fissile nuclides in the package or in the consignment if shipped unpackaged*[7]*.*

Exclusions (a) and (b) rely on the definition of natural uranium and depleted uranium that is given in Paragraph 247:

> *Natural uranium shall mean uranium (which may be chemically separated) having the naturally occurring distribution of uranium isotopes (approximately 99.28% uranium-238 and 0.72% uranium-235 by mass*[8]*).*
>
> *Depleted uranium shall mean uranium containing a lesser mass percentage of uranium-235 than natural uranium.*

The use of the term 'approximately' is not defined and this is assumed to mean that the small variation that occurs in natural uranium from various parts of the world is acceptable but that material which has been deliberately enriched above this level in any way is not acceptable.

[7] *Waste consignments would be packaged for transport to the GDF, rather than transported unpackaged.*

[8] *More correctly, natural uranium contains approximately 99.28% uranium-238 and 0.72% uranium-235 by atom.*

Waste packages containing uranium which is either of natural isotopic concentration (i.e. ~0.72% U-235) or less and which has not been exposed to any type of neutron irradiation can be excluded from the definition of fissile material by Paragraph 222(a) and would not therefore need further consideration as far as transport is concerned.

Paragraph 246 defines 'unirradiated uranium' as:

> *Unirradiated uranium shall mean uranium containing not more than $2x10^3$ Bq of plutonium per gram of uranium-235, not more than $9x10^6$ Bq of fission products per gram of uranium-235 and not more than $5x10^{-3}$ g of uranium-236 per gram of uranium 235.*

In principle, this allows very lightly irradiated natural or depleted uranium to be excluded from the definition of fissile material according to Paragraph 222(a), although the burn-up that would result in a concentration of $2x10^3$ Bq of plutonium per gram of U-235 is very small (of the order of $10^{-5}$ GWd/tU). Furthermore, the natural concentration of plutonium (i.e. that created as a result of cosmic neutrons) in unirradiated uranium is likely to be close to the specified limit and this will make demonstration of compliance with the limit difficult even for uranium that has been only very lightly irradiated. Similarly, depleted uranium that has arisen from the reprocessing of Magnox fuel is unlikely to qualify as 'unirradiated uranium' as it typically contains well in excess of $2x10^3$ Bq of plutonium per gram of U-235.

Paragraph 222(b) states that natural or depleted uranium that has been irradiated in a thermal reactor is also excluded from the definition of fissile material. Whilst neither the IAEA Transport Regulations nor the Advisory Material contain a definition of what constitutes a 'thermal reactor' these are assumed to be reactors typified by having moderating materials to reduce the speed of neutrons to low (or 'thermal') velocity, with the objective of maintaining a controlled neutron chain reaction by the fissioning of uranium-235. Of the many reactor types that have operated in the UK, only the fleet of Magnox power stations and the plutonium production piles at Windscale are thermal reactors predominantly fuelled by natural uranium which could be excluded from the definition of fissile material by Paragraph 222(b). However, some of the Magnox stations and the Windscale Piles did use some slightly enriched fuel and it may not always be possible to guarantee that particular wastes arising from those reactors would contain only irradiated natural uranium.

A number of UK reactor types use or used enriched uranium fuels, including the Advanced Gas-cooled Reactors, the Sizewell Pressurised Water Reactor, the Winfrith Steam Generating Heavy Water Reactor, submarine propulsion reactors and several experimental reactors. It is also expected that any new build reactors would use enriched uranium fuel. Examples of facilities in the UK which would not be classified as 'thermal reactors' include the fast reactors at Dounreay, experimental fast reactor assemblies at other sites, and the Joint European Torus facility at Culham. Fissile-nuclide-bearing wastes irradiated in these reactors and facilities would be defined as fissile material by Paragraph 222.

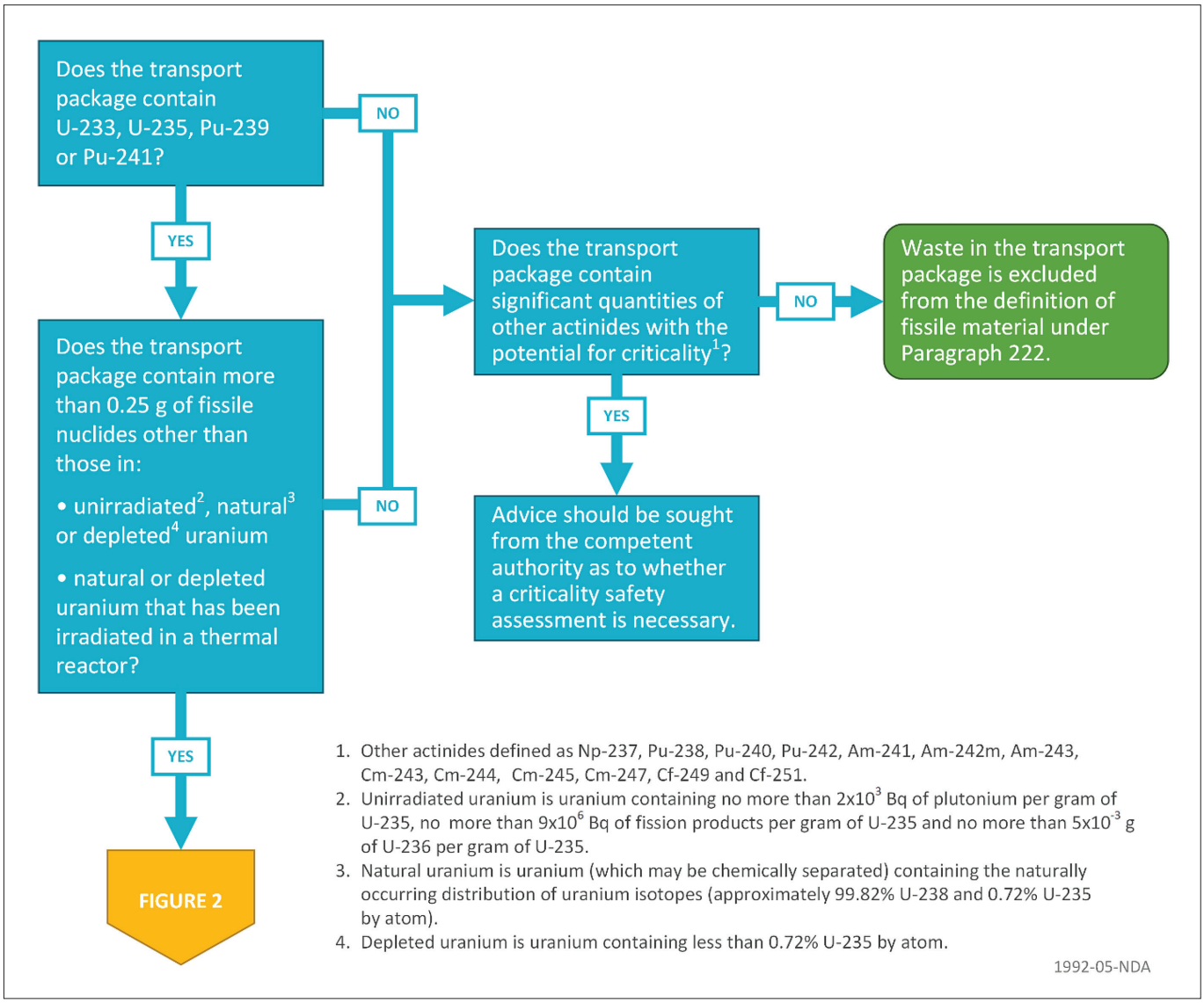
The Advisory Material (Paragraphs 222.1 to 222.3) explains that the basis used to select the radionuclides defined as fissile material relies on the ease of accumulating sufficient mass for a potential criticality. However, it also makes reference to a potential special case where significant quantities of certain other actinides exist in the consignment. The radionuclides in question are Np-237, Pu-238, Pu-240, Pu-242, Am 241, Am-242m, Am-243, Cm-243, Cm-244, Cm-245, Cm-247, Cf-249 and Cf-251. The sub-critical mass limits for these materials range from a few hundred grams to several tens of kilograms, and are reported in ANSI/ANS-815-1981 [16]. The Advisory Material states that advice needs to be sought from the competent authority where significant quantities of these radionuclides are to be transported.

Note that Paragraph 222 does not represent a general exclusion of all natural and depleted uranium from definition as fissile material. As explained in the Advisory Material (Paragraph 222.7), if other fissile materials were present, the fissile nuclides in natural or depleted uranium could increase reactivity. When the contents of a package include any fissile nuclides not excluded from the definition of fissile material, all fissile nuclides within the package are defined as fissile material.

Paragraph 222(c) states that material with fissile nuclides less than a total of 0.25 g is excluded from the definition of fissile material, although the scale at which the 0.25 g limit would be applied is not stated. However, the Advisory Material (Paragraphs 222.5 and 222.6) refers to application of the exclusion at the waste package scale (within a consignment that may include fissile waste packages).

Figure 1 shows the circumstances under which waste could be excluded from the definition of fissile material under Paragraph 222.

**Figure 1: Exclusion from the definition of fissile material according to Paragraph 222 of the IAEA Transport Regulations**



## 3.2 Paragraph 417: Classification of fissile material

Paragraph 417 of the IAEA Transport Regulations covers classification of fissile material and packages containing fissile material (where the material cannot be excluded from the definition of fissile material given in Paragraph 222):

> *Fissile material and packages containing fissile material shall be classified under the relevant entry as "FISSILE" in accordance with Table 1 unless excepted by one of the provisions of subparagraphs (a)-(f) of this paragraph and transported subject to the requirements of para. 570. All provisions apply only to material in packages that meet the requirements of para. 636, unless unpackaged material is specifically allowed in the provision.*

Paragraph 417 contains six separate conditions under which the material may be excepted from classification as fissile. It is important, however, to recognise that, according to Paragraph 570(a), only one type of exception (i.e. 417(a), (b), (c), (d), (e) or (f)) is allowed per consignment. Thus, if a consignment consists of more than one transport package, each of which can be excepted from classification as fissile, the consignment may not be excepted unless the same sub-paragraph is used to except each individual transport package. This is potentially a concern for the transport of groups of ILW packages in the same consignment.

The individual sub-paragraphs of Paragraph 417 are discussed below. Note that Paragraphs 417(e) and 417(f) are most likely to be applicable to the transport of low heat generating waste.

### 3.2.1 Paragraph 417(a)

Paragraph 417(a) provides criteria by which slightly enriched uranium can be classified as fissile-excepted:

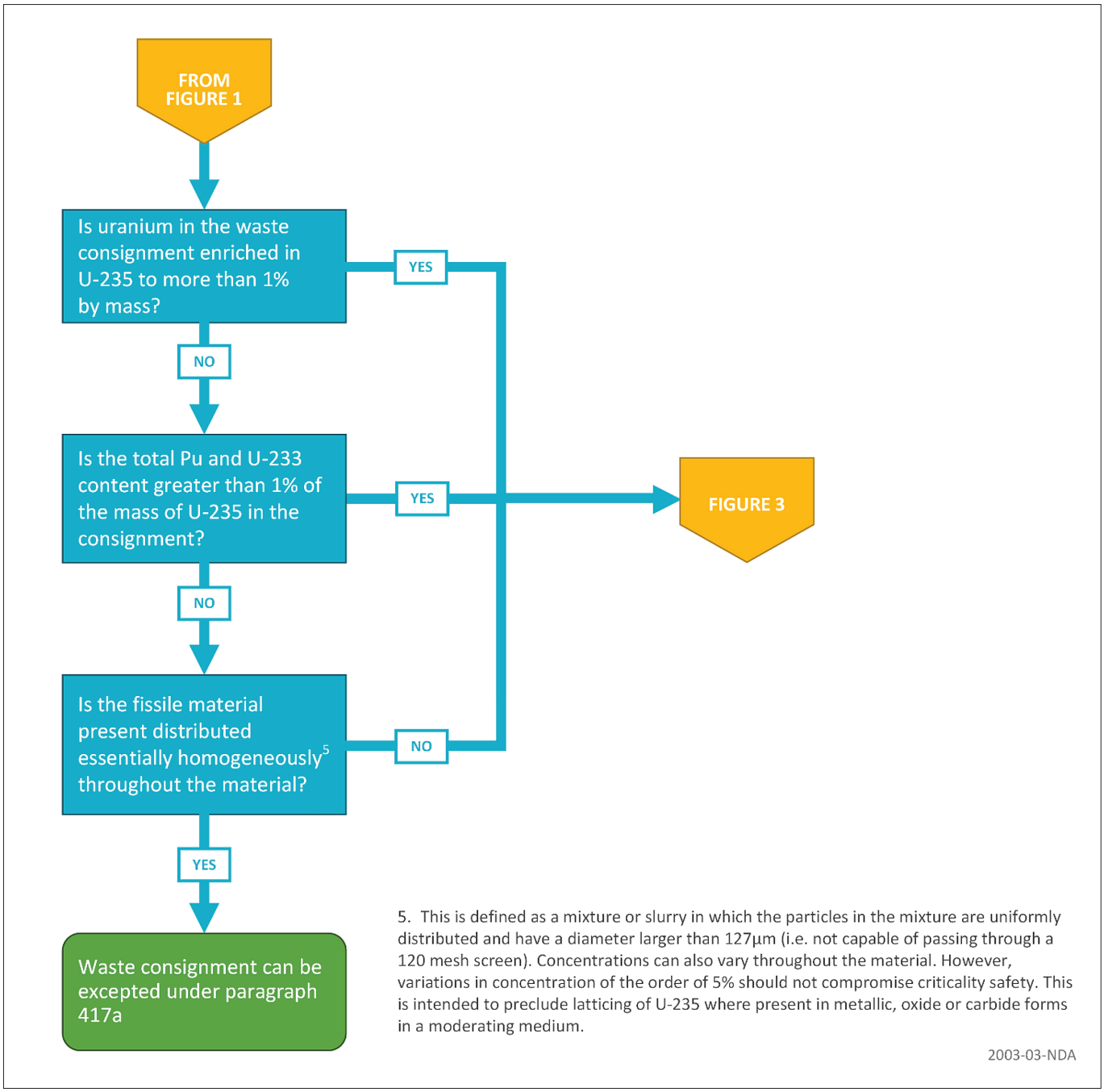
Uranium enriched in uranium-235 to a maximum of 1% by mass, and with a total plutonium and uranium-233 content not exceeding 1% of the mass of uranium-235, provided that the fissile nuclides are distributed essentially homogeneously throughout the material. In addition, if uranium-235 is present in metallic,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

A flowchart indicating how slightly enriched uranium could be excepted by the use of Paragraph 417(a) is shown in Figure 2. The sub-paragraph includes the proviso that the fissile material is distributed 'essentially homogeneously'. The Advisory Material defines the required degree of distribution by reference to a mixture or slurry *'in which the particles in the mixture are uniformly distributed and have a diameter no larger than 127μm*[9]*'.* Concentrations are permitted to vary through the material by up to the order of 5%. The intent is to avoid compromising criticality safety by the creation of a 'lattice' of uranium-235 in a metallic, oxide or carbide form within a moderating medium. This requirement is included on the basis that a heterogeneous lattice arrangement provides a higher reactivity for low enriched uranium systems than a homogeneous distribution of the same quantity of material.

[9] *Defined as particles that are not capable of passing through a 120 mesh screen.*

The limit on the proportion of the mass of plutonium and uranium-233 compared to uranium-235 precludes this exception from being applicable to most low heat generating waste. Further, since the wasteform specification for low heat generating waste packages [4] precludes the presence of free liquids, this exception would not apply unless it could be shown that a mixture of fissile material in a solid matrix satisfied the distribution criteria. This would include ensuring that the process feed prohibited the inclusion of 'oversize' (i.e. > 127µm) particles of fissile material. Consequently, this exception is not anticipated to be relevant for low heat generating waste.

**Figure 2: Classification as fissile-excepted according to Paragraph 417(a)**



### 3.2.2 Paragraph 417(b)

Paragraph 417(b) provides criteria by which uranyl nitrate solutions can be classified as fissile-excepted:

> *'Liquid solutions of uranyl nitrate enriched in uranium-235 to a maximum of 2% by mass, with a total plutonium and uranium-233 content not exceeding 0.002% of the mass of uranium, and with a minimum nitrogen to uranium atomic ratio (N/U) of 2.'*

The wasteform requirements for waste packages containing low heat generating waste [3, 4] require that free liquids are excluded or at least minimised if exclusion is not possible. Therefore, this exception would not apply to any waste packages destined for a GDF.

### 3.2.3 Paragraph 417(c)

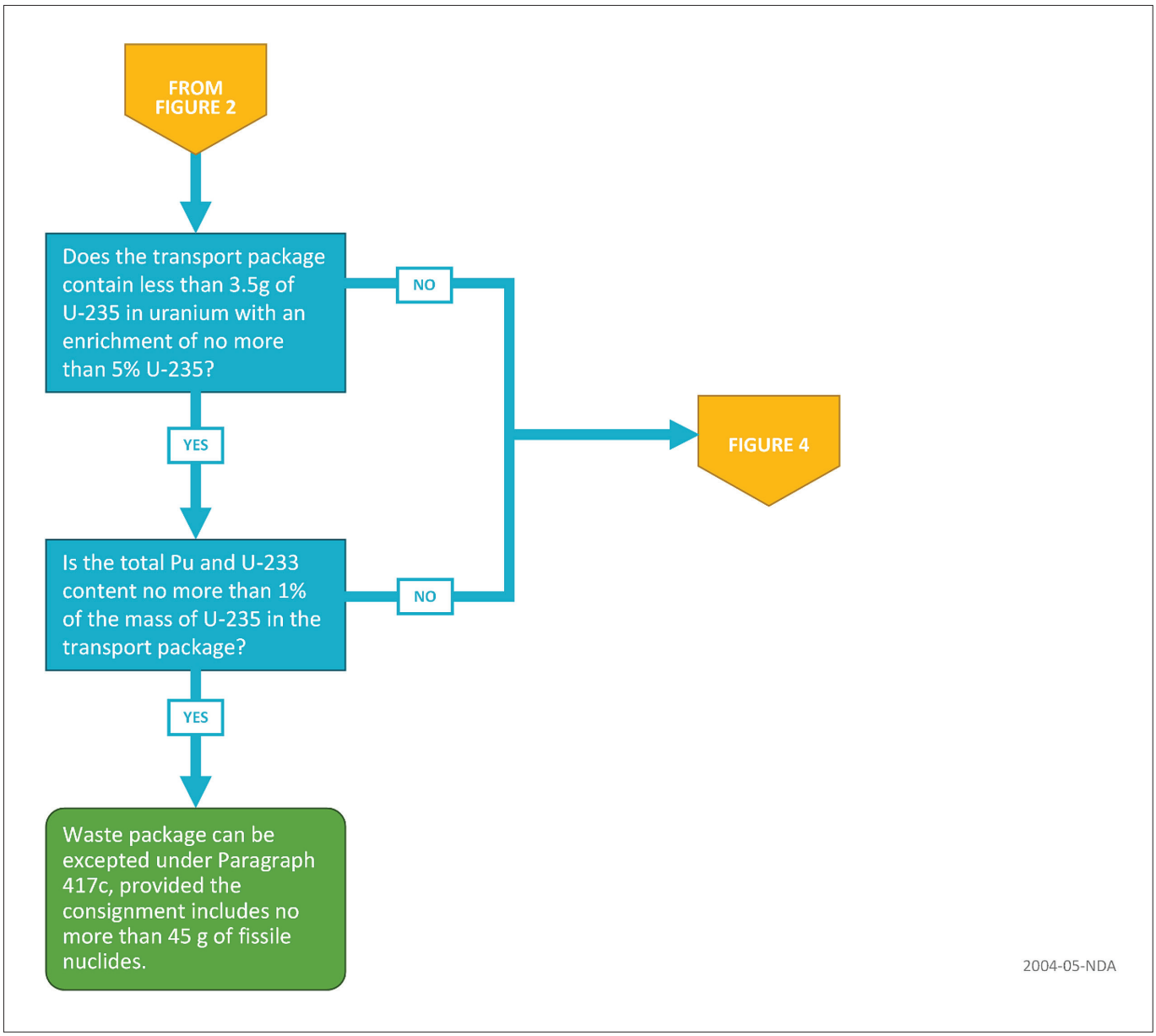
Paragraph 417(c) provides criteria by which low enriched uranium (up to 5% U-235 by mass) can be classified as fissile-excepted:

> *Uranium with a maximum uranium enrichment of 5% by mass uranium-235 provided:*
>
> (i) *There is no more than 3.5g of uranium-235 per package.*
>
> (ii) *The total plutonium and uranium-233 content does not exceed 1% of the mass of uranium-235 per package.*
>
> (iii) *Transport of the package is subject to the consignment limit provided in para. 570(c).*

The flowchart in Figure 3 illustrates the application of this exception. However, whilst this sub-paragraph permits the uranium-235 content of a consignment to be up to 45g (as specified by Paragraph 570(c)), it also specifies a limit of 3.5g of uranium-235 on the individual packages that make up the consignment. The Advisory Material explains that this provision is intended to enable shipment of limited quantities of uranium-235 enriched up to 5% by mass, such as shipment of uranium hexafluoride samples based on historic practice. Safety is ensured by the consignment limit being a small fraction of the critical mass.

The limit on the proportion of the mass of plutonium and uranium-233 compared to uranium-235 precludes this exception from being applicable to most low heat generating waste. Further, the limit of 3.5g of uranium-235 per package is more restrictive than the limit set out in Paragraph 417(e).

Figure 3: Classification as fissile-excepted according to Paragraph 417(c)




### 3.2.4 Paragraph 417(d)

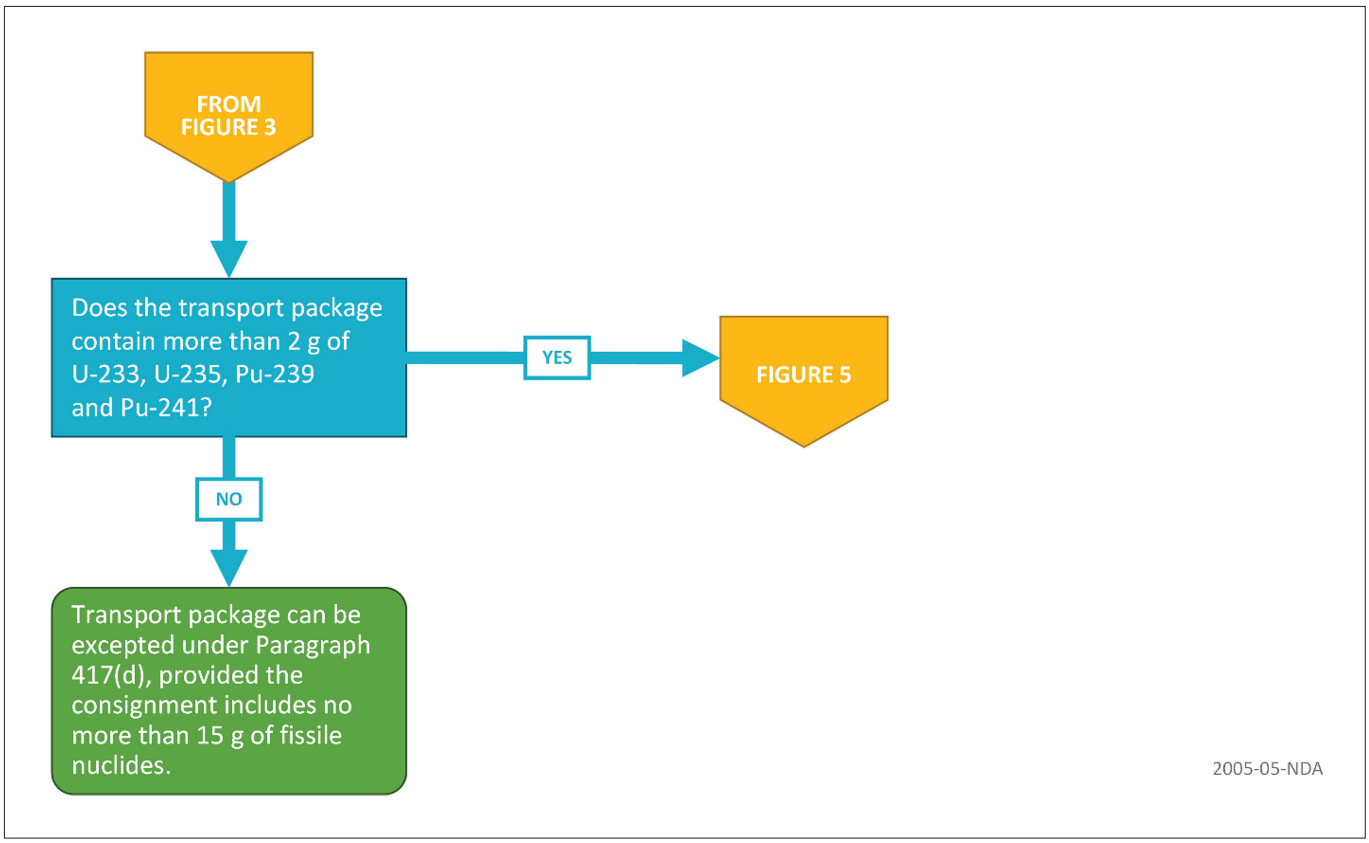
Paragraph 417(d) provides criteria by which packages containing only traces of fissile nuclides can be classified as fissile-excepted:

Fissile nuclides with a total mass not greater than 2.0 g per package provided the package is transported subject to the consignment limit provided in para. 570(d).

Figure 4 shows the exception application for such packages. The Advisory Material explains that this provision is intended to enable shipment of small samples of unirradiated or irradiated fissile material. Safety is ensured by the consignment limit being a small fraction of the critical mass (15 g of fissile nuclides according to Paragraph 570(d)).

The limit of 2.0 g of fissile nuclides per package is more restrictive than the limits set out in Paragraph 417(e). Consequently, this exception is not anticipated to be relevant for low heat generating waste.

Figure 4: Classification as fissile-excepted according to Paragraph 417(d)




### 3.2.5 Paragraph 417(e)

Paragraph 417(e) provides criteria by which material including up to 45 g of fissile nuclides can be classified as fissile-excepted:

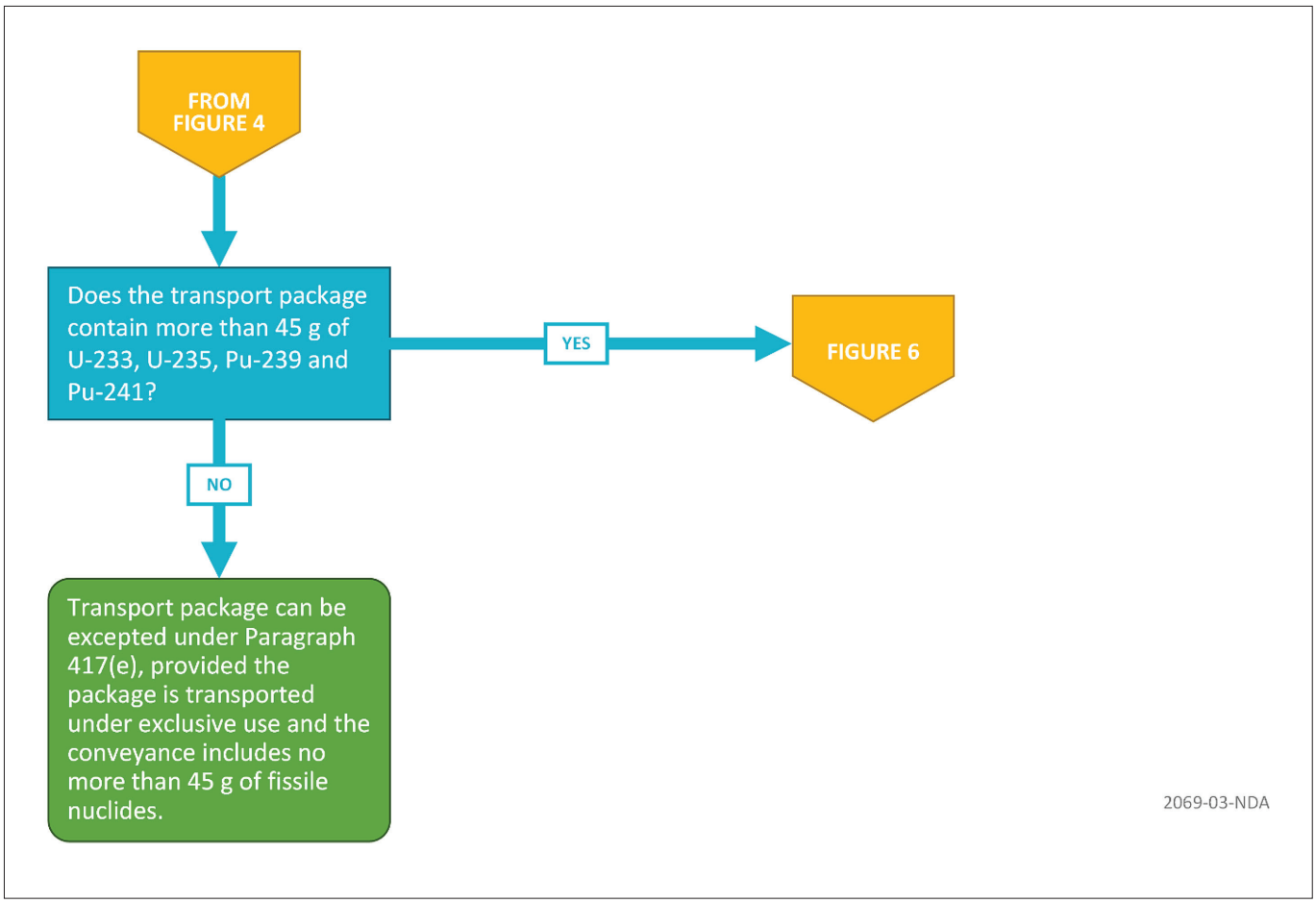
> *Fissile nuclides with a total mass not greater than 45 g, either packaged or unpackaged, subject to the limits provided in para. 570(e).*

This exception is concerned with the mass of fissile nuclides transported on a conveyance (i.e. a road vehicle, a rail wagon, or for transport by water, any vessel, hold, compartment or defined deck area). Under this exception, an accumulation of transport packages in a conveyance is permitted to contain a total of 45 g of fissile nuclides (Paragraph 570(e)). These fissile nuclides could be contained in a single package or distributed throughout a collection of packages. Safety is ensured by the conveyance limit being a fraction of the critical mass and through the requirement for the transport operation to be carried out under the conditions of 'exclusive use'[10] (according to Paragraph 570(e)). This exception may be applicable to a variety of waste packages containing small amounts of fissile nuclides, as shown in **Figure 5**.

Of the exceptions that make up Paragraph 417, this is the most useful when applied to the transport of ILW in shielded waste packages, even though the waste packages would have to be transported under the conditions of exclusive use.

[10] *Paragraph 221 defines exclusive use as '…the sole use, by a single consignor, of a conveyance or of a large freight container, in respect of which all initial, intermediate and final loading and unloading is carried out in accordance with the directions of the consignor or consignee'. If all of these provisions do not apply to a transport operation it is deemed to take place under the conditions of 'non-exclusive use'. The controls on several aspects of transport package performance (e.g. external dose rate, surface temperature, quantities of fissile material) are less onerous if transport takes place under the more restrictive operational conditions of exclusive use.*

Figure 5: Classification as fissile-excepted according to Paragraph 417(e)




### 3.2.6 Paragraph 417(f)

The fissile exception in Paragraph 417(f) requires that the fissile material is subcritical without the need for accumulation control, being defined as:

> *A fissile material that meets the requirements of paras. 570(b), 606 and 802.*

The steps in the application of this exception are shown in the flowchart in Figure 6. The provision permits applicants to request competent authority approval for specified fissile material to be excepted from classification as 'fissile' (Paragraph 802). Consistent with Paragraph 606, the applicant will need to ensure that the specified fissile material is (or will be) appropriately characterised and a safety case must be prepared with a detailed justification that the material will remain subcritical under normal and accident conditions of transport and for water in-leakage resulting in maximum neutron multiplication without the need for accumulation control of the material. Paragraph 606 is applicable under the conditions of Paragraph 673(a), the provisions of Paragraphs 685(a) and 685(b), and the conditions of Paragraph 683(a) (if transported by air).

Examples of cases that could be deemed appropriate would be those where $k_{\infty}$[11] of the material is adequately subcritical or the mass/volume of material required to cause a criticality hazard is too large to be of practical concern. Subject to competent authority approval, an argument can be made that although $k_{\infty} > 1$ for the material, the quantity of material required to obtain an unsafe $k_{eff}$[11] could not conceivably occur during transport.

The Advisory Material provides an example of the exception defined by Paragraph 417(f), found within US regulations, which excepts low concentrations of solid fissile material mixed with solid non-fissile material provided there are at least:

- 2,000 g of non-fissile material for every 1 g of fissile nuclides; or
- 200 g of non-fissile material for every 1 g of fissile nuclides with a transport package limit of 15 g of fissile nuclides.

RWM has developed a criticality safety assessment to support a fissile exception application for material containing a low concentration of fissile nuclides [**17**], for which ONR approval is being sought. In this case:

- Fissile nuclides must be distributed throughout solid non-fissile material, such that the mass of fissile nuclides distributed within each 280 kg mass of contiguous[12] non-fissile material is less than 140 g for uranium-235 or 112g for plutonium or uranium-233[13]. For materials containing a mixture of fissile nuclides these limits may be applied as a mass weighted average.
- Lead, beryllium, zirconium, bismuth, magnesium and their compounds, graphite, hydrogenous material enriched in deuterium, combustible materials and leachable materials may be present in the material but must not be included in determining the mass of solid non-fissile material.
- Plutonium may be of any isotopic composition provided that the amount of plutonium-241 is less than that of plutonium-240.

According to Paragraph 570(b), only one approved fissile material is allowed per consignment, unless multiple materials are authorised in the certificate of approval.

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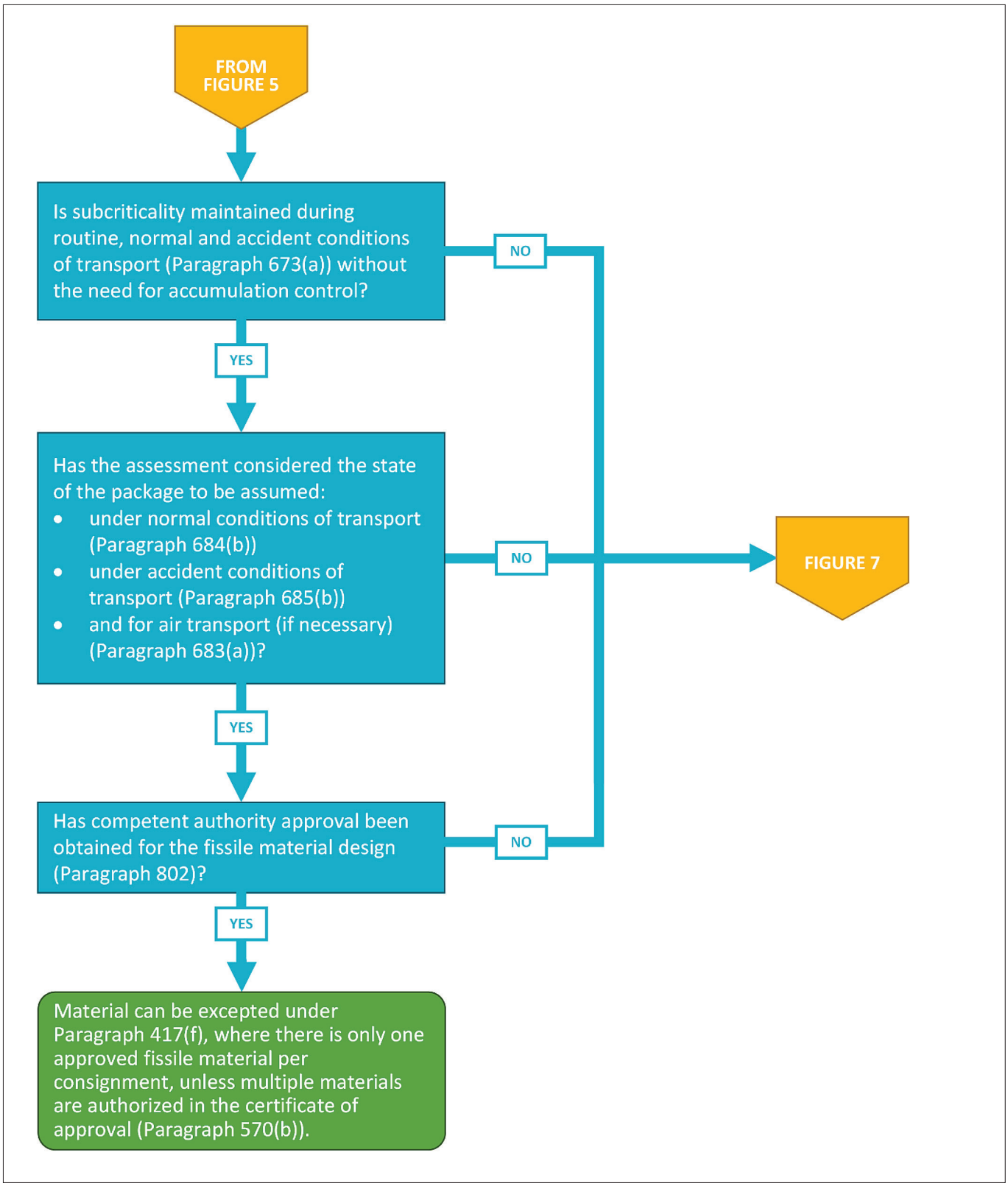
[11] *$k_{\infty}$ and $k_{eff}$ are 'neutron multiplication factors' and quantify the number of neutrons created by a fission that go on to cause further fissions. For a chain-reacting system, the value of the neutron multiplication factor must exceed unity. $k_{\infty}$ applies to an 'infinite' arrangement where no neutrons are 'lost' from the system whereas $k_{eff}$ applies to a real arrangement (i.e. a waste package) where neutrons can be lost from the system.*

[12] *Contiguous material means a continuous portion of material. Contiguous material is split into notional portions for assessment. The boundary of a notional portion must not be contrived to divide a localised concentration of fissile nuclides. If a notional portion has a non-fissile mass less than 280 kg, the fissile nuclide limit needs to be reduced in proportion to the reduction in non-fissile mass.*

[13] *These masses equate to non-fissile to fissile mass ratios of 2000:1 for uranium-235 and 2500:1 for plutonium or uranium-233. All plutonium nuclides are to be counted as fissile nuclides.*

Figure 6: Classification as fissile-excepted according to Paragraph 417(f)



## 3.3 Paragraphs 673-675: Requirements for packages that contain fissile material

Paragraph 674 defines the conditions under which limited quantities of fissile material may be transported using a package design not requiring competent authority approval to contain fissile material. The context for these conditions is presented in Paragraph 673, which is discussed first. Paragraph 675 is also discussed for completeness but is unlikely to be applicable to the transport of low heat generating waste.

### 3.3.1 Paragraph 673

Paragraph 673 sets out requirements for the transport of packages containing fissile material and refers to exception criteria in Paragraph 673(b):

*Fissile material shall be transported so as to:*

*(a) Maintain subcriticality during routine, normal and accident conditions of transport; in particular, the following contingencies shall be considered:*

*(i) Leakage of water into or out of packages;*

*(ii) Loss of efficiency of built-in neutron absorbers or moderators;*

*(iii) Rearrangement of the contents either within the package or as a result of loss from the package;*

*(iv) Reduction of spaces within or between packages;*

*(v) Packages becoming immersed in water or buried in snow;*

*(vi) Temperature changes.*

*(b) Meet the requirements:*

*(i) Of para. 636 except for unpackaged material when specifically allowed by para. 417(e);*

*(ii) Prescribed elsewhere in these Regulations that pertain to the radioactive properties of the material;*

*(iii) Of para. 637 unless the material is excepted by para. 417;*

*(iv) Of paras 676–686, unless the material is excepted by para. 417, 674 or 675.*

Paragraph 673(b)(iv) provides criteria by which packages containing fissile material may be excepted from the requirements specified in Paragraphs 676–686. Designs for packages containing material excepted by Paragraphs 417, 674 or 675 do not have to be approved by a competent authority to contain fissile material (Paragraph 802(a)(v)). The exception criteria of Paragraphs 674 and 675 are discussed below.

### 3.3.2 Paragraph 674

If the mass of fissile nuclides is limited to specified quantities, the package is self-certified to meet the performance criteria noted in **one of** sub-paragraphs 674(a)-(c), and the mass of certain neutron moderators that have low neutron-absorption cross-sections is limited to the quantities specified in sub-paragraph 674(d), then the package can be transported subject to Criticality Safety Index (CSI) accumulation control. The actual packaging to be used is not specified in the IAEA Transport Regulations.

Paragraph 674 is as follows:

*Packages containing fissile material that meets the requirements of para. 674(d) and one of the provisions of paras 674(a)–(c) are excepted from the requirements of paras 676–686.*

*(a) Packages containing fissile material in any form provided that:*

*(i) The smallest external dimension of the package is not less than 10 cm.*

*(ii) The CSI of the package is calculated using the following formula:*

*CSI = 50 × 5 × {[mass of U-235 in package (g)] / Z + [mass of other fissile nuclides[14] in package (g)] / 280}*

*where the values of Z are taken from* ***Table 13****.*

*(iii) The CSI of any package does not exceed 10.*

*(b) Packages containing fissile material in any form provided that:*

*(i) The smallest external dimension of the package is not less than 30 cm;*

*(ii) The package, after being subjected to the tests specified in paras 719–724:*

*— Retains its fissile material contents;*

*— Preserves the minimum overall outside dimensions of the package to at least 30 cm;*

*— Prevents the entry of a 10 cm cube.*

*(iii) The CSI of the package is calculated using the following formula:*

*CSI = 50 × 2 × {[mass of U-235 in package (g)] / Z + [mass of other fissile nuclides[14] in package (g)] / 280}*

*where the values of Z are taken from* ***Table 13****.*

*(iv) The CSI of any package does not exceed 10.*

*(c) Packages containing fissile material in any form provided that:*

*(i) The smallest external dimension of the package is not less than 10 cm;*

*(ii) The package, after being subjected to the tests specified in paras 719–724:*

*— Retains its fissile material contents;*

*— Preserves the minimum overall outside dimensions of the package to at least 10 cm;*

*— Prevents the entry of a 10 cm cube.*

*(iii) The CSI of the package is calculated using the following formula:*

*CSI = 50 × 2 × {[mass of U-235 in package (g)]/ 450 + [mass of other fissile nuclides[14] in package (g)] / 280}*

*(iv) The maximum mass of fissile nuclides[14] in any package does not exceed 15 g.*

*(d) The total mass of beryllium, hydrogenous material enriched in deuterium, graphite and other allotropic forms of carbon in an individual package shall not be greater than the mass of fissile nuclides in the package except where their total concentration does not exceed 1 g in any 1000 g of material. Beryllium incorporated in copper alloys up to 4% in* weight of the alloy does not need to be considered.

*[14] Plutonium may be of any isotopic composition provided that the amount of Pu-241 is less than that of Pu-240 in the package.*

Table 13: Values of Z for calculation of CSI in accordance with Paragraph 674

| *Enrichment* [a] | *Z* |
|---|---|
| *Uranium enriched up to 1.5%* | *2200* |
| *Uranium enriched up to 5%* | *850* |
| *Uranium enriched up to 10%* | *660* |
| *Uranium enriched up to 20%* | *580* |
| *Uranium enriched up to 100%* | *450* |
| [a] *If a package contains uranium with varying enrichments of U-235, then the value corresponding to the highest enrichment shall be used for Z.* | |

Paragraph 674(b) applies the most onerous package design performance requirements and provides the least restrictive fissile nuclide limits. Paragraph 674(a) applies more restrictive limits because it does not require the use of a package that will retain its contents under normal conditions of transport. Paragraph 674(c) covers situations when the minimum package dimension may be less than 30 cm under normal conditions. It is assumed in the specification for waste packages containing low heat generating waste [3, 4] that only Type B and Type IP transport packages will be used, although it is possible that Type A or Type IF transport packages could be used in certain circumstances. Each of these transport package types would retain their contents under normal conditions of transport. Additionally, all waste packages for low heat generating waste are anticipated to satisfy the 30 cm requirement for the smallest external dimension. Therefore, it is anticipated that all transport packages for low heat generating waste will meet the package design performance criteria for 674(b) and there is no need to consider Paragraphs 674(a) or (c).

Transport and storage of waste consignments of fissile transport packages are subject to CSI control. The IAEA Transport Regulations limit the CSI of any group of packages stored in transit, or under conditions of non-exclusive use[15] of a consignment or of the accumulation of packages in a conveyance to 50.

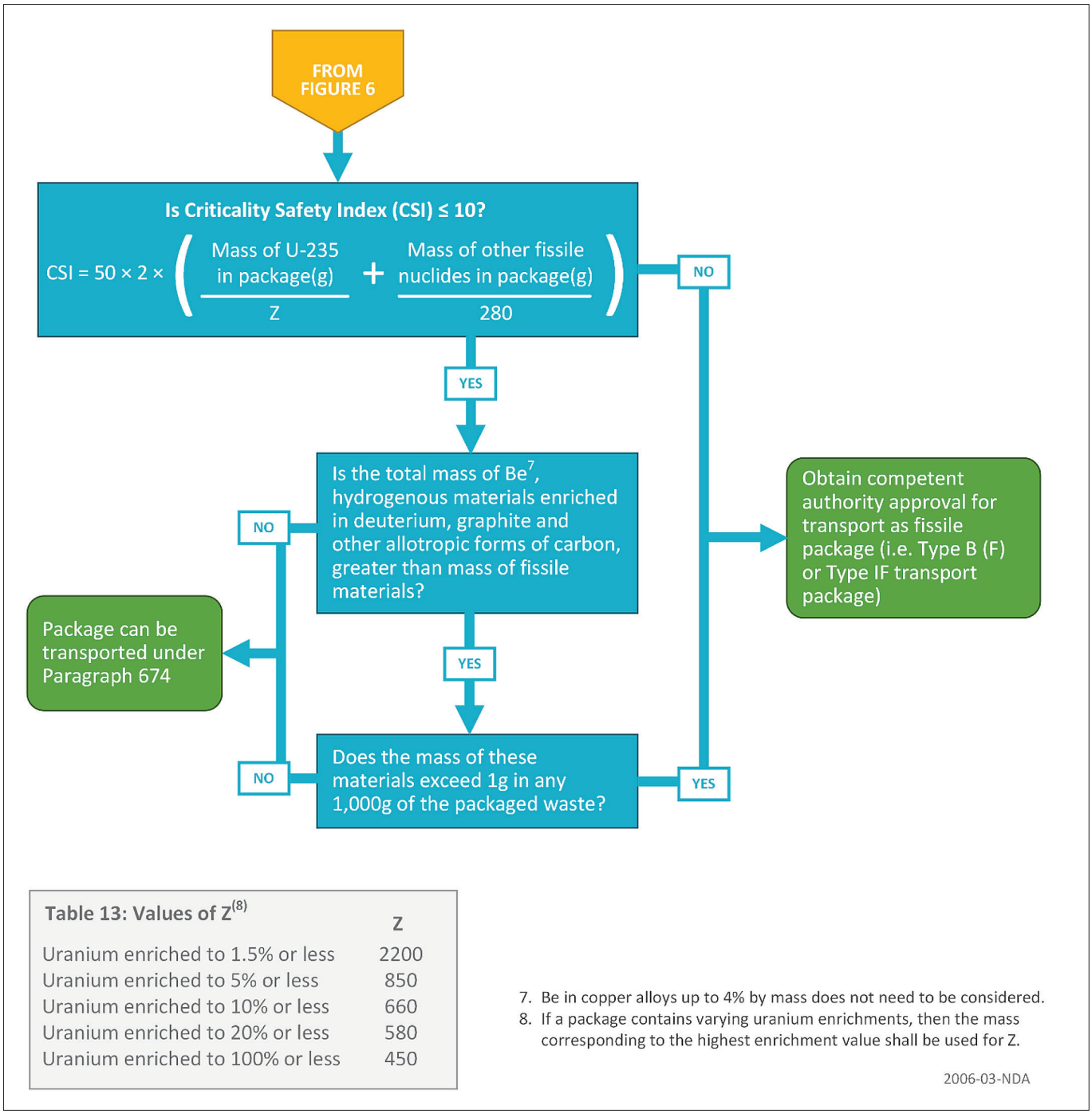
Figure 7 shows the circumstances where packages may be excepted from the requirement for competent authority approval to contain fissile material. This is limited to a consideration of Paragraph 674(b).

[15] *Under conditions of exclusive use, the IAEA Transport Regulations limit the CSI of the accumulation of transport packages in a conveyance to 100. However, multilateral approval of a shipment is required if the CSI of the accumulation of transport packages in a conveyance exceeds 50.*

In Figure 7, the first decision point is the level of enrichment of any uranium in the package. This will determine the value of Z to use (from Table 13 of the IAEA Transport Regulations as reproduced above). In order to meet the CSI condition of Paragraph 674(b), the U-235 mass of any package must not exceed values in the range 45-220 g depending on the level of enrichment (provided there are no other fissile nuclides are present). Where plutonium is present, any isotopic composition is accepted provided that the quantity of Pu-241 is less than that of Pu-240. In order to meet the CSI condition of Paragraph 674(b) the mass of other fissile nuclides in a package must not exceed 28 g (where U-235 is not present).

The presence of beryllium, deuterium, graphite and other allotropic forms of carbon must be controlled, as stated in Paragraph 674(d), because they are efficient neutron moderators.

**Figure7: Exception of a package containing fissile material from requiring competent authority approval according to Paragraph 674(b)**




| Table 13: Values of Z[8] | Z |
|---|---|
| Uranium enriched to 1.5% or less | 2200 |
| Uranium enriched to 5% or less | 850 |
| Uranium enriched to 10% or less | 660 |
| Uranium enriched to 20% or less | 580 |
| Uranium enriched to 100% or less | 450 |

7. Be in copper alloys up to 4% by mass does not need to be considered.
8. If a package contains varying uranium enrichments, then the mass corresponding to the highest enrichment value shall be used for Z.

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### 3.3.3 Paragraph 675

The exception according to Paragraph 675 is as follows:

Packages containing not more than 1000g of plutonium are excepted from the application of paras 676–686 provided that:

*(a) Not more than 20% of the plutonium by mass is fissile nuclides;*

*(b) The CSI of the package is calculated using the following formula:*

*CSI = 50 × 2 × [mass of plutonium (g) / 1000];*

*(c) If uranium is present with the plutonium, the mass of uranium shall be no more than 1% of the mass of the plutonium.*

This paragraph is not anticipated to be relevant for waste packages containing low heat generating waste as it requires an unusual plutonium isotope ratio. This paragraph is intended to enable the shipment of plutonium which predominantly comprises Pu-238 and which is used as a thermo-electric power source in a number of applications (e.g. heart pacemakers, spacecraft power sources) [15].

# 4. Identification of potential problems with the application of the IAEA Transport Regulations requirements for packages containing fissile material

The nature of UK low heat generating waste means that there will be some instances in which application of the exception criteria relating to criticality safety assessment in the IAEA Transport Regulations will present particular challenges to the waste packager, principally from a lack of 'scalability' in those requirements. Permitted fissile material masses or moderator masses are specified and apply to any size of package with external dimensions greater than 10 cm, or 30 cm in the case of Paragraph 674(b). Due to the large volume of waste (i.e. many cubic metres) that would be packaged in shielded waste packages some key characteristics of the waste, such as the concentration of fissile material or moderator, will vary widely. This can lead to some unintended consequences, such as the inability to except some innocuous wastes from the requirements for packages containing fissile material.

The risk is that problems in applying fissile exceptions could act as a disincentive to optimise waste management strategies such as waste volume minimisation and efficient use of waste packages. If following a fissile exception route results in additional packages being produced, this may not be the best option.

Whilst RWM can provide advice, it cannot relieve a waste packager of the requirement to work within the prevailing legal and regulatory framework whilst making responsible waste management decisions. In addition to the criticality safety arguments, the waste packager needs to consider the regulatory and financial risks associated with their waste packaging plans in the context of the current IAEA Transport Regulations, and a judgment of the likely regulatory climate at the reference date of 2040 for the opening of a GDF.

Ultimately however, if a transport package cannot comply with any of the requirements defined by the Paragraphs 222, 417 or 674, it will need to be transported as a suitably designed 'fissile' package (i.e. a Type B(U)F, B(M)F or IF), for which the necessary competent authority approvals will have to be obtained.

The following sub-sections consider particular issues that could arise if fissile exception is being considered when packaging low heat generating waste for transport to a GDF.

## 4.1 Fissile material in Magnox fuel debris and sludges

As discussed in Section 3.1, Paragraph 222 can be used to class most wastes containing uranium from Magnox power stations as 'non-fissile', the obvious exception being for those stations where slightly enriched fuel was used. However, waste packagers also need to consider whether any post-irradiation processing of the fuel may have increased the reactivity of fissile material in the waste over that assumed for 'irradiated natural uranium'. This can arise because the production of plutonium in Magnox fuel is greater at the surface than in the centre of the uranium and the plutonium concentration in the outer skin of the fuel can thus be significantly higher than the mean value for the whole of the fuel. Material from the surface layer of the fuel can, as a consequence, have greater reactivity than material from the bulk of the fuel. The surface layer material can have reactivity similar to that of low enriched uranium.

Accordingly, for wastes containing uranium predominantly derived from the surface of Magnox fuel elements, including shards of metal removed during mechanical processing of the fuel, or sludges containing the corroded outer layer of the fuel, Paragraph 222 might not apply and if fissile exception is to be sought, it may have to be by way of one of the other routes explained in Section 3.

## 4.2 Waste of mixed origin

In some facilities, notably those which have been used for the storage of fuel and fuel related materials for a long period, the potential for the mixing of fissile material in waste exists. This can result in a waste stream containing predominantly natural or low enriched uranium being mixed with small quantities of more highly enriched uranium. The presence of the latter would preclude exclusion under Paragraph 222. If Paragraph 674 were used the worst-case Z-factor from Table 13 of the IAEA Transport Regulations would have to be used.

## 4.3 Waste from non-thermal reactors

Material containing irradiated natural or depleted uranium from 'non-thermal' reactors (e.g. fast breeder reactors or fusion facilities) will always be considered as fissile material, and quantities must be assessed and demonstrated to establish compliance with the exception requirements for packages not requiring competent authority approval (Paragraph 674). This obligation is one that will be unnecessary for many wastes from thermal reactors. For non-thermal reactors, some construction materials will invariably contain trace quantities of natural thorium and uranium, and irradiation of this may need to be considered in terms of likely fissile content.

## 4.4 The presence of neutron moderators and reflectors

Paragraph 674(d) sets limits on the quantities of certain neutron moderators (i.e. beryllium, hydrogenous material enriched in deuterium, graphite and other allotropic forms of carbon) in individual transport packages in order that they can be excepted from the requirement for competent authority approval to contain fissile material.

Whilst these limits represent significant relaxations of the onerous restriction on the quantities of beryllium and deuterium in previous editions of the IAEA Transport Regulations, the inclusion of graphite in the list is a potentially significant restriction to the use of Paragraphs 674(a), (b) or (c).

## 4.5 Rail transport

For rail transport, the question arises as to whether a consignment will always be a single transport package (e.g. a single transport container holding up to four waste packages). Paragraphs 417(d) and (e) place different fissile nuclide limits on a consignment and on a conveyance.

Paragraph 217 defines a conveyance as:

> *(a) for transport by road or rail: any vehicle.*
>
> *(b) for transport by water: any vessel, or any hold, compartment, or defined deck area of a vessel.*
>
> *(c) for transport by air: any aircraft.*

Paragraph 248 states that:

> *vehicle shall mean a road vehicle (including an articulated vehicle, i.e. tractor and semi-trailer combination) or railroad car or railway wagon. Each trailer shall be considered as a separate vehicle.*

Thus, each railway wagon is a separate vehicle and therefore a separate conveyance. A consignment comprises the package or packages presented by the consignor for transport, which may be one or more conveyances. Each conveyance maybe a single transport package.

# 5. Summary

There may be benefits to waste consignors in excluding transport packages from the IAEA Transport Regulations for packages containing fissile material. This can be achieved, as summarised in **Figure 8**, by:

(i) defining packages as non-fissile under Paragraph 222;

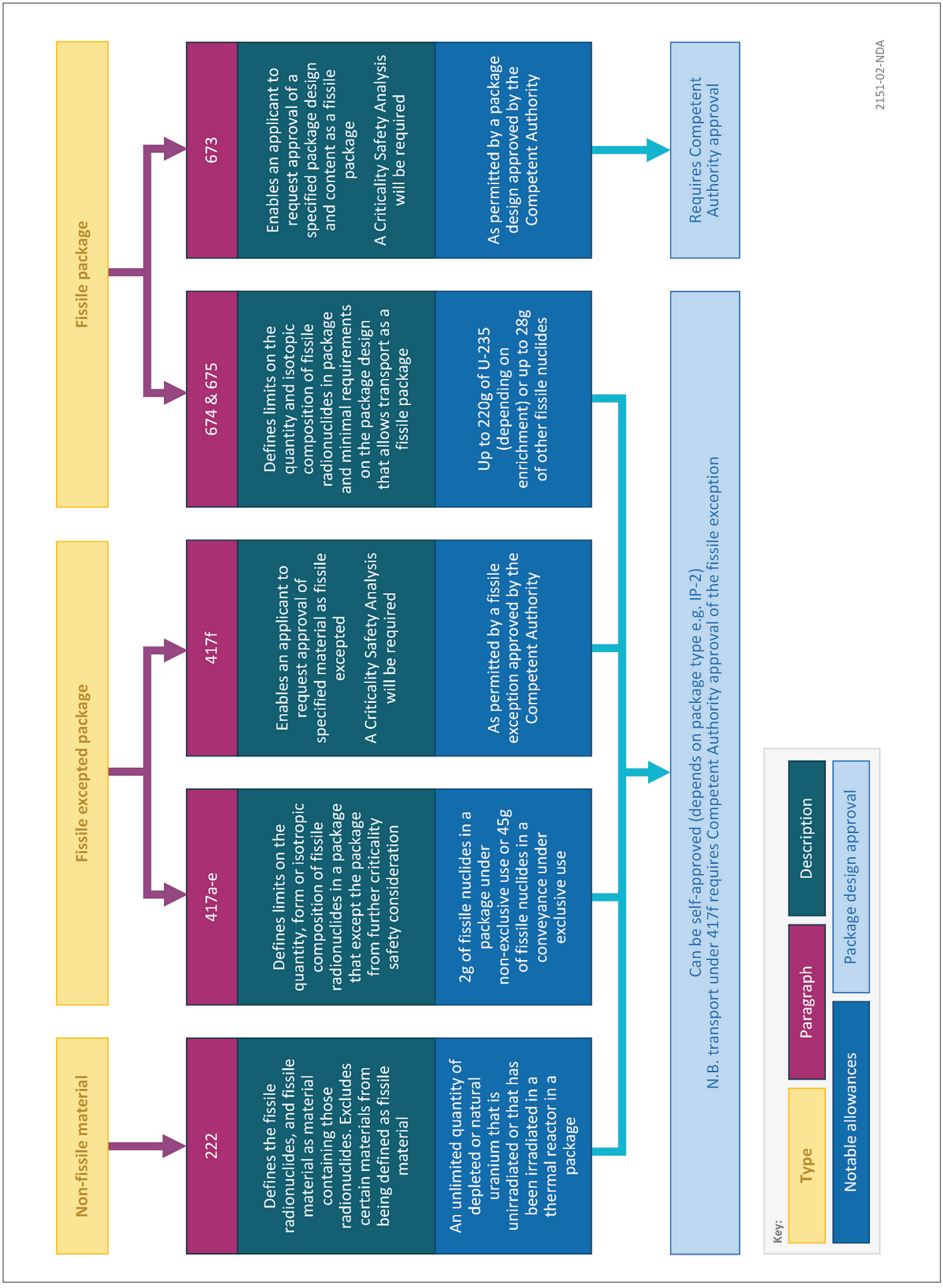
(ii) classifying packages as fissile-excepted under Paragraph 417; or

(iii) controlling the contents of the packages such that it can be transported without a requirement for competent authority approval to contain fissile material, under Paragraph 674.

This guidance provides the waste consignor with a means of assessing whether proposed waste packages can meet any of the above conditions. The IAEA guidance on application of the provisions of these paragraphs also includes a summary of mass limits associated with the application of each paragraph [**15**, Table 2].

Waste packagers and other organisations involved in the development of proposals to package low heat generating waste for geological disposal are encouraged to raise challenges that they have in applying the current criticality safety requirements to their proposed waste packages in order to obtain advice from RWM at an early stage in the development of packaging proposals and also to aid RWM in the identification of issues that may need to be addressed during future updates of the IAEA Transport Regulations.

Figure 8: Summary of the key paragraphs from the IAEA Transport Regulations pertaining to fissile material transport



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# Glossary of terms used in this document

**activity**
The number of atoms of a radioactive substance which decay by nuclear disintegration each second. The SI unit of activity is the Becquerel (Bq).

The IAEA Transport Regulations define a unit of activity, the $A_2$, as a means of standardising the dose consequences of different radionuclides on the basis of the different possible exposure pathways that could occur following the release of radionuclides from a transport package. $A_2$ values (in TBq) for a wide range of radionuclides are listed in Table 2 of the IAEA Transport Regulations [6].

**criticality**
A state in which a quantity of fissile material can maintain a self-sustaining neutron chain reaction. Criticality requires that a sufficiently large quantity of fissile material (a critical mass) be assembled into a geometry that can sustain a chain reaction; unless both of these requirements are met, no chain reaction can take place and the system is said to be sub-critical.

**criticality safety**
A methodology used to define the conditions required to ensure the continued sub-criticality of waste containing fissile material.

**disposability assessment**
The process by which proposals for the production of waste packages are analysed for compatibility with all stages of waste management. The outcome of a disposability assessment is an Assessment Report, detailing the results of the analysis and providing advice on the proposals. Where possible, the outcome includes endorsement by issue of a Letter of Compliance.

**disposal**
In the context of solid waste, disposal is the placement of waste in a suitable facility without intent to retrieve it at a later date. If retrieval is intended the appropriate term is storage, not disposal.

**Environment Agency (EA)**
The environmental regulator for England. The Agency's role is the enforcement of specified laws and regulations aimed at protecting the environment, in the context of sustainable development, predominantly by authorising and controlling radioactive discharges and waste disposal to air, water and land. The Environment Agency also regulates nuclear sites under the Environmental Permitting Regulations and issues consents for non-radioactive discharges.

**fissile material**
Material which is capable of undergoing fission by interaction with slow neutrons (i.e., neutrons of thermal energy), specifically material containing U-233, U-235, Pu-239, Pu-241 or any combination of these radionuclides.

**geological disposal**
A long term management option involving the emplacement of radioactive waste in an engineered underground facility, where the geology (rock structure) provides a barrier against the escape of radioactivity and there is no intention to retrieve the waste once the facility is closed.

**geological disposal facility (GDF)**
An engineered underground facility for the disposal of solid radioactive wastes.

**Industrial Package (Type-IP)**
A category of transport package, defined by the IAEA Transport Regulations for the transport of radioactive materials with low specific activities.

**intermediate level waste (ILW)**
Wastes exceeding the upper boundaries for LLW, but which do not need heat to be taken into account in the design of storage or disposal facilities.

**International Atomic Energy Agency (IAEA)**
The IAEA is the world's centre of cooperation in the nuclear field. It was set up as the world's "Atoms for Peace" organisation in 1957 within the United Nations family. The Agency works with its Member States and multiple partners worldwide to promote safe, secure and peaceful nuclear technologies.

**Letter of Compliance (LoC)**
A document, prepared by RWM, that indicates to a waste packager that a proposed waste package is compliant with the relevant packaging criteria and disposal safety assessments, and is therefore deemed to be compatible with the requirements for storage, transport, handling and disposal.

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

**Office for Nuclear Regulation (ONR)**
ONR is a Public Corporation. It maintains and improves safety standards for work with ionising radiation at licensed nuclear installations in the UK. It sets national regulatory standards and helps develop international nuclear safety standards. Through its licensing powers it assesses safety cases and inspects sites for licence compliance. ONR sets out in conditions attached to a nuclear site licence the general safety requirements to deal with the risks on a nuclear site.

**plutonium (Pu)**
A radioactive element occurring in very small quantities in uranium ores but mainly produced artificially, including for use in nuclear fuel, by neutron bombardment of uranium.

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

**transport package**
The complete assembly of the radioactive material and its outer packaging, as presented for transport.

**Transport Regulations**
The IAEA Regulations for the Safe Transport of Radioactive Material and/or those regulations as transposed into an EU Directive, and in turn into regulations that apply within the UK. The generic term 'Transport Regulations' can refer to any or all of these, since the essential wording is identical in all cases.

**transport system**
The transport system covers the transport modes, infrastructure, design and operations. It can be divided in two main areas: the transport of construction materials, spoil and personnel associated with building a GDF and the more specialised transport of the radioactive waste to a GDF by inland waterway, sea, rail and/or road.

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

**uranium (U)**
A heavy, naturally occurring and weakly radioactive element, commercially extracted from uranium ores. By nuclear fission (the nucleus splitting into two or more nuclei and releasing energy) it is used as a fuel in nuclear reactors to generate heat.

Uranium is often categorised by way of the proportion of the radionuclide uranium-235 it contains:

- natural uranium, with a uranium-235 content of 0.711% by weight;
- depleted uranium, with a uranium-235 content less than 0.711% by weight;
- low enriched uranium, with a uranium-235 content of between 0.711% and 20% by weight; and
- highly enriched uranium, with a uranium-235 content of greater than 20% by weight.

**waste container**
The vessel into which a wasteform manufactured from certain waste types (i.e. LHGW) is placed to form a waste package suitable for handling, transport, storage and disposal.

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

**waste package**
The product of conditioning that includes the wasteform and any container(s) and internal barriers (e.g. absorbing materials and liner), as prepared in accordance with requirements for handling, transport, storage and disposal.

**waste packager**
An organisation responsible for the packaging of radioactive waste in a form suitable for transport and disposal.


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