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Geological Disposal

Radioactive wastes and assessment of the disposability of waste packages

December 2010

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Abstract

Geological disposal is the UK Government's policy for the higher activity radioactive wastes. As part of the process for the implementation of the geological disposal option we have developed the Disposal System Safety Case (DSSC) the prime purpose of which is to allow us to demonstrate that geological disposal can be implemented in a safe manner and in such a way that would meet all applicable regulatory requirements.

In this report, one of a series of supporting reports that form part of our generic DSSC, we provide background material on the range of higher activity radioactive wastes and materials that may come forward for geological disposal and describe the assessment process that we use to assess disposability (including transportability) of these materials.

An important input to the DSSC is the definition of the nature and quantity of wastes and materials that could be destined for geological disposal. By drawing upon published information regarding existing stocks and anticipated future arisings of such materials and together with its detailed understanding of these materials, the Radioactive Waste Management Directorate of the NDA collates the necessary information in the form of a consistent data set which is published as part of the DSSC. This report provides background information on the higher activity wastes and materials, describes the process by which information on the nature and quantity of wastes and materials is generated, how the assessment inventory is reviewed and assembled and how this information is used within the DSSC.

The report also describes the disposability assessment process that is routinely used to assist the holders of radioactive wastes in treating and conditioning these materials into a form that is compatible with plans for eventual transport and disposal. This is an important process within the UK as it facilitates early conditioning of wastes reducing hazard, whilst giving confidence regarding its management in the long-term. In cases where proposed waste packages are determined to be compliant with geological disposal this can be signified by the issue of a Letter of Compliance. The Letter of Compliance disposability assessment process is in turn an important confidence building mechanism for the DSSC as we describe further in this report

Executive summary

The UK has accumulated a legacy of higher activity radioactive waste from electricity generation, defence activities and other industrial, medical, agricultural and research activities. The Government has undertaken a wide-ranging consultation on the best means of dealing with these wastes and has concluded that geological disposal, preceded by safe and secure interim storage, is the way forward for their long-term management. The *Managing Radioactive Waste Safely* (MRWS) White Paper explains the Government's envisaged way forward for implementing a geological disposal facility (GDF) in the UK.

We, the Nuclear Decommissioning Authority (NDA), have been charged with implementing Government policy for the long-term management of higher activity radioactive waste by planning, building and operating a GDF.

A GDF is an engineered facility for the disposal of radioactive waste. It is likely to be located at a depth of between 200m and 1,000m below ground, in a stable geology that provides long-term isolation of the wastes from the human environment.

The wastes for disposal in a GDF include high level waste (HLW), intermediate level waste (ILW), and low level waste (LLW) unsuitable for near-surface disposal. There are also other nuclear materials that have not been declared as wastes by the Government (because they are still considered to be of potential use), but which might be the subject of geological disposal in the future, namely spent nuclear fuel, separated plutonium and uranium.

By drawing on UK and overseas experience we have developed illustrative geological disposal concept examples that are relevant to the UK context, inventory and available geological environments. These illustrative examples are all based on the principle of passive safety provided by a combination of engineered barriers designed to complement the natural barrier provided by the geological environment. The system of multiple barriers will ensure that the radioactivity in the wastes is sufficiently contained so that regulatory requirements are met and that exposures resulting from any releases to the surface to be as low as reasonably achievable and, in any event, less than a small fraction of the exposures everyone receives each year from naturally occurring sources of radioactivity in the environment.

The implementation of a GDF for higher activity radioactive wastes requires us to demonstrate our confidence that such a facility would be safe, during both the operational period and after it has been sealed and closed. As part of that process we have developed the Disposal System Safety Case (DSSC) the prime purpose of which is to demonstrate that a GDF can be implemented in a safe manner and in such a way that would meet all regulatory requirements.

This report has been produced as part of the suite of documents that make up the DSSC its purpose being to provide background information regarding the radioactive wastes (including those radioactive materials which may in the future be considered as such) that are assumed to be destined for geological disposal in the UK. It also contains a description of the methods by which we ensure that packaged radioactive waste has the characteristics necessary for safe transport to and disposal in a GDF, and that is compliant with the assumptions made in the DSSC.

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List of acronyms

ALARP	as low as reasonably practicable
BSL	Basic Safety Level
BSO	Basic Safety Objective
CoRWM	Committee on Radioactive Waste Management
DfT	Department for Transport
DNLEU	depleted, natural and low enriched uranium
DSSC	Disposal System Safety Case
EA	Environment Agency
ESC	Environmental Safety Case
GDF	geological disposal facility
GWPS	Generic Waste Package Specification
HEU	highly enriched uranium
HLW	high level waste
HSE	Health and Safety Executive
IAEA	International Atomic Energy Agency
ILW	intermediate level waste
LLW	low level waste
LoC	Letter of Compliance
LSA	low specific activity (material)
MRWS	Managing Radioactive Waste Safely
NDA	Nuclear Decommissioning Authority
OSC	Operational Safety Case
PCSA	Post-closure Safety Assessment
PDSR	Package Design Safety Report
RWMC	radioactive waste management case
RWMD	Radioactive Waste Management Directorate
SAPs	Safety Assessment Principles
SCO	surface contaminated object
SLC	Site Licence Company
TSC	Transport Safety Case
TSSA	Transport System Safety Assessment
UKRWI	United Kingdom Radioactive Waste Inventory
WAC	waste acceptance criteria
WPrS	waste product specification

1 Introduction

In 2001 the UK Government initiated the *Managing Radioactive Waste Safely* (MRWS) programme with the aim of finding a practicable solution for the long-term management of the UK's higher activity radioactive wastes. Underpinning this aim was a need to achieve long-term protection of people and the environment in an open and transparent way that was based on sound science and that made effective use of public monies.

In October 2006, the UK Government accepted the recommendations from the *Committee on Radioactive Waste Management* (CoRWM) [1] that geological disposal, preceded by a period of safe and secure interim storage, was the best available approach for the long-term management of higher activity radioactive wastes.

In June 2008, in response to CoRWM's recommendations, and following further consultation, the UK Government in conjunction with the devolved administrations for Wales and Northern Ireland, published the MRWS White Paper [2] setting out the UK Government's framework for managing higher activity radioactive waste in the long-term through geological disposal.

The White Paper outlines an approach to geological disposal site selection based on voluntarism and partnership and with us, the Radioactive Waste Management Directorate (RWMD) of the NDA, as the body ultimately responsible for the planning and implementation of a geological disposal facility (GDF). This is anticipated to be by way of an open and transparent approach which enables the public and stakeholders to be involved throughout.

As part of the process for the implementation of the geological disposal option we have developed the generic Disposal System Safety Case (DSSC) [3]. The prime purpose of the DSSC is to allow us to assess the risks associated with geological disposal and to demonstrate that a GDF can be implemented in a safe manner and in such a way that would meet all applicable regulatory requirements.

This report has been produced as part of the suite of documents that make up the DSSC and provides background information regarding the radioactive wastes (including those radioactive materials which may in the future be considered as such) that are assumed to be destined for geological disposal in the UK. It also contains a description of the methods by which we ensure that packaged radioactive waste has the characteristics necessary for safe transport to and disposal in a GDF, and that is compliant with the assumptions made in the safety cases that make up the DSSC.

2 Background

2.1 The Disposal System Specification

We have developed the Disposal System Specification (DSS) to provide a unified reference point to set out a clear definition of the requirements on the disposal system. It forms an important input to the development of cost-effective engineering designs and assessment of their fitness for purpose.

It is not the purpose of the DSS to specify or describe the processes[1] that should be undertaken to develop the disposal system these are covered in other documents such as the RWMD Safety and Environmental Management Prospectus (SEMP) [4]. The SEMP describes the management arrangements we have implemented for safety and environmental protection and identifies the need for a DSS.

The DSS comprises two documents:

- the Disposal System Functional Specification (DSFS) [5], the purpose of the DSFS is to identify and document the overall goals, objectives and constraints of the disposal system. It describes the high-level requirements for the disposal system and is in a form suitable for a wide range of stakeholders. The DSFS is subject to approval of the RWMD Board, as will be subsequent changes to the document;
- the Disposal System Technical Specification (DSTS) [6], underpins the DSFS and develops this high-level specification by describing in more detail the requirements and constraints on the disposal system, together with a justification for each requirement. The DSTS is a starting point for the development of a GDF design and its transport system. It defines the scope and bounds of the engineering design work and provides the designers of the disposal system with the requirements that must be satisfied.

A disposal system design is developed to meet these specifications and subject to assessment of its safety and environmental performance. The output of this iterative process is then used to identify the R&D needed, improve the design and refine the disposal system requirements.

2.2 The Disposal System Safety Case

The disposal system will be underpinned by a suite of safety cases brought together and integrated through the DSSC, which will demonstrate that the disposal system adequately meets safety and environmental goals and performance criteria, and is supported by appropriate scientific and technical information and data.

There will be a number of important steps in the development of a GDF which will take place over an extended period of time which is anticipated to run into many decades. These include:

- site selection and characterisation;
- construction of the disposal facility;

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[1] For example, the design process for a GDF will follow a flexible, step-by-step design and development process, including periodic peer review and other independent substantiation of design decisions. The design process should be integrated with site characterisation and safety case development.

- operation
- sealing and closing the facility; and
- eventual withdrawal of control of the site.

At each step we will use the DSSC and supporting safety cases to produce a tailored safety case submission to support the regulatory licence instrument or authorisation and allow us to proceed to the next stage of developing the disposal facility.

In the DSSC we consider the safety of all aspects of the long-term management of radioactive waste following its preparation for disposal at the site of its arising. This includes:

- the transport of the packaged waste from the site of arising to a GDF;
- the construction, operation, decommissioning and closure of the disposal facility; and
- the safety of the disposal facility in the very long term, after it has been sealed and closed.

In Section 4 we provide a brief overview of the three safety cases (i.e. for transport and the GDF operational and post-closure periods), particularly from the perspective of how they are affected by the characteristics of wastes and waste packages. In the case of the Operational Safety Case (OSC), which includes assessments of safety during both GDF construction and active operations, only the latter will be considered in this document.

3 Nature and quantities of radioactive wastes and other materials which may be destined for geological disposal

3.1 The nature of radioactive materials

The MRWS White Paper [2] defines radioactive material as ‘Material designated in national law or by a regulatory body as being subject to regulatory control because of its radioactivity’. The same document defines radioactive waste as ‘Any material contaminated by or incorporating radioactivity above certain thresholds defined in legislation, and for which no further use is envisaged’.

Radioactive materials are characterised by the spontaneous emission of ‘radiation’ or energy in the form of either particles (alpha-particles, beta-particles or neutrons) or electromagnetic radiation (gamma radiation or, in rare cases, X-rays). The emission of radiation by a radioactive source is usually at a steady but declining rate[2] , the rate of decline being characterised by the ‘half-life’ of the radionuclides producing the radiation. The value of the half life of a particular radionuclide is fixed and can vary from fractions of a second to many billions of years.

The radioactive materials that are present in wastes that are expected to be the subject of geological disposal arise from three main sources:

- Natural radioactive materials (e.g. uranium and thorium) that have been mined, extracted and concentrated for use in the nuclear industry;
- Fission products produced as a result of the fission of uranium and plutonium in nuclear reactors; and
- Activation products produced as a result of the neutron irradiation of non-radioactive materials in nuclear reactors.

3.2 Risks posed by radioactive materials

All radiation has the potential to damage matter, including living cells which can suffer damage to their genetic material which can in turn lead to cell mutation.

Humans can be exposed to radiation by two different mechanisms:

- External exposure; where a remote radioactive source (or one in contact with the skin) can cause radiation to pass through the skin and into the cells of the body; or
- Internal exposure; where radioactive material which has been ingested (e.g. by the inhalation of radioactive materials present in air or the consumption of foodstuffs contaminated with radioactive material) and which can result in the direct exposure of cells to radiation.

The type and degree of exposure will depend on a number of factors including the nature of the radiation and the form of the radioactive material. For example, alpha-radiation cannot cause significant external exposure as it has insufficient energy to allow it penetrate human skin, although if ingested it can cause significant internal exposure. Also, internal exposure would normally only result from the ingestion of radioactive material in liquid, gaseous or finely divided particulate form.

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[2] One exception to this behaviour is known as ‘in-growth’ which occurs when a parent radionuclide decays to form a daughter radionuclide which has a higher activity. A notable example of this is the case of plutonium-241 which decays to form americium-241.

Radioactive materials emit radiation spontaneously and, whilst the rate of emission cannot be controlled, the exposure of humans to this radiation, and the consequential risk to health, can be controlled by one or more of the following basic approaches:

- by limiting the time that a person is exposed to radiation;
- by increasing the physical separation between the person and a source of radiation. The further away a person is from a source of radiation, the smaller will be the exposure. For some radiations (e.g. alpha and beta radiation) separation by a suitable distance can eliminate exposure totally, for others (e.g. gamma radiation) increased separation results in reduced exposure; or
- by the use of shielding, particularly when shields are made of dense materials such as steel or lead which can eliminate, or at least significantly reduce, exposure?

Steps can also be taken to significantly limit exposure to radiation from radioactive material in particulate form[3] by the use of high efficiency filters or other screening materials as part of personal protective equipment or facility ventilation systems.

Some radionuclides (e.g. uranium-235 and plutonium-239) are known as ‘fissile material’ in that, if permitted to accumulate in sufficient quantities, they can support a neutron chain reaction which if uncontrolled can lead to a sudden release of neutron radiation in the form of a nuclear ‘criticality’. Such an event is accompanied by the sudden release of energy, in the form of heat and ionising radiation, and the production of additional quantities of fission product radionuclides. The risk of such an event occurring during any stage in the long-term management of waste containing fissile materials is generally controlled by limiting the quantities of such material that can be present in waste packages.

Many of the materials contained in radioactive waste, be they themselves radioactive or not, also possess other hazardous properties. The radioactive wastes held in the UK include materials which are flammable, explosive, pyrophoric, chemo-toxic, carcinogenic or oxidising, or have the potential to degrade over time such as to develop such properties. Many materials with such properties are subject to regulatory controls over and above that which are required of radioactive material. They may also require particular treatment during the retrieval and packaging of waste as a means of removing them from the waste or allowing them to be treated to reduce or eliminate their potential risk.

3.3 Categories of materials potentially destined for geological disposal

The MRWS White Paper [2] identifies the higher activity radioactive wastes that would be managed in the long term through geological disposal as those that:

- cannot be managed under the *Policy for the Long-term Management of Solid Low Level Radioactive Waste in the United Kingdom* published in March 2007 [7], and
- are not managed under the Scottish Executive’s policy for higher activity radioactive waste [8].

As part of specifying the requirements of the disposal system the DSTS defines the higher activity wastes and materials for which the design and the safety cases need to be developed. This includes the type and number of waste packages and their dimensions and masses. The DSTS identifies the following categories of waste that are assumed to be managed in the long-term by way of geological disposal:

- High level waste (HLW) arising from the reprocessing of spent fuel in which the temperature may rise significantly as a result of their radioactivity, so that this factor,

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3 Such as is capable of becoming readily airborne and of being inhaled by humans.

amongst others, has to be taken into account in designing storage or disposal facilities;

- Intermediate level waste (ILW) with radioactivity levels exceeding the upper boundaries for low level waste[4] (LLW), but for which heating is not a significant issue in the design of storage or disposal facilities[5]; and
- LLW which is unsuitable for near-surface disposal[6].

The MRWS White Paper also identifies the following radioactive materials that are not currently classified as wastes but which may, if it were decided at some point that they had no further use, be so classified and need to be managed through geological disposal. Hence, the DSTS also defines the inventory and types of waste packages anticipated for the following radioactive materials:

- spent fuel from existing nuclear power reactors that is not destined for reprocessing or from any new nuclear power stations that may be constructed in the UK;
- plutonium extracted from spent fuel by reprocessing; and
- uranium that is a by-product of uranium enrichment or the reprocessing of spent fuel[7].

3.4 Quantities of wastes and other materials that may be considered for geological disposal

The *UK Radioactive Waste Inventory* (UKRWI) provides the definitive public compilation of data on the existing stocks and expected arisings of radioactive wastes arising from historical and ongoing operations at UK nuclear sites. The data recorded in the UKRWI includes information on the quantities and physical, chemical and radiological characteristics of these wastes. The UKRWI is produced jointly by Defra and the NDA and is updated on a roughly 3 year cycle, the latest version (the 2007 UKRWI), for a stock date of 1 April 2007, was published in June 2008 [9].

The MRWS White Paper provides an estimate - the *Baseline Inventory* - of the higher activity radioactive waste and other materials that that might need to be managed in the future through geological disposal. The Baseline Inventory[8] (Table 1) is based on the 2007 UKRWI but also includes materials not currently classified as waste, such as spent nuclear

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[4] LLW is defined as material having a radioactive content not exceeding 4GBq/te of alpha activity or 12GBq/te of beta/gamma activity.

[5] In practice, the heat output of ILW packages is considered in the detailed design of transport, storage and disposal facilities.

[6] This is defined as LLW which is not capable of satisfying the waste acceptance criteria for disposal at the Low Level Waste Repository in Cumbria.

[7] Uranium that could require geological disposal falls into four broad categories:

- natural uranium; with a uranium-235 content of ~0.7%;
- depleted uranium; with a uranium-235 content less than ~0.7%;
- low enriched uranium; with a uranium-235 content of between ~0.7% and ~20%; and
- highly enriched uranium (HEU); with a uranium -235 content of greater than ~20%.

The first three categories of uranium are considered together in the context of their disposal and are referred to as ‘depleted, natural and low enriched uranium’ (DNLEU).

[8] It should be noted that at present the Baseline Inventory is based on UKRWI figures and includes higher activity wastes that would be managed under current Scottish Government policy [8].

fuel, separated plutonium and uranium. However, it excludes LLW that can be managed under the Government's policy for the long-term management of solid LLW [9] which is included in the UKRWI.

Table 1 The Baseline Inventory

Materials	Notes	Packaged volume		Radioactivity (At 1 April 2040)	
		Cubic Metres	%	Terabequerels	%
HLW	1, 2, 3, 5	1,400	0.3%	36,000,000	41.3%
ILW	1, 2, 5	364,000	76.3%	2,200,000	2.5%
LLW (not for LLWR)	1, 2, 5	17,000	3.6%	<100	0.0%
Spent nuclear fuel	1, 4, 5	11,200	2.3%	45,000,000	51.6%
Plutonium	1, 4, 5	3,300	0.7%	4,000,000	4.6%
Uranium	1, 4, 5	80,000	16.8%	3,000	0.0%
Total		**476,900**	**100**	**87,200,000**	**100**

Notes
1. Quantities of radioactive materials and wastes are consistent with the 2007 UK Radioactive Waste Inventory [4].
2. Packaging assumptions for HLW, ILW and LLW not suitable for disposal at the existing national LLWR are taken from the 2007 UKRWI. Note that they may change in the future.
3. The HLW packaged volume may increase when the facility for disposing the canisters, in which the vitrified HLW is currently stored, has been implemented.
4. Packaging assumptions for plutonium, uranium and spent nuclear fuels are taken from the 2005 CoRWM Baseline Inventory [14]. Note that they may change in the future.
5. Radioactivity data for wastes and materials was derived using the 2007 UK Radioactive Waste Inventory. 2040 is the assumed start date for the geological disposal facility.
6. It should be noted that at present the Baseline Inventory is based on UK Inventory figures, and as such, currently contains waste expected to be managed under the Scottish Executive's policy of interim near-surface, near-site storage as announced on 25 June 2007 [15].

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Whilst the UKRWI reflects the best available public domain information concerning the quantities of all of the radioactive materials in the UK that may eventually be subject to geological disposal, it does not contain sufficient detail to allow it to be used in the development of plans for their long-term management. For this purpose we have developed a more detailed inventory based upon the Baseline Inventory and using the information from the UKRWI [10]. We use the term 'Derived Inventory' to explain this, but in the first instance this should be seen as a more detailed description of the Baseline Inventory, rather than a separate distinct inventory. Individual Derived Inventories have been produced for ILW/LLW [11], HLW and spent fuel from existing power stations [12] and for uranium and plutonium [13]. While being based on the same data from the UKRWI that was used to produce the Baseline Inventory, the 'Derived Inventory' represents a greater level of detail regarding the individual waste streams, and considers this information at the 'waste package level'. Development of the Derived Inventory involved consideration of specific waste packaging concepts which may be adopted for different waste types, some of which have been assessed by way of the disposability assessment process. This allows information on expected waste conditioning factors to be used to determine the actual volumes of packaged waste that would need to be accommodated in a GDF.

Also, as the UK Government has stated that it believes new nuclear power stations should have a role to play in the UK's future energy mix [14] and considers that it would be technically possible and desirable to dispose of both waste arising from new nuclear power stations and existing legacy waste in the same GDF and that this should be explored through the MRWS programme. Accordingly a Derived Inventory for the wastes anticipated to arise[9] from of a representative fleet of such stations[10] has been produced [15].

One of the ways in which we evaluate the robustness of the DSSC is through consideration of alternative inventory scenarios. The Derived Inventory therefore comprises a Reference Case Derived Inventory and an Upper Inventory which allow us to consider the impact of uncertainty in the inventory. The assumptions underpinning the Reference Case Derived Inventory are set out in the individual derived inventory reports and these are used together with full details (e.g. volumes, chemical constituents, radionuclides) of specific waste streams as stored, as conditioned or as predicted to arise from existing nuclear facilities are given in those reports and in the DSTS, which also provides details of the expected number of each type of waste package. The DSTS [6] will be updated periodically and should be consulted for the latest analysis of the Derived Inventory - a summary of the present position in terms of waste package numbers, total packaged volumes and radioactivity for each waste type, the current version of which is given in Table 2.

There are further sources of uncertainty in the eventual inventory requiring geological disposal which are also covered by our work programme. These include uncertainties in the volumes and radionuclide contents of the currently identified wastes and materials in the Baseline Inventory and uncertainties in scenarios for the future operation of the nuclear plants that produce these wastes and materials.

We can create a range of scenarios for the inventory of wastes that may require geological disposal in order to evaluate the implications of these uncertainties for the geological disposal programme. In particular we have developed an Upper Inventory to give an indication of the quantities that might need disposal. We want to be able to demonstrate that a GDF can be developed to deal with this inventory safely and securely in addition to being confident that the same will be true for a lesser inventory. The Upper Inventory also provides visibility to local communities that are considering participation in the site selection process of what might be involved in hosting a GDF.

We have developed the Upper Inventory, based on existing waste management activities and plans and building on the approach taken by CoRWM in addressing such uncertainties [16]. In deriving the Upper Inventory we considered the likelihood of each of the identified scenarios occurring based on an understanding of current priorities and factors that are driving approaches and developments in UK radioactive waste management. The Upper Inventory also considers how current Government and industry policy, strategy and planning might impact radioactive waste arisings. The waste packaging implications of those scenarios considered most likely to occur are included in the Upper Inventory are discussed in the DSTS [6] and summarised in Table 3. We have also determined an inventory of wastes and materials arising from the operation and decommissioning of possible new nuclear power stations, which can also be found in the DSTS

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[9] These comprise all wastes and materials expected to arise during station operation and decommissioning and includes HLW, ILW, LLW unsuitable for shallow disposal and spent fuel, together with wastes and materials (notably depleted uranium) produced as a result of fuel fabrication.

[10] Assumed to comprise four Westinghouse AP1000 reactors and four Areva/EdF European Pressurised Water Reactors providing a total nuclear generating capacity of approximately 10GWe and operating for 60 years.

Table 2 The Reference Case Derived Inventory [6]

Waste Type	Notes	LLW	UILW	SILW	HLW	AGR SF	PWR SF	Pu	HEU	DNLEU
Conditioned Volume (cubic metres)	-	15,656	190,173	84,723	1,422	1,933	492	3,049	44	77,795
Packaged Volume (cubic metres)	1	16,632	239,827	121,865	7,457	8,491	1,872	6,989	102	94,400
Number of Waste Packages	2	273 drums; 823 boxes	157,520 drums; 44,208 boxes	6,310 boxes	3,656	5,341	655	3,426	50	165,325 drums
Number of Disposal Units	3	892	83,588	6,310	3,656	5,341	655	3,426	50	41,332
Radionuclide activity decayed to 2040 (Becquerels)	4	8.2×10^{10}	1.6×10^{18}	1.5×10^{16}	1.7×10^{19}	2.6×10^{19}	1.2×10^{19}	3.8×10^{18}	3.3×10^{12}	5.0×10^{15}

Notes
1. The packaged volumes of HLW, SF, Pu and HEU in the Derived Inventory are based on the assumption that HLW, SF, Pu and HEU would be packaged in copper 'KBS-3V style' packages; the calculated package volumes in these reports include the cast-iron insert and copper container. Packaged volumes may be different for alternative disposal concepts.
2. Unshielded ILW (UILW) and Shielded ILW (SILW) boxes are assumed to be a mixture of waste package types as described in the Generic Waste Package Specification. Nirex Report N/104, 2007. Each HLW package is assumed to contain two Sellafield WVP canisters.
3. Drums are disposed of in stillages of four.
4. Radionuclide activity rounded to two significant figures.

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Table 3 Comparison of packaged volumes for the Reference Case and Upper Inventory

Materials	**Packaged volume (m^3)**	
	Reference Case	**Upper Inventory**
LLW	16,632	155,843
ILW	361,692	583,979
HLW	7,457	23,026
Spent nuclear fuel	10,363	22,325
Plutonium	6,989	10,401
Uranium	94,502	175,102
Total volume	497,635	970,676

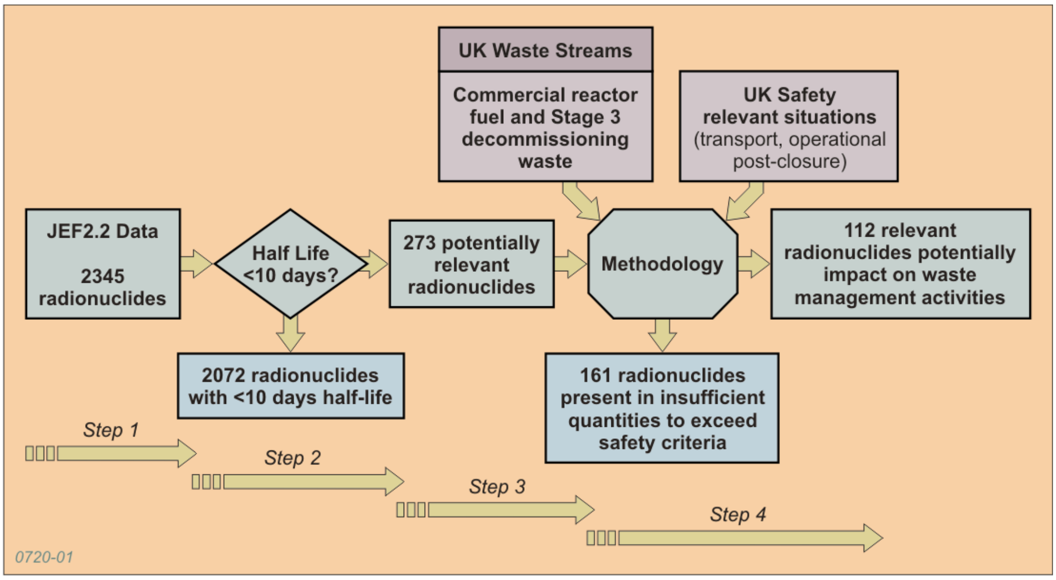
3.5 The identification of radionuclides of relevance to the geological disposal of higher activity waste

It has long been acknowledged, by the UK nuclear industry and the industry regulators, that not all of the radionuclides known to exist will be present in radioactive waste and, of those that are present, only a limited number will have relevance to the safety of long-term management of the waste. It has accordingly been recognised that it is neither necessary nor practical for the radionuclide content of waste to be recorded in terms of all known radionuclides and that this should be limited to a smaller number of radionuclides whose presence does have such relevance.

In 1998 Nirex developed a methodology for the identification of a list of radionuclides which had relevance to the safety of the long-term management of radioactive waste. The methodology, which is illustrated in Figure 1, has been used to screen the 2,345 known radionuclides (as identified in the JEF2.2 nuclear data library [17]), to identify a smaller sub-set that can be considered significant for long-term waste management. Of the initial 2,345 radionuclides, almost 90% can be screened out on the basis that their short half-lives means that they have decayed to vanishingly small quantities before the wastes are packaged. The methodology assumes a 10 day half-life for this screening step and this leads to 273 radionuclides being carried forward to the next stage of screening. Of the remaining radionuclides some are parents of short-lived daughters. If such a daughter is capable of making a significant contribution to, for example, radiation dose or heat generation this will be added to that made by the parent.

Consideration of the remaining 273 radionuclides revealed that 161 either existed in such small quantities in the UK inventory and/or would have no significant impact on the safety of the three main stages of geological disposal (i.e. transport, GDF operations and the post-closure period) such that they could also be ignored. The remaining 112 'relevant radionuclides' provide the basis for the radionuclide information requirements for all waste packages containing ILW and for the safety assessments reported in the DSSC [18].

Figure 1 Method for the identification of 'relevant radionuclides'



Whilst the original definition of the list of 112 radionuclides was carried out on the basis of the geological disposal of ILW and LLW[11], we believe that it is broadly valid for other categories of higher activity radioactive waste. Given that the methodology requires input from safety cases, it is recognised that the list must be maintained and periodically reviewed and updated. It is planned that the next such review and update will take account of the full range of wastes and other radioactive materials and will also be based upon the safety assessments undertaken in support of the DSSC.

[11] The definition of the list was also based on the radionuclides that would be expected to be present in wastes arising from the reprocessing of uranium fuel irradiated in thermal reactors only.

4 The assessment of safety of geological disposal

As discussed in Section 3.2, the hazards to humans associated with the handling of radioactive material can arise as a result of external or internal exposure to radiation. As noted earlier the overall process for the geological disposal of radioactive material, following the packaging and interim storage of the packaged material can be divided into three distinct stages; transport, GDF construction, operations, decommissioning and closure and the post-closure period. Each of these stages has the potential to result in external or internal exposure to radiation to both workers involved with operations (for the first two stages) and members of the public.

The means by which such exposure can occur during these three stages are distinctly different and, as a consequence, are addressed by three separate safety assessments. These comprise:

- the Transport Safety Case (TSC) [19];
- the Operational Safety Case (OSC) [20]; and
- the Environmental Safety Case (ESC)[12] [21].

4.1 Transport

The transport of waste packages between nuclear licensed sites presents a number of particular circumstances by which both transport workers and members of the public could be exposed to the hazards associated with radioactive waste.

Waste packages may be transported by road, rail or sea (or a combination), either inside protective transport containers, which provide radiation shielding and additional containment of the radioactive contents, or without such overpacking[13]. Whichever mode is used the possibility exists for external and internal exposure to radiation to transport workers or members of the public during normal operations by:

- the routine release of very small quantities of radioactive gases or particles from the transport package, through the transport container and/or waste package seals;
- non-fixed surface contamination of the transport package; or
- radiation emitted from the transport package.

Exposure can also result from transport accidents which may involve extreme mechanical (i.e. impacts) and thermal (i.e. fires) challenges to waste packages and/or transport packages.

The transport of waste packages through the public domain is subject to the *Regulations for the Safe Transport of Radioactive Material*[14] [22] produced by the International Atomic Energy Agency (IAEA) and implemented in the UK through the *Carriage of Dangerous Goods Act* [23]. The regulations are aimed at minimising the radiation exposure of workers and members of the public under both normal and accident conditions of transport.

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[12] The ESC also considers the environmental impact of liquid and gaseous discharges from the facility during the operational period

[13] The term ‘transport package’ is used to describe either the combination of an overpacking transport container and waste package(s) or a waste package transported without overpacking.

[14] Known colloquially as the ‘IAEA Transport Regulations’.

Specifically the regulations place controls on the properties and performance of transport packages in respect of:

- external radiation dose rate;
- releases of radioactive material in gaseous and particulate form;
- the presence of non-fixed contamination of external surfaces; and
- the elimination of the possibility of an accidental criticality.

The TSC [19] demonstrates at this generic stage why we believe that transport of higher activity wastes and materials will be accomplished safely. The TSC addresses the specific contribution of the form of packaging in the Transport Package Safety report [24], describing in detail the controls applied to packaging and the means by which these are defined and recorded within a *Package Design Safety Report* (PDSR). A PDSR defines the permitted radionuclide and physical/chemical inventory of a specific design of transport package such that it can be transported in accordance with the deterministic criteria defined in or derived from the IAEA Transport Regulations.

All of the requirements imposed on waste packages by the transport operation, and the associated regulatory controls are reflected in the relevant generic specifications, as described in Section 5.2. It should be noted however that whilst many of the quantified requirements of the IAEA Transport Regulations are directly incorporated into generic specifications, these values are only upper limits and the principle of ensuring that the risks arising from transport will be as low as reasonably practicable (ALARP) will be applied during waste package manufacture and the preparation of packages for transport.

4.2 GDF operational period

The OSC considers four distinct aspects of the operational safety of a GDF:

- non-radiological safety during construction of the facility [25];
- radiological safety during routine operations at the facility (i.e. receipt, emplacement and storage of waste packages) [26];
- the radiological consequences of accidents during the operational period [27]; and
- criticality safety during the operational period [28].

Following receipt at a GDF, transport packages and, where relevant, their enclosed waste packages will be subject to a range of handling and stacking operations. Some of these have the potential to result in accidents that could result in waste packages being exposed to impacts and/or fires. Radioactive material released as a result of such accidents has the potential to cause radiation dose to GDF workers and, were it to be occur in such a manner as to cause an off-site release, members of the public.

The routine release of radioactive material from waste packages in the form of gases (e.g. radioactive gases such as tritium (hydrogen-3), isotopes of radon and other gases containing radionuclides such as tritium and carbon-14) may also result in on- and off-site exposure.

Waste packages containing fissile materials may be more susceptible to accidental criticality when stacked in arrays and this could result in the exposure of workers and, in principle, members of the public.

The radiological consequences of such potential accidents are subject to limits and targets defined by the HSE and are set down in the Safety Assessment Principles (SAPs) for nuclear licensed sites [29]. The SAPs set down Basic Safety Objectives (BSOs) and Basic Safety Levels (BSLs) for on- and off-site exposure to radiation under both normal operations and potential accidents where radioactive material is released from its ‘normal’ containment (i.e. in the case of a GDF from a waste package). These are reflected in the targets and limits defined by our *Radiological Protection Policy Manual* (RPPM) [30].

An analysis of the potential for accidents capable of resulting in the release of waste package contents during the operational period of a GDF has been undertaken on a generic design for a GDF and presented within the OSC. This analysis will be refined in an iterative manner as the GDF development programme progresses. As the MRWS site selection process progresses we expect to move from generic DSS, designs and safety cases to specifications, designs and safety cases tailored for specific sites. This iterative process will identify the nature, severity and frequency of potential accidents and based on a determination of the radiological consequences, identify appropriate disposal system design requirements and design improvements. This process will be used to inform our specified requirements for waste packages and may be used to refine the definition for these criteria in the generic specifications (see Section 5.2).

4.3 GDF post-closure period

Following emplacement in a GDF the risk of exposure of persons to radiation is significantly reduced by the combination of the barriers provided by the disposal system. When the facility is finally closed and sealed it is said to have entered the ‘post-closure’ period and the risk of exposure to radiation in the immediate term is reduced further still. However the timescale over which exposure must be considered extends to many millions of years, as the risk associated with the post-closure period are those resulting from the return of radionuclides to the geosphere. Exposure to radiation would therefore be to future generations living on the surface in the vicinity of the facility and, depending on the geological environment in which a GDF is located, to neighbouring communities at a wider radius.

The Post-closure Safety Assessment (PCSA) [31] supports the ESC [21] in addressing the environmental requirements associated with the authorisation of the disposal of radioactive waste in a GDF. This includes the detailed regulatory Principles and Requirements contained in the Guidance on Requirements for Authorisation (GRA) [32], which encompass management, radiological and technical aspects of the safety case for a GDF.

The GRA requires the assessment of radiological and non-radiological hazards associated with a GDF, including:

- Radiological risk to the public after the period of authorisation, including risks from possible gas releases, releases to groundwater and potentially disruptive natural events (such as erosion resulting from glacial action and climate change) including human intrusion.
- Consequences of inadvertent human intrusion of a GDF in terms of radiation doses to individuals undertaking the intrusion and individuals and other organisms who might occupy the area affected by releases from the intrusion event.
- Criticality. We will need to demonstrate that the possibility of a local accumulation of fissile material such as to produce a neutron chain reaction is not a significant concern, and investigate, as a variant scenario, the impact of a postulated criticality event on the performance of the disposal system.
- Radiological hazards to the accessible environment from possible releases, e.g., through damaging habitat quality, and to non-human species.
- Non-radiological risks to the public and the environment. Our assessments consider additional performance measures beyond radiological dose and risk that can be used to evaluate the safety of a GDF and the performance of individual barriers, e.g., radionuclide fluxes.

In the PCSA we explain our approach to assessing these risks, in particular how we treat the uncertainties which inevitably arise because of the requirement to demonstrate safety for a very long time. A quantitative analysis is presented for the groundwater pathway, the pathway by which radionuclides could give rise to a radiological risk to future populations by dissolution and transport in groundwater. Current knowledge of the potential consequences of gas generated in a GDF is summarised. Two variant scenarios are considered in this assessment: inadvertent human intrusion into a GDF and the likelihood of an accumulation of fissile material leading to a criticality.

5 The packaging of radioactive material for geological disposal

5.1 General requirements for packaged waste

Much of the waste destined for geological disposal does not arise in a form that is immediately suitable for such disposal and must be treated or conditioned and packaged in such a way as to render it:

- passively safe, such that it can be stored safely with the minimum need for actively managed safety systems, monitoring or prompt human intervention;
- capable of safe handling during interim storage[15], transport to and emplacement in a GDF;
- 'disposable', in that it can be shown to be compliant with all the relevant regulations and safety cases for transport to and disposal in a GDF.

In most cases this will require the use of a waste container and for many, especially those in which the radionuclides are 'mobile' (e.g. liquids, slurries, particulates), this will also require the waste to be conditioned or 'immobilised' to form a solid product or 'wasteform'.

The waste package thus formed provides a physical containment barrier against the early release of radionuclides into the GDF near-field and constitutes one of the barriers that make up the multi-barrier containment system that is a key characteristic of any concept for the geological disposal of radioactive waste. Depending on the physical and chemical nature of the waste this barrier can be provided by either or both of two components of the waste package, or by a combination of the two, namely the conditioned wasteform andthe waste container.

It should be noted that the term 'conditioned wasteform' can be used to describe a number of distinctly different types of waste package contents. Depending on the nature of the waste it can be:

- the waste itself, notably for materials such as spent nuclear fuel and irradiated metals and graphite in which the radionuclides form part of the atomic structure of the material itself;
- waste which, together with its associated radionuclides, has been physically 'encapsulated' by mixing it with a cementitious or polymeric material based matrix to produce a monolithic wasteform; or
- waste that has been subjected to a high temperature process to convert it to a very durable 'vitrified' or ceramic wasteform, into which the radionuclides are bound by the structure of the wasteform.

The wasteform and the waste container provide distinct safety functions to waste packages which contribute to the safety case for the waste package during all periods of its long-term management. During transport and GDF operations many of the safety functions (e.g. radionuclide containment, package handling) are assumed to be provided by the waste container and others (e.g. maintenance of sub-criticality) by the wasteform. During the post-closure period, following loss of the containment provided by the waste container, the wasteform is assumed to provide a stable, low-solubility matrix that limits the rate of release of the majority of radionuclides by dissolution in groundwater that comes into contact with it.

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[15] After packaging it is expected that many waste packages will need to be stored safely pending the provision of a GDF.

As well as providing some fundamental waste package properties (e.g. a standard dimensional envelope, lifting features, identification) the waste container will also provide a number of safety functions including:

- protecting the wasteform from physical disruption (e.g. by movement in the bedrock);
- preventing groundwater from reaching the wasteform[16];
- controlling the redox conditions in the vicinity of the wasteform by corrosion reactions, thus controlling the solubility of some radionuclides; and
- allowing the passage of gas from the wasteform into the surrounding engineered barrier system.

The relative importance of each of these two barriers will depend on the category of the waste, particularly the degree of the long-term durability that will be required of the waste package for that waste. This is summarised for the different categories of higher activity waste, together with those materials that could be declared as waste in the future, in Table 4.

Table 4 Summary of relative role of waste package components for different waste types

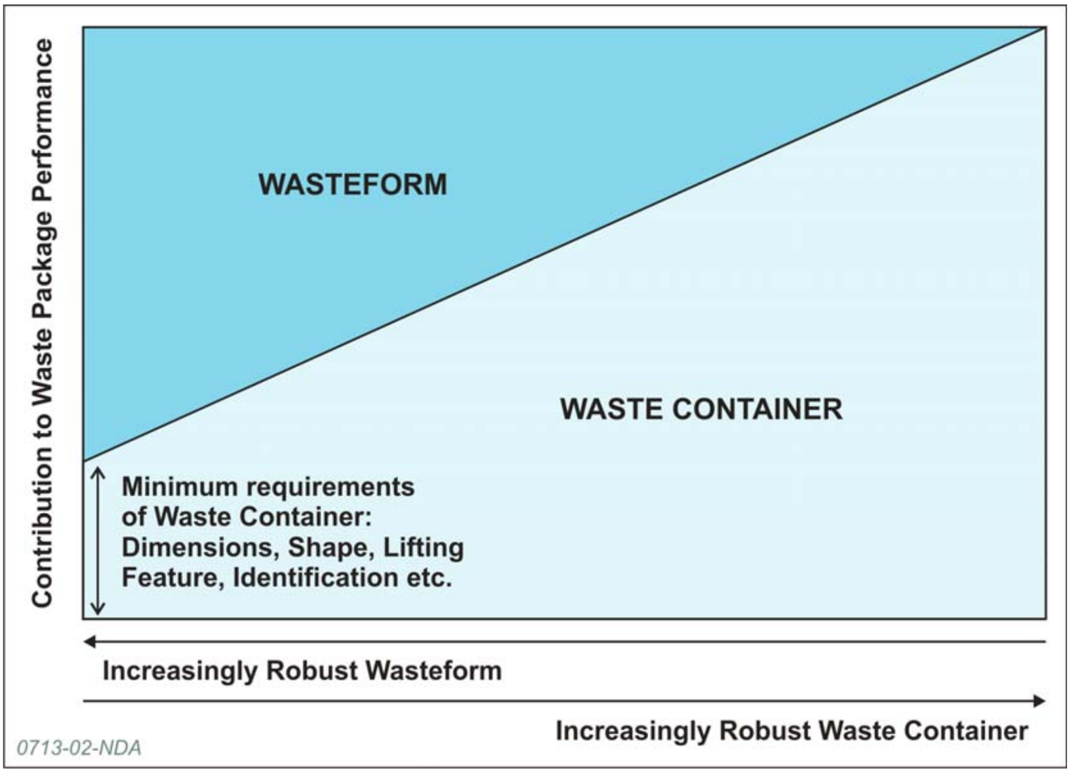
<table>
<tr><th rowspan="2">Waste type</th><th colspan="3">Relative roles played by the components of waste packages in the containment of radionuclides</th></tr>
<tr><th>Waste</th><th>Wasteform</th><th>Waste container</th></tr>
<tr><td>ILW</td><td rowspan="2">Generally low, but can be significant for neutron-activated metals and graphite</td><td colspan="2" rowspan="2">Relative importance depends on nature of waste container. For thin-walled containers, wasteform will play significant role which will reduce with increasing waste container robustness</td></tr>
<tr><td>LLW</td></tr>
<tr><td>HLW</td><td colspan="2">High – Wasteform comprises vitrified waste within stainless steel canister</td><td>Extent of role will depend on the long-term durability of the vitrified waste and/or the canister</td></tr>
<tr><td>Spent nuclear fuel</td><td colspan="2">Waste (i.e. fuel assemblies) is wasteform and provides significant containment of radionuclides, particularly in short-term</td><td>High - Waste container will play important long-term role</td></tr>
<tr><td>Plutonium</td><td rowspan="2">Assumed to play little or no role unless waste already exists in, or is to be conditioned into, a ceramic form</td><td>High - Waste will be incorporated into high durability wasteform</td><td>Extent of role will depend on the long-term durability of the wasteform.</td></tr>
<tr><td>Uranium</td><td colspan="2">Relative importance depends on nature of waste container. For thin-walled containers, wasteform may play significant role which will reduce with increasing waste container robustness</td></tr>
</table>

The relative importance of the wasteform and waste container to waste package performance for a particular category of waste is illustrated in Figure 2. This shows how the use of a more robust waste container can reduce the required contribution of the wasteform to overall waste package performance. The reverse is also the case in that the

[16]This can be a complete or partial barrier as it is expected that even after corrosion has breached it the waste container will still limit the movement of groundwater in and around the wasteform.

production of a robust wasteform (e.g. one comprising vitrified waste) can lead to a reduced contribution to waste package performance by the waste container. In all cases the overall performance of the waste package, and its compliance with the requirements for transport and disposal, are the governing criteria.

Figure 2 Relative contribution of the waste container and wasteform to waste package performance



The required timescale for the durability of the containment provided by a waste container will depend to a large extent on the safety case and the disposal concept that will be adopted for a particular waste type. Containment will be provided for the period required by the use of container material with the necessary combination of adequate thickness and corrosion characteristics. For example, the current target durability timescale for ILW containers [33] of 500 years could equally be achieved by the use of relatively thin sections (i.e. a few mm) of a material with a high corrosion resistance (e.g. austenitic stainless steel) or a more robust container (i.e. wall thicknesses of a few 10's of mm) made from less resistant material (e.g. cast iron). The possible means for the achievement of the necessary durability requirements for waste packages containing all categories of material that could be destined for geological disposal is discussed in [34].

The mechanism for determining the optimal contribution of the wasteform and waste container is the disposability assessment process and this is described in more detail in Section 6.

5.2 Specifications for packaged waste

For many years we, and our predecessor organisation Nirex, have produced specifications for packaged radioactive waste. These specifications define generic standards and performance requirements for waste packages which will be compatible with the systems and safety cases for transport to and disposal in a GDF.

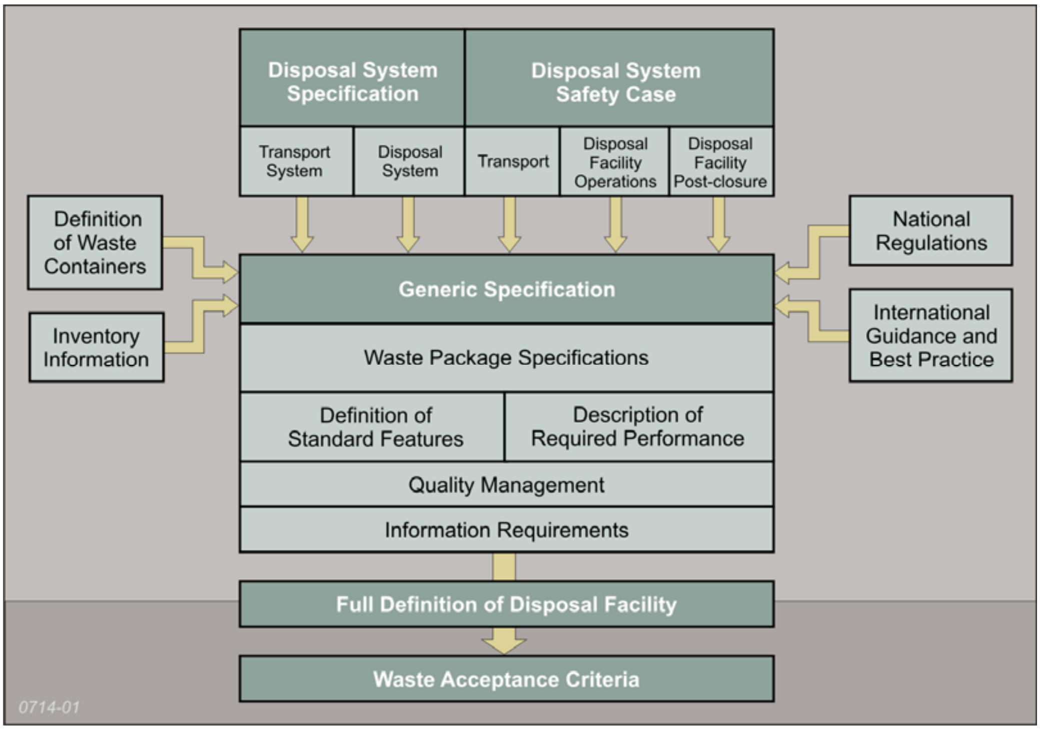
These generic specifications[17] play an important role in ensuring the safe and efficient preparation of waste for disposal in a GDF by providing a baseline which waste packagers can use to determine how to package wastes and meet the requirements for passive safety and compatibility with transport and disposal. Generic specifications are important part of our disposability assessment process (discussed in Section 6) and act as the preliminary waste acceptance criteria (WAC) for the GDF.

We have established a methodology for the production of generic specifications (Figure 3) which ensures that such a specification is founded on:

- the definition of a disposal concept for the waste;
- the designs of the systems for transport and disposal developed to meet the DSS (as discussed in Section 2.1);
- safety cases for transport, disposal facility operations and the post-closure period; and
- regulations for the storage, transport and disposal of radioactive material.

Each generic specification also provides a definition of the standardised waste containers that can be used for the manufacture of waste packages containing the particular type of waste.

Figure 3 Methodology for the production of generic specifications



17 Generic specifications are sometimes referred to as 'waste package specifications'.

Currently generic specifications exist for two broad categories of waste, the *Generic Waste Package Specification* (GWPS) [33], for waste packages containing ILW and LLW and a specification for waste packages containing vitrified HLW and spent nuclear fuel [35]. Following publication of the DSSC suite of documentation we intend to revise these documents and extend the range of generic specifications to encompass all categories of waste that could be destined for geological disposal [36].

6 The RWMD disposability assessment process

6.1 Background

The RWMD disposability assessment process exists to support SLCs that wish to condition and package higher activity wastes in a form that is compatible with plans for the implementation of a GDF. It is also used to support the ongoing development of the safety cases for geological disposal by the provision of information regarding the numbers and properties of the waste packages that will eventually require transport to and disposal in a GDF.

The disposability assessment process was originally developed back in the 1980s[18] primarily as a means to assist site operators to convert intermediate level wastes into passive safe and disposable forms. The assessment process continues today to provide the same service to SLCs albeit in a far more structured and rigorous way and in line with regulatory expectations for the long term management of all higher activity waste [37].

The '*Letter of Compliance*[19]' (LoC) disposability assessment process also plays an important role in underpinning the DSSC as it provides confidence that the safety cases, which are based on generic assumptions regarding the wastes and the form of packaging, are compatible with 'real' waste packages being developed by industry. Through application of the disposability assessment process we, together with the site operator and regulators, gain confidence that proposed waste packages will ultimately be compliant with requirements for transport and disposability. This may involve us together considering different packaging approaches and determining which combination of barriers (wasteform and waste container) best meet the needs for waste retrieval, processing, storage and ultimately, disposal. This is important as it gives confidence that packaging strategies, and ultimately investment decisions, are soundly based and will result in waste packages designed in line with transport and disposal requirements. Confidence in the developing DSSC is built up over time through a periodic review process by which the validity of disposability assessments are maintained by ensuring that they remain up to date and consistent with the DSSC as concepts for geological disposal evolve towards an operational GDF.

The main purposes of disposability assessments are therefore to:

- give confidence to site operators (and waste owners) that the implementation of their proposals for waste packaging will result in waste packages that best meet the needs for processing and storage whilst being compliant with the eventual needs for transport to and disposal in a GDF;
- provide us with confidence that the disposal concepts considered within the DSSC will be appropriate for the wastes they will be expected to cover; and
- permit the identification of wastes that could challenge current disposal concepts and allow early consideration of what changes may be required to these concepts to permit the wastes to be accommodated.

Since the mid-1980s, waste producers in the UK have made significant investment in waste retrieval and packaging plant as a means of ensuring that such wastes are rendered passively safe and suitable for disposal in a GDF. Historically Nirex was responsible for

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[18] At that time it was known as the 'Letter of Comfort' process.

[19] The Letter of Compliance is discussed later in this Section

the assessment and endorsement of the suitability of waste packagers' proposals to package waste for these needs, a responsibility assumed by RWMD in 2007 following Nirex's incorporation into the NDA.

The assessment of the disposability of waste packages was originally carried out by way of the 'Letter of Comfort' assessment process which, following two decades of use and development, has evolved into the current LoC disposability assessment process [38].

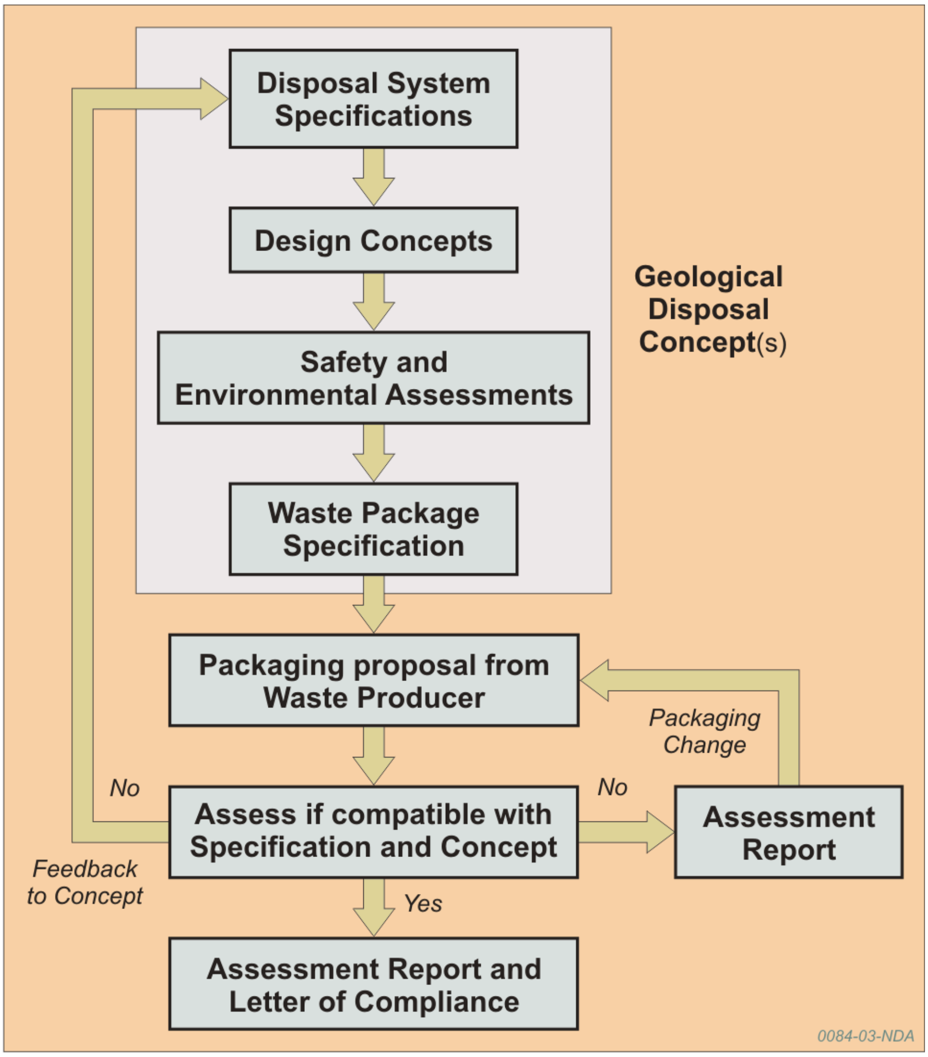
The role played by the disposability assessment process is summarised in Figure 4 which also illustrates the relationship between the process, the DSS, the safety and environmental assessments and the packaging specifications (see also Section 5.2). In practice the process requires the waste packager to provide information to RWMD regarding the wastes, any pre-treatments proposed, conditioning techniques and form of packaging. Following assessment we will provide detailed advice on transport and disposability issues and where necessary to ultimately complete the assessments, request further information or flag the need for further development and/or research.

In undertaking disposability assessments we determine whether packaged wastes will have characteristics compliant with the safety case requirements for transport to, and operations at a GDF, and ultimately whether the wastes could be accommodated within a GDF post-closure safety case, i.e. that the packages are 'disposable'. The main output of the assessment is an Assessment Report detailing the work undertaken and which may be accompanied by a Letter of Compliance. The LoC is simply a statement to the effect that the waste package as described in the submission has been assessed and found to be compliant with transport and geological disposal as currently defined.

Figure 4 illustrates that the disposability assessment process has the potential to allow site operators and RWMD to iterate through the assessment cycle – this is particularly useful where the operator and/or RWMD recognises that there would be benefit in exploring alternative packaging options, particularly where there is a need to balance potentially conflicting requirements from site safety cases and disposal safety cases. This is described further in Section 6.5.

Regulators' guidance [37] requires that waste packagers (Site Licensees) produce a radioactive waste management case (RWMC) which includes reasoned argument why packaged waste will be disposable – the disposability assessment and accompanying LoC will provide an important component of such a case.

Figure 4 Summary of the disposability assessment process



6.2 RWMD disposability assessment policy and principles

We have produced a policy statement and list of principles to define the philosophy that underpins our approach to the assessment of the disposability of waste packages [39].

The policy and principles, which can be found in Appendix A, have been produced with the objectives of:

- providing a succinct policy statement to encapsulate the purpose of our work in support of waste packaging and disposability assessment;
- setting down the underlying principles governing the provision of disposability assessments and the issue of LoCs; and
- setting down the conditions under which an LoC can be issued, and the status of that LoC, at each stage of the assessment process.

The policy and principles are defined in such a manner as to:

- be applicable to all higher activity wastes;
- align with Government policy [2] and regulatory guidance [40]; and

- reflect the NDA mission statement to adopt a safe and cost effective approach to the management of waste and the reduction of the hazard posed by such waste.

6.3 Application of the disposability assessment process

In conjunction with the site operators we apply the disposability assessment process throughout all the phases in the development of a waste packaging facility. Our involvement ideally will commence at the option selection stage when the operator is identifying management options and packaging concepts for a particular waste stream and would want to be guided by our perspective on disposability issues. The interactions would then be expected to continue through design and construction of the facility, to final commissioning and active operations.

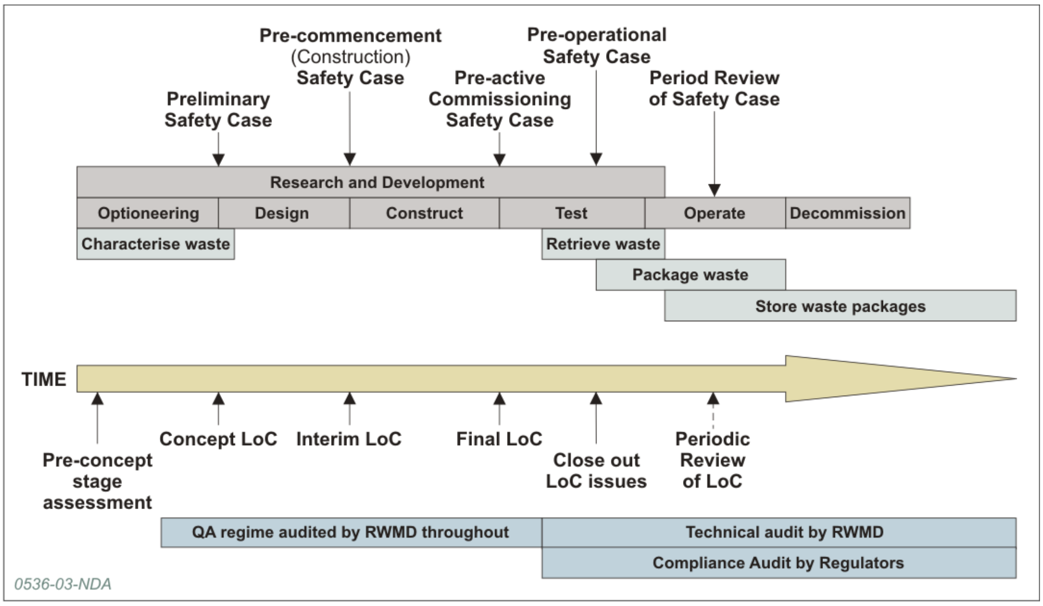
The LoC disposability assessment itself would typically commence when the site operator has undertaken sufficient work to identify a preferred packaging approach and can describe a waste packaging proposal [41]. This would then act as a trigger to a sequence of interactions between RWMD and the operator which typically takes the form illustrated in Figure 5.

The assessment process is normally divided into three stages which are aimed to correspond with the three key phases of the development of a packaging facility and associated safety cases, i.e.:

- initial consideration of the packaging concept;
- development of the concept and packaging facility, and;
- licensing of the packaging facility.

The approximate points in the process when the different stages of the assessment process would normally be sought are shown in Figure 5.

Figure 5 Interactions between RWMD and the waste packager on a typical packaging project



The objectives of the three stages of the assessment process reflect the needs of these key phases namely:

- At the Conceptual stage the compatibility of the proposed waste treatment and packaging process with anticipated long-term waste management requirements is assessed. Such assessment is based on information describing the expected waste inventory and volume, outline packaging proposals and development plans. At this stage it is expected that the disposability assessment would be in outline form only, but sufficiently developed to judge the overall feasibility of the packaging concept.

- At the Interim stage detailed inventory data and final design specifications, including results from research and development are assessed in order to confirm that the intended waste packages would be compliant with the standards and specifications defined within the relevant generic specification. The disposability assessment would be nearing completion with fewer gaps and information needs.
- At the Final stage all the research and development related to the waste package should be complete and all the information needed to complete the disposability assessment available. Confirmation that the waste packages, as proposed to be manufactured in the as-built plant, will be compliant with the relevant generic specification and the needs for disposal in a GDF, will be signified by the issue of the Final stage LoC.

The disposability assessment will also require RWMD and the SLC to interact and identify the data that will need to be measured and/or recorded on the wastes, on the waste package and on the waste packaging process, and subsequent waste management stages. The waste package data record will be a very important output from the process enabling the waste package to progress through subsequent waste management stages. This is discussed further in Section 6.9. The process will also ensure that all activities undertaken in connection with the development of the waste package, including design, research and development, characterisation and sampling of the waste, are undertaken under an appropriate quality management system. The requirements are specified by RWMD [42] and are subject to periodic audit.

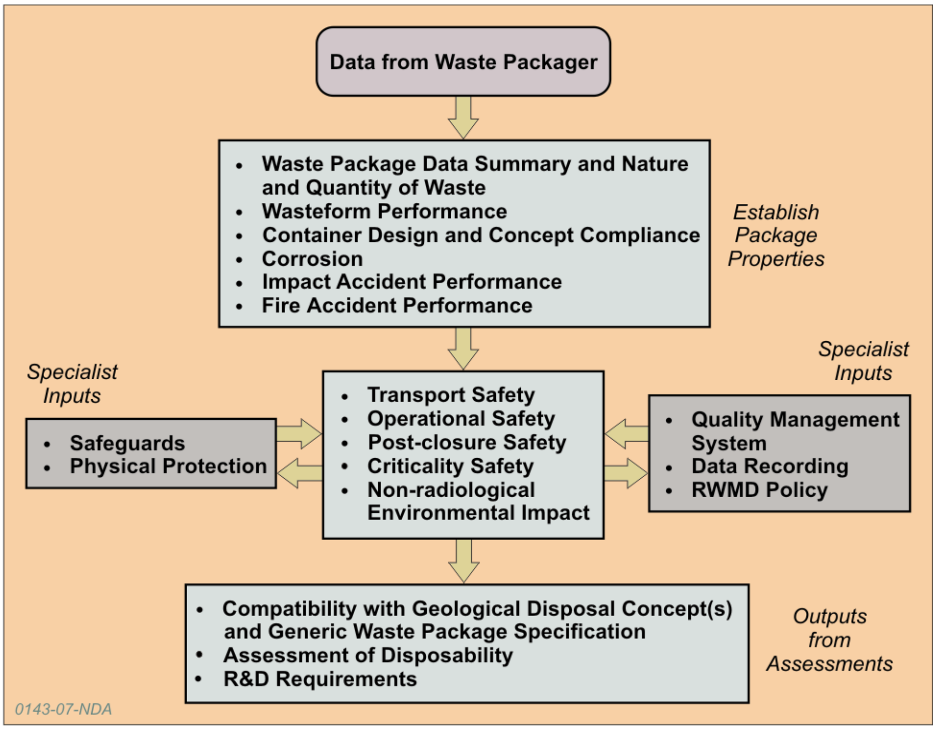
In practice, interactions may not always follow the course shown in Figure 5, as the packaging plant once established, may then be used to process other waste streams or waste types for which a separate disposability assessment may be required.

Each disposability assessment process has two distinct components:

- Establishing a good understanding of the properties of the proposed waste packages. This is achieved by way of the series of technical evaluations, which establish that the characteristics of the waste package are understood in sufficient detail; and
- Comparing the performance of the packaged waste against the safety, environmental and security assessments for transport and the operational and post-closure periods of a GDF.

In order to achieve these objectives effectively and efficiently, and to provide assurance as to the robustness and traceability of the assessment process, we have developed a methodology as illustrated in Figure 6 and described below.

Figure 6 Outline of the disposability assessment process



6.3.1 The technical evaluations

We carry out a series of technical evaluations to allow us to develop the required level of understanding of the properties and performance of waste packages to enable subsequent comparison with our existing transport and disposal safety assessments. These require us to:

- carry out an independent review of the radionuclide and physical/chemical inventory of the waste and, where necessary, augmentation to ensure that the assessment inventory is comprehensive and that any potential information 'gaps' have been addressed;
- determine the expected performance of the waste package under normal and potential impact and fire accident conditions, based on waste package specific modelling or analogue data;
- evaluate the expected behaviour of the waste package under extended storage and disposal conditions.

Table 5 summarises the main objectives of each of the six technical evaluations carried out during each disposability assessment[20].

[20] It should be noted that not all of technical evaluations are carried out at every stage of the assessment process and that the depth of the evaluations will vary depending on which stage is reached. For more information see [41].

Table 5 Objectives of technical evaluations

Evaluation description	Objective
Nature and quantity of waste	Production of a waste package data summary sheet describing the characteristics of the waste, and defining average and maximum inventories of the proposed waste packages and the expected number and type of waste packages.
Wasteform performance	Design and compatibility of any encapsulating matrix. Properties and evolution of resultant wasteform. Behaviour under storage and disposal conditions.
Container design and concept compliance	Consistency of container design with GDF handling and performance requirements. Compatibility of waste package with concept design.
Corrosion	Consistency of waste container with durability requirements over extended storage periods.
Impact accident performance	Release fractions (RFs) from waste packages under credible impact accident conditions Effect of ageing under storage conditions on RFs.
Fire accident performance	RFs from waste packages under credible fire accident conditions Effect of ageing under storage conditions on RFs.

6.3.2 Comparison with the concept safety assessments

The definition of the expected properties and performance of the proposed waste packages in the initial part of the assessment process is necessary to confirm the robustness of the packaging proposal but also provides a vital input to the assessment of the safety of the transport and disposal of the waste packages. This latter requirement involves a comparison of waste package performance against assessments of the safety of transport and the operational and post-closure periods of a GDF. The safety cases produced as part of the DSSC (and discussed in Section 4) will serve this purpose in the future.

The second part of the disposability assessment process plays an important role in ensuring that each of the concept safety assessments reflect actual plans to package waste. Each of the safety assessments has been developed based on our understanding of the total quantity of waste that will ultimately come forward for disposal in a GDF. Using information from the UKRWI [9] and the DSTS [6], regarding radionuclide inventory and the assumed forms of packaging that will be applied to each waste stream, we have produced estimates of the numbers of each type of waste package that would be eventually be produced from the packaging of the entire inventory. This information, together with estimates of the radionuclide inventories of the projected waste packages and assumption regarding their performance characteristics (e.g. for impact and fire accident performance) are key inputs to the safety assessments.

As discussed above, an output of the technical evaluations carried out as part of a disposability assessment is a full definition of the waste packages that would result from the implementation of a proposal to package a particular waste stream. This will comprise waste package numbers, mean and maximum radionuclide inventories and a range of quantified performance characteristics (e.g. impact and fire accidents RFs, external dose rate, gas generation rates etc.).

This information is then substituted for the generic assumptions made for the waste stream in the concept safety assessments. In this way proposals to package a waste stream are 'tested' against each of the concept safety assessments to determine whether the real package data would change the outcomes of any of the assessments. The disposability assessment process therefore plays an important role in building confidence that the DSSC is robust when used in conjunction with data from real waste packages.

This is the part of the disposability assessment process where we can consider the performance of the proposed waste package in the context of the GDF (and transport) safety cases. In Section 5.1, we noted that the waste package, comprising wasteform and waste container, contributes two of the barriers within the overall multi-barrier containment system. It is within this part of the assessment that we get to test these against the disposal concept and iterate with the waste packager if necessary, to arrive at a fixed package design which balances the needs of the safety cases for processing and storage, transport and disposal.

Some examples of how this process has been used in the past to develop optimal packaging solutions are recorded in Appendix B.

The disposability assessment therefore has an important role in ensuring that the information on which the concept safety assessments are based remains up to date with the packaging of waste (both actual and planned). This will be achieved by progressively replacing the originally assumed generic information on the numbers of waste packages and their performance with actual information produced by disposability assessments.

Transport safety

The assessment of the safety of the transport of the proposed waste packages comprises two parts:

- A deterministic assessment of the compliance of the anticipated transport packages[21] against quantitative criteria specified in or derived from the IAEA Transport Regulations [22]; and
- A probabilistic assessment of the effect of the proposed waste package on the total doses predicted from the Baseline Inventory in the transport safety case.

In the case of the first assessment this will require the classification of the expected transport packages (i.e. either Type IP-2 or Type B) and confirmation that the relevant limits for external radiation dose rate, heat output, gas generation and the release of activity under normal and accident conditions will not be exceeded. It will also be necessary to show that the inventory of fissile materials within the expected waste packages will be such that the required level of criticality safety will be maintained under both normal and accident conditions of transport.

The second assessment predicts the average annual dose received by workers on the transport system from the proposed waste packages. It then compares these doses to the average annual dose received by workers from all waste streams in the Baseline Inventory, based on estimated exposure and proximity information. The assessment confirms that the average annual dose from all waste packages, including the proposal, is below our RPPM criteria.

[21] A 'transport package' is defined as a package as prepared for transport. As such it may be a waste package with or without an overpacking transport container.

Doses are calculated for:

- A train driver
- An HGV driver
- A ship's crew
- A crane operator at the GDF.

GDF operational safety

As in the case of transport the assessment of safety during the operational period of a GDF, as considered in the OSC [20] includes both deterministic and probabilistic elements.

Our RPPM [30] defines deterministic safety criteria in terms of targets and limits for on- and off-site dose during the GDF operational period which are based on those specified in the HSE SAPs [29]. The SAPs define basic safety objectives (BSO) and basic safety limits (BSL) for radiation dose the latter reflecting a tiered approach to limiting dose, depending on the expected frequency of the relevant initiating fault or design basis accident (DBA) that could lead to the release of activity from its normal containment[22].

In addition to the specific criteria indicated above, the following general criteria are also considered in the assessment:

- limits on dose to workers under normal operational conditions;
- limits on toxic chemical release;
- limits on radioactive gas release (dose to public under normal operating conditions);
- impact on probabilistic risk for a GDF as a whole; and
- compliance with operational criticality safety limits.

GDF post-closure safety

A staged process is adopted to consider the impact of each waste packaging proposal with respect to the ESC [21] and hence long-term safety and environmental protection issues. The extent of the post-closure performance assessment at each assessment stage will depend on the potential significance of the waste to the overall long-term safety of a GDF.

During a Conceptual stage disposability assessment an initial screening assessment is undertaken to determine whether or not a more detailed post-closure assessment is necessary, and to define the nature and extent of any such assessment.

The initial screening assessment is based on the comparison of six aspects of the packaging proposal with the post-closure safety case (which would be the ESC in the future):

- the general nature of the proposed waste packages;
- whether or not the waste stream is included within the inventory assessed in the safety case;
- the waste composition, including the inventory of inactive materials and chemotoxic species;
- the radionuclide inventory of the waste;
- the influence of any complexing agents present in or produced by the waste

[22] In the case of a GDF this would be the waste packages.

- the spatial distribution of radionuclides arising from the proposed waste packages and whether this distribution could undermine the assumption of homogeneous radionuclide chemistry made in the safety case.

In each case, the initial screening may identify issues that require further, more detailed assessment. In this manner, the nature and extent of any detailed assessment is defined.

Such a more detailed evaluation would require the examination of the consequences of the proposed waste packages for overall GDF performance in a number of key areas and would be required to show that the assessed radiological risks would remain consistent with the 10^{-6} per year regulatory guidance level. It would also be required to show that consideration had been given to the possible radiological impacts associated with inadvertent future human intrusion, and that they had been optimised with respect to impacts from other possible exposure pathways.

In addition to these quantitative criteria, a number of other general issues are considered, and their potential impact on post-closure performance scoped. These include a consideration of the influence of a number of materials that could be present in waste including:

- halogenated polymers;
- other organic materials, including non-aqueous phase liquids;
- reactive metals; and
- aggressive chemical species that have the potential to effect the chemical conditioning of GDF chemistry.

There is also a consideration of the significance of any toxic materials in the waste and of heat generated by the proposed waste packages.

Finally, it is necessary to consider the potential influence of the proposed waste packages on the criticality safety of a GDF in the post-closure period.

6.3.3 Consideration of the consequences of different geologies

In the production of the DSSC we have considered the implications for safety of the implementation and long-term performance of a GDF in a range of different geological environments in the UK [3] and this is reflected in the OSC and the ESC[23]. From this we have concluded that a safe GDF can be designed to suit a wide variety of such environments. It is our intention that the disposability assessment process will utilise this consideration of different geologies which will take place during the comparison of proposed waste packages with the concept safety assessments.

We generally believe that the operational safety of a GDF constructed in a geological environment defined as ‘higher strength rock’ would bound that for the other two geological environments considered in the DSSC (i.e. lower strength sedimentary rock and evaporites). This belief is founded on the assumption that the physical size of the disposal vaults that could be constructed in a higher strength rock environment would be larger than those for other geological environments and that this would affect a number of the challenges that would be presented to waste packages. For example, the mechanical challenges that could result from impact accidents would be lower for smaller disposal vaults in which waste packages were not stacked as high as that assumed for a GDF constructed in a higher strength rock environment.

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[23] It should be noted that the TSC considers the implications for transport safety of locating a GDF in any *geographical location* in England and Wales and that the impact of different geological environments for this safety case is taken into account through any difference in disposal canisters that would result.

In the case of post-closure safety the differences are more subtle, the most notable being the magnitude of groundwater flow which is assumed to be greatest in higher strength rocks.

Our confidence in the post-closure environmental safety of a GDF developed in a higher strength host rock is based on several decades of research and development by both Nirex and the national waste management organisations in Sweden and Finland, supplemented by our own work to understand any modifications that might be required to adapt the concept to UK conditions. With regard to the post-closure environmental safety of a GDF developed in alternative geological environments we are building on the work of national waste management organisations in a range of countries (i.e. Switzerland, France, Germany and the USA). Consideration of the work in these countries has allowed us to develop a good understanding of the major chemical and physical processes that would provide containment of the inventory and retardation of any radionuclides that are released from the waste packages [21].

Whilst we acknowledge that our understanding of the post-closure performance of a GDF constructed in a higher strength host rock is more developed than that for other geological environments, we believe that our understanding is sufficiently developed for us to carry out qualitative assessments of the consequences of alternative geologies as part of the assessment of the post-closure safety of packaging proposals.

6.3.4 Other aspects of disposability assessments

As part of each disposability assessment, usually at the Conceptual stage, we carry out a non-radiological environmental assessment of the packaging proposal to check that there are no aspects of the proposal that are inconsistent with wider environmental protection considerations. This includes an assessment of the impact of the implementation of the proposal with regard to protection of human health and the natural environment.

We also review the packaging proposal from the perspective of various specialist functions which will influence the design and/or required characteristics of the waste package. This includes:

- reviewing the status of the waste package contents from the perspective of international Safeguards to ensure that they will be consistent with the Safeguards arrangements currently envisaged for a GDF;
- reviewing the status of the waste packages from the perspective of physical security to ensure that they will be compliant with the security plan developed for transport and operations at a GDF. Advice from the Office for Civil Nuclear Security may be sought in this area;
- providing confirmation that the SLC is meeting the requirements for quality management [43] and the recording of data pertaining to the waste packages during manufacture and storage [42];
- reviewing the packaging proposal from the perspective of our assessment policy and principles (Section 6.2, [14]) and our environmental and safety policies [4].

6.4 Possible outcomes of the disposability assessment process

Each stage of the disposability assessment process will result in the production of an assessment report which draws together the results of the technical evaluations and comparisons with the concept safety assessments and presents them in the form of a disposability assessment. The disposability assessment is intended to show in a transparent and visible way those respects in which the packaging proposal is compliant with the relevant packaging standards and specifications and with the underlying safety, environmental and security assessments for transport and disposal.

At the Conceptual stage it is to be expected that the disposability assessment will be in outline form only, but sufficiently developed to judge the overall feasibility of the packaging concept. As noted previously, at this stage the assessment may be provided as a means of comparing different conditioning and packaging options, as an input to an optimisation process.

As the packaging concept is developed through the Interim and Final stages it is to be expected that the disposability assessment will become progressively developed such that at the Final stage it is robustly supported by all necessary design and research and can be presented to the waste packager as a disposability case. In line with regulatory guidance [15] it is envisaged that the disposability case presented at the conclusion of the Final stage assessment will be of sufficient quality and scope that it can be adopted by the site operator and incorporated into the RWMC as part of the overall safety case for the packaging plant.

In the event that a disposability assessment identifies no significant uncertainties in the ability of the proposed packaging approach to produce disposable waste packages, an LoC will be issued to accompany the assessment report and endorse the packaging proposal. Depending on the stage of the assessment the issue of an LoC indicates:

- Conceptual stage: That the proposed waste package would in principle be compliant with the generic geological disposal concept(s).
- Interim stage: That evidence has shown that the as-designed waste package would be compliant with the generic geological disposal concept(s).
- Final stage: That evidence has shown that the as-manufactured waste package would be compliant with the generic geological disposal concept(s).

Where significant uncertainties remain at the end of an assessment, such as to prevent the issue of an LoC, this will result in the identification of one or more ‘action-points’ requesting close-out of the uncertainty. In some cases of limited uncertainty a ‘qualified’ LoC may be issued. Such qualification may comprise:

- a *caveated* LoC; where there is uncertainty as to whether an issue may arise during packaging, which may result in a need for remedial action during or after the manufacture of waste packages;
- a *conditional* LoC; where further evidence is required regarding the proposed packaging process, that may have to be obtained during active commissioning of the packaging plant; or
- an LoC with *exclusions*; where specified components of the waste stream are excluded from the endorsement.

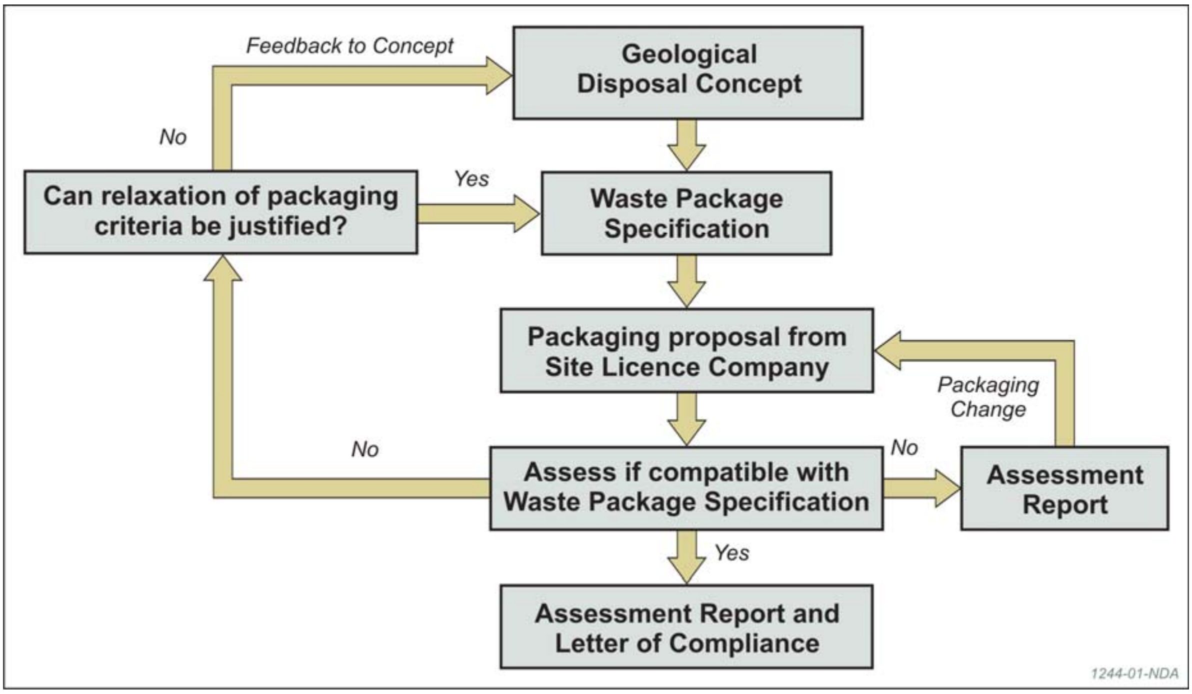
6.5 Change control and the disposability assessment process

As noted above, the performance of a disposability assessment may or may not result in the issue of an LoC endorsing the disposability of the waste packages which would be expected to result from the implementation of a proposed approach to packaging. The failure to gain such endorsement may mean that the waste packages would not comply with one or more of the following:

- the relevant specification for the selected waste package type;
- the geological disposal concept, as currently defined; and/or
- one or more of the three safety cases produced for the transport and disposal of waste packages.

Figure 7 illustrates the possible outcomes of a disposability assessment and shows the routes available in the event that the outcome of and assessment cannot be immediately accompanied by an LoC.

Figure 7 Possible outcomes of a disposability assessment



This shows that there are three approaches which could be adopted to permit the issue of an LoC under such circumstances:

- By changing some aspect of the packaging proposal (e.g. by reducing the proposed radionuclide inventory or by adopting alternative conditioning processes) such that previous areas of non-compliance are removed;
- By considering the basis for the definition of the packaging requirement with which compliance could not be shown, to investigate whether a quantified requirement (e.g. package heat output, fissile material content) could be changed without any risk to overall safety; or
- By changing some aspect of the disposal concept to accommodate the proposed waste packages.

For changes involving either of the latter two approaches we have established a procedure for disposal concept change control [44]. The purpose of this procedure is to ensure that proposed changes to the geological disposal concept are recorded, assessed and implemented at an appropriate time and in a consistent way. This would include assessing the effects of any change on the disposal safety cases and ensuring that changes are recorded in the relevant documentation, such as the disposal systems designs and the packaging specifications.

6.6 Control of the manufacture of waste packages

The issue of a Final stage LoC is not a one off event but is simply a step in the process for the long-term management of the waste. Controls will be established to ensure that implementation of the packaging proposal and the manufacture of waste packages takes place in compliance with the processes which were assessed and against which the endorsement of the processes to result in disposable waste packages was carried out. This will include ensuring that:

- waste packages are produced and stored in accordance with a defined Waste Product Specification (WPrS);
- sufficient data of an adequate quality are generated during the manufacture of the waste package and its subsequent storage, and are recorded in a manner that ensures the long term availability of that data;
- packaging and storage have been carried out in accordance with an approved quality management system; and that
- independent checks have been made to confirm that packaging and storage have taken place in accordance with the terms of the LoC endorsement.

A WPrS is a document that describes the waste package that is to be manufactured by the proposed processes by defining the key limits and controls that will apply during manufacture [45]. A WPrS will have been produced by the SLC and assessed and agreed as part of the disposability assessment.

This important document will eventually be used, together with other records, to demonstrate that waste packages are compatible with all future stages of waste management and will meet the WAC for a GDF. It can also be used to confirm that the packaging process and resultant product are compliant with that considered during the disposability assessment and endorsed by the Final stage LoC.

A key part of a WPrS is the criticality compliance assurance documentation [46] which will describe the procedures that will be followed to control the quantities of fissile material that are included in waste packages during manufacture. This control is important in ensuring that waste packages will be compliant with the assumptions made during the assessment of criticality of waste packages during all stages of long-term waste management, including disposal. The SLC will be required to determine an appropriate safe fissile mass for the proposed waste packages, based on assessments of the criticality safety of the waste packages during interim storage, transport and GDF operations.

We will require SLCs to permit verification that waste package manufacture and storage is taking place in accordance with the terms of the LoC endorsement and with the various control documentation (notably the WPrS). It is anticipated that this will be by way of ongoing technical audit by ourselves and compliance audits by the regulators.

6.7 Post-manufacture treatment of waste packages

Following their manufacture waste packages may spend an extended period (i.e. up to several decades) in interim surface storage prior to their transport to a GDF. Waste packages would be expected to evolve during this time and it is therefore important that:

- the environment in the store is maintained in such a manner to minimise the deleterious effects of such evolution; and
- the condition of waste packages is monitored to identify waste packages which have evolved in such a way that they:
    - are no longer compliant with the needs for their ongoing management; or
    - are showing signs of deterioration that may lead to them being non-compliant prior to transport.

We have produced guidance on the control of the environmental conditions during interim surface storage [47] and on the waste package monitoring regimes that should be instituted during such storage [48].

For waste packages which are more than 10 years old it is anticipated that the process for the periodic review of LoC endorsement (see Section 6.8) would include a review of the waste package monitoring arrangements and a consideration of the consequences of any package evolution that this monitoring has identified.

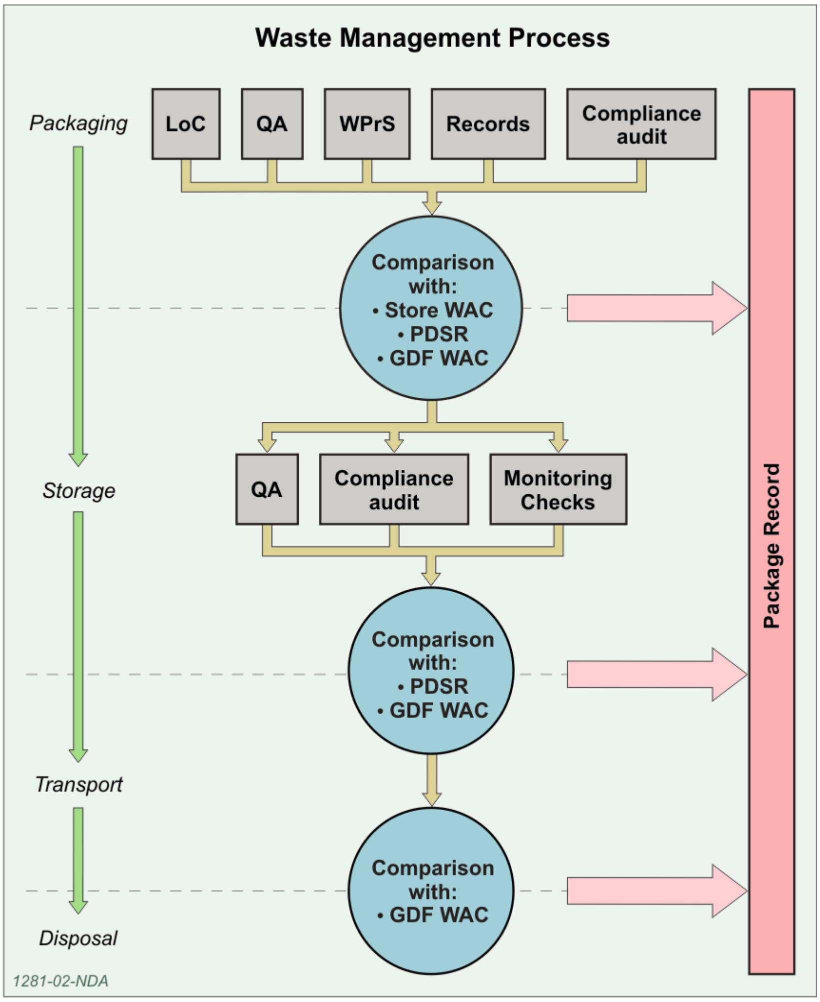
6.8 Periodic review of LoC endorsement

The LoC and accompanying disposability case must be maintained up to date otherwise they will eventually lose relevance and the benefits of the assessment process would be lost. We operate a periodic review process [49], whereby LoCs and their underpinning disposability assessments are revisited and updated on a notional ten-yearly cycle. This means that the LoC and its associated records are kept 'live' and the disposability case would never be more than 10 years old.

6.9 Creation and maintenance of the package record

As part of the implementation of a packaging proposal, and the manufacture of waste packages, is the creation of a 'package record' which will follow each waste packages through the subsequent stages of its onward long-term management. The contents and role of the package record is summarised in Figure 8, the latter aspect being expanded in the following sections.

Figure 8 Contents and role of the package record



The key roles of the package record is to demonstrate that the waste package has been manufactured and stored in accordance with the terms of the LoC endorsement and to ensure the maintenance of adequate records of the package's contents and treatment during and subsequent to manufacture. To achieve this each package record should include the original LoC together with information from periodic reviews (Section 6.8), the WPrS and associated manufacturing records (Section 6.6), and any records created during interim storage most notably the results of waste package monitoring and inspection (Section 6.7).

The package record will play an important role in supporting the safety cases for all subsequent periods of the waste package's long term management including interim storage at the SLC's site, transport to and emplacement operations at a GDF and for the GDF post-closure period. It will also play an essential role in demonstrating compliance with the requirements for transport (Section 6.10.1) and the WAC for a GDF (Section 6.10.2).

6.10 Compliance checks for waste packages

When a GDF has been constructed and licensed to receive waste, a programme for the emptying of interim stores will commence. Up to this point the ability of waste packages to be compliant with the needs of transport and disposal will have been addressed by the criteria defined within the relevant generic specification. However, once the design, location and mode of operation of a GDF have been agreed and licensed, the generic specification would be replaced by facility specific WAC based on the site licence and environmental authorisation. In addition waste packages will need to be demonstrated as being compliant with the requirements for transport. Some of these requirement (as discussed below) will be defined by direct quantified applications of the relevant regulatory requirements (i.e. for either transport and/or disposal) whilst others will be driven by the needs of the transport and/or GDF systems.

6.10.1 Compliance of waste packages with needs of transport

As discussed earlier, the transport of waste packages between nuclear licensed sites through the public domain will be subject to the requirements of the IAEA Transport Regulations. Demonstrating compliance with these regulations will be by way of a formal check that a transport package (which may comprise a waste package or one or more wastes packages transported within a transport container) is compliant with the relevant approval.

The processes used to approve the transport of radioactive waste are explained in full in the Transport Package Safety (TPS) report [50].

For Type B transport packages and all transport packages containing significant quantities of fissile material approval is by way of a two stage process which comprises:

- Approval by a Competent Authority (e.g. the Department for Transport - DfT) of the PDSR for a specific design of transport package and the granting of a *Certificate of Approval*; and
- A demonstration by the waste consignor that the proposed payload inventory of a transport package is compliant with the terms of the Certificate of Approval.

For transport packages that are not subject to Competent Authority approval (for example Industrial Packages that carry limited quantities of radioactive material) a process of 'self approval' is used [51].

Compliance with the regulations for transport is the responsibility of the package consignor. Certificates of approval for package design define the limits and controls on transport. Typically, for packages that carry a complex range of material a *contents specification* is used to define what can be transported. A contents specification uses the various transport package limits defined by the IAEA Transport Regulations to derive numerical limits on the waste package radionuclide inventory for the full range of radionuclides that could be present (see Section 3.5). These limits are set on the basis of:

- total activity;
- radiogenic heat generation;
- external radiation dose rate;
- radioactive gas generation and release;
- activity release under normal and accident conditions of transport; and
- criticality safety.

For some transport packages, notably those classed as Type IP, it would also be necessary to show that the radionuclide inventory and physical properties of the waste package contents are such that they can be classed as low specific activity (LSA) material or surface contaminated objects (SCOs)[24] and which are capable of being excepted from the requirements for packages containing fissile material[25],. For waste packages transported without overpacking, compliance with regulatory requirements for limits on non-fixed surface contamination will also be required.

The demonstration of the compliance of waste packages with the relevant contents specification, and therefore with the PDSR, will be mainly by way of the package record. This will supply bounding values for quantities such as the radionuclide inventory of waste packages containing material from a particular waste stream. This would be backed up by physical measurements (e.g. of external dose rate, heat emission, non-fixed surface contamination) and visual examination to confirm the lack of visible signs of any deterioration of the waste packages which could have occurred since manufacture (e.g. waste container corrosion, lid seal deterioration).

6.10.2 Compliance of waste packages with the WAC for a GDF

It is assumed that a GDF would be a nuclear licensed site and, as such, will be subject to the terms of the operating licence granted by the Nuclear Installations Inspectorate. As in the case of the requirements for transport, the generic counterparts to these site-specific requirements are currently incorporated in the relevant generic specification. However, whilst the generic specification reflects the requirements for both transport to and disposal in a GDF, the WAC will only reflect those for the latter.

We anticipate that the WAC will have two strands:

- Limits on the nature and quantity of the contents of waste packages, in particular their radionuclide inventory, to ensure compliance with the safety case for disposal; and
- Performance requirements derived from the needs of a GDF, such as waste package dimensions, handling features, stacking performance and impact and fire accident performance.

As in the case of transport, the process of demonstrating compliance will be by a combination of administrative checks backed up by measurements and/or visual inspections. These would be expected to include:

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[24] LSA material and SCOs are two classes of radioactive material defined by the IAEA Transport Regulations [22].

[25] The requirements for such ‘fissile exception’ are defined by the IAEA Transport Regulations [22].

- Confirmation of the validity of the current WPrS (or equivalent);
- Analysis of the package record and comparison with the WAC;
- Outcomes of the handover process (the ‘handshake’) between the waste consigner and the transport operator prior to despatch;
- Outcomes of the handshake between the transport operator and the GDF operator on receipt; and
- Visual checks prior to emplacement in the disposal vaults (e.g. visual inspection of external surfaces of waste packages for deformation, damage or deterioration of surface, and confirmation of the legibility and validity of the package identification number).

7 Summary

In order that geological disposal can be safely implemented for the long-term management of the UK's higher activity radioactive waste, it is important that the materials that could be destined for such an approach are identified and quantified. By drawing on published information regarding the existing stocks and anticipated future arising of such materials in the UK this report has described and discussed the nature and quantities of the following categories of waste and materials which may be defined as waste in the future:

- low level waste which is unsuitable for near-surface disposal;
- intermediate level waste;
- high level waste;
- spent nuclear fuel;
- plutonium; and
- uranium.

This report has discussed both the general risks involved in the long-term management of radioactive materials as well as those specific to the geological disposal of the materials identified. It has also described the disposability assessment process that is routinely used to assist sites in the treatment and conditioning of these materials into a form that is compatible with plans for eventual transport and disposal. It highlights the important role by the process in facilitating early conditioning of wastes thus reducing the hazard they present, whilst giving confidence regarding its management in the long-term.

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44. NDA/RWMD, *Geological Disposal Facility Concept Change Management*, RWPR40, 2009.

45. RWMD, *Waste Product Specifications: Guide to Structure and Format*, WPS/620/02, 2008.

46. RWMD, *Guidance on the Preparation of Criticality Compliance Assurance Documentation for Waste Packaging Proposals*, WPS/625/02, 2008.

47. RWMD, *Guidance on Environmental Conditions during Storage of Waste Packages*, WPS/630/02, 2008.

48. RWMD, *Guidance on Monitoring of Waste Packages during Storage*, WPS/640/02, 2008.

49. RWMD, *Guidance on the Scope of Periodic Review of Final stage Letters of Compliance*, WPS/909, 2009.

50. RWMD, *Geological Disposal: Transport Package Safety*, NDA/RWMD/023, 2010.

51. Transport Container Standardisation Committee, *Transport of Radioactive Material Code of Practice. Self Assessment and Approval of Package Types IP-1, IP-2, IP-3 & Type A*, TCSC 1078, 2009.

Appendix A RWMD Disposability Assessment Policy and Principles

A1 Disposability Assessment Policy Statement

The RWMD Disposability Assessment Process exists to facilitate effective and efficient implementation of geological disposal of higher activity radioactive waste, and as an enabler for hazard reduction on UK nuclear sites.

A2 Disposability Assessment Principles

1. Independent disposability assessments of waste packages containing higher activity waste (or materials) will be provided following assessment against published packaging standards and specifications based on appropriate transport and disposal concepts, with appropriate consideration given to storage insofar as it should not jeopardise the latter stages.

2. Letters of Compliance will be issued to signify that a waste package is compliant with safety cases underpinning the geological disposal concept and will be included within the "disposal inventory" for which RWMD (and successor GDF operator) seeks authorisation under RSA 93.

   The Letter of Compliance is not a guarantee of acceptance however and does not remove the need for waste packages to satisfy future Waste Acceptance Criteria for disposal in a Geological Disposal Facility, or regulations (e.g. for transport) that may be in force at the time.

3. Endorsement of proposals to package waste through the Letter of Compliance process will be contingent on the proposals being seen by the NDA as being compatible with Government policy on geological disposal. This may be achieved for example by demonstration of application of the waste hierarchy, or by demonstration that the proposal represents the Best Practicable Environmental Option, or by provision of a business case demonstrating that the proposal represents a net overall benefit.

   Wastes covered by a Letter of Compliance should also be demonstrated as being the liability of the NDA or other UK waste holding organisation.

4. Waste retrieval and conditioning projects' stage gate approvals, will be supported by provision of disposability assessments suitable for incorporation into the Radioactive Waste Management Case and through the issue of Letters of Compliance at discrete stages, defined to suit the needs of the project. The issue of a Letter of Compliance at each of these stages indicates:

   - Conceptual stage: That the proposed waste package will in principle be compliant with the current geological disposal concept.
   - Interim stage: That evidence has shown that the as designed waste package will be compliant with the current geological disposal concept.
   - Final stage: That evidence has shown that the as manufactured waste package will be compliant with the current geological disposal concept.

5. A systematic approach to the evaluation of uncertainties which could affect the ability of a proposed packaging process to produce disposable waste packages will be adopted. Where significant uncertainty exists, a Letter of Compliance will not be issued, although where such uncertainty is more limited, a qualified Letter of Compliance may be issued.

6. Standardisation of waste package designs and sharing of knowledge gained during waste package assessments will be promoted through the publication of waste package specification and associated guidance materials and by the provision of standard waste package descriptions.

7. The need for flexibility in conditioning and packaging is recognised and will be encouraged by early engagement with waste holders as a means of promoting approaches that are both innovative and proportionate to the hazard presented by the waste.

   Where appropriate, RWMD will modify disposal concepts and/or packaging standards where safety is not compromised and there is an overall net benefit.

8. The step-wise manufacture of waste packages will be supported by Letters of Compliance in cases where:

   - there is a justifiable benefit in such an approach;
   - each step represents a progressive step towards a disposable waste package;
   - each step brings about a progressive reduction in the hazard potential of the waste; and
   - each step is considered credible within the constraints of current technology.

9. The risk of future non-compliance with GDF Waste Acceptance Criteria will be minimised by a process of periodic review of Letters of Compliance and Disposability Assessments. This will be designed as part of a structured transition from LoC endorsement to a GDF waste acceptance process and give confidence as to the continued currency of LoCs based on plant operational experience and up to date GDF safety cases.

10. The principles of openness and transparency will be applied to the disposability assessment process and RWMD will engage with stakeholders, within the constraints of security, commercial and contractual considerations.

Appendix B Examples of the role played by the disposability assessment process in the optimisation of packaging approaches

This appendix describes three case studies where the disposability assessment process has been used to facilitate the production of waste packages that have been demonstrated to meet the needs of transport and disposal and which have also met the safety case needs for processing and storage.

B1 Technetium-99 abatement

During the period 2003/04 the disposability process was applied to assist BNFL (the then operator of the Sellafield site) reduce discharges of the radionuclide technetium-99 to the Irish Sea[26].

In August 2003 BNFL submitted a formal application to Nirex for a Letter of Comfort covering waste packages that would be produced as a result of a plant-scale trial of the tetraphenyl phosphonium bromide (TPPB) abatement technology proposed to be introduced into the Enhanced Actinide Removal Plant (EARP). The proposal was to treat a quantity of medium active concentrate (MAC) containing a significant quantity of technetium-99. The concentrated floc produced in EARP would then be mixed with flocs from other sources and packaged for disposal in 500 litre drums in the Waste Encapsulation and Packaging Plant (WPEP).

During the disposability assessment of the proposal the fundamental aim for Nirex was to ensure that the waste packages produced as a result of the plant-scale trial (involving the processing of 240m^3 of MAC containing 31TBq of technetium-99) would be compatible with requirements for their geological disposal. A secondary consideration was to determine, in the event that the trial was a success, the acceptability of the further waste packages that would result from the processing of all remaining stocks of MAC (1,910m^3 of MAC containing 245TBq of technetium-99) in the same manner.

Nirex concluded that a Letter of Comfort could be issued for waste packages produced by a plant-scale trial based on the following rationale and conclusions:

- The total technetium-99 inventory assumed for disposal would be 921TBq with a bounding case inventory of 1,830 TBq;
- Laboratory trials suggested that whilst the addition of TPPB would affect viscosity of the floc it should affect the quality or performance of the proposed waste packages (Confirmation of this would be required as part of the trial);
- Transport and operational safety would not be expected to be adversely affected by the use of TPPB or of the presence of the additional technetium-99;
- A post-closure assessment utilising a pessimistic approach demonstrated that the additional technetium-99 would not lead to the 10^{-6} regulatory risk target being exceeded;
- Assessment of the effect of technetium-99 on redox potential in the disposal environment was investigated and concluded that there are many factors that would predicate against establishment of oxidising conditions;
- The potential for breakdown of TPPB and for the degradation products to complex radionuclides was investigated in experiments involving degradation products and plutonium, no increase in solubility was detected;

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[26] http://ndahqsrv014:8093/news/pdffiles/na40421.pdf

- For other post-closure pathways, gas and human intrusion, no additional impacts were noted, likewise there was no additional burden with regard to chemical toxicity.

Nirex issued a Final stage LoC for the plant-scale trial waste packages in September 2003. The trial results were encouraging and in April 2004 Nirex was able to issue a Final stage LoC for the processing of the remaining MAC stocks using this process.

B2 Packaging options for vitrified HLW

During the period 2007-09 RWMD provided a preliminary assessment[27] of the disposability of vitrified HLW product produced in the Wastes Vitrification Plant (WVP) at Sellafield. This assessment was unusual insofar that the products for disposal were already being manufactured and whilst they were thought to be disposable this had never been formally demonstrated. The engagement with RWMD was initiated in order to allow RWMD and Sellafield to get to a position where a formal Letter of Compliance could be issued, but also to facilitate assessment of alternative packaging options, such that (as discussed in Section 6.1) the iterative assessment cycle be used to identify an optimal packaging (and disposal) arrangement.

The assessment was initially conducted taking a base case that is consistent with the assumptions of the DSSC for HLW (i.e. that two vitrified product containers would be overpacked inside a sealed copper disposal canister prior to dispatch to the GDF) and that the final waste packages would be emplaced in the GDF following the same process as envisaged for spent fuel.

The assessment also considered a further three options:

- three vitrified product containers in a copper disposal canister;
- the use of a mild steel disposal canister;
- the disposal of vitrified product without overpacking.

Proposals to increase the 'incorporation rate' of HLW in WVP products were also considered.

The preliminary assessment concluded that it may be feasible to make a disposability case for the three vitrified product container variant, based on a generic geology and that several advantages (e.g. a reduced GDF footprint, a reduced number of transport operations) were identified from adopting a larger overpack. To make this feasible, it may be necessary to provide certain design enhancements for this larger overpack to enhance its impact accident performance.

The assessment also concluded that it should be possible to make a disposability case for all packaging options where a robust disposal canister (i.e. copper or mild steel) is used on the basis of the assumed generic geological environment. The mild steel variant would be expected to perform in a largely similar fashion to the base case (i.e. copper) under similar conditions, except perhaps in respect of its longevity due to poorer corrosion performance. However, earlier degradation of the waste container barrier does not appear to have any significant effect on post-closure risk. Use of a mild steel disposal canister may also provide some advantage over the use of copper in terms of resources, cost and availability and this may need to be explored further.

In the case of the option where vitrified product containers are themselves treated as the disposal package, there are a number of specific issues that would need to be addressed

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[27] http://www.nda.gov.uk/documents/upload/Executive-Summary-Letter-of-Compliance-Assessment-Report-Vitrified-High-Level-Waste-April-2009.pdf

in order to make a disposability case if this option were to be pursued. In particular, consideration would need to be given to:

- near-field heat loading (and associated performance of the bentonite backfill);
- corrosion performance of the package;
- the control of surface contamination and its implications on accident performance;
- impact accident performance; and
- the glass dissolution rate under water saturated geological conditions.

In the case of the assessment of safety during transport it was noted that further information on the behaviour of vitrified product under impact conditions would enable a less conservative assessment to be undertaken.

The submission provided detailed information on the radionuclide inventory of individual batches of WVP products and the assessment identified that the heat output of these packages should be low enough to present opportunities for their emplacement in the GDF sooner than the previously assumed date of 2075.

Initial indications suggest that increasing the HLW incorporation rate in WVP products should not adversely affect disposability, though the dissolution behaviour of vitrified wasteforms under saturated conditions needs to be better understood before it would be possible to provide Final stage endorsement of waste packages containing such products.

A number of research activities were identified for Sellafield and for RWMD in order to close out residual uncertainties. These essentially revolve around the earlier discussion around Figure 2 regarding the relative importance of the wasteform and the waste container as contributors to the multiple barrier containment system.

B3 High temperature processing of ILW

In 2007/08 RWMD carried out a disposability assessment[28] which did not consider proposals to package a particular waste stream but rather a conditioning process that could be applied to a range of wastes. The assessment was carried out on behalf of the developer of a process for the high temperature treatment of radioactive waste that could be used to transform a wide range of typical intermediate level waste materials into a stable vitreous and crystalline material that could be suitable for disposal in a GDF. The process which to date has been used for the treatment of materials overseas can also destroy, remove, or permanently immobilise chemical contaminants within waste. The process offers the potential for significant volume reductions over more conventional conditioning processes (e.g. the mixing of wastes with a cementitious grout) as well as cost savings.

A preliminary disposability assessment was carried out to determine the compatibility of the vitrified waste product with the expected requirements for long-term management in the UK.

The process of assessing what is in effect a new wasteform for intermediate level waste needs to consider the compatibility of the proposed wasteform with the other barriers within the disposal system. In the case of intermediate level wastes, the backfill which is proposed to be used to infill voids around waste packages, comprises cementitious materials within the illustrative examples concepts for higher strength rocks and lower strength sedimentary rocks. The outcome of this preliminary assessment has identified the potential for incompatibility between the wasteform and backfill as currently planned. The assessment

[28] http://www.nda.gov.uk/documents/upload/Executive-Summary-Letter-of-Compliance-Assessment-Report-GeoMelt-Vitrification-of-ILW-May-2008.pdf

has therefore played an important role in evolving both the development of vitrified products and of the disposal concept to accommodate them.

The assessment confirmed that the process can potentially reduce the volume of the waste requiring geological disposal and that it could also use contaminated soil as part of the glass-forming materials that would need to be added as part of the process. This therefore has the potential to further reduce the volume of the waste ultimately requiring disposal. It also showed that:

- adequate standards of transport safety would be possible for waste packages containing the vitrified product, including those with significant fissile material content;
- waste packages containing vitrified product could be safely handled and stored during the operational period of a GDF; and that
- vitrification of ILW could lead to benefits in the longer term as the post-closure safety case would have lower inventory of organic content and the wasteform would provide potentially lower leach rate of radionuclides and reduced gas generation.

The assessment identified a number of areas where research would be needed to provide the evidence base needed to support the disposability assessment. The assessment also highlighted that the optimal solution would be to develop a tailored disposal concept which utilised a backfill that was specifically developed to work together with the wasteform. The necessary design studies and research are currently in hand.

Appendix C Glossary of terms used in this report

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).

Advanced Gas-cooled Reactor (AGR)

The reactor type used in the UK's second generation nuclear power plants.

alpha activity

Alpha activity takes the form of particles (helium nuclei) ejected from a decaying (radioactive) atom. Alpha particles cause ionisation in biological tissue which may lead to damage. The particles have a very short range in air (typically about 5 cm) and alpha particles present in materials that are outside of the body are prevented from doing biological damage by the superficial dead skin cells, but become significant if inhaled or swallowed.

Andra

The organisation responsible for waste management and the development and operation of disposal facilities in France.

backfill

A material used to fill voids in a GDF. Three types of backfill are recognised:

- local backfill, which is emplaced to fill the free space between and around waste packages;
- peripheral backfill, which is emplaced in disposal modules between waste and local backfill, and the near-field rock or access ways; and
- mass backfill, which is the bulk material used to backfill the excavated volume apart from the disposal areas.

backfilling

The refilling of the excavated portions of a disposal facility after emplacement of the waste.

barrier

A physical or chemical means of preventing or inhibiting the movement of radionuclides.

Baseline Inventory

An estimate of the higher activity radioactive waste and other materials that could, possibly, come to be regarded as wastes that might need to be managed in the future through geological disposal drawn from the UK Radioactive Waste Inventory.

becquerel (Bq)

The standard international unit of radioactivity equal to one radioactive decay per second. Multiples of becquerels commonly used to define radioactive waste activity are:

- kilobecquerels (kBq) equal to 1 thousand (10^3) Bq
- megabecquerels (MBq) equal to 1 million (10^6) Bq
- gigabecquerels (GBq) equal to 1 billion (10^9) Bq
- terabecquerels (TBq) equal to 1 trillion (10^{12}) Bq

beta activity

Beta activity takes the form of particles (electrons) emitted during radioactive decay from the nucleus of an atom. Beta particles cause ionisation in biological tissue which may lead to damage. Most beta particles can pass through the skin and penetrate the body, but a few millimetres of light materials, such as aluminium, will generally shield against them.

biosphere

Regions of the earth’s surface and atmosphere normally inhabited by living organisms.

buffer

An engineered barrier that protects the waste package and limits the migration of radionuclides following their release from a waste package.

canister

A term used in specific concepts to describe the waste container into which a wasteform is placed.

conditioning

Treatment of a radioactive waste material to create, or assist in the creation of, a wasteform that has passive safety

conditioned waste volume

The conditioned waste volume is the volume of the wasteform (waste plus immobilising medium) within the container.

container

The vessel into which a wasteform is placed to form a waste package suitable for handling, transport, storage and disposal.

containment

The engineered barriers, including the waste form and packaging, shall be so designed, and a host geological formation shall so be selected, as to provide containment of the waste during the period when waste produces heat energy in amounts that could adversely affect the containment, and when radioactive decay has not yet significantly reduced the hazard posed by the waste

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.

decommissioning

The process whereby a nuclear facility, at the end of its economic life, is taken permanently out of service and its site made available for other purposes. The term ‘site clean-up’ is sometimes used to describe the work undertaken to make the site available for other purposes.

decommissioning waste

Radioactive waste produced during operations involved in the decommissioning of a nuclear facility (as distinct from *operational waste*).

disposability

The ability of a waste package to satisfy the defined requirement for disposal.

disposability assessment

The process by which the *disposability* of proposed waste packages is assessed. The outcome of a disposability assessment may be a *Letter of Compliance* endorsing the disposability of the proposed waste packages.

disposal

In the context of solid waste, disposal is the emplacement of waste in a suitable facility without intent to retrieve it at a later date; retrieval may be possible but, if intended, the appropriate term is storage.

disposal canister

A term used to describe the assembly of certain waste types (e.g. HLW, spent fuel, plutonium, HEU) within a metal container, as prepared for disposal.

disposal facility (for solid radioactive waste)

An engineered facility for the disposal of solid radioactive wastes.

disposal system

All the aspects of the waste, the disposal facility and its surroundings that affect the radiological impact.

disposal unit

A waste package, or group of waste packages, which is handled as a single unit for the purposes of transport and/or disposal.

disposal vault

Underground opening where ILW or LLW waste packages are emplaced.

dose

A measure of the energy deposited by radiation in a target.

dose rate

The effective dose equivalent per unit time. Typical units of effective dose are sievert/hour (Svh^{-1}), millisieverts/hour ($mSvh^{-1}$) and sievert/year (Svy^{-1}).

emplacement (of waste in a disposal facility)

The placement of a waste package in a designated location for disposal, with no intent to reposition or retrieve it subsequently.

engineered barrier system

The combination of the man-made engineered components of a disposal facility, including the waste packages/disposal canisters, buffer, backfills and seals.

enrichment (uranium)

The proportion (usually expressed as a % of the total mass) of uranium-235 in uranium.

Environment Agency (EA)

The environmental regulator for England and Wales. 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 (surface water, groundwater) and land. The Environment Agency also regulates nuclear sites under the Environmental Permitting Regulations and issues consents for non-radioactive discharges.

environmental safety

The safety of people and the environment both at the time of disposal and in the future. (Definition taken from the GRA.)

environmental safety case

The collection of arguments, provided by the developer or operator of a disposal facility, that seeks to demonstrate that the required standard of environmental safety is achieved.

evaporite

The generic term for a geological environment created by the evaporation of water from a salt bearing solution to form a solid structure.

external irradiation

The exposure of a body to radiation arising from sources located outside of the body.

fissile material

Fissile material is that which undergoes fission under neutron irradiation. For regulatory purposes material containing any of the following nuclides is considered to be 'fissile': uranium-233, urainium-235, plutonium-239 and plutonium-241.

fission product

A radionuclide produced by nuclear fission.

gamma activity

An electromagnetic radiation similar in some respects to visible light, but with higher energy. Gamma rays cause ionisations in biological tissue which may lead to damage. Gamma rays are very penetrating and are attenuated only by shields of dense metal or concrete, perhaps some metres thick, depending on their energy. Their emission during radioactive decay is usually accompanied by particle emission (beta or alpha activity).

geological disposal

A long term management option involving the emplacement of radioactive waste in an engineered underground geological disposal facility or repository, 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.

geological environment

The structure, composition and physical and chemical characteristics of the rocks that make up the geosphere.

geosphere

The rock surrounding a GDF that is located below the depth affected by normal human activities and is therefore not considered to be part of the biosphere.

groundwater

Water located beneath the earth's surface in rock pores and fractures.

half-life

The time taken for the activity of a given amount of a radioactive substance to decay to half of its initial value. Each radionuclide has a unique half-life.

hazardous materials

Materials that can endanger human health if improperly handled. As defined by the Control of Substances Hazardous to Health Regulations, 2002.

Health and Safety Executive (HSE)

A statutory body whose role is the enforcement of work related health and safety law. HSE is the licensing authority for nuclear installations. The Nuclear Safety Directorate of HSE exercises this delegated authority through the Nuclear Installations Inspectorate (NII) who are responsible for regulating the nuclear, radiological and industrial safety of UK nuclear installations under the Nuclear Installations Act 1965 (NIA 65).

higher activity radioactive waste

Generally used to include the following categories of radioactive waste: low level waste not suitable for near surface disposal, intermediate level waste and high level waste.

higher strength rock

Typically crystalline igneous and metamorphic rocks or geologically older sedimentary rocks where any fluid movement is predominantly through discontinuities.

high level waste (HLW)

Radioactive wastes in which the temperature may rise significantly as a result of their radioactivity, so this factor has to be taken into account in the design of storage or disposal facilities.

highly enriched uranium (HEU)

Uranium in which the proportion of uranium-235 is greater than ~20%.

immobilisation

A process by which the potential for the migration or dispersion of the radioactivity present in a material is reduced. This is often achieved by converting the material to a monolithic form that confers passive safety to the material.

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)

Radioactive wastes exceeding the upper activity boundaries for LLW but which do not need heat to be taken into account in the design of storage or disposal facilities.

internal irradiation

The exposure of a body to radiation arising from sources located inside the body.

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" organization 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.

ionisation

When radiation (alpha, beta, and gamma activity) interacts with matter, it can cause atoms and molecules to become unstable (creating ions). This process is called ionisation. Ionisation within biological tissue from radiation is the first stage in radiation leading to possible change or damage within the tissue.

isolation

A GDF shall be sited in a geological formation and at a depth that provide isolation of the waste from the biosphere and from humans over the long term, for at least several thousand years, with account of both the natural evolution of the geological disposal system, and events that could disturb the facility.

Letter of Compliance (LoC)

A document, prepared by RWMD, 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 disposal in a GDF.

low enriched uranium (LEU)

Uranium in which the proportion of uranium-235 is greater than ~0.7% but less than ~20%.

lower strength sedimentary rock

Typically geologically 'young' sedimentary rocks where any fluid movement is predominantly through the rock matrix.

low level waste (LLW)

Defined as "radioactive waste having a radioactive content not exceeding 4 gigabecquerels per tonne (GBq/te) of alpha or 12 GBq/te of beta/gamma activity".

Low Level Waste Repository (LLWR)

The UK national facility for the near surface disposal of solid LLW, located near to the village of Drigg in Cumbria.

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.'

Managing Radioactive Waste Safely (MRWS)

A phrase covering the whole process of public consultation, work by CoRWM, and subsequent actions by Government, to identify and implement the option, or combination of options, for the long term management of the UK's higher activity radioactive waste.

natural uranium

Uranium containing the naturally occurring distribution of uranium isotopes (approximately 99.28% uranium-238 and 0.72% uranium-235 by mass).

near field

The engineered barrier system (including the wasteform, waste containers, buffer materials, backfill, and seals), as well as the host rock within which the GDF is situated, to whatever distance the properties of the host rock have been affected by the presence of a GDF.

Nirex (United Kingdom Nirex Limited)

An organisation previously owned jointly by Department for the Environment, Food and Rural Affairs and the Department for Trade and Industry. Its objectives were, in support of Government policy, to develop and advise on safe, environmentally sound and publicly acceptable options for the long-term management of radioactive materials in the United Kingdom. The Government's response to Committee on Radioactive Waste Management in October 2006 initiated the incorporation of Nirex functions into the NDA, a process which was completed in March 2007.

Nuclear Decommissioning Authority (NDA)

The NDA is the implementing organisation, responsible for planning and delivering the GDF. The NDA was set up on 1 April 2005, under the Energy Act 2004. It is a non-departmental public body with designated responsibility for managing the liabilities at specific sites. These sites are operated under contract by site licensee companies (initially British Nuclear Group Sellafield Limited, Magnox Electric Limited, Springfields Fuels Limited and UK Atomic Energy Authority). The NDA has a statutory requirement under the Energy Act 2004, to publish and consult on its Strategy and Annual Plans, which have to be agreed by the Secretary of State (currently the Secretary of State for Trade and Industry) and Scottish Ministers.

Nuclear Installations Act 1965 (NIA65)

UK legislation which provides for the operation and regulation of nuclear installations within the UK.

Nuclear Installations Inspectorate (NII)

See HSE

nuclear material

Fissile material or material that can be used to produce fissile material (i.e. source material). This includes all isotopes of uranium, plutonium and thorium, together with certain isotopes of neptunium and americium.

Office for Civil Nuclear Security (OCNS)

The independent security regulator for the UK civil nuclear industry.

operational period (of a disposal facility)

The period during which a disposal facility is used for its intended purpose, up until closure.

operational waste

Radioactive waste produced during the normal operations of a nuclear facility (as distinct from *decommissioning waste*).

overpack

A secondary or additional outer container used for the handling, transport, storage or disposal of waste packages

package

See waste package, transport package.

packaged waste volume

The packaged waste volume is the displacement volume of a container used to package a wasteform.

passive safety

The need to provide and maintain a safety function by minimising the need for active safety systems, monitoring or prompt human intervention. Requires radioactive wastes to be immobilised and packaged in a form that is physically and chemically stable. The package should be stored in a manner that is resistant to degradation and hazards, and which minimises the need for control and safety systems, maintenance, monitoring and human intervention.

permeability

A measure of the rate at which a gas or a liquid moves under a pressure gradient through a porous material.

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.

porewater

Groundwater held within a space or pore in rock.

post-closure period (of a disposal facility)

The period following sealing and closure of a facility and the removal of active institutional controls.

quality management system (QMS)

A quality management system is the overall system by which an organisation determines, implements and ensures quality.

radioactive decay

The process by which radioactive material loses activity, e.g. alpha activity naturally. The rate at which atoms disintegrate is measured in becquerels.

radioactive material

Material designated in national law or by a regulatory body as being subject to regulatory control because of its radioactivity.

Radioactive Substances Act 1993 (RSA 93)

UK legislation which provides for regulation of the disposal of radioactive wastes, including liquid and gaseous discharges to the environment.

radioactive waste

Any material contaminated by or incorporating radioactivity above certain thresholds defined in legislation, and for which no further use is envisaged, is known as radioactive waste.

Radioactive Waste Management Directorate (RWMD)

The NDA Directorate established to design and build an effective delivery organisation to implement a safe, sustainable, publicly acceptable geological disposal programme. It is envisaged that this directorate will become a wholly owned subsidiary company of the NDA. Ultimately, it will evolve under the NDA into the organisation responsible for the delivery of the GDF. Ownership of this organisation can then be opened up to competition, in due course, in line with other NDA sites.

radioactivity

Atoms undergoing spontaneous random disintegration, usually accompanied by the emission of radiation.

radionuclide

A radioactive form of an element, for example carbon-14 or caesium-137.

resaturation

The process of returning the concentration of water in a system to its maximum holding capacity.

retrievability

A feature of the design of a GDF that enables the waste to be withdrawn, even after the disposal vaults have been backfilled

safeguards

Measures used to verify that nation states comply with their international obligations not to use nuclear materials (plutonium, uranium and thorium) for nuclear explosives purposes. Global recognition of the need for such verification is reflected in the requirements of the Treaty on the Non-Proliferation of Nuclear Weapons (NPT) for the application of safeguards by the International Atomic Energy Agency. Also, the Treaty Establishing the European Atomic Energy Community (the Euratom Treaty) includes requirements for the application of safeguards by the EC.

safety cases

A ‘safety case’ is the written documentation demonstrating that risks associated with a site, a plant, part of a plant or a plant modification are as low as reasonably practicable and that the relevant standards have been met. Safety cases for licensable activities at nuclear sites are required as license conditions under NIA65.

safety function

A specific purpose that must be accomplished for safety.

Scottish Environment Protection Agency (SEPA)

The environmental regulator for Scotland. SEPA’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 (surface water, groundwater) and land. SEPA also regulates nuclear sites under the Pollution Prevention and Control Regulations and issues consents for non-radioactive discharges.

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.

shielding

Shielding is the protective use of materials to reduce the dose rate outside of the shielding material. The amount of shielding required to ensure that the dose rate is as low as reasonably practicable (ALARP) will therefore depend on the type of radiation, the activity of the source, and on the dose rate that is acceptable outside the shielding material.

spent nuclear fuel

Nuclear fuel removed from a reactor following irradiation that is no longer usable in its present form because of depletion of fissile material, poison build-up or radiation damage.

stack (or waste packages)

A stack of waste packages placed vertically one on top of each other.

stillage

A metal frame designed to hold four 500 litre drum waste packages so that they can be handled, stacked and transported as a single *disposal unit.*

surface contaminated object (SCO)

A solid object which is not itself radioactive but which has radioactive material distributed on its surfaces.

transport container

A reusable container into which waste packages are placed for transport, the whole assembly then being referred to as a *transport package.*

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.

UK Radioactive Waste Inventory (UKRWI)

A compilation of data on UK radioactive waste holdings, produced about every three years. The latest version, for a holding date of 1 April 2007, was published in June 2008. It is produced by Defra and the NDA. It is the latest public record of information on the sources, quantities and properties of LLW, ILW and HLW in the UK. It comprises of a number of reports and additional detailed information on the quantities and properties of radioactive wastes in the UK that existed at 1 April 2007 and those that were projected to arise after that date.

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 (see natural uranium, depleted uranium, low enriched uranium and highly enriched uranium) *waste acceptance criteria (WAC)*

Quantitative and/or qualitative criteria, specified by the operator of a *disposal facility* and approved by the regulator, for solid radioactive waste to be accepted for disposal.

Quantitative or qualitative criteria specified by the regulatory body, or specified by an operator and approved by the regulatory body, for radioactive waste to be accepted by the operator of a repository for disposal, or by the operator of a storage facility for storage.

waste container

Any vessel used to contain a wasteform for 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 waste form and any container(s) and internal barriers (e.g. absorbing materials and liner), as prepared in accordance with requirements for handling, transport, storage and/ or disposal.

waste packager

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

Certificate No 4002929

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