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DEVELOPMENT OF CONTENTS SPECIFICATIONS FOR THE TRANSPORT OF RADIOACTIVE WASTE

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ABSTRACT

As part of the process in the UK to assess the suitability of proposals for the packaging of intermediate level radioactive waste (ILW) for long-term storage and ultimate deep disposal, the proposals are compared with Waste Package Specifications and the underlying Phased Geological Repository Concept. However, as an integral part of this consideration must be given to the suitability of the proposed waste packages for transport in the public domain and, in order to do this. It is necessary to specify what can be transported through the public domain based on the requirements and limits defined in the IAEA Transport Regulations.

Radioactive waste arises in the UK from the operation and decommissioning of a wide range of facilities and hence there is significant variability in the waste. Furthermore, this means that it is not practicable to have a single waste container, but instead a range of waste containers have been developed to meet the different requirements for the various types of waste.

Consequently, it is necessary to establish contents specifications for each type of waste package and a methodology for comparing package waste inventories with these specifications at both the planning and operational stages.

This paper discusses the basis for such contents specifications, focussing on activity limits for individual radionuclides algorithms for mixture of radionuclides.

INTRODUCTION

In support of UK Government policy, the mission of the Nuclear Decommissioning Authority Radioactive Waste Management Directorate (NDA RWMD) is to develop and advise on safe, environmentally sound and publicly acceptable options for the long-term management of radioactive materials in the UK. The NDA RWMD Phased Geological Repository Concept has been developed for the long-term management of intermediate level (ILW) and certain low level (LLW) radioactive wastes. The concept is supported by safety assessments of transport to, and operations at, the repository.

One objective of this process is to allow the assessment of waste packaging proposals submitted by Waste Producers for compliance with NDA RWMD Waste Package Specifications, and the underlying Phased Geological Repository Concept. In order to do this it is necessary to specify what can be transported through the public domain based on the requirements and limits defined in the IAEA Transport Regulations [1].

Radioactive waste arises in the UK from the operation and decommissioning of a wide range of facilities, including manufacture of nuclear fuel, nuclear power stations, reprocessing of spent nuclear fuel and research and development programmes. Consequently, there is significant variability in the waste, with nearly six hundred different ILW waste streams with a wide range of parameters. NDA RWMD has specifications for a range of standard waste packages for the storage, transport and ultimate disposal of ILW and LLW.

It is necessary to define how much of each waste type can be shipped in these standard waste packages, ahead of construction of waste packaging facilities, in order to have confidence that the resultant waste packages are suitable for storage, transport and ultimate disposal. Consequently, it is necessary to establish contents specifications for each type of waste package and a methodology for comparing package waste inventories with these specifications at both the planning and operational stages, and the development of aspects of these contents specifications, together with their application, is discussed in this paper.

WASTE PACKAGE TYPES

In order to achieve a cost-effective approach to the packaging, storage and ultimate disposal of ILW in the UK, a limited number of standard waste packages have been determined. These fall into two categories:

- Shielded waste packages that include integral shielding and meet the relevant requirements of the IAEA Transport Regulations [1] in their own right;
- Unshielded waste packages that require to be transported in a transport container.

The standard shielded waste packages are the 4 metre Box and 2 metre Box, whilst the standard unshielded waste packages are the 500 litre drum, 3 m^3 box and 3 m^3 drum. Further details of these are given in [2].

TRANSPORT CONTAINERS

The NDA is developing reusable Standard Waste Transport Containers (SWTC) for the transport of the standard unshielded waste packages from UK waste producing sites on the public transport network to a future disposal facility or to long-term stores. The SWTC concept comprises a family of transport containers; all of the same basic conceptual design, but with detailed differences, mainly in having different shielding thicknesses, so that the waste packages carried in the SWTC can be transported with an appropriate shielding thickness. The SWTC-285 has the largest shielding thickness of 285 mm of steel shielding. The SWTCs are designed to carry four standard 500 litre drums in a transport stillage, one 3 m^3 Drum or one 3 m^3 Box. The combination of the SWTC and the contents is required to meet the regulatory requirements [1] for a Type B package.

There are three objectives in developing the SWTC designs:

- Ensuring the feasibility of the overall transport system for a future disposal facility in the UK;
- Enabling the design of a future disposal facility to interface with incoming transport packages;
- Providing advice to NDA's customers on the suitability of their waste packaging proposals for transport.

CONTENTS SPECIFICATION

The UK Competent Authority for radioactive materials transport, the Department for Transport (DfT), does not wish to receive a separate application for approval for the shipment in a SWTC for each of the wastestreams that could be transported in a SWTC. Instead, the strategy is to develop contents specifications for each type of waste package that would be transported within a SWTC and submit those as part of the applications for approval.

Prior to despatch, each consignor would be required to demonstrate under a quality management system that the specific waste packages to be shipped are in full compliance with the relevant contents specification.

However, significant volumes of radioactive waste are being packaged in the UK for long-term storage and ultimate disposal and it is therefore necessary that organisations involved in waste packaging have assurance that the resultant waste packages will be acceptable for future transport and ultimate disposal. NDA has a significant role in providing such assurance, as set out in joint guidance [3] from nuclear installation and environmental regulators in the UK.

Contents specifications have been developed for the transport of 500 litre drums, 3 m^3 Drum and 3 m^3 Box within a SWTC, together with a methodology for comparing package waste inventories with these specifications at both the planning and operational stages.

Radionuclide-specific limits are derived from consideration of the following:

- Heat generation limits;
- Permitted dose rates on the outside of the SWTC;
- Containment requirements;
- Pressurisation of the SWTC cavity;
- Prevention of criticality.

RELEVANT RADIONUCLIDES

From an analysis of the exiting and anticipated UK radioactive waste arisings [4], the NDA has identified that there are 112 radionuclides that are of potential significance for the long-term storage, transport and ultimate disposal of waste packages. Consequently, the contents specifications are based on consideration of each of these radionuclides. However, should a waste package be produced with a radionuclide that is of potential significance for transport, the methodology set out in the contents specifications can be applied to the specific radionuclide.

Their activities are to be specified at the time of shipment and the limits take account of all significant daughter radionuclides.

The A_2 values used for the majority of these radionuclides are those given in Table I of the IAEA Transport Regulations [1]. For other radionuclides, the general values listed in Table II of the IAEA Transport Regulations [1] are used. (Only A_2 values are considered, as the A_1 values are for special form material and the contents of the SWTC-285 will not be special form material.)

HEAT GENERATION LIMITS

The waste package heat generation limits are derived from the performance of the disposal facility into which it is anticipated they will be placed. These limits are determined to be 200 W per 3 m^3

Box or 3 m^3 Drum, and 50 W for a 500 litre drum [2]. Activity limits, A (TBq) for individual radionuclides are derived from these heat generation limits by using the following methodology.

$$A = \frac{\text{specific activity of the radionuclide (TBq/g)} \times \text{heat generation limit (W)}}{\text{isotopic power } (\alpha + \beta + \gamma)\ (W/g)}$$

Having established the activity limit in units of TBq, these are converted to numbers of A_2 by dividing the limit in TBq by the appropriate A_2 value in TBq. in Table I of the IAEA Transport Regulations [1]. The A_2 values used for the majority of radionuclides are those given in Table I of the IAEA Transport Regulations [1], but for other radionuclides, the general values listed in Table II of [1]. (Only A_2 values are considered, as the A_1 values are for special form material and the contents of the SWTC-285 are not special form material). Examples of the results from this are shown in the following table.

Radionuclide	Heat Generation Activity Limits (per 500 litre drum)		Heat Generation Activity Limits (per 3 m^3 Box or 3 m^3 Drum)	
	TBq/drum	A_2/drum	TBq/box or drum	A_2/box or drum
Co 60	1.20E+02	3.00E+02	4.80E+02	1.20E+03
Cs 134	1.82E+02	2.60E+02	7.28E+02	1.04E+03
Cs 135	5.60E+03	5.60E+03	2.24E+04	2.24E+04
Cs 137	4.70E+02	7.83E+02	1.88E+03	3.13E+03

SWTC DOSE RATES

There are two sets of criteria which apply to the dose rates on the outside of the SWTC-285, depending upon whether the SWTC-285 is being transported under exclusive use or non-exclusive use, as defined in the IAEA Transport Regulations [1]. For planning purposes, the non-exclusive use limits are used, as this effectively provides a target to work to in the context of ensuring dose uptake is as low as reasonably practicable, whilst recognising that for some waste streams, it may be appropriate to work to the higher limits permitted under exclusive use.

Under non-exclusive use, the maximum permitted dose rates are:

- The dose rate on the surface of the package is not to exceed 2 mSv/hr as specified in Paragraph 531 of the IAEA Transport Regulations [1];
- The dose rate at 1 m from the surface of the package is not to exceed 0.1 mSv/hr.

The value of 0.1 mSv/h is derived from the Transport Index (TI) value of 10 (Table VII [1]) which is applicable to the package, with the TI determined by multiplying the dose rate at 1m from the package by a factor of 100 (Paragraph 526 (a) [1]).

Not all of the 112 radionuclides will give rise to significant dose rates outside the SWTC-285, irrespective of the inventory contained in the drums. These are:

- Nuclides that are purely alpha or beta emitters;
- Nuclides with short half-lives, which will have effectively decayed to very low levels prior to transport;
- Nuclides that have only very low energy gamma emissions and therefore the gamma rays will not penetrate the walls of the SWTC-285.

It is unnecessary to carry out explicit shielding calculations for those radionuclides that fall into one or more of the above categories. Hence, any radionuclides that fell into the above categories were screened from detailed consideration.

For the remaining radionuclides, Microshield was initially used to calculate dose rates for the SWTC-285 containing four 500 litre drums. Dose rates were evaluated at several points around the transport container to evaluate the worst-case dose rates.

It was assumed that the contents of each drum were encapsulated in concrete and that the density of the encapsulated waste was 2300 kg m^{-3}. The calculations are based on the SWTC-285 providing 285 mm of steel shielding between the waste packages and the outside surface of the SWTC-285. Dose rates were calculated above and to the side of the SWTC-285 to determine which dose points gave the highest dose rate for each of the criteria for transport. Two sets of dose points were chosen for each surface of the SWTC-285, one directly adjacent to a drum and one at the centre point of the surface. For each dose point, the doses were calculated at the surface and at 1 m from the surface. Having carried out the analysis for the 500 litre drums, this approach was repeated for the 3 m^3 Box and 3 m^3 Drum, with examples of the results shown in the following table.

Radionuclide	**Dose Rate Activity Limits for Non-Exclusive Use Transport**					
	TBq/500 litre drum	**A_2/500 litre drum**	**TBq/3 m^3 Box**	**A_2/3m^3 Box**	**TBq/3 m^3 Drum**	**A_2/3m^3 Drum**
Co 60	5.00E+01	1.25E+02	1.42E+02	3.55E+02	1.16E+02	2.91E+02
Cs 134	3.29E+02	4.69E+02	2.62E+03	3.75E+03	2.13E+03	3.05E+03
Cs 135	1.00E+05	1.00E+05	1.00E+05	1.00E+05	1.00E+05	1.00E+05
Cs 137	1.30E+04	2.17E+04	3.24E+04	5.41E+04	2.60E+04	4.33E+04

CONTAINMENT REQUIREMENTS

Overview

The two key containment criteria to be met are taken from the IAEA Transport Regulations [1].

- During normal conditions of transport (NCT), the loss of radioactive contents is to be restricted to no more than 10^{-6} A_2 per hour;
- The loss of radioactive contents in one week as a result of accident conditions of transport (ACT) is to be no greater than 10 A_2 for Kr-85 and A_2 for all other radionuclides.

Limits on drum contents activity and gas generation rates are derived by firstly determining what the maximum gas leakage rate from the SWTC-285 is and then modelling the performance of solids and gases within the cavity.

The sealing arrangements on the SWTC-285 comprise sets of double O-ring seals that are located in the lid and purge/vent valve and are compressed as the seal carrier is secured in place, e.g. when the lid is bolted to the body. The maximum SWTC-285 leakage rates have been determined to be 10^{-3} bar cm^3/s SLR for normal conditions of transport (NCT) and 10^{-2} bar cm^3/s SLR for accident conditions of transport (ACT), based on a test programme.

Normal Conditions of Transport

The behaviour of radioactive particulates within the SWTC cavity during transport has been assessed and it is concluded that under NCT the only activity available for release from the SWTC will be any contamination present on the outside of the waste packages. The gas flow within the container is never great enough to remove active material from the drum surface and the inertial forces generated in the container during transport will not be large enough to re-suspend material.

Therefore there will be no release of particulate material from the SWTC during NCT and the activity that may be present within the waste packages is unlimited.

Limits on the permissible gas concentration within the SWTC cavity are calculated for NCT based on the SWTC leakage rate and the containment criterion of 10^{-6} A_2/hr. The cavity limit for NCT is then used to determine a gas generation rate limit based upon the maximum shipment period for the SWTC. For a shipment period of 28 days, the maximum permitted gaseous release rate from a single 500 litre drum is determined to be 0.16 A_2/year.

Tritium is dealt with separately because of the higher permeation of tritium through the seals compared with other gases, but the same methodology as for other gases is followed. This approach gives maximum permitted tritium release rate from a single 500 litre drum of 0.038 A_2/year.

Accident Conditions of Transport

Significant research programmes have been carried out to establish the release fractions (RFs) from waste packages under impact and fire accidents. This information also includes RFs for different particulate size ranges for impact accidents and RFs for a number of groups of radionuclides, with each group having similar physical properties.

It is assumed that the leakage rate quoted above represents a single capillary that bypasses the seal and that particulate material in the SWTC cavity that is smaller than the calculated capillary diameter has the potential to be released from the cavity under the driving pressure of the cavity. This release through the leak path is assumed to be a homogenous mixture of package contents. As time proceeds, the particles form and grow by Brownian agglomeration, with the larger particles settling under gravity and the rate of loss of material through the leak path therefore tends to diminish. This can be modelled to determine the relationship between the material in the SWTC cavity and the release from the SWTC.

When this is combined with the information on RFs from the waste packages and the permitted release from the SWTC, limits on the waste package contents can be determined. Examples of such limits are as follows:

- The maximum permitted activity in a 500 litre drum based on the impact accident is 1.67×10^7 A_2;
- The maximum permitted activity in a 500 litre drum based on the thermal accident is 20.2 A_2 for a radionuclide that is reasonably volatile and could be released as a vapour.

Radionuclides that would be released as a gas following the thermal accident would have a higher RF than those that are reasonably volatile and the maximum permitted activity for these radionuclides is 5.06 A_2 for a single 500 litre drum. Permeation needs to be considered for tritium and the limit for tritium is 1.58 A_2 for a single 500 litre drum.

PRESSURISATION OF THE SWTC CAVITY

The SWTC cavity pressure must not exceed the maximum normal operating pressure (MNOP) of 7 bar g that is set for the SWTC-285, which is in line with Para 662 of the IAEA Transport Regulations [1]. The cavity pressure can increase as a result of:

- Rising cavity gas temperature caused by an increase in ambient temperature and the heat generated by the waste package(s);
- Gas generation from the waste package(s), whether the gas is radioactive or not.

The increase in cavity gas temperature is pessimistically taken as going from the SWTC minimum design operating temperature up to the calculated maximum waste package temperature during NCT. It is also assumed that there is no leakage from the SWTC during the maximum shipment period. From this, the increase in cavity pressure, ΔP_c, can be determined and the allowable increase in cavity pressure from gas generation, ΔP_g, is therefore given by $\Delta P_g = 7 - \Delta P_c$.

From this, the number of moles of gas required to cause this cavity pressure increase can be determined, and combining this with the maximum shipment period leads to the maximum gas generation rate. For a single 500 litre drum, the limiting value is 26.2 m^3/year.

PREVENTION OF CRITICALITY

The contents of most waste packages to be transported within an SWTC-285 are such that the resultant transport package would be fissile excepted.

However, for those waste packages where this is not the case, a number of bounding cases providing limits for fissile and moderating material for waste packages in the SWTC-285 have been developed. The consignor will have to either show compliance with one of these bounding cases or demonstrate criticality safety specifically for that waste package.

ACCEPTABILITY OF A WASTE PACKAGE FOR TRANSPORT IN AN SWTC-285

The SWTC-285 activity limit for a specific radionuclide will be whichever of the package limits based on heat generation, dose rate or containment is the most restrictive.

Similarly, the SWTC-285 gas generation rate limit for a specific gas will be whichever of the gas generation rate limits based on containment or pressure is the most restrictive.

The package activity limit for a mixture of radionuclides or the gas generation rate limit for a mixture of different gases being generated is expressed as a sum of the respective fractions of the package limit or gas generation rate limit for each radionuclide or gas in the mixture, where the limit for each relevant specific criterion (shielding, heat generation, containment and pressure) is:

$\Sigma_i (AC_i/P_{Ci}) < 1$ (summed over all radionuclides in the contents to be transported or over all gases being generated)

where AC_i = actual activity or gas generation rate of the i^{th} radionuclide in the contents to be transported (as determined at the time of shipment), or actual generation rate of the i^{th} gas being generated.

P_{Ci} = package activity limit or gas generation rate P for a specific criterion C, for the i^{th} radionuclide or i^{th} gas.

The steps to be undertaken to determine whether a 3 m^3 Box waste package complies with the contents specification limits are set out in diagrammatic form in Figure 1. A similar approach would be followed for a 3 m^3 Drum or four 500 litre drums in a transport stillage are being transported in the SWTC.

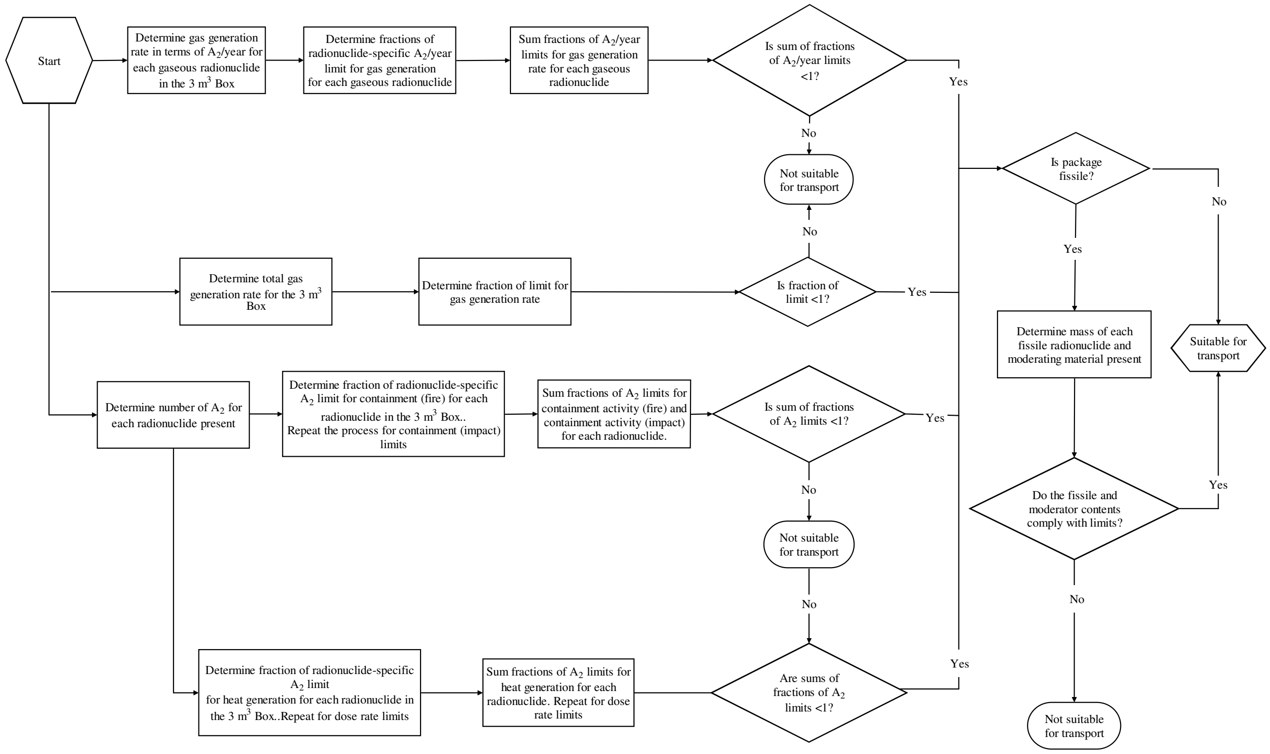

Figure 1: Decision Flow Diagram to Assess Compliance with Waste Package Contents Specification

CONCLUSIONS

Contents specifications have been developed for the standard UK unshielded waste packages that require to be transported in a transport container, namely the 500 litre drum, 3 m^3 box and 3 m^3 drum. These contents specifications are based on factors that are directly related to compliance with the IAEA Transport Regulations when these waste packages are transported in an SWTC and include activity limits for a large number of radionuclides that could be present in the waste packages. Included within the contents specifications are algorithms for mixture of radionuclides and these can be used to determine the suitability of a waste package for transport at any time, ranging from the planning stage for the waste package through to pre-despatch checks.

REFERENCES

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