Radioactive Waste Management

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Inventory for geological disposal

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Radioactive Waste Management Ltd
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UK

email: rwmdfeedback@nda.gov.uk

Preface

Radioactive Waste Management Limited (RWM) has been established as the delivery organisation responsible for the implementation of a safe, sustainable and publicly acceptable programme for the geological disposal of the higher activity radioactive wastes in the UK. As a pioneer of nuclear technology, the UK has accumulated a legacy of higher activity wastes and material from electricity generation, defence activities and other industrial, medical and research activities. Most of this radioactive waste has already arisen and is being stored on an interim basis at nuclear sites across the UK. More will arise in the future from the continued operation and decommissioning of existing facilities and the operation and subsequent decommissioning of future nuclear power stations.

Geological disposal is the UK Governments' policy for higher activity radioactive wastes. The principle of geological disposal is to isolate these wastes deep underground inside a suitable rock formation, to ensure that no harmful quantities of radioactivity will reach the surface environment. To achieve this, the wastes will be placed in an engineered underground facility – a geological disposal facility (GDF). The facility design will be based on a multi-barrier concept where natural and man-made barriers work together to isolate and contain the radioactive wastes.

To identify potentially suitable sites where a GDF could be located, the Government has developed a consent-based approach based on working with interested communities that are willing to participate in the siting process. The siting process is on-going and no site has yet been identified for a GDF.

Prior to site identification, RWM is undertaking preparatory studies which consider a number of generic geological host environments and a range of illustrative disposal concepts. As part of this work, RWM maintains a generic Disposal System Safety Case (DSSC). The generic DSSC is an integrated suite of documents which together give confidence that geological disposal can be implemented safely in the UK.

Executive Summary

The UK has been producing radioactive waste inventories for over 30 years and this is now a well-established iterative process. This report presents the 2016 inventory for geological disposal (IGD), which represents a light update to the 2013 iteration. The IGD is based on Government policy, industry plans and publicly available information.

Data are presented on the quantity, activity, and material composition of the waste. The key points are that:

- the packaged volume of the 2016 IGD is estimated to be 744,000 m^3, while the total activity at 2200 is estimated to be 27,900,000 TBq
- the low heat generating waste forms the majority of the 2016 IGD by packaged volume (nearly 90%), but contributes only a small fraction of the activity (nearly 5%). Conversely, the high heat generating waste makes only a small contribution to the packaged volume (roughly 10%) but dominates the activity (roughly 95%)
- although waste and spent fuel from the assumed new build programme would dominate the activity for over 100,000 years after closure of the geological disposal facility, at extremely long times it is the legacy waste and spent fuel (specifically the depleted, natural and low enriched uranium) that would dominate the activity

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1 Introduction

1.1 The generic Disposal System Safety Case

RWM has been established as the delivery organisation responsible for the implementation of a safe, sustainable and publicly acceptable programme for geological disposal of the UK's higher activity radioactive waste. Information on the approach of the UK Government and devolved administrations of Wales and Northern Ireland[1] to implementing geological disposal, and RWM's role in the process, is included in an overview of the generic Disposal System Safety Case (the Overview) [1].

A geological disposal facility (GDF) will be a highly-engineered facility, located deep underground, where the waste will be isolated within a multi-barrier system of engineered and natural barriers designed to prevent the release of harmful quantities of radioactivity and non-radioactive contaminants to the surface environment. To identify potentially suitable sites where a GDF could be located, the Government is developing a voluntarism approach based on working with interested communities that are willing to participate in the siting process [2]. Development of the siting process is ongoing and no site has yet been identified for a GDF.

In order to progress the programme for geological disposal while potential disposal sites are being sought, RWM has developed illustrative disposal concepts for three types of host rock. These host rocks are typical of those being considered in other countries, and have been chosen because they represent the range that may need to be addressed when developing a GDF in the UK. The host rocks considered are:

- higher strength rock, for example, granite
- lower strength sedimentary rock, for example, clay
- evaporite rock, for example, halite

The inventory for disposal in the GDF is defined in the Government White Paper on implementing geological disposal [2]. The inventory includes the higher activity radioactive wastes and nuclear materials that could, potentially, be declared as wastes in the future. For the purposes of developing disposal concepts, these wastes have been grouped as follows:

- high heat generating wastes (HHGW): that is, spent fuel from existing and future power stations and high level waste (HLW) from spent fuel reprocessing. High fissile activity wastes, that is, plutonium (Pu) and highly enriched uranium (HEU), are also included in this group. These have similar disposal requirements, even though they don't generate significant amounts of heat.
- low heat generating wastes (LHGW): that is, intermediate level waste (ILW) arising from the operation and decommissioning of reactors and other nuclear facilities, together with a small amount of low level waste (LLW) unsuitable for near surface disposal, and stocks of depleted, natural and low-enriched uranium (DNLEU).

RWM has developed six illustrative disposal concepts, comprising separate concepts for HHGW and LHGW for each of the three host rock types. Designs and safety assessments for the GDF are based on these illustrative disposal concepts.

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[1] Hereafter, references to Government mean the UK Government including the devolved administrations of Wales and Northern Ireland. Scottish Government policy is that the long term management of higher activity radioactive waste should be in near-surface facilities and that these should be located as near as possible to the site where the waste is produced.

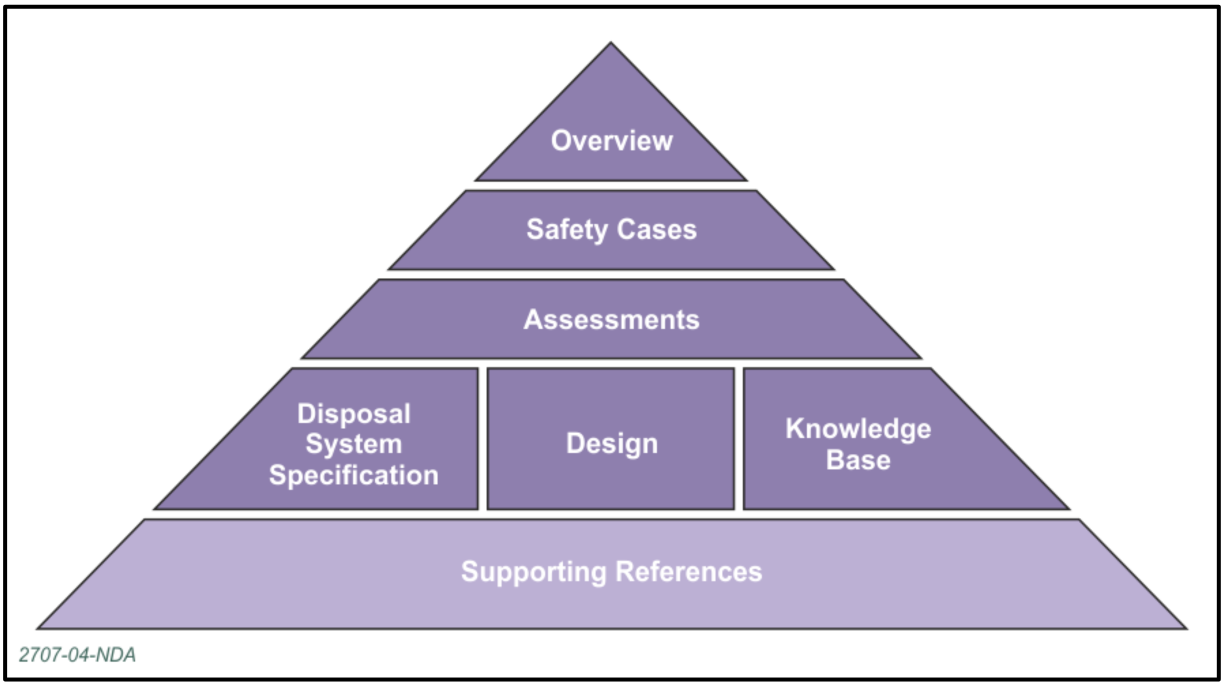
High level information on the inventory for disposal, the illustrative disposal concepts and other aspects of the disposal system is collated in a technical background document (the Technical Background) [3] that supports this generic Disposal System Safety Case.

The generic Disposal System Safety Case (DSSC) plays a key role in the iterative development of a geological disposal system. This iterative development process starts with the identification of the requirements for the disposal system, from which a disposal system specification is developed. Designs, based on the illustrative disposal concepts, are developed to meet these requirements, which are then assessed for safety and environmental impacts. An ongoing programme of research and development informs these activities. Conclusions from the safety and environmental assessments identify where further research is needed, and these advances in understanding feed back into the disposal system specification and facility designs.

The generic DSSC provides a demonstration that geological disposal can be implemented safely. The generic DSSC also forms a benchmark against which RWM provides advice to waste producers on the packaging of wastes for disposal.

Document types that make up the generic DSSC are shown in Figure 1. The Overview provides a point of entry to the suite of DSSC documents and presents an overview of the safety arguments that support geological disposal. The safety cases present the safety arguments for the transportation of radioactive wastes to the GDF, for the operation of the facility, and for long-term safety following facility closure. The assessments support the safety cases and also address non-radiological, health and socio-economic considerations. The disposal system specification, design and knowledge base provide the basis for these assessments. Underpinning these documents is an extensive set of supporting references. A full list of the documents that make up the generic DSSC, together with details of the flow of information between them, is given in the Overview.

Figure 1 Structure of the generic DSSC



1.2 Introduction to the '2016 Inventory for geological disposal'

This document is the '2016 inventory for geological disposal: main report'. It is one of five reports that deal with various aspects of the 2016 inventory for geological disposal (IGD). The other four reports are:

- the 'Method report' [4], which describes how IGDs are developed and updated
- the 'Differences report' [5], which sets out the differences between the 2016 IGD and the previous version (the 2013 IGD [6][2])
- the 'Implications report' [7], which describes the implications of the 2016 IGD for the generic DSSC
- the 'Alternative scenarios report' [8], which provides information on how changes to the scenario for future waste arisings would affect the 2013 IGD, and which is updated in the Differences report [5]

The IGD is based largely on the UK Radioactive Waste and Materials Inventory (RWI). The UK has been producing RWIs for over 30 years. The production process has been improved iteratively and is now well-established. Each UK RWI contains details of stocks and arisings of all radioactive waste from existing sources (often called legacy wastes).

Currently, the UK RWI is updated every three years, after which the IGD is updated, as shown in Figure 2. Waste that will be managed through other routes (eg waste that is destined for the Low Level Waste Repository (LLWR)) is removed from the UK RWI dataset and the remaining data are reviewed and, where appropriate, enhanced[3]. The dataset is further enhanced to take account of Government policy industry plans and other assumptions (these are discussed in sections 2.1 to 2.3) to produce the inventory for geological disposal. Finally, following the production of the UK RWI (and IGD), NDA and key users of the UK RWI (LLWR and RWM) meet with waste producers to discuss key inventory improvements. In addition, further characterisation of wastes is carried out to support decommissioning, leading to improvements in the inventory data. This iterative process drives continuous improvements in the UK RWI data and, as a consequence, the IGD.

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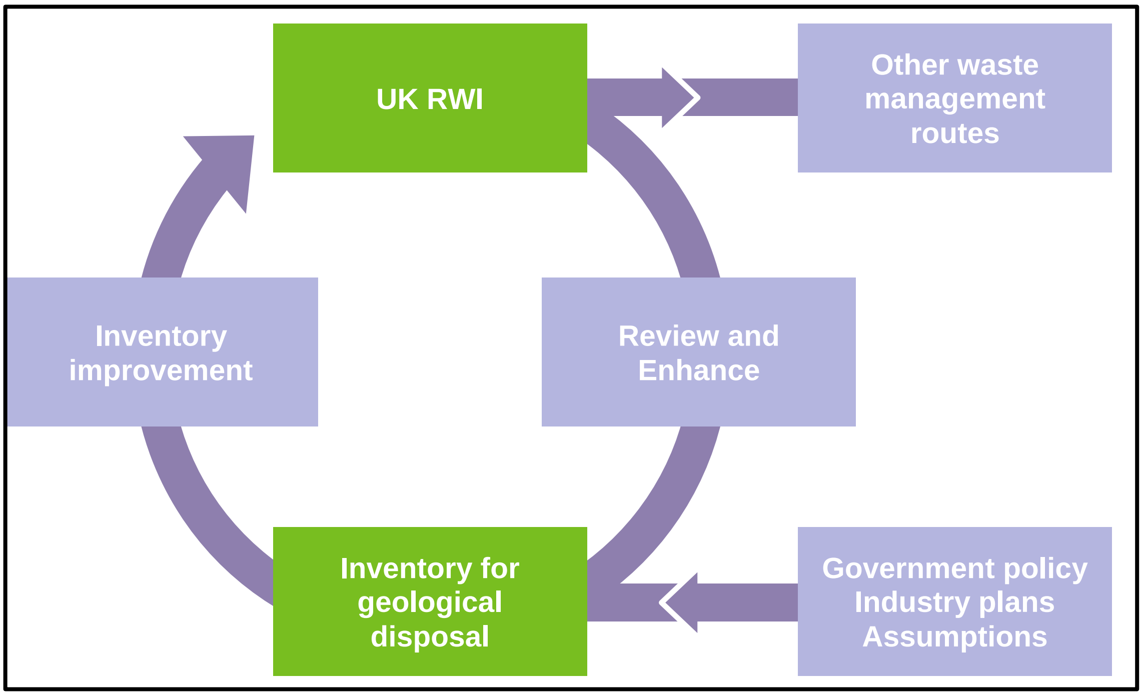
2 Originally published as the 2013 Derived Inventory; it is referred to here as the 2013 IGD.

3 For the purposes of this work, 'review' is defined as the process of identifying omissions, differences and inconsistencies within the 2016 UK RWI itself, and with other sources of data. 'Enhancement' is defined as the process of filling gaps and providing fully justified numeric and other data where these are not reported in the 2016 UK RWI. For example, the UK RWI only provides the mass of spent fuels; the enhancement process adds the radionuclide activities and materials and packaging assumptions.

Figure 2 The iterative development of the inventory for geological disposal



The most recent version of the UK RWI [9] is based on a stock date of 1st April 2016 and is referred to here as the 2016 UK RWI. The generic DSSC was published in 2017 and was based on the 2013 IGD [10][4], which in turn was based on the previous 2013 UK RWI [11].

The 2016 IGD is based on the 2016 UK RWI and is a 'light update'[5] to the 2013 IGD. In a 'light update', the full review and enhancement process is not carried out: where waste streams are unchanged, the enhancements from the previous inventory are carried over. In addition, some calculations (for example, calculations of metal geometry to support the gas pathway analysis) are not carried out.

This report replaces the main report on the 2013 IGD [12] within the generic DSSC suite of documents.

1.3 Objective

The objective of the IGD is to provide information on the quantities and characteristics of the components of the inventory that is sufficiently detailed for use in RWM's design and safety and environmental assessment work.

This report presents detailed technical information and is targeted at an audience of scientists and engineers, in particular RWM staff and contractors who will use this information as a basis for generic geological disposal design and assessment work.

1.4 Scope

1.4.1 Definition of the inventory for geological disposal

The waste and material types that comprise the inventory for geological disposal are defined in paragraph 2.17 of the 2014 Implementing Geological Disposal White Paper:

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[4] Originally published as the 2013 'Derived Inventory', it is referred to here as the 2013 IGD.

[5] The differences between a light and a full update are explained in the Method report [4].

2.17. The specific types of higher activity radioactive waste (and nuclear materials that could be declared as waste) which would comprise the inventory for disposal in a GDF are:

- *HLW arising from the reprocessing of spent nuclear fuel at Sellafield;*
- *ILW arising from existing nuclear licensed sites, and defence, medical, industrial and educational activities;*
- *The small proportion of LLW that is not suitable for disposal in the national Low Level Waste Repository;*
- *Spent fuel from existing commercial reactors (yet to be declared waste) and research reactors that is not reprocessed;*
- *Spent fuel (yet to be declared waste) and ILW from a new build programme up to a defined amount (see paragraphs 7.39 – 7.41);*
- *Plutonium stocks – residual plutonium not re-used in new fuel manufacture (yet to be declared waste);*
- *Uranium stocks – including that arising from enrichment and fuel fabrication activities (yet to be declared waste);*
- *Irradiated fuel and nuclear materials (yet to be declared waste) from the UK defence programme.*

1.4.2 Waste groups

RWM's generic disposal facility designs [13] recognise the different packaging and disposal processes for different types of higher activity radioactive waste (HAW): LLW, ILW and DNLEU are assumed to be disposed of in a LHGW area; HLW, spent fuels (SFs), plutonium and HEU are assumed to be disposed of in a HHGW area[6].

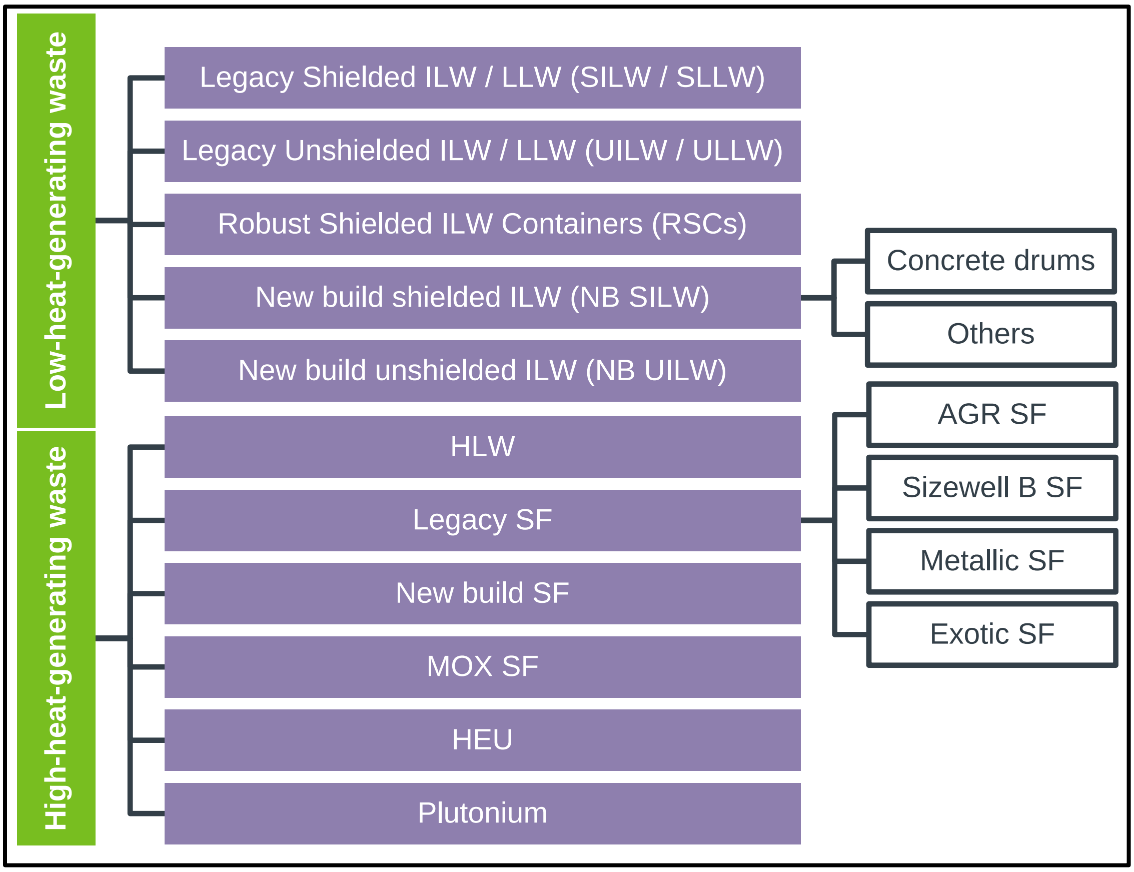
The inventory for geological disposal has been broken down into waste groups (shown in purple in Figure 3) that have been chosen to reflect the different sources of waste and how they will be disposed of in the GDF. The sources of waste considered are:

- legacy: wastes and materials that already exist or that will arise in the future as a result of the operation of existing nuclear facilities
- new build: wastes and spent fuels from the proposed new build programme
- mixed oxide (MOX): at this stage only spent fuel is included

There are also a number of sub-groups to reflect the more detailed groups that the designs and assessments use; these are shown in white in Figure 3. The sub-group for concrete drums reflects the fact that they are assumed to be disposed of in a separate vault. The legacy SF is split into advanced gas-cooled reactor (AGR) SF, Sizewell B SF, metallic SF (which is assumed to be Magnox SF) and Exotic SF (also referred to as non-standard SF).

[6] HEU does not generate significant heat; it is included in the HHGW area as its disposal concept is very similar to that of the other HHGW.

Figure 3 The two high-level partitions of the inventory (green boxes), the waste groups (purple boxes) and the sub-groups (white boxes)



1.4.3 Data

Summary data for the 2016 inventory for geological disposal data are presented in Section 3, with a more detailed breakdown of the data by waste groups presented in the appendices. The data presented include:

- volumes: the stored, conditioned and packaged volume of the inventory
- activities: the IGD contains information on all 112 of the radionuclides identified as being relevant to geological disposal [14]. Data on key radionuclides are presented along with the total activity from all 112 'relevant radionuclides'
- the number of disposal units associated with each type of package
- materials: the IGD contains material composition data on two levels: the bulk materials that make up the wastes, conditioning and capping materials and disposal containers; and elemental compositions. As this is a light update, the elemental compositions have not been revised from the 2013 IGD

All data have been presented to three significant figures; this is considered to provide an appropriate quantification of the inventory data.

As a result of the rounding, some tables will show totals that may not represent the sum of the rounded data that are presented within the tables. Instead, the totals represent the sum of the data rounded to three significant figures. This approach ensures an appropriate and consistent level of precision in all of the data.

1.4.4 Exclusions

The scope of this report excludes reporting the method for the production of the inventory and a consideration of different inventory scenarios. These are addressed in the ‘method report’ [4] and the ‘alternative scenarios report’ [8, 5])

1.5 Report structure

The remainder of the report is structured as follows:

- Section 2 provides the basis of the quantified inventory for disposal
- Section 3 presents a summary of inventory for disposal
- Section 4 contains a summary of the key messages

In addition, this report contains three appendices:

- Appendix A contains details of the 2016 IGD scenario
- Appendix B provides data broken down by waste group
- Appendix C presents summary tables

2 Scenario for the inventory for geological disposal

Summary of the Scenario for the IGD

The IGD is defined in the Implementing Geological Disposal White Paper. The IGD is based on Government policy, industry plans and other publicly available information; these are used to produce the scenario for the IGD. The IGD scenario represents RWM's best estimate of how the waste will arise and the key points are:

- quantities of legacy wastes and their times of arising are based on the data that waste producers have provided for the 2016 UK RWI
- HAW arising in Scotland is excluded from the IGD
- 95% of the civil plutonium stockpile is converted to MOX fuel and irradiated
- a new build programme of 16 GW(e) is included

The Implementing Geological Disposal White Paper [2] defines the waste and material types that comprise the IGD (see Section 1.4.1). A scenario is used to describe how these waste and material types will arise. The IGD scenario represents RWM's best estimate of how the waste will arise; alternative scenarios are considered separately [8].

The data for future waste arisings in the UK RWI are projections made by the organisations that operate the sites where radioactive waste is generated. The projections are based on informed assumptions as to the nature, scale and timing of future operations and activities. For the 2016 UK RWI, these projections represent planning assumptions at 1 April 2016.

The UK RWI is the foundation of the scenario for the IGD, but does not provide all of the information that is required. As a result, a number of assumptions have to be made to complete the scenario for the IGD; these are based on informed judgements.

Figure 4 is based on the scenario for the 2016 IGD and provides a high-level overview of the timings of the different activities; full details are provided in Table A1, while Table A2 provides details of the scenario broken down by waste group. The remainder of this section provides details and justifications for the assumptions in the 2016 IGD's scenario.

2.1 Government policy

2.1.1 Management of HAW in Scotland

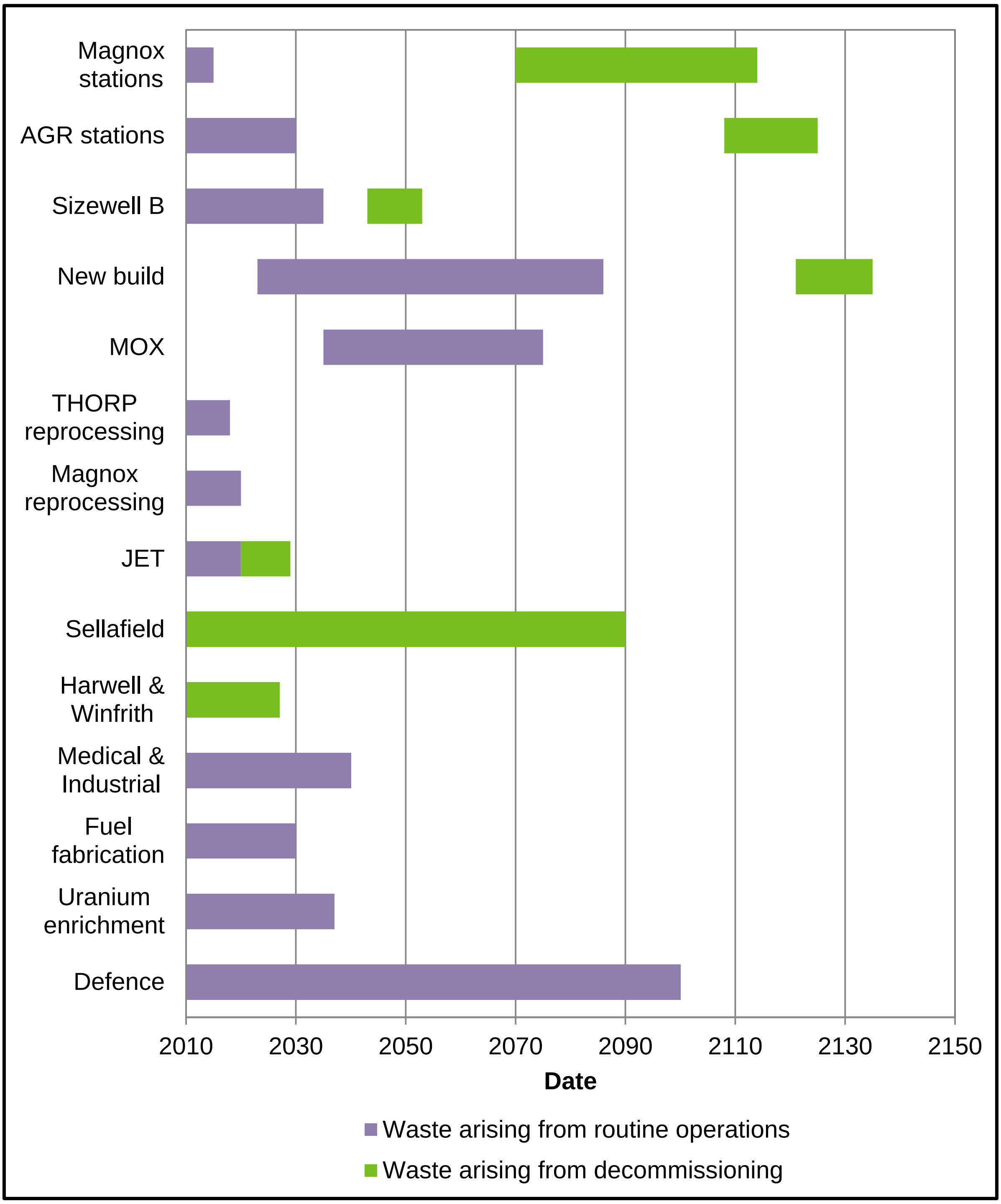
Radioactive waste disposal is a devolved issue and policies differ across the UK. The policies of the UK Government [2] and the Welsh Government [15] are that HAW in England and Wales should be managed in the long-term through geological disposal, coupled with safe and secure interim storage and ongoing research and development to support its optimised implementation.

The Scottish Government's policy is for the HAW arising in Scotland to be managed in near-surface facilities[7] [16]. Waste that is covered by the Scottish Government's policy[8] is therefore excluded from the IGD.

[7] Facilities should be located as near to the site where the waste is produced as possible. Developers will need to demonstrate how the facilities will be monitored and how the waste packages, or waste, could be retrieved. All long-term waste management options will be subject to robust regulatory requirements. See paragraph 1.19 of reference [16].

[8] The policy does not cover radioactive wastes arising from the nuclear submarine bases on the Clyde, the Vulcan naval reactor test establishment, or the decommissioning and dismantling of redundant nuclear submarines. The policy does not apply to wastes that have been dealt with under the policies of previous governments.

Figure 4 The assumed dates of operation and decommissioning for activities that contribute to the 2016 IGD[9]



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9 Decommissioning of the Magnox reprocessing plant and the thermal oxide reprocessing plant (THORP) are covered by Sellafield decommissioning. No decommissioning dates have been specified for 'Fuel fabrication', 'Medical and industrial', 'Enrichment' or 'Defence' as there is either no HAW decommissioning waste arising or the waste producer has not included an estimate of the decommissioning waste. JET is the Joint European Torus.

2.1.2 Management of plutonium

The UK Government's preferred policy for the long-term management of plutonium is that it should be re-used in the form of mixed oxide fuel [17]. The UK Government has not made any decision on the fate of the UK's plutonium stocks, and the NDA's Position Paper [18] also identified CANDU and PRISM reactors as credible options for the re-use of plutonium. Only when the UK Government is satisfied that its preferred policy could be implemented safely, securely and in a way that offers value for money, will it be in a position to proceed.

There are a range of options for using MOX fuel and the Government has yet to establish the most viable and cost effective option. As a result, the assumptions regarding MOX have been decoupled from those for a new build programme. As such, the MOX spent fuel is considered as an addition to the spent fuels from new build. However, no nuclear power plant, MOX manufacturing plant or UO_2 fuel has been included.

In discussions with NDA, RWM has agreed that it is appropriate to assume that MOX is burned for a 40 year period starting in 2035. Arisings of MOX SF are assumed to be uniform over this 40 year period.

Uncertainties about the quantity of plutonium, and hence MOX SF, arise principally because:

- the assumed quantity of plutonium is based on predictions of the final reprocessing outturn, which have uncertainties associated with them; and
- government policy allows the UK to take title to overseas plutonium under commercial terms (see paragraph 1.8 of [17]) and it is uncertain whether this will occur

The fraction of the plutonium that will be suitable for manufacture into MOX fuel is also difficult to quantify. In discussions with NDA, it was agreed that 115 t was a reasonable estimate of the UK-owned plutonium at the end of reprocessing and that it was appropriate to assume that 95% of the 115 t of could be converted to MOX. The remaining 5% is assumed to be disposed of using the can-in-canister concept[10].

2.2 Industry plans

2.2.1 New build

The 2016 UK RWI does not contain information on wastes and SFs that might arise from new build reactors. Hence, it has been necessary to make assumptions regarding the size of the new build programme.

Because this is a light update to the 2013 IGD, and to retain consistency with the Implementing Geological Disposal White Paper, a 16 GW(e) new build programme is assumed. This is assumed to comprise six UK EPRs (each producing 1.6 GW(e)) and six AP1000s (each producing 1.14 GW(e)). However, it is acknowledged that:

- there are only plans for the construction of four UK EPRs, two at Hinkley Point and two at Sizewell
- until 2017 there were plans for the construction of three AP1000s at Moorside. However, a different reactor design may be chosen, and the number of reactors may change, when the company developing the site (NuGen Ltd) is sold [19]

[10] In this concept, the waste is immobilised in a titanate-based puck. Twenty pucks are assumed to be loaded into a stainless steel can and 28 of these cans encapsulated in borosilicate glass within a large canister. This canister is placed in a disposal container. The can-in canister concept is non-optimal. However, until further work that justifies an alternative assumption has been completed, it remains the reference packaging assumption.

- there are plans for the construction of four UK advanced boiling water reactors (ABWRs), two at Wylfa and two at Oldbury
- under a strategic investment agreement signed in October 2015, China General Nuclear agreed to take a stake in the development of Hinkley Point C as well as jointly develop new nuclear power plants at Sizewell and Bradwell, with the new plant at Bradwell featuring the Hualong One design
- these developments mean that there are uncertainties about the size and composition of the new build programme. Some of these uncertainties are considered in an alternative inventory scenario [8,5] that contains the data required to assess the impact of additional reactors

Inventory data for the UK EPR and the AP1000 has been taken from the disposability assessment reports [20, 21, 22, 23] published as part of the Generic Design Assessment (GDA) process [24]. Inventory data for the UK ABWR has also been published as part of the GDA process [25, 26]. As noted above, the UK ABWR is not included in the 2016 IGD. However, the inventory data associated with the UK ABWR are included in the inventory differences report [5] and its impact on the generic DSSC is discussed in reference [7].

The assumed timetable for the reactors becoming operational is provided in Table 1[11]. Inventory data has been published for burn-ups of 50 GWd/tU and 65 GWd/tU and it has been assumed here that the fuel will have a burn-up of 65 GWd/tU. Both lead to a similar number of disposal containers since more of the lower burn-up assemblies can be disposed of in a single disposal container. The higher burn-up has been assumed as this maximises the inventory of higher actinides and, therefore, the neutron dose rate.

The 2016 IGD does not include any depleted uranium arising in the UK from uranium enrichment that is part of the manufacturing process for new build reactor fuel.

Table 1 The number of reactors assumed to start operating in each year

Reactor	2023	2024	2025	2026	2027	2028
UK EPR	2	2	2			
AP1000				2	2	2

2.3 Other assumptions

2.3.1 Legacy spent fuels

Whilst the UK RWI includes data on the quantity of spent fuels, at present it does not include any details of the materials that comprise the fuels, or their radionuclide inventories. It is necessary for RWM to make assumptions that allow the inventories to be calculated. Appendix A3 provides further details of the assumptions made for the legacy spent fuels.

Metallic SFs

For the purposes of the 2016 IGD, the composition and packaging assumptions are taken to be those for Magnox SF (disposal in a high-integrity disposal container), which is likely to be a major component, with a lower burn-up than current commercial SFs.

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11 It is acknowledged that Hinkley Point C will not be operational in 2023, and that the contracts incentivise operations starting in 2025. However, as this is a light update to the 2013 IGD, the assumptions regarding timing have been retained.

Exotic SFs

Exotic SFs are assumed to consist only of prototype fast reactor (PFR) SF because PFR fuel is a large component of exotic SFs by volume, (see section B8.1). This is a high-level assumption and uncertainty over the types and quantities of exotic SFs will remain until THORP operations cease in 2018. Once THORP ceases operations, further data may become available.

Table 2 Key parameters in the calculation of the fuel inventories

Spent fuel type	Enrichment [%]	Burn-up [GWd/tHM]	Cooling time [years]
AGR (pre-2013)	2.9	28	9
AGR (post-2013)	3.2 / 3.78	33	Arises as 1 yr cooled
Sizewell B (pre-2013)	4.2	45	11
Sizewell B (post-2013)	4.4	55	Arises as 1 yr cooled
Metallic fuels	0.71	4.1	39
Exotic fuels	(Pu) 29.5	189	22

2.3.2 Defence materials

Irradiated submarine fuel

Irradiated submarine fuel differs from civil nuclear fuel in composition, mode of use and other characteristics. Although final decisions on the disposal of irradiated submarine fuel have yet to be made, the Ministry of Defence (MOD) is in dialogue with RWM, through the disposability assessment process, to explore potential disposal options for this material. This will support the MOD's decision making.

The quantity of irradiated submarine fuel in the inventory for disposal will be significantly smaller than the contributions from the following civil sources of SFs:

- legacy reactor (eg AGR and pressurised water reactor (PWR)) SFs
- new build SFs and
- MOX SF

RWM considers that, at this stage, the inclusion of the irradiated submarine fuel in the inventory can be bounded by sensitivity studies on the quantities of these other fuels and the disposability issues associated with this type of SF taken into account in RWM's generic DSSC.

Uranium

The 1998 Strategic Defence Review [27] gives the UK stocks of HEU as 21.9 t. It is possible that this stockpile has reduced, or will reduce further, as a result of its use in the production of submarine fuel.

This strategic material is not destined for a GDF but for the purposes of developing the 2016 IGD, HEU is assumed to be immobilised in a titanate-based ceramic that contains 11.9% HEU dioxide by mass, which would then be disposed of using the can-in-canister concept.

The 1998 Strategic Defence Review also indicates that the MOD holds 15,000 t of 'other forms of uranium'. For the purposes of developing the 2016 IGD, this is assumed to be depleted uranium with isotopic ratios within the range of ratios of the uranium tails arising at URENCO's Capenhurst site.

Plutonium

The UK is currently a nuclear weapons state and strategic materials are not destined for the GDF. However, if this were to change then it is expected that the options for the military stocks of plutonium would be considered in the same way as the UK's civil stocks of plutonium have been considered. The MOD has already placed plutonium that is surplus to requirements into International Safeguards; this material will be treated in the same way as civil material.

It is expected that all of the MOD's plutonium would be suitable for use as MOX fuel and that the quantity is small when compared with the anticipated stock of civil plutonium. For the purposes of developing the 2016 IGD, the MOD's stocks of plutonium are assumed to be 7.6 t of plutonium [27] and this is assumed to be managed in the same way as the civil plutonium so that the GDF has sufficient capacity for this eventuality.

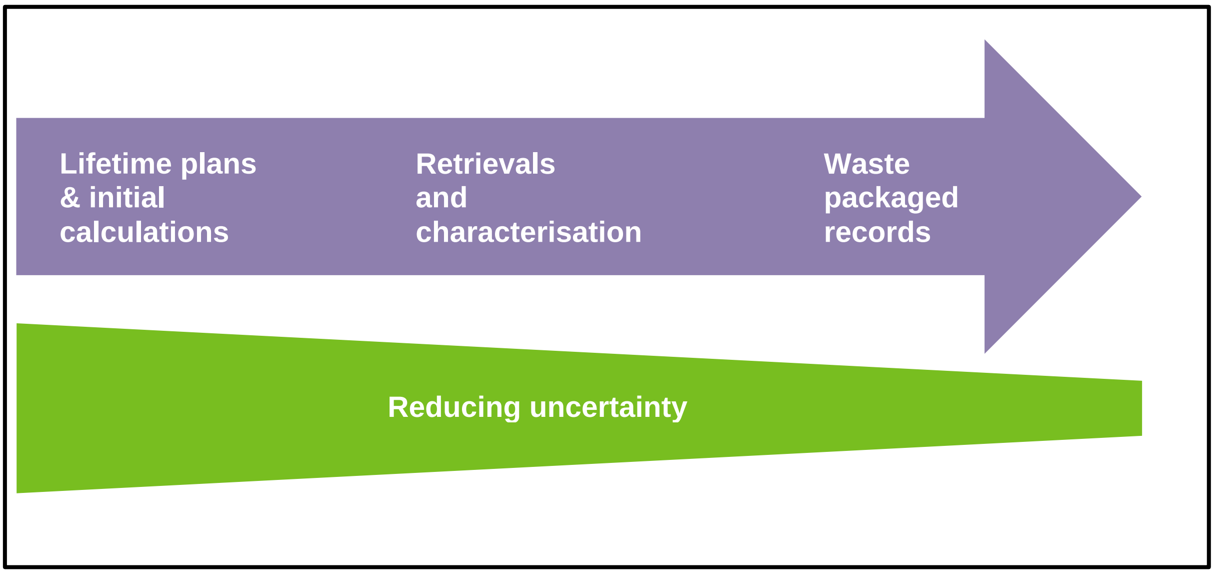
2.3.3 Packaging assumptions

In order for a waste stream to be disposed of, it must complete RWM's Disposability Assessment process. The uncertainty associated with how waste will be packaged reduces as the waste progresses through the Disposability Assessment process. Characterisation of the waste, whether to support disposability assessment work or as part of the packaging of the waste reduces the uncertainty surrounding the material composition and radionuclide inventory of the waste. Figure 5 presents a schematic showing how the uncertainty surrounding the waste reduces with time.

The conditioned and packaged waste volumes presented in this report are projections based on current and forecast methods of preparing wastes for long-term management. Uncertainty in waste packaging assumptions is not considered here, and is considered in RWM's alternative inventory scenarios report.

In preparing the inventory for geological disposal, RWM reviews the waste packages assigned to the ILW and LLW by waste producers; this may result in the waste containers being reassigned for some waste streams.

Figure 5 Reducing uncertainty in the packaging and characterisation of the waste



Review of waste container assignments

As this is a light update to the 2013 IGD, waste streams are unchanged from the 2013 UK RWI and have had their enhancements from the 2013 IGD carried over. For new waste streams (or those that have changed) the packaging assumptions are reviewed where:

- the waste container has not been specified
- RWM has thought it necessary to review the waste container type
- a non-standard waste container is specified[12]
- a waste stream has been allocated more than one container type

A further verification of the waste packages is carried out based on the dose rate and heat output of the waste packages: where these have exceeded the transport limits by greater than 25%, a new waste container type is assigned.

The most significant result of the review of waste container assignments relates to TRU-shield containers. The 2016 UK RWI reports the use of TRU-Shield containers for some Magnox wastes. However, these have not completed RWM's change management process and there is not an associated level three waste package specification. As a result, wastes that were assigned to TRU-Shield containers have been reassigned to either a 500 l drums or a 6 m^3 box.

Waste containers used

Low heat generating wastes

RWM's illustrative geological disposal concepts for LHGW are based on three broad categories of waste container: unshielded, shielded and robust shielded packages. For ILW and LLW, RWM has a suite of waste package specifications that define the requirements for the transport and geological disposal of waste packages manufactured using standardised designs of waste container.

The UK RWI does not provide information on the packaging of DNLEU and there are no formal designs for waste containers that would be used for its packaging. However, based on the preferred options identified by RWM's uranium integrated project team [28], the IGD makes the following packaging assumptions for the DNLEU that is less than 1% enriched:

- the current / planned wasteform for storage would be used for disposal (ie unencapsulated UO_3 and U_3O_8 powders)
- the powders would remain in their current / planned storage containers:
  - depleted uranium tails (U_3O_8 powder) in mild steel DV-70s
  - older Magnox depleted uranium (MDU) (UO_3 powder) in mild steel 200 l drums that have been overpacked in larger (approximately 500 l) stainless steel drums
  - more recent MDU (UO_3 powder) in 210 l stainless steel drums
- the current / planned storage containers would be disposed of in a stainless steel transport and disposal container (TDC), which is a 20-foot IP-2 rated International Organisation for Standardisation (ISO) container:
  - 2.3 m high and containing four DV-70s for depleted uranium tails
  - 2.4 m high and containing twenty-eight 200 l drums overpacked in approximately 500 l drums for older MDU

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12 For ILW and LLW, the 2016 IGD only uses waste containers that have completed RWM's change management process and have level three waste package specifications. The UK RWI does not specify waste containers for HLW, SFs or nuclear materials.

  - 2.1 m high and containing fifty-four 210 l drums for more recent MDU
- The TDCs would be infilled with a 3:1 mixture of BFS / PFA:OPC grout prior to disposal

The remaining DNLEU (ie miscellaneous DNLEU, THORP product uranium (TPU)) is assumed to be converted into a triuranium octoxide (U_3O_8) powder, which would be mixed with a pulverised fuel ash / Ordinary Portland cement (PFA / OPC) encapsulant and repackaged into 500 l drums for disposal. Defence DNLEU is also assumed to be disposed of in this way.

High heat generating wastes

The UK RWI does not provide any information on the packaging of HHGW. As a result, the packages must be assigned by RWM. RWM has defined illustrative geological disposal concept examples for HLW and spent fuels in a range of potentially suitable UK geological environments[13] [3]. Detailed design work has been carried out for HLW, AGR SF and PWR SF [29]. Two container variants were considered:

- Variant 1: a disposal container designed for a higher strength host rock and based on SKB's copper / cast iron KBS-3 disposal canister concept [30]
- Variant 2: a disposal container designed for a lower strength sedimentary host rock and based on NAGRA's mild steel disposal concept [31]

For the purposes of quantifying the inventory for geological disposal, it is assumed that the Variant 1 container is used. The differences between the two variants are mainly in the materials used and masses; the volumes are very similar.

The inventory for geological disposal includes other spent fuels, and the packaging assumptions for these are assumed to be similar to those for AGR SF and PWR SF (ie, a copper container with a cast iron insert).

Plutonium residues and HEU are also assumed to be packaged in a copper disposal container with a cast iron insert. In these cases, it is assumed that: the material would be immobilised in a titanate-based puck; twenty pucks would be loaded into a stainless steel can; 28 of these cans would be encapsulated in borosilicate glass within a large canister; this canister is placed in the disposal container.

2.3.4 Others

The UK RWI includes ILW streams that waste producers expect to manage as LLW by using radioactive decay storage and / or decontamination processes[14]. Some combustible wastes are expected to be incinerated and some metal wastes are expected to be recycled. However, only those ILW streams where there is an established decontamination or incineration process are excluded from the inventory for geological disposal[15]. All other ILW waste streams that are expected to be managed as LLW will continue to be included in the inventory for disposal until incineration, recycling or disposal routes other than geological disposal are authorised.

The inventory for geological disposal includes LLW in the UK RWI that is identified as unsuitable for consignment to the LLWR and which is not being treated by incineration or being recycled. LLW streams unsuitable for consignment to the LLWR that are being treated by incineration or are recycled are not included in the inventory for geological disposal. Any

[13] These are not necessarily the concepts that RWM will implement in the relevant geological setting; at this stage no disposal concept has been ruled out.

[14] The 2016 UK RWI includes 37 such waste streams.

[15] For the 2016 IGD these are: 1B04, 1B05, 1B07, 1B10 and 1B11.

residues from treating these wastes are expected to have very small volumes and contain insignificant quantities of radionuclides in comparison with total quantities in the inventory for geological disposal.

A proportion of the waste from THORP and the Magnox reprocessing plant at Sellafield results from the reprocessing of overseas spent fuels. All reprocessing contracts with overseas customers that have been signed since 1976 include a provision to return packaged wastes to the country of origin. Waste substitution arrangements are currently being implemented whereby an additional amount of HLW from reprocessing is returned instead of the ILW and LLW associated with the reprocessing of the customers' spent fuels. The HLW is smaller in volume but equivalent to the ILW and LLW in radiological terms. The inventory for geological disposal excludes all HLW that will be exported and includes the ILW and LLW that remains in the UK (in fact, all LLW from overseas fuel reprocessing is suitable for consignment to the LLWR and so is not included).

It has been assumed when producing the IGD that a facility (or facilities) for the disposal of LLW continues to be available, and that the waste acceptance criteria will be similar to those currently being applied at the LLWR.

Superplasticisers

The 2016 IGD assumes that superplasticisers comprise 0.5 wt% of all cementitious materials. This assumption is thought to be bounding and, for legacy plant, it is unlikely that it will be possible to obtain any data. However, information may be available for the waste containers and capping / conditioning grouts in existing waste packages. In addition, RWM has completed work on superplasticisers [32], which shows that the use of polycarboxylate ether (PCE) superplasticisers is acceptable in a number of situations. As a result, the use of superplasticisers in future packages should be easier to quantify, and it may be possible to improve the estimate of superplasticisers (both the quantity and type) in the inventory.

3 The inventory for geological disposal

Summary of the inventory for geological disposal

The stored volume of the 2016 IGD is estimated to be approximately 393,000 m^3, less than 10% of the stored volume of wastes reported in the 2016 UK RWI.

The total packaged volume of the 2016 IGD is estimated to be approximately 744,000 m^3 The assumed new build programme contributes just over 10% of this. The total packaged volume is dominated by the LHGW, with the Legacy ILW and DNLEU comprising more than 80% of this volume.

The activity of the 2016 IGD at 2200 is estimated to be 27,900,000 TBq and this is dominated by the spent fuels. New build spent fuel dominates the activity for over 100,000 years after GDF closure but at extremely long times DNLEU activity dominates.

The total mass of materials for the 2016 IGD is estimated to be 604,400 t. The breakdown by mass of stored wasteform is approximately: 21% are metals; 2% are organics; 76% are inorganics; and 0.3% is unspecified.

This section presents summary information for the whole inventory; Appendix B presents a more detailed breakdown of the inventory data by the waste groups shown in Figure 3. The data presented in this report are estimates that are based on the 2016 IGD scenario described in Section 2.

3.1 Volumes

As shown in Figure 2, the production of the IGD starts from the UK RWI. Those wastes that are not destined for a geological disposal facility are removed, and additional wastes, eg from an assumed new build programme are added. Figure 6 shows the routing[16] of the wastes in the UK RWI, and also those wastes that are not reported in the UK RWI: MOD materials (taken from the 1998 strategic defence review [27], see Section 2.3.2) and wastes from an assumed 16 GW(e) new build programme. It can be seen that:

- the stored volume of waste from an assumed 16 GW(e) new build programme is small in comparison to the total
- the stored volume of MOD materials is small in comparison to the total
- only a small fraction of the UK RWI wastes are destined for a geological disposal facility: the stored volume of the wastes in the 2016 IGD (approximately 393,000 m^3) is less than 10% of the stored volume of the wastes reported in the UK RWI (approximately 4,490,000 m^3)

Table 3 presents the total stored, conditioned and packaged volume of waste in the 2016 IGD broken down into six broad waste categories. The volume of the waste is dominated by the ILW and uranium, and that the proportion of the volume attributable to the spent fuels and HLW increases significantly once packaging is taken into account.

16 The thicknesses of the lines are proportional to the stored volume of the waste. Only the masses of uranium, plutonium and spent fuels are reported in the UK RWI; the stored volumes are based on assumptions made by RWM. As this figure deals with stored volume, there is no MOX fuel, instead the volume of plutonium is included. The contribution of wastes from a new build programme is shown separately, as is the contribution of the MOD uranium and plutonium. No estimate of irradiated submarine fuel has been included. VLLW is very low level waste.

Table 4 presents a breakdown of the packaged volume by waste group. It can be seen that the packaged volume of the 2016 IGD is dominated by low heat generating wastes: between them, the Legacy UILW / ULLW, DNLEU and Legacy SILW / SLLW contribute over 80% of the packaged volume of the waste. The ILW and spent fuel from the assumed new build programme contribute just over 10% of the total packaged volume.

Figure 7 shows the increase in the packaged volume of the 2016 IGD with time broken down by waste group. The rate at which the packaged volume increases is greatest from the present until 2037, when enrichment activities are assumed to stop. It can be seen that all of the waste has arisen by 2138.

Figure 6 The routing of the UK RWI wastes (by stored volume). Wastes from other sources that are added to the IGD by RWM are also shown

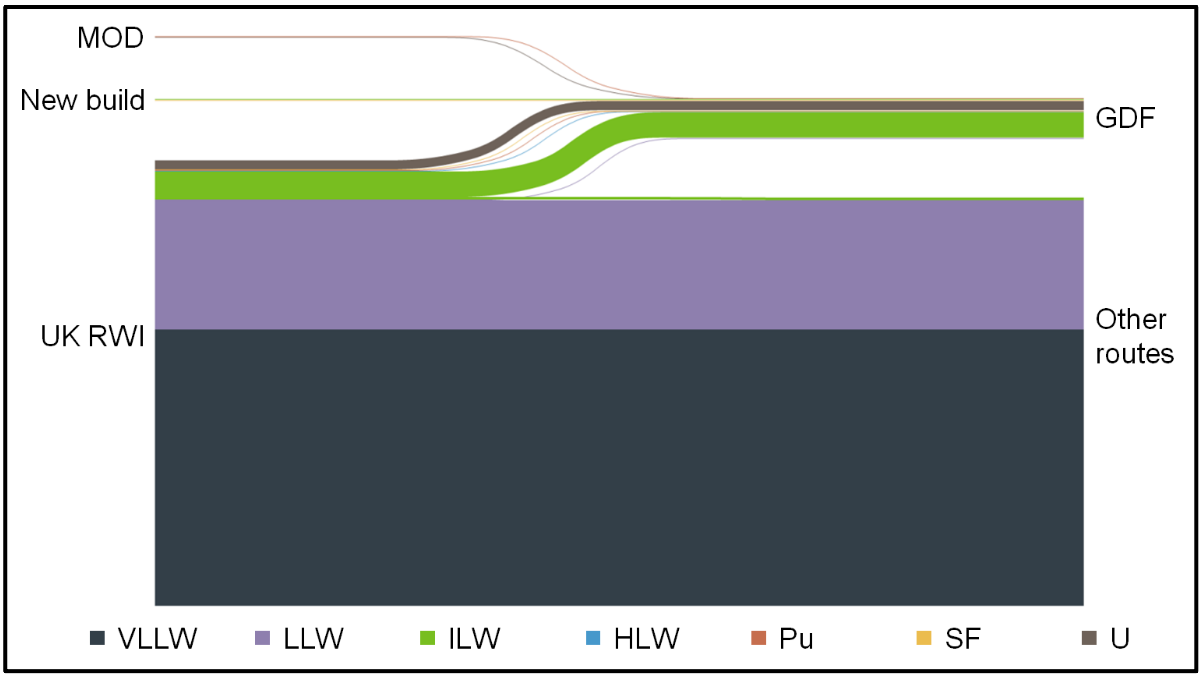


Table 3 The total volume of waste[17]

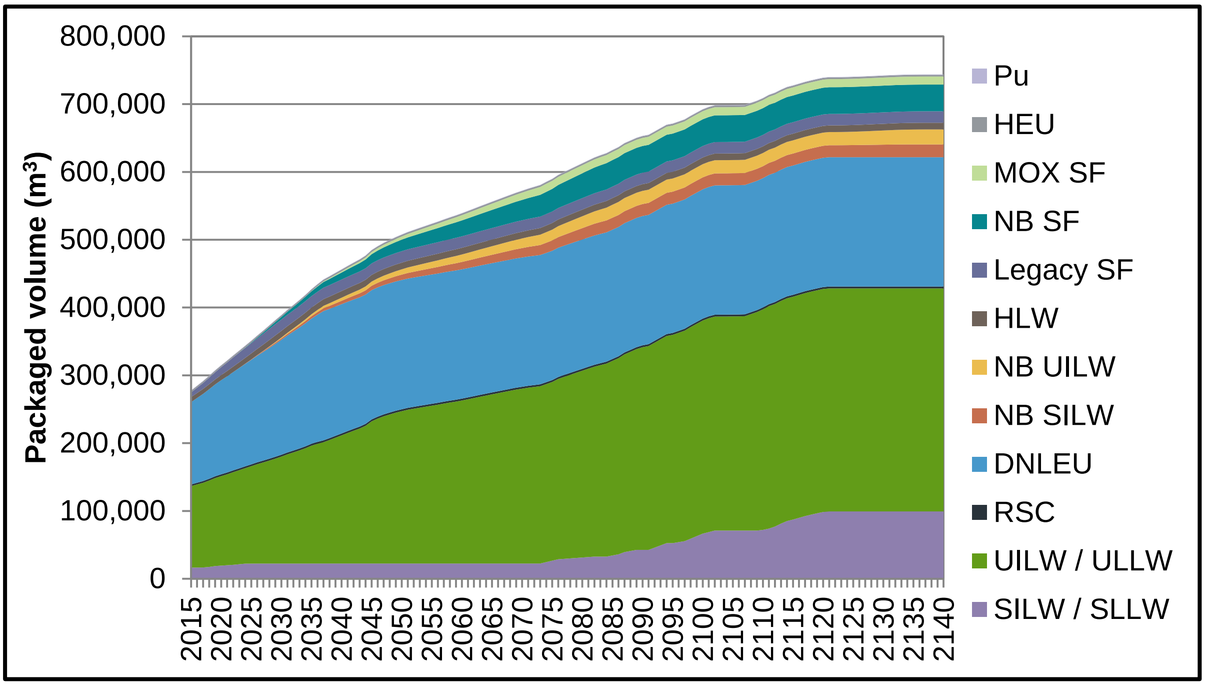
Waste category	Stored volume [m^3]	Conditioned volume [m^3]	Packaged volume [m^3]
HLW	1,500	1,500	9,860
ILW	273,000	355,000	461,000
LLW	8,880	10,700	11,400
Pu	0.567	174	620
Spent fuels	10,300	10,300	68,200
U	99,100	140,000	193,000
Total	393,000	518,000	744,000

Table 4 The packaged volume associated with each of the waste groups

Waste container	Volume [m^3]	Fraction of total [%]
Legacy SILW / SLLW	99,300	13%
Legacy UILW / ULLW	329,000	44%
RSCs	2,730	0.4%
DNLEU	191,000	26%
NB SILW	18,900	3%
NB UILW	22,100	3%
HLW	9,860	1%
Legacy SF	16,900	2%
NB SF	39,400	5%
MOX SF	11,900	2%
HEU	2,470	0.3%
Pu	620	0.1%
Total	744,000	n/a

[17] Volumes are rounded so subtotals do not sum to totals

Figure 7 The arisings profile of the 2016 IGD broken down by waste group



3.1.1 Waste origin by operation

HAW has been produced in the UK through electricity generation, defence activities and other industrial, medical and research activities. HAW continues to be produced from these activities and further waste is projected from a programme of new nuclear power stations.

Figure 8 shows a breakdown of the packaged volume of wastes in the IGD by the type of operation from which they originate. The following types of operation are included:

- use of MOX spent fuel
- new build commercial reactor operation
- commercial reactor operation (includes wastes from Magnox reactors, AGRs and Sizewell B)
- Sellafield (includes wastes from reprocessing and other activities at Sellafield[18])
- fuel fabrication and enrichment (includes wastes from Springfields and Capenhurst)
- medical and industrial (includes wastes from GE Healthcare, the LLWR and minor waste producers)
- MOD
- research and development (includes wastes from Harwell, Windscale, Winfrith, Culham and Berkeley Centre)

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18 Only wastes from the historically separate licensed sites of Windscale and Calder Hall are excluded; these wastes are included under the 'nuclear energy research and development' and 'commercial reactor operation' industries, respectively.

The contribution of “medical and industrial” is only a very small part of the total packaged volume (<0.1%). As would be expected, the packaged volume of the waste is dominated by nuclear fuel cycle activities and reactor operation.

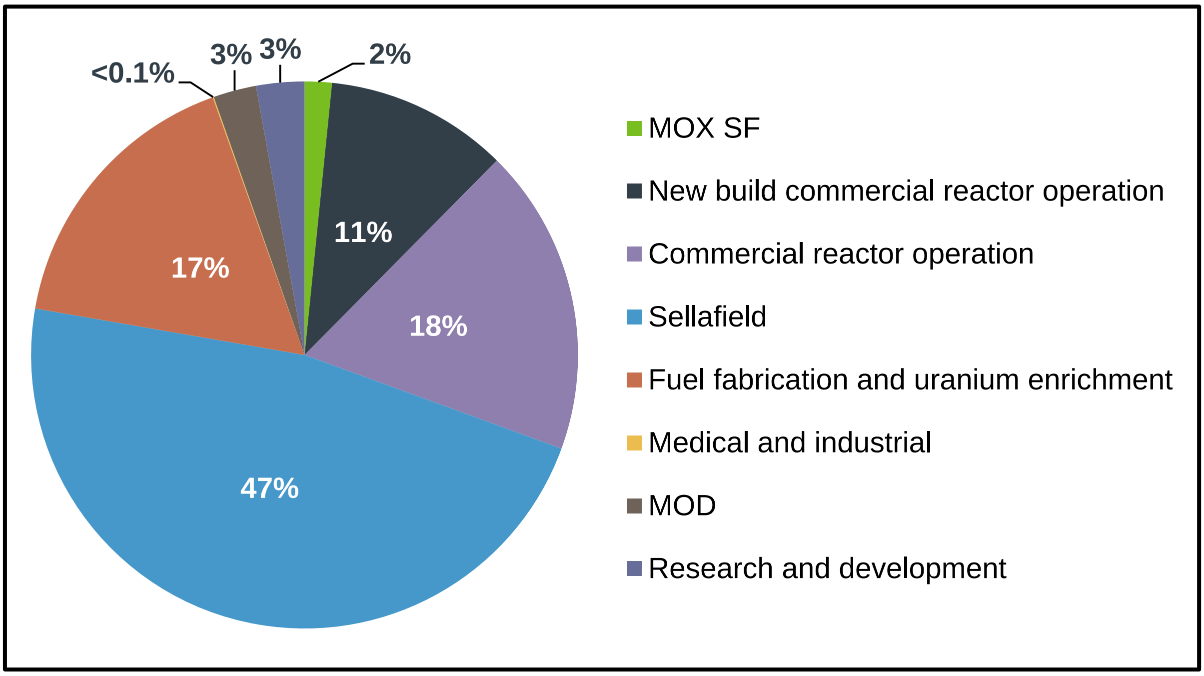


Figure 8 A breakdown of the packaged volume by origin

3.2 Disposal units

GDF throughput is measured in terms of disposal units. The majority of waste packages are handled singularly as disposal units. However, four 500 l drums are handled together in a stillage is a single disposal unit. The estimated numbers of disposal units in each waste group is presented in Table 5. Legacy UILW / ULLW waste group dominates the number of disposal units; this is consistent with the fact that this waste group dominates the packaged volume. However, the DNLEU waste group, which contributed 26% of the packaged volume, only contributes 7% of the disposal units. This is because a significant proportion of this waste group is packaged in TDCs, which are large in comparison to other waste packages.

Appendix B contains full details of each waste group, including details of the types of packages.

Table 5 The number of disposal units associated with each package type

Waste container	Disposal units [-]	Fraction of total [%]
Legacy SILW / SLLW	5,403	3%
Legacy UILW / ULLW	108,732	66%
RSCs	966	0.6%
DNLEU	12,302	7%
NB SILW	10,140	6%
NB UILW	8,227	5%
HLW	2,549	2%
Legacy SF	4,121	2%
NB SF	8,941	5%
MOX SF	2,707	2%
HEU	780	0.5%
Pu	196	0.1%
Total	165,287	n/a

3.3 Activities

The activity associated with the 2016 IGD at 2200 is estimated to be 27,900,000 TBq. The breakdown of the activity into the different waste groups is shown in Table 6. It is clear that the activity is dominated by the spent fuels: 68% of the activity is attributable to the new build spent fuels, while 13% is attributable to MOX SF, and 10% to the legacy SFs. Less than 10% of the total activity is associated with LHGW.

The activity of key radionuclides at 2040 and 2200 are presented in Table 7. Whilst it might be expected that the activities would decrease between 2040 and 2200, the fact that waste is still arising in between these dates (see

Figure 7) means that this is not always the case. For the radionuclides that are long-lived with respect to the time difference, for example
U-238, the activity increases between 2040 and 2200; for radionuclides that are short-lived with respect to the time difference, such as Co-60, the activity reduces between 2040 and 2200 despite there being additional arisings.

Table 6 The activity associated with each of the waste groups at 2200

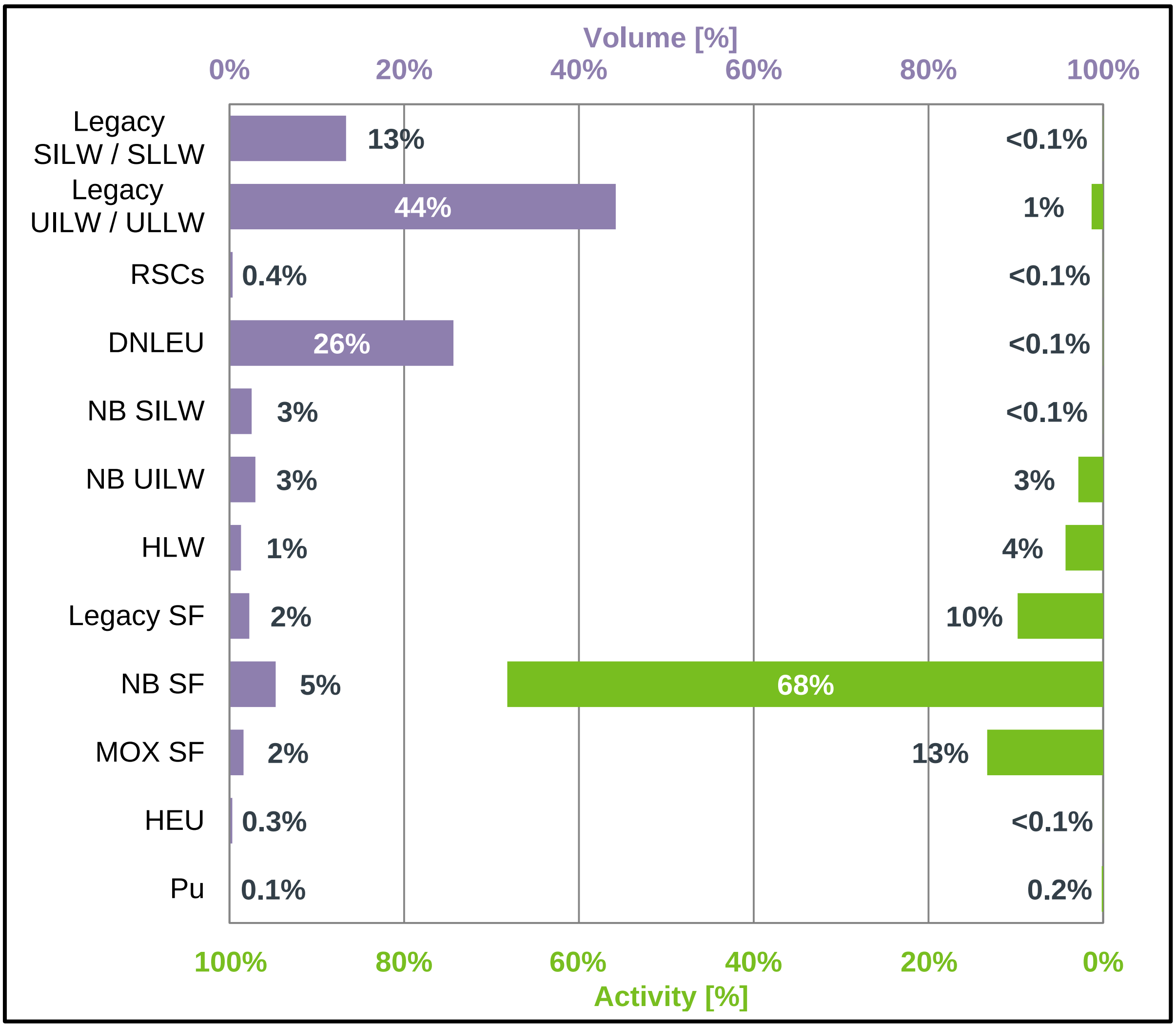
Waste container	Activity [TBq]	Fraction of total [%]
Legacy SILW / SLLW	13,800	<0.1%
Legacy UILW / ULLW	372,000	1%
RSCs	1,110	<0.1%
DNLEU	9,560	<0.1%
NB SILW	154	<0.1%
NB UILW	793,000	3%
HLW	1,200,000	4%
Legacy SF	2,730,000	10%
NB SF	19,000,000	68%
MOX SF	3,700,000	13%
HEU	53.8	<0.1%
Pu	43,700	0.2%
Total	27,900,000	n/a

Table 7 The activities of priority 1 radionuclides at 2040 and 2200

Radionuclide	Activity [TBq]		Radionuclide	Activity [TBq]	
	At 2040	At 2200		At 2040	At 2200
C-14	2,050	17,500	Cs-135	482	944
Cl-36	32.6	115	Cs-137	50,700,000	5,140,000
Co-60	725,000	2.12	U-233	1.57	2.49
Se-79	49.2	100	U-235	55.5	60.4
Kr-85	1,870,000	1,250	U-238	2,800	2,940
Tc-99	9,080	19,800	Np-237	291	851
I-129	16.8	43.3			

Figure 9 shows a comparison of the volume and the activity (at 2200) associated with each waste group; it can be seen that those waste groups that have a large volume tend to have a small activity, and vice-versa. New build spent fuel dominates the activity for over 100,000 years after GDF closure but DNLEU dominates the activity at extremely long times.

Figure 9 Comparison of the fraction of the activity (at 2200) and volume associated with each waste group



Although new build spent fuel dominates the activity at early times, legacy wastes and SF dominate the activity at later times. This is because the shorter-lived fission products will have decayed (reducing the activity of the spent fuels); whilst the longer lived radionuclides (eg naturally occurring uranium isotope U-238) from DNLEU persist. Indeed, the activity associated with DNLEU initially increases with time as the short-lived daughters of the uranium isotopes grow in. The short-lived daughters are present in natural uranium ore, but are removed when the material is refined. Figure 10 shows the evolution of the activities of the various different waste groups with time. The increase in the activity of DNLEU waste group is clear. Whilst new build wastes dominate at early times, this is not always the case. This is illustrated more clearly in Figure 11.

Figure 10 The evolution of the total activity and key waste groups. Minor contributors have been grouped into "Others"

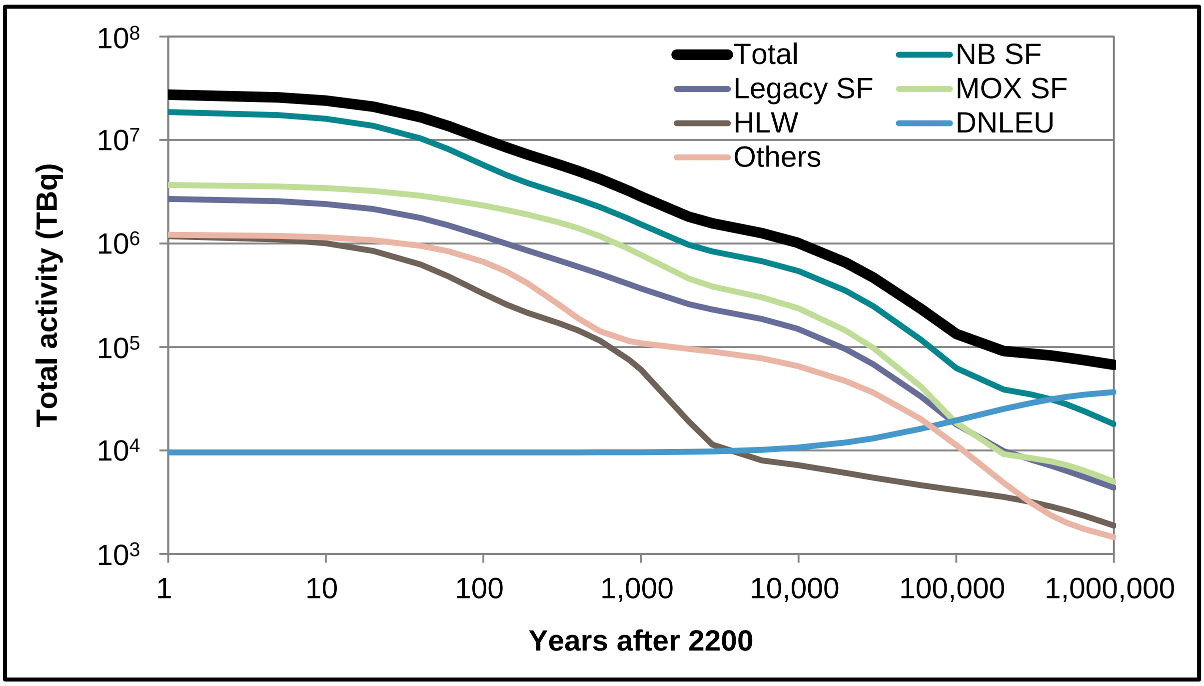
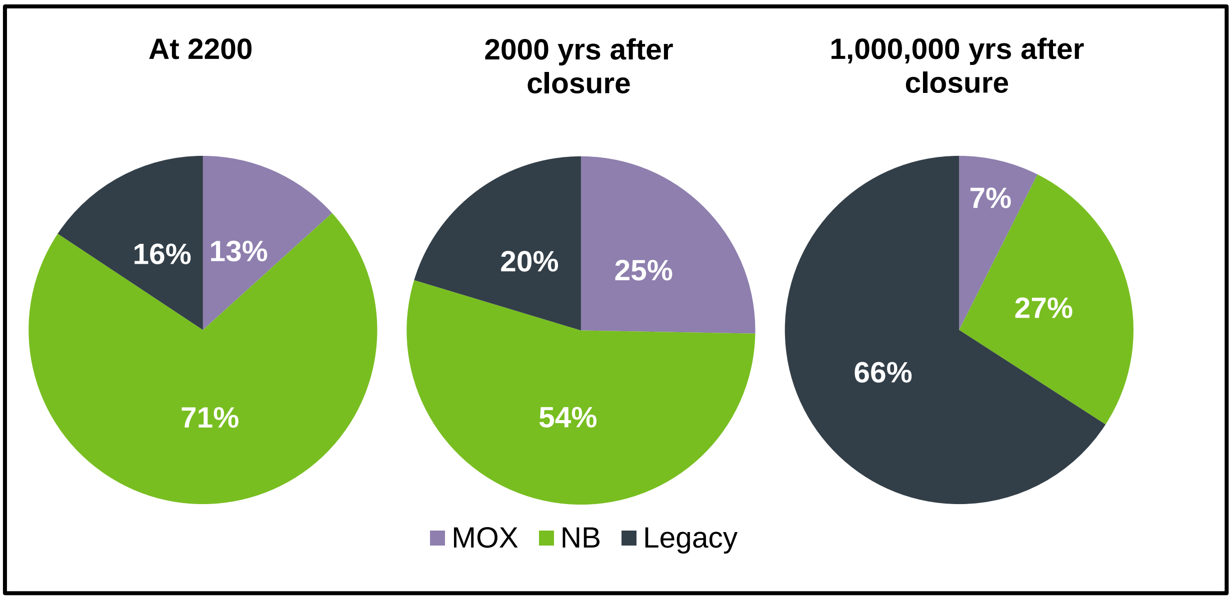


Figure 11 The fraction of the total activity that is attributable to wastes and materials from new build (NB), MOX and legacy facilities at GDF closure (2200), 2000 years after closure and 1,000,000 years after closure



3.4 Materials data

3.4.1 Broad Categories of Materials

The materials that make up the IGD are shown in Table 8 split into three broad categories: metals, organics and inorganics. The data presented only takes account of the stored form of the waste. Where the waste has been conditioned, this will include any conditioning matrix. However, in general, the data exclude materials associated with conditioning and capping of the waste, as well as any materials associated with the waste packages.

It can be seen in Table 8 that the inventory is dominated by inorganics, which account for approximately 76% of the inventory by mass; metals account for approximately 21% by mass, and organics approximately 2%. The remainder (approximately 0.3% by mass) is not specified. Appendix B discusses the breakdown of the materials in each waste group, while Appendix C includes data on the masses of the materials that make up the capping and conditioning matrix, as well as the materials associated with the waste packages.

It is assumed that superplasticisers have been used in the construction of legacy plant, some of which will be disposed of to a GDF. The chemical composition of superplasticisers means that they could complex with actinides and potentially increase their solubility. Consistent with the 2013 IGD, the 2016 IGD adopts a conservative assumption that all cementitious materials (including wastes, encapsulating and capping materials and waste containers) contain 0.5 wt% superplasticiser.

Table 8 The material masses and the percentage of the total mass

	Material	Material mass [t]	Percentage of total [%]
Metals	Stainless steel	40,200	6.7%
	Other ferrous metals[19]	71,000	11.8%
	Magnox/magnesium	6,300	1.0%
	Aluminium (and alloys)	1,730	0.3%
	Zircaloy/zirconium	6,290	1.0%
	Copper (and alloys)	291	<0.1%
	Nickel (and alloys)	434	0.1%
	Uranium	1,720	0.3%
	Lead	805	0.1%
	Other metals	322	0.1%
	Total Metals	129,000	21.4%

19 Principally mild steel

	Material	Material mass [t]	Percentage of total [%]
Organics	Cellulose	2,170	0.4%
	Halogenated plastics	3,630	0.6%
	Non-halogenated plastics	2,180	0.4%
	Rubbers	1,700	0.3%
	Organic ion ex. resins	3,470	0.6%
	Other organics	475	0.1%
	Total organics	13,600	2.3%
Other Materials	Graphite	78,400	13.0%
	Asbestos	311	0.1%
	Sludges & flocs	22,000	3.6%
	Cementitious materials[20]	55,000	9.1%
	Ion exchange materials	4,760	0.8%
	Heavy metal oxide	280,000	46.3%
	Glass, ceramics & sand	3,720	0.6%
	Soil, brick, stone & rubble	2,970	0.5%
	Other inorganics	13,100	2.2%
	Total other materials	460,000	76.1%
	Total Unspecified	1,680	0.3%

3.4.2 Hazardous materials and non-hazardous pollutants

The Environmental Permitting (England and Wales) Regulations 2016 [33] gives effect to certain provisions of Directive 2000/60/EC (Water Framework Directive) [34] and Directive 2006/118/EC (Groundwater Daughter Directive) [35] in England and Wales. It is noted that the legislation governing Scotland [36] and Northern Ireland [37] is different to that governing England and Wales.

The Environmental Permitting (England and Wales) Regulations 2016 prevent anyone carrying out an activity (such as geological disposal) that might result in the input of pollutants into groundwater unless they have been granted a permit to do so by the relevant environment agency. In granting a permit for such an activity, the relevant agency must ensure that inputs of hazardous substances to groundwater will be prevented and inputs of non-hazardous pollutants will be limited so as to avoid pollution. This will require RWM to inform the relevant agency of the quantities of hazardous substances and non-hazardous pollutants that will be present in a geological disposal system and demonstrate the adequacy

[20] All cementitious materials are assumed to contain 0.5 wt% superplasticiser.

of the controls it will have in place to prevent and limit (respectively) inputs of these substances to groundwater.

The UK RWI (and therefore the IGD) already includes data on a number of hazardous substances and non-hazardous pollutants. However, RWM has not completed work towards establishing the reporting requirements for hazardous substances and non-hazardous pollutants. This work is currently underway or planned (see Tasks 051 – 054 in RWM's Science and Technology Plan [38]). It is possible that this review will identify new reporting requirements for hazardous substances and non-hazardous pollutants. If this is the case, then these requirements will then be incorporated into a future iteration of the UK RWI, which will result in their inclusion in the IGD (if found to be present in the waste).

4 Key messages

Summary of key messages

The IGD is based on Government policy, industry plans and publicly available information.

The majority of the activity in the inventory is located in a very small volume of waste. The activity associated with the inventory decays quickly and, whilst spent fuel and wastes from an assumed new build programme dominate for over 100,000 years after GDF closure, it is the legacy wastes and materials that dominate at extremely long times.

The development of the inventory is an iterative process and RWM is currently undertaking work to inform the reporting requirements for the hazardous substances and non-hazardous pollutants in the inventory for geological disposal.

Most of the data for legacy wastes and materials are taken from the UK Radioactive Waste Inventory.

The UK has been producing radioactive waste inventories for over 30 years and this is now a well-established process. This report presents the 2016 IGD, which represents a light update to the 2013 IGD. As such, many of the assumptions from the 2013 IGD have been carried forward into this report.

The inventory for geological disposal is based on Government policy, industry plans and other publicly available information; the key assumptions are presented in Section 2:

- quantities of legacy wastes and their times of arising are taken from the UK RWI
- wastes covered by the Scottish Government's policy for the management of higher activity radioactive wastes are assumed to be disposed of via other routes
- 95% of the civil plutonium stockpile is assumed to have been converted to MOX fuel
- assumptions have been made regarding the physical / chemical form and radionuclide inventory of the legacy spent fuels, uranium, plutonium and MOX SF
- an assumed new build programme of 16 GW(e) has been included
- the quantities of MOD materials are taken from the 1998 strategic defence review
- HHGW are assumed to be disposed of in high-integrity disposal containers
- LHGW are assumed to be disposed of in an approved container type

Data have been presented on the quantity, activity, and material composition of the waste. The key points are that:

- the volume is dominated by the LHGW waste groups, which make a small contribution to the total activity at 2200 (the assumed date of GDF closure)
- at 2200 the activity is dominated by the spent fuel waste groups, which make only a small contribution to the volume
- although waste and spent fuel from the assumed new build programme dominate for over 100,000 years after GDF closure, it is the legacy wastes and materials that dominate at extremely long times

The development of the inventory is an iterative process and RWM is currently undertaking work to inform the reporting requirements for hazardous substances and non-hazardous pollutants in the inventory for geological disposal.

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Glossary

Term	Definition
ABWR	Advanced Boiling Water Reactor. Horizon nuclear power are proposing to build UK ABWRs at Wylfa and Oldbury
AGR	Advanced Gas-cooled Reactor
AP1000	Pressurised water reactor sold by Westinghouse Electric Company
BFS	Blast furnace slag
Conditioned volume	The conditioned waste volume is the volume of the wasteform (waste plus immobilising medium) within the container
Cooling time	Average time after the irradiation of fuel elements in a reactor stops
CSA	Criticality safety assessment
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.
DNLEU	Depleted, natural and low enriched uranium
DSSC	Disposal system safety case
DU	Depleted uranium
DU tails	Depleted uranium left over from enrichment operations
EBS	Engineered barrier system
EPR	EPR is now used by AREVA as a reactor name, it was previously used to mean European Pressurized Reactor and Evolutionary Power Reactor
ESC	Environmental safety case
FED	Fuel element debris
GDA	Generic design assessment
GDF	Geological Disposal Facility
gESA	generic Environmental Safety Assessment
gOSC	generic Operational Safety Case
gTSC	Generic Transport Safety Case
GWd/tU	Gigawatt days per ton of uranium (1 ton = 1,000 kg)
GW(e)	Gigawatts electrical
HAW	Higher activity radioactive waste
HEU	Highly enriched uranium

HHGW	High heat generating waste
HLW	High level waste
IAEA	International Atomic Energy Agency
IGD	Inventory for geological disposal
ILW	Intermediate level waste
ISA	Isosaccharinic acid
ISO	International organisation for standardization
JET	Joint European Torus
LAW	Low active waste
Legacy waste	Radioactive waste which already exists or whose arising is committed in future by the operation of an existing facility
LEU	Low enriched uranium
LHGW	Low heat generating waste. Some wastes have negligible heat output; these are included in this category
LLW	Low level waste
LLWR	Low Level Waste Repository
LWR	Light Water Reactor
MBGWS	Mixed Beta Gamma Waste Store
MDU	Magnox depleted uranium
MOD	Ministry of Defence
MOX	Mixed oxide fuel
MSSS	Magnox Swarf Storage Silo
NB	New build
OESA	Operational environmental safety assessment
OPC	Ordinary Portland cement
OSC	Operational safety case
Packaged volume	The packaged waste volume is the displacement volume of a container used to package a wasteform
Payload	Usable internal volume of a waste package
PCM	Plutonium contaminated materials
PCSA	Post-closure safety assessment

PCSR	Pre-construction Safety Report
PFA	Pulverised fuel ash
PFR	Prototype Fast Reactor
POCO	Post-operational clean-out
ppm	Parts per million
Priority 1 radionuclide	Highest priority score for those radionuclides having greatest effect on, wasteform, packaging, transport, criticality and GDF design
Pu	Plutonium
PVC	Polyvinyl chloride
PWR	Pressurised Water Reactor
RAL	Rutherford Appleton Laboratory
RGL	Regulatory guidance level
RPCM	Radiological protection criteria manual
RS	Robust shielded
RSC	Robust shielded container
SF(s)	Spent fuel(s): 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
SILW	Shielded ILW
SILW waste package	Waste package not requiring additional shielding
SLLW	Shielded LLW
SRL	Scientific readiness level: A scale calibrating the scientific maturity of underpinning science between 1 and 9 where 1 is the least mature and 6 the most established understanding
SS	Stainless steel
Superplasticiser	Commonly used to improve the flow characteristics of cements and concrete and also allow the water to cement ratio to be reduced (this produces stronger concretes). Superplasticisers could enhance the solubility of actinides
SWTC	Standard Waste Transport Container
TDC	Transport and disposal container
tHM	Tons of heavy metal (1 ton = 1,000 kg)
THORP	Thermal oxide reprocessing plant

TPS	Transport package safety
TPU	THORP product uranium
TSC	Transport safety case
TSD	Transport system design
TSSA	Transport system safety assessment
tU	Tons of uranium (1 ton = 1,000 kg)
UILW	Unshielded ILW
UILW waste package	Waste package requiring additional shielding
UK RWI	UK radioactive waste inventory (also referred to as UK RWMI - UK radioactive waste and materials inventory)
ULLW	Unshielded LLW
VLLW	Very low level waste
WVP	Waste Vitrification Plant

Appendix A – 2016 IGD scenario

A1 Timings and duration of activities

Table A1 The timing and duration of activities in the scenario for the 2016 IGD

Sector	Assumptions[21]
Civil nuclear power stations	Sizewell B shuts down in 2035 AGRs: Shuts down in 2023: Hinkley Point B, Hunterston B Shuts down in 2024: Heysham 1, Hartlepool Shuts down in 2028: Dungeness B Shuts down in 2030: Heysham 2 Deferral of Magnox and AGR final stage decommissioning for up to about 85 years after shutdown; all decommissioning complete by 2125 Prompt decommissioning of Sizewell B (completed by 2053) New build programme of 16 GW(e) comprising 6 UK EPRs and 6 AP1000s. Assumes 60 years operation, transport of decommissioning wastes to GDF 40 years after reactor shutdown
Pu	95% of civil (and all MOD) Pu re-used as MOX fuel 5% of civil Pu treated as waste
U enrichment	Continues to 2037
Spent fuel reprocessing	Magnox fuel reprocessing continues until 2020 (55,000 tU in total) Oxide fuel reprocessing in THORP continues until 2018 (5,000 tU AGR SF and 4,400 tU overseas SF) All reprocessing facilities fully decommissioned by 2090 5,500 tU AGR SF is not reprocessed Sizewell B SF, new build SFs and MOX SF are not reprocessed
Research	The Joint European Torus (JET) operates until end of 2020
Harwell & Winfrith	All redundant facilities are fully decommissioned by 2027
Defence	A continuing nuclear defence capability (waste estimated to 2080) A continuing nuclear powered submarine programme (waste estimated to 2110)
Medical & industrial sources	The medical uses of radioactivity continue (arisings estimated to 2040
Fuel fabrication	Continues until 2030 (although no operational or decommissioning HAW is produced through the manufacturing process)

21 Excludes wastes managed under the Scottish Government's Policy for HAW.

A2 Assumptions regarding quantities

Table A2 The estimated contents of each waste group

Waste group	2016 Derived Inventory[22]
SILW / SLLW UILW / ULLW RSCs	All 2016 UK RWI ILW, excluding those wastes with an established management strategy of incineration, recycling or near surface disposal All 2016 UK RWI LLW unsuitable for near-surface disposal
DNLEU	200,000 tU from civil fuel enrichment and civil spent fuel reprocessing 15,000 tU from defence programmes
NB SILW NB UILW	ILW from a 16 GW(e) new build programme
HLW[23]	All 2016 UK RWI HLW from reprocessing 55,000 tU Magnox SF and 5,000 tU Advanced gas-cooled reactor (AGR) SF
Legacy SF	5,500 tU AGR SF 1,050 tU Sizewell B Pressurised Water Reactor (PWR) SF 760 tU metallic SF 10 tHM exotic SF Irradiated submarine fuel not quantified
NB SF	8,260 tU UK EPR SF 6,030 tU AP1000 SF
MOX SF	1,460 tHM MOX SF (includes fuel made from 7.6 t of defence Pu) 8%wt Pu
HEU	1.0 tU from civil programmes 21.9 tU from defence programmes
Pu	5.75 tHM separated Pu residues from reprocessing of civil SFs (representing 5% of the 115 tHM UK owned Pu unsuitable for re-use as MOX fuel)

22 Excludes wastes managed under the Scottish Government's Policy for HAW.

23 Note that a small portion of HLW created from reprocessing UK SFs will be returned to overseas customers under waste substitution arrangements that are described further in Section 2.3.4.

A3 2016 IGD scenario: spent fuel enhancements

The UK RWI only presents information on the masses of the spent fuels. RWM has made assumptions regarding the level of irradiation that these fuels have received; these were presented in Table 2 and are repeated in Table A3 below for convenience. In the case of AGR fuel, it is assumed that the arisings can be divided evenly between the two enrichments of the robust fuel [A1].

In addition to the assumptions regarding the irradiation conditions, RWM has had to make assumptions regarding the material composition of the fuels; these are presented in Table A4.

Table A3 Key parameters in the calculation of the fuel inventories[24]

Spent fuel type	Enrichment [%]	Burn-up [GWd/tHM]	Cooling time [years]
AGR (pre-2013)	2.9	28	9
AGR (post-2013)	3.2 / 3.78	33	Arises as 1 yr cooled
Sizewell B (pre-2013)	4.2	45	11
Sizewell B (post-2013)	4.4	55	Arises as 1 yr cooled
Metallic fuels	0.71	4.1	39
Exotic fuels	(Pu) 29.5	189	22
MOX SF	(Pu) 8	50	Arises as 1 yr cooled
UK EPR SF	5	65	Arises as 1 yr cooled
AP1000 SF	4.5	65	Arises as 1 yr cooled

Table A4 Bulk materials per disposal container

	Component	Material	Mass [t]
PFR	Fuel	UO_2 / PuO_2 (U/Pu)	0.624 (0.550)
	Cladding	Nimonic	0.166
	SS canisters	Type 304 SS	0.488
AGR	Fuel	UO_2 (U)	2.34 (2.06)
	Cladding	Type 20/25 Nb SS	0.282[25]
	Sintox discs	Al_2O_3	0.016

24 Note that the inventories for the new build spent fuels are included for completeness only. The radionuclide inventories are taken from the GDA disposability assessment reports and have not been enhanced by RWM.

25 Consistent with the 2007 Derived Inventory, the radionuclide activity use for AGR SF has assumed 0.27 t of cladding.

	Component	Material	Mass [t]
	Slotted cans	Type 316 SS	0.197
Sizewell B PWR	Fuel	UO_2 (U)	2.08 (1.834)
	Cladding[26]	Zircaloy 4	0.4688
	Plenum springs	Type 304 SS	$9.60\ 10^{-3}$
	Grids	Inconel 718	$2.68\ 10^{-2}$
	Grid sleeves	Type 304 SS	$4.80\ 10^{-3}$
	Top & bottom nozzles[27]	Type 304 SS	$5.04\ 10^{-2}$
Magnox[28]	Fuel	Uranium metal	0.886
	Cladding[29]	Magnox Al80	0.159
	WVP canisters	Type 309 SS	0.381
UK EPR	Fuel	UO_2 (U)	1.79 (1.58)
	Cladding, grids, etc	Zircaloy M5	0.486
	Springs	Inconel 718	$1.31\ 10^{-2}$
	Nozzles	AISI 304L SS	$4.38\ 10^{-2}$
	Insulating pellets	Al_2O_3	$1.79\ 10^{-3}$
AP1000	Fuel	UO_2 (U)	1.84 (1.62)
	Cladding, grids, etc	Zirlo	0.469
	Springs	Inconel 718	$1.55\ 10^{-2}$
	Nozzles	Type 304 SS	$4.37\ 10^{-2}$
	Insulating pellets	Al_2O_3	$1.70\ 10^{-3}$

26 Note that for the arisings this is assumed to be M5 and not Zircaloy 4.

27 This mass is reduced to 10% of the stated value in the activation calculations in order to model the reduced flux that is experienced at the ends of the fuel assembly.

28 Averages for five different Magnox fuel elements are used for the fuel and cladding masses:
Calder Hall / Chapelcross: total element mass 13.2 kg; uranium mass 11.4 kg
Dungeness A: total element mass 12.9 kg; uranium mass 11.0 kg
Sizewell A: total element mass 14.0 kg; uranium mass 11.9 kg
Oldbury: total element mass 12.9 kg; uranium mass 10.6 kg

29 Mass includes stainless steel sheathed bottom cone (mass unknown).

Appendix A references

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Appendix B – Inventory data by waste group

In this appendix a separate section is used to present the inventory data for each of the waste groups. In each case, the same data are presented:

- information on volumes
- information on the number of disposal units
- information on the activity
- information on the materials

The sections contain only a brief discussion of the materials data, which are given in detail in Appendix C.

As the 2016 IGD is a light update to the inventory, the following have not been calculated:

- the gas generation parameters (metal geometry / thicknesses)
- the elemental composition of the waste

As such, no data are presented on these. The most up to date information on these parameters are published in the 2013 IGD [B1].

B1 Legacy shielded ILW / LLW

There are three broad categories of waste packages for legacy ILW / LLW: shielded, unshielded and robust shielded. This waste group deals with the legacy wastes (those that have arisen, or will arise from existing facilities) that are packaged in shielded waste containers.

B1.1 Volumes

The total packaged volume of waste in this waste group is estimated to be 99,300 m^3. The stored, conditioned and packaged volumes associated with each of the waste containers in this waste group are presented in Table B1. Some of the waste containers have variable levels of internal shielding and the 6 m^3 concrete box has standard and high density (SD and HD) variants.

Figure B1 shows the arisings and total packaged volume of the waste group plotted against date. The majority of the shielded legacy waste arises as the reactor sites enter their final site clearance phases; the step changes in the arisings profile correspond to individual reactor sites starting (and completing) their final site clearance.

Table B1 The number of disposal units and volumes associated with each container type in the legacy shielded ILW / LLW waste group

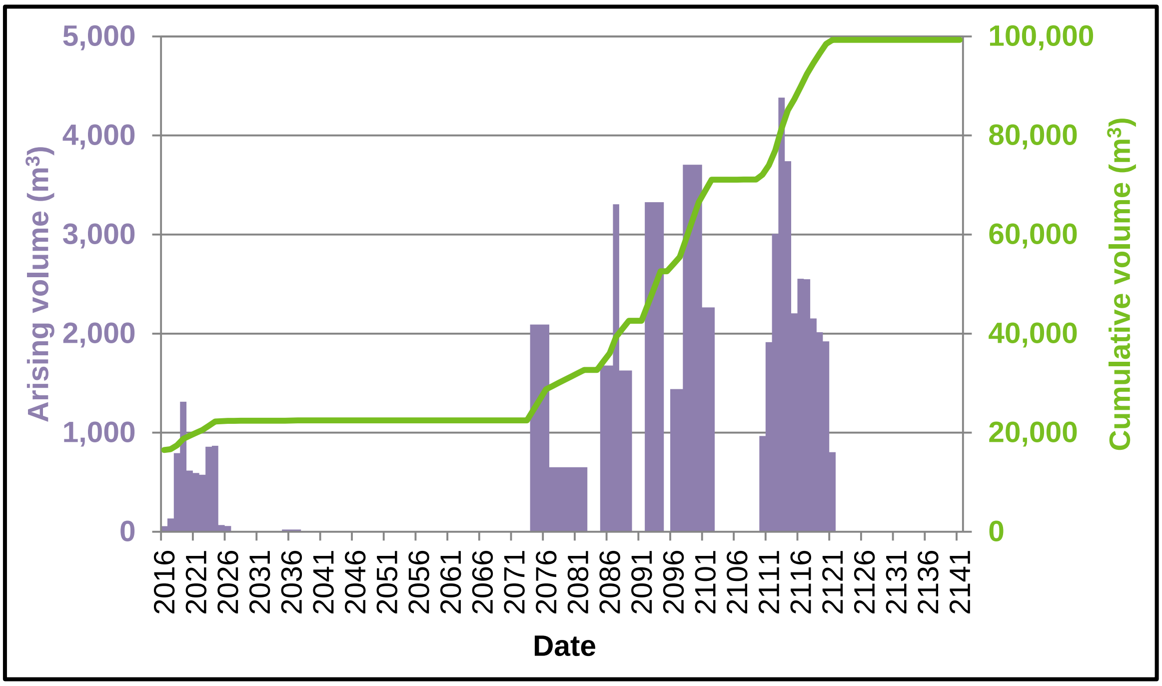
Waste container	No. disposal units [-]	Volume [m^3]		
		Stored	Conditioned	Packaged
4 m box (0 mm concrete)	2,730	43,900	51,600	54,700
4 m box (100 mm concrete)	1,230	14,400	17,500	24,500
4 m box (200 mm concrete)	362	1,830	3,950	7,250
6 m^3 concrete box (HD)	169	446	923	2,000
6 m^3 concrete box (SD)	909	3,260	5,270	10,800
Total	5,400	63,900	79,300	99,300

B1.2 Disposal units

This waste group has 5,400 disposal units associated with it;

Table B1 shows the breakdown by waste container type. It can be seen that the 4 m boxes dominate the number of disposal units.

Figure B1 The arisings and total packaged volume profiles for legacy shielded waste



B1.3 Activities

The total activity of this waste group at 2040 is estimated to be 15,100 TBq and despite the fact that the majority of waste (by volume) arises after this, the activity at 2200 has fallen to 13,800 TBq as a result of radioactive decay. At both 2040 and 2200, the most significant contributor to the total activity of the waste group is Ni-63.

The activity associated with the priority 1 radionuclides at 2040 and 2200 is shown in Table B2. The activity associated with shorter lived radionuclides (eg Co-60) has fallen between 2040 and 2200 due to decay, while the activity associated with longer-lived radionuclides such as C-14 and Cl-36 has increased as more waste, largely graphite from reactor decommissioning, has arisen.

Table B2 The activity of the priority 1 radionuclides in legacy shielded waste

Radionuclide	Activity [TBq]		Radionuclide	Activity [TBq]	
	At 2040	At 2200		At 2040	At 2200
C-14	65.5	6,400	Cs-135	$4.56\ 10^{-2}$	$4.56\ 10^{-2}$
Cl-36	0.484	26.2	Cs-137	221	5.61
Co-60	1,390	$1.62\ 10^{-3}$	U-233	$5.60\ 10^{-2}$	$5.60\ 10^{-2}$
Se-79	$3.50\ 10^{-4}$	$3.50\ 10^{-4}$	U-235	$4.19\ 10^{-4}$	$4.19\ 10^{-4}$
Kr-85	0.727	$2.36\ 10^{-5}$	U-238	$3.16\ 10^{-2}$	$3.16\ 10^{-2}$
Tc-99	0.192	0.394	Np-237	$3.51\ 10^{-2}$	$3.57\ 10^{-2}$
I-129	$2.27\ 10^{-4}$	$2.27\ 10^{-4}$			

B1.4 Materials

Appendix C2 presents the materials data for LHGW. In keeping with the general trend outlined in Section 3.4, the materials comprising the legacy SILW / SLLW waste group are predominantly the “metals” and “other materials”. The most significant contributors are graphite (predominantly from the cores of AGRs and Magnox reactors) and other ferrous metals.

Capping and conditioning is predominantly cementitious (although there is a small amount of polymer encapsulation), while the waste package materials are dominated by concrete and stainless steels.

B2 Legacy unshielded ILW / LLW

There are three broad categories of waste packages for legacy ILW / LLW: shielded, unshielded and robust shielded. This waste group deals with the legacy wastes that are packaged in unshielded waste containers.

B2.1 Volumes

The total packaged volume of waste in this waste group is estimated to be 329,000 m^3. Table B3 presents the stored, conditioned and packaged volumes associated with each of the waste containers in this waste group. Some of the waste containers have a number of variants, eg the 500 l drum has two enhanced variants. The conditioned volume of waste associated with a container type can be less than the stored volume if the wastes are compactible (eg for 200 l drums compacted into pucks and grouted into 500 l drums).

Figure B1 shows the arisings and total packaged volume of the waste group plotted against date. Unshielded legacy waste arises continuously because the waste arising as a result of the decommissioning at Sellafield is expected to continue throughout the period that the reactors are in their care and maintenance phase. Large spikes in the arisings are associated with specific events (eg at 2045 a large volume of Magnox pond furniture arises). The broader peak from 2108 to 2111 is predominantly associated with final site clearance wastes at Calder Hall.

Table B3 The number of disposal units and volumes associated with each container type in legacy unshielded waste

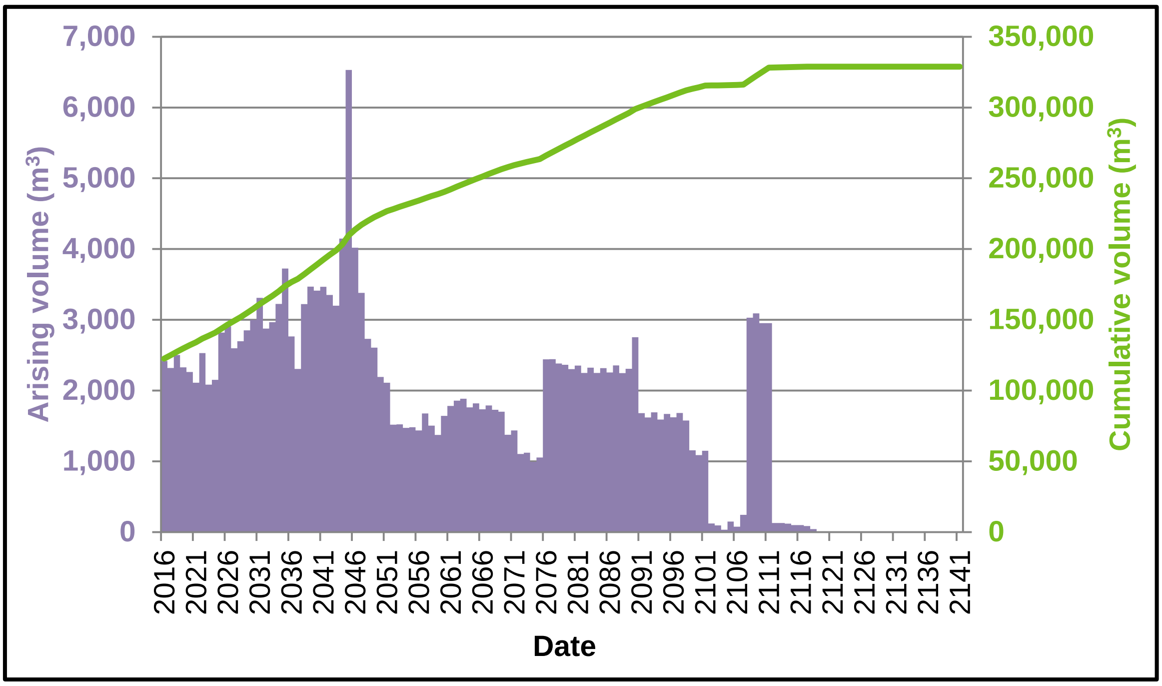
Waste container	No. disposal units[30] [-]	Volume [m^3]		
		Stored	Conditioned	Packaged
3 m^3 box (side lifting)	4,430	13,000	11,800	14,500
3 m^3 box (corner lifting)	688	199	1,930	2,480
3 m^3 drum	545	898	1,220	1,420
3 m^3 Sellafield box[31]	54,600	50,400	148,000	180,000
3 m^3 enhanced Sellafield box[31]	16,100	19,600	34,500	53,000
MBGWS box	1,380	4,770	4,830	6,490
500 l drum	24,700	49,200	45,500	56,300
Enhanced 500 l drum (with basket)[32]	6,180	69,700	12,500	14,100
Enhanced 500 l drum (pre-cast)[32]	205	318	334	469
Total	109,000	208,000	260,000	329,000

[30] Four 500 l drums are disposed of together in a stillage, which is defined as a disposal unit.

[31] A Sellafield specific example of a 3 m^3 box (corner lifting) box.

[32] A specific design of 500 l drum.

Figure B2 The arising and total packaged volume profiles for legacy UILW / ULLW



B2.2 Disposal units

This waste group has 109,000 disposal units associated with it; Table B3 shows the breakdown by waste container type.

B2.3 Activities

The total activity of this waste group at 2040 is estimated to be 1,940,000 TBq and despite the fact that the majority of waste (by volume) arises after this, the activity at 2200 has fallen to 372,000 TBq as a result of radioactive decay. At both 2040 and 2200 the most significant contributor to the total activity of the waste group is Ni-63.

The activity associated with the priority 1 radionuclides at 2040 and 2200 is shown in. Table B4 The activity associated with shorter lived radionuclides (eg Co-60) has fallen between 2040 and 2200, while the activity associated with longer-lived radionuclides such as C-14 and Cl-36 has increased as more waste containing these radionuclides has arisen.

Table B4 The activity of the priority 1 radionuclides in legacy unshielded waste

Radionuclide	Activity [TBq]		Radionuclide	Activity [TBq]	
	At 2040	At 2200		At 2040	At 2200
C-14	535	1,200	Cs-135	6.47	6.47
Cl-36	8.07	9.44	Cs-137	257,000	6,570
Co-60	92,000	$8.54\ 10^{-4}$	U-233	0.983	1.07
Se-79	0.555	0.556	U-235	0.535	0.552
Kr-85	853	$2.77\ 10^{-2}$	U-238	17.9	18.3
Tc-99	1,010	1,020	Np-237	106	108
I-129	0.706	0.707			

B2.4 Materials

Appendix C2 presents the materials data for LHGW. In keeping with the general trend outlined in Section 3.4, the materials comprising the legacy UILW / ULLW waste group are predominantly the “metals” and “other materials”. The most significant contributors are cementitious material, sludges and flocs, other ferrous metals and stainless steel. In absolute terms this waste group has more organic matter than any other, with halogenated plastics, cellulosics, organic ion exchange resins and rubbers the key contributors.

Capping and conditioning is predominantly cementitious (although there is a small amount of polymer encapsulation), while the waste package materials are dominated by concrete and stainless steels.

B3 Robust shielded ILW containers

There are three broad categories of waste packages for legacy ILW / LLW: shielded, unshielded and robust shielded. This waste group deals with the legacy wastes that are packaged in robust shielded waste containers.

B3.1 Volumes

The 500 l robust shielded (RS) drum and the 3 m^3 RS box are the only robust shielded ILW containers (RSCs) in the inventory. The total packaged volume of waste in this waste group is estimated to be 2,730 m^3. The stored, conditioned and packaged volumes associated with each of the waste containers in this waste group are presented in Table B5. The waste packagers have the option to include lead shielding within the 500 l RS drums in order to meet the relevant criteria for the dose rate external to the completed waste package. This shielding is provided by lead inserts with thicknesses of up to 120 mm. RS drums with a variety of different thicknesses of lead shielding are used in the inventory for geological disposal.

Figure B3 shows the arisings and total packaged volume of the waste group plotted against date. Only EDF Energy and Magnox use (or are proposing to use) RSCs for the packaging of their wastes. As can be seen in Figure B3, the future arising of wastes that are anticipated to be packaged in RSCs is limited.

Table B5 The number of disposal units and volumes associated with each container type in RSCs

Waste container	No. disposal units [-]	Volume [m^3]		
		Stored	Conditioned	Packaged
3 m^3 RS box	354	1,050	883	1,920
500 l RS drum (0 mm Pb)	478	257	257	630
500 l RS drum (20 mm Pb)	54	21.4	22.8	70.2
500 l RS drum (30 mm Pb)	16	0.74	5.80	20.6
500 l RS drum (50 mm Pb)	8	3.06	3.23	9.87
500 l RS drum (80 mm Pb)	3	0.200	0.697	3.77
500 l RS drum (90 mm Pb)	38	1.01	8.38	49.9
500 l RS drum (120 mm Pb)	15	0.42	2.47	19.6
Total	966	1,330	1,180	2,730

B3.2 Disposal units

This waste group has 966 disposal units associated with it; Table B5 shows the breakdown by waste container type.

B3.3 Activities

The total activity of this waste group at 2040 is estimated to be 4,340 TBq and this has decayed to 1,110 TBq by 2200. As there are no RSC arisings between 2040 and 2200, the change is solely a result of decay (and ingrowth).

Table B6 shows the activity of the priority 1 radionuclides that are associated with the RSCs at 2040 and 2200. The activity at both 2040 and 2200 is dominated by the contribution from Ni-63.

Figure B3 The arising and total packaged volume profiles for RSCs

Table B6 The activity of the priority 1 radionuclides in RSCs

Radionuclide	Activity [TBq]		Radionuclide	Activity [TBq]	
	At 2040	At 2200		At 2040	At 2200
C-14	4.95	5.69	Cs-135	$7.59\ 10^{-3}$	$7.65\ 10^{-3}$
Cl-36	0.254	0.254	Cs-137	479	12.4
Co-60	20.3	$2.37\ 10^{-8}$	U-233	$1.57\ 10^{-4}$	$1.63\ 10^{-4}$
Se-79	$7.79\ 10^{-5}$	$7.86\ 10^{-5}$	U-235	$2.90\ 10^{-4}$	$2.91\ 10^{-4}$
Kr-85	0.104	$1.12\ 10^{-5}$	U-238	$9.63\ 10^{-3}$	$9.64\ 10^{-3}$
Tc-99	$3.10\ 10^{-2}$	$3.26\ 10^{-2}$	Np-237	$7.92\ 10^{-3}$	$8.06\ 10^{-3}$
I-129	$4.47\ 10^{-5}$	$5.01\ 10^{-5}$			

B3.4 Materials

Appendix C2 presents the materials data for LHGW. In keeping with the general trend outlined in Section 3.4, the materials comprising RSC waste group are predominantly the “metals” and “other materials”. The most significant contributors are other ferrous metals, graphite and sludges and flocs.

RSCs have no capping or conditioning materials and the packages themselves comprise cast iron and lead.

B4 Depleted, natural and low-enriched uranium

The majority of the UK DNLEU comprises uranic materials produced in the UK thermal reactor fuel cycle: depleted uranium (DU) from fuel enrichment operations and reprocessing of spent fuels. Low-enriched uranium (LEU) arises from a variety of fuel cycle and research activities and makes up a small component of the overall DNLEU inventory. A breakdown of the components of the DNLEU inventory is provided in Table B7.

The components of the DNLEU inventory are:

- Magnox depleted uranium (MDU), which arises from the reprocessing of Magnox fuel
- THORP product uranium (TPU), which arises from the reprocessing of oxide fuel at THORP
- depleted uranium tails from uranium enrichment. The ‘irradiated’ tails have arisen from enrichment activities that used MDU as the feedstock
- defense DNLEU is uranium that is owned by MOD and that does not fall into the HEU category
- miscellaneous DNLEU covers DNLEU from other sources
-

Table B7 The components of the DNLEU inventory

DNLEU category	Assumed disposed form	Quantity [tU]	Waste container
MDU in 200 l drums	UO_3	23,100	TDC (2.4 m high)
MDU in 210 l drums	UO_3	14,900	TDC (2.1 m high)
THORP product uranium	U_3O_8	5,000	500 l drum (DNLEU)
DU tails (irradiated)	U_3O_8	15,500	TDC (2.3 m high)
DU tails (unirradiated)	U_3O_8	138,500	TDC (2.3 m high)
Defence DNLEU	U_3O_8	15,000	500 l drum (DNLEU)
Miscellaneous DNLEU	U_3O_8	3,000	500 l drum (DNLEU)
Total	n/a	215,000	n/a

B4.1 Volumes

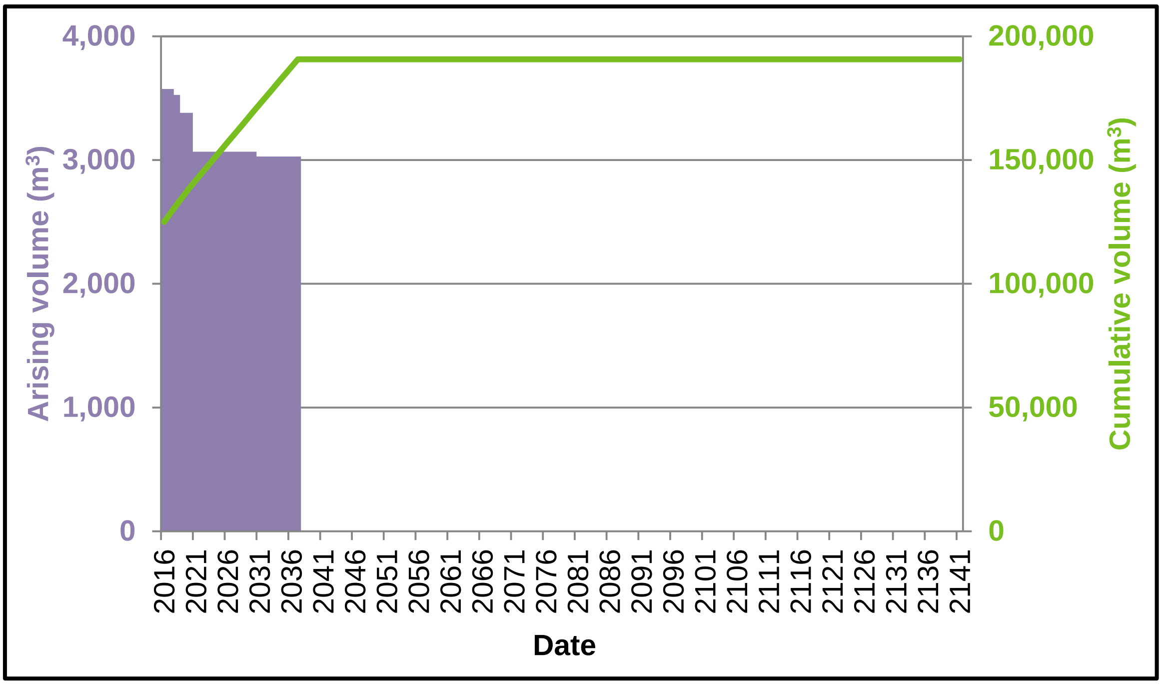
The stored, conditioned and packaged volumes of the DNLEU waste group are presented in Table B8, the vast majority of which is DU tails. Future arisings of DNLEU are predominantly from the enrichment activities at Capenhurst and the reprocessing of Magnox and oxide spent fuels at Sellafield. All of these operations are assumed to finish by 2037. This can be seen in Figure B4, which shows the total packaged volume of the DNLEU plotted against the date.

For the MDU and DU tails, the 'stored volume' refers to the volume of the container in which the uranium is currently stored[33], while for the wastes that are assumed to be packaged in 500 l drums, the stored volume refers to the assumed volume of U_3O_8 powder that the uranium would be converted to.

Table B8 The number of disposal units and volumes associated with each container type in the DNLEU waste group

Waste container	No. disposal units [-]	Volume [m³]		
		Stored	Conditioned	Packaged
500 l drum (DNLEU)	5,970[34]	3,280	11,200	13,600
Uranium TDC (2.1 m high)	460	6,520	8,630	11,700
Uranium TDC (2.3 m high)	4,430	68,400	87,800	123,000
Uranium TDC (2.4 m high)	1,450	20,800	31,700	42,000
Total	12,300	99,100	139,000	191,000

Figure B4 The arisings and total packaged volume profiles of DNLEU



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33 DV-70s for the DU tails and 200 l drums overpacked in larger (approximately 500 l) drums or 210 l drums for the MDU.

34 Four 500 l drums are disposed of together in a stillage, which is defined as a disposal unit.

B4.2 Disposal units

This waste group has 12,300 disposal units associated with it; Table B8 shows the breakdown by waste container type. Transport and disposal containers (TDCs) with three different heights are used.

B4.3 Activities

DNLEU has very low quantities of impurities and is predominantly composed of U-238. At early times, the activity of the DNLEU is dominated by that of the U-238 and its daughters Th-234, half-life 24.1 days, and Pa-234m, half-life 1.17 minutes. Because the half-life of U-238 is very long, the total activity associated with the DNLEU does not change significantly between 2040 and 2200; instead, it remains relatively constant at 6,850 TBq. Of the total activity, 40% is U-238; 40% is Th-234 with the remainder made up from the remaining uranium isotopes. Unlike other waste groups, the activity associated with the DNLEU will increase with time as a result of the ingrowth of daughters; Figure 10 illustrates this. The activity associated with the priority 1 radionuclides in the DNLEU is shown at 2040 and 2200 in Table B9.

Table B9 The activity of the priority 1 radionuclides in DNLEU

Radionuclide	Activity [TBq]		Radionuclide	Activity [TBq]	
	At 2040	At 2200		At 2040	At 2200
C-14	$6.77\ 10^{-10}$	$6.64\ 10^{-10}$	Cs-135	$2.41\ 10^{-8}$	$2.41\ 10^{-8}$
Cl-36	0	0	Cs-137	$1.97\ 10^{-3}$	$4.98\ 10^{-5}$
Co-60	$1.64\ 10^{-20}$	$1.20\ 10^{-29}$	U-233	$1.60\ 10^{-3}$	$1.61\ 10^{-3}$
Se-79	$1.78\ 10^{-9}$	$1.78\ 10^{-9}$	U-235	47.8	47.8
Kr-85	0	0	U-238	2,660	2,660
Tc-99	0.645	0.645	Np-237	$1.66\ 10^{-2}$	$1.66\ 10^{-2}$
I-129	$1.60\ 10^{-9}$	$1.60\ 10^{-9}$			

B4.4 Materials

Appendix C2 presents the materials data for LHGW. The materials comprising the DNLEU waste group are dominated by the heavy metal oxides. The conditioning and capping materials are largely cementitious, while the packages themselves are stainless steel.

B5 New build shielded ILW

This waste group deals with the wastes arising from an assumed new build programme that are packaged in shielded waste containers. The inventory data for this waste group are based on an assumed 16 GW(e) new build programme. The new build shielded ILW waste group has two sub-groups: ‘concrete drums’ and 4m boxes. Information associated with these is included in Table B10. The total activity for the sub-group is reported in section B5.3.

B5.1 Volumes

The total packaged volume of waste in this waste group is estimated to be 18,900 m^3. The stored, conditioned and packaged volumes associated with each of the waste containers in this waste group are presented in Table B7. Some of the waste containers have variable levels of internal shielding, for example, the concrete drums can have different levels of steel shielding.

Figure B5 shows the arisings and total packaged volume of the waste group plotted against date. It can be seen that the SILW arises in two blocks: firstly, the operational wastes and then the decommissioning wastes. The reason for the gradual increase and decrease in the arising volumes is that the operation of the reactors is assumed to be staggered (see Table 1).

Table B10 The number of disposal units and volumes associated with each container type in new build shielded waste

Waste container	No. disposal units [-]	Volume [m^3]		
		Stored	Conditioned	Packaged
1 m^3 concrete drum (0 mm steel)	1,800	720	1,590	3,600
1 m^3 concrete drum (40 mm steel)	2,880	1,080	1,790	5,760
1 m^3 concrete drum (70 mm steel)	2,160	900	1,100	4,320
500 l concrete drum (40 mm steel)	3,240	900	942	4,000
4 m box (100 mm concrete)	60	138	858	1,200
Total	10,100	3,740	6,280	18,900

B5.2 Disposal units

This waste group has 10,100 disposal units associated with it; Table B10 shows the breakdown by waste container type.

B5.3 Activities

The total activity of this waste group at 2040 is estimated to be 197 TBq. At this stage, the new build reactors would be approximately one quarter of the way through their operational lifetimes. By 2200, the reactors would have been fully decommissioned and the total activity is estimated to be 154 TBq. The main contributor to the total activity at both 2040 and 2200 is Ni-63.

The activity associated with the priority 1 radionuclides is shown in Table B11. The activity associated with the shorter lived radionuclides (eg Co-60) has fallen. The activity associated with the longer lived radionuclides, such as C-14 and Cl-36 is seen to increase as more waste containing these radionuclides has arisen.

Because the concrete drums are used for operational wastes, while the 4 m box is used for decommissioning waste, the concrete drums account for all of the activity at 2040. At 2200, when the decommissioning wastes have arisen, the activity associated with the concrete drums is 92.2 TBq, or 60% of the total.

Figure B5 The arisings and total packaged volume profiles for new build shielded waste

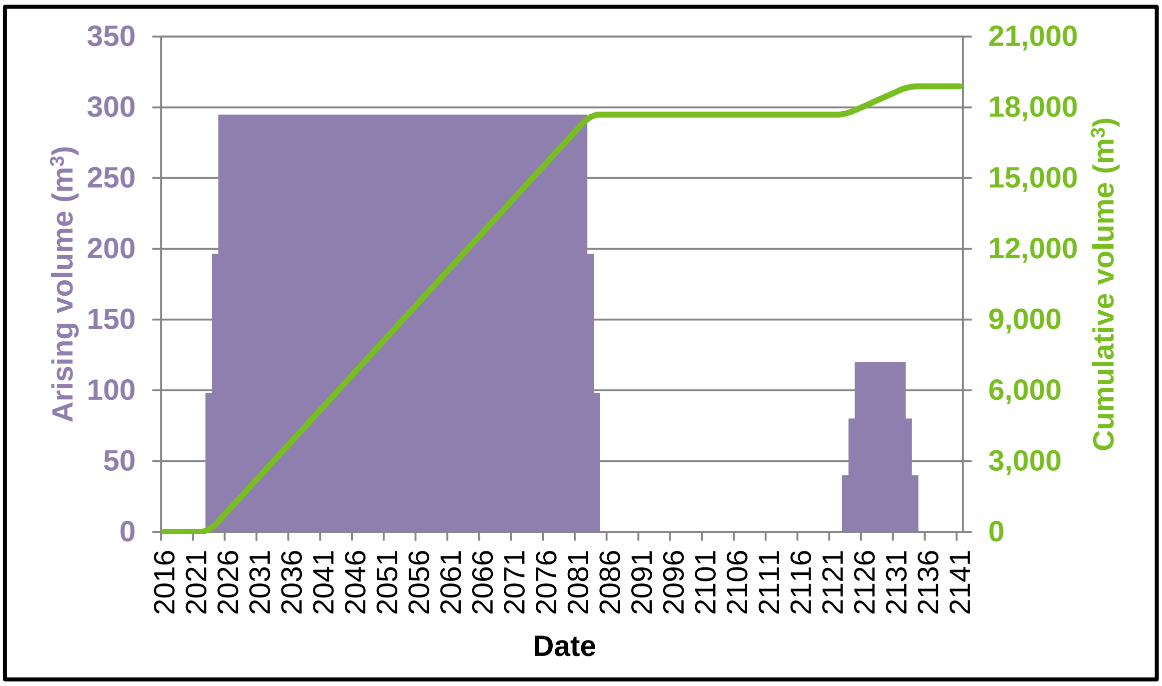


Table B11 The activity of the priority 1 radionuclides in new build shielded waste

Radionuclide	Activity [TBq]		Radionuclide	Activity [TBq]	
	At 2040	At 2200		At 2040	At 2200
C-14	1.42	5.44	Cs-135	$1.08\ 10^{-4}$	$4.06\ 10^{-4}$
Cl-36	$3.59\ 10^{-4}$	$1.53\ 10^{-3}$	Cs-137	19.3	3.28
Co-60	46.4	$3.68\ 10^{-4}$	U-233	$1.59\ 10^{-9}$	$1.81\ 10^{-5}$
Se-79	$4.06\ 10^{-4}$	$1.65\ 10^{-3}$	U-235	$4.22\ 10^{-7}$	$1.59\ 10^{-6}$
Kr-85	0	$7.91\ 10^{-5}$	U-238	$1.04\ 10^{-5}$	$3.91\ 10^{-5}$
Tc-99	$1.73\ 10^{-3}$	$1.57\ 10^{-2}$	Np-237	$2.40\ 10^{-5}$	$1.16\ 10^{-4}$
I-129	$2.31\ 10^{-5}$	$8.67\ 10^{-5}$			

B5.4 Materials

Appendix C2 presents the materials data for LHGW. The new build SILW waste group has the highest proportion of organics (approximately three eighths by mass). The organics are dominated by organic ion exchange resins, while other significant contributors are other ferrous materials and stainless steel.

Capping and conditioning is predominantly cementitious (although there is a small amount of polymer encapsulation), while the waste package materials are dominated by carbon steel and reinforced concrete.

B6 New build unshielded ILW

There are three broad categories of waste packages for LHGW: shielded, unshielded and robust shielded. This waste group deals with the wastes arising from an assumed new build programme that are packaged in unshielded waste containers. The inventory data for this waste group are based on an assumed 16 GW(e) new build programme.

B6.1 Volumes

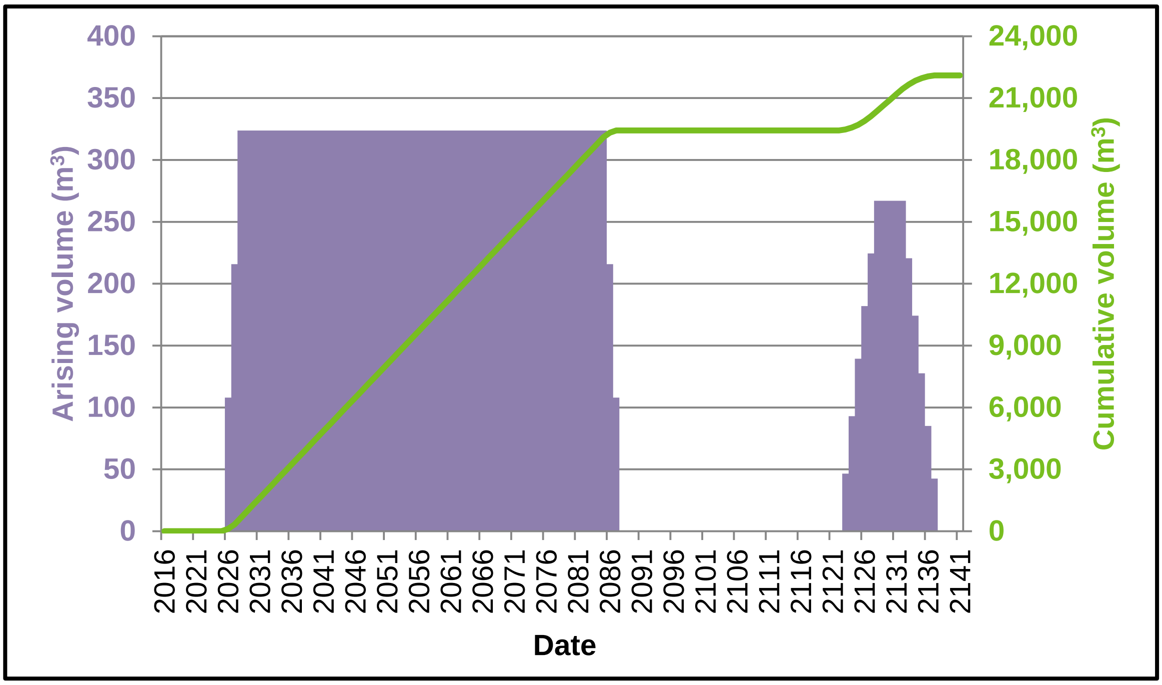
The total packaged volume of waste in this waste group is estimated to be 22,100 m^3. The stored, conditioned and packaged volumes associated with each of the waste containers in this waste group are presented in Table B12.

Figure B6 shows the arisings and total packaged volume of the waste group plotted against date. It can be seen that the UILW arises in two blocks: firstly, the operational wastes and then the decommissioning wastes. The reason for the gradual increase and decrease in the arising volumes is that the operation of the reactors is assumed to be staggered (see Table 1).

Table B12 The number of disposal units and volumes associated with each container type in new build unshielded waste

Waste container	No. disposal units [-]	Volume [m^3]		
		Stored	Conditioned	Packaged
3 m^3 box (side lifting)	961	652	2,550	3,140
3 m^3 drum	7,270	4,050	16,200	19,000
Total	8,230	4,700	18,800	22,100

Figure B6 The arisings and total packaged volume profiles for new build unshielded waste



B6.2 Disposal units

This waste group has 8,230 disposal units associated with it; Table B12 shows the breakdown by waste container type.

B6.3 Activities

The total activity of this waste group at 2040 is estimated to be 875 TBq. At this stage, the new build reactors would be approximately one quarter of the way through their operational lifetimes. By 2200, the reactors would have been fully decommissioned and the total activity is estimated to be 793,000 TBq. The main contributor to the total activity at 2040 is Cs-137 (and its short-lived daughter Ba-137m). By 2200, the activity is dominated by Ni-63.

The activity associated with the priority 1 radionuclides is shown in Table B13. The activity associated with the shorter lived radionuclides (eg Co-60) has fallen. The activity associated with the longer lived radionuclides, such as C-14 and Cl-36 is seen to increase as more waste containing these radionuclides has arisen.

Table B13 The activity of the priority 1 radionuclides in the new build unshielded ILW waste group at 2040 and 2200

Radionuclide	Activity [TBq]		Radionuclide	Activity [TBq]	
	At 2040	At 2200		At 2040	At 2200
C-14	0.697	6,670	Cs-135	$1.92\ 10^{-3}$	$1.58\ 10^{-2}$
Cl-36	$2.16\ 10^{-3}$	0.618	Cs-137	308	101
Co-60	32.9	1.98	U-233	$5.86\ 10^{-7}$	0.114
Se-79	$1.61\ 10^{-4}$	0.428	U-235	$1.39\ 10^{-6}$	$1.07\ 10^{-5}$
Kr-85	0	0.261	U-238	$3.72\ 10^{-5}$	$1.73\ 10^{-4}$
Tc-99	0.123	32.1	Np-237	$6.83\ 10^{-5}$	$6.55\ 10^{-4}$
I-129	$3.57\ 10^{-2}$	0.165			

B6.4 Materials

Appendix C2 presents the materials data for LHGW. The new build UILW waste group is approximately 50% metals (stainless steel and other ferrous metals) with equal amounts of organic and inorganic materials (ion exchange resins in both cases).

Capping and conditioning is cementitious, while the waste package materials are all stainless steels.

B7 High level waste

HLW arises from the reprocessing of Magnox and oxide spent fuels at Sellafield and the post operational clean out of the vitrification plant facilities. These operations are anticipated to finish in 2029 and the arisings of HLW will cease at this point. This can be seen in Figure B7, which shows the arisings and total packaged volumes and numbers of packages associated with the HLW.

A proportion of the waste from THORP and the Magnox reprocessing plant at Sellafield results from the reprocessing of overseas spent fuels. All reprocessing contracts with overseas customers that have been signed since 1976 include a provision to return packaged wastes to the country of origin. Waste substitution arrangements are being implemented whereby an additional amount of HLW from reprocessing is returned, which is smaller in volume but equivalent in radiological terms to the customers' ILW and LLW that would otherwise be returned.

B7.1 Volumes

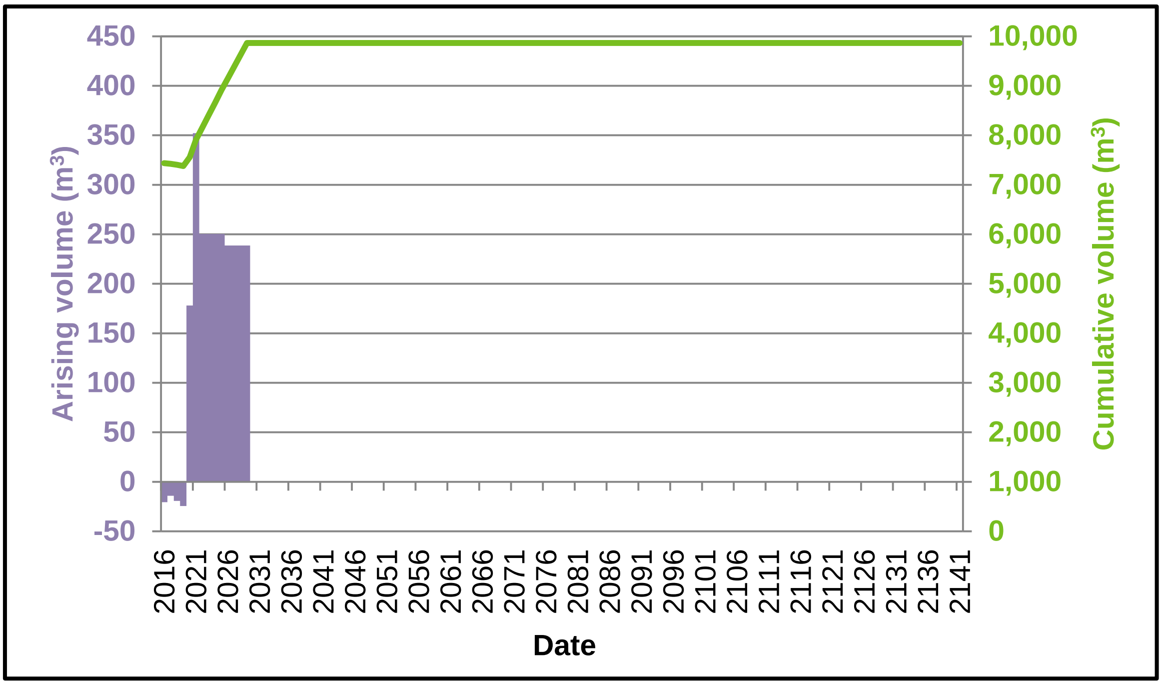
The total packaged volume of waste in this waste group is estimated to be 9,860 m^3. The stored, conditioned and packaged volumes associated with each of the waste containers in this waste group are presented in Table B14.

Figure B7 shows the arisings and total packaged volume of the waste group plotted against date. The reduction in volume resulting from return of HLW to overseas reprocessing customers is clearly visible.

Table B14 The number of disposal units and volumes associated with each container type in the HLW waste group

Waste container	No. disposal units [-]	Volume [m^3]		
		Stored	Conditioned	Packaged
HLW Disposal Container	2,550	1,500	1,500	9,860

Figure B7 The arisings and total packaged volume profiles for HLW



B7.2 Disposal units

This waste group has 2,550 disposal units associated with it. All HLW is assumed to be packaged in a copper disposal container.

B7.3 Activities

The total activity of this waste group at 2040 is estimated to be 38,800,000 TBq. By 2200, the total activity is estimated to have decayed to 1,200,000 TBq. The key contributor to the activity at both 2040 and 2200 is Cs-137 and its short-lived daughter Ba-137m.

As there are no HLW arisings between 2040 and 2200, the changes in activities are solely a result of decay and ingrowth. The activity associated with the priority 1 radionuclides is shown in Table B15.

Table B15 The activity of the priority 1 radionuclides in HLW at 2040 and 2200

Radionuclide	Activity [TBq]		Radionuclide	Activity [TBq]	
	At 2040	At 2200		At 2040	At 2200
C-14	0	0	Cs-135	185	185
Cl-36	1.51	1.51	Cs-137	11,400,000	288,000
Co-60	545	$3.98\ 10^{-7}$	U-233	$5.41\ 10^{-3}$	$3.60\ 10^{-2}$
Se-79	17.2	17.2	U-235	$9.86\ 10^{-4}$	$1.03\ 10^{-3}$
Kr-85	0	0	U-238	$2.61\ 10^{-2}$	$2.61\ 10^{-2}$
Tc-99	2,760	2,760	Np-237	36.1	51.1
I-129	$9.05\ 10^{-2}$	$9.05\ 10^{-2}$			

B7.4 Materials

Appendix C3 presents the materials data for HHGW. The HLW waste group is dominated by glass (ie the vitrified product) and stainless steel (from the waste vitrification plan canisters).

The containers are assumed to be predominantly copper and cast iron.

B8 Legacy spent fuels

There are various types of spent fuels that have arisen, or are arising, from legacy commercial and research reactors in the UK and these have different characteristics. These differences are important to RWM's safety cases and data are therefore presented for each of the individual types of spent fuel. The types of spent fuel considered are:

- AGR spent fuel that is not reprocessed
- Sizewell B spent fuel
- metallic spent fuels, including fuel that will be recovered from Sellafield legacy ponds (and is assumed to be low burn-up Magnox spent fuel)
- exotic spent fuels (also referred to as non-standard fuels). Exotic spent fuels present management challenges as a result of their diverse properties. PFR spent fuel is a major component of this category and is the only type of exotic spent fuel that has been included in the inventory for geological disposal

In total, the 2016 IGD contains 5,500 tU of AGR SF, 1,050 tU of Sizewell B PWR SF, 760 tU of metallic SF, and 10 tHM of exotic (PFR) SF. This waste group also contains irradiated submarine fuel, which has not been quantified (see Section 2.3.2).

B8.1 Volumes

When all of the legacy spent fuels have been packaged for disposal, they are estimated to have a packaged volume of 16,900 m^3. The future arisings come from the operations of AGR stations and Sizewell B PWR. These reactors will all be shut down by 2035 and the arisings of legacy spent fuels will cease at this point. This can be seen in Figure B8, which shows the arisings and total packaged volume of the spent fuels plotted against date. Table B16 shows the packaged volumes and number of disposal units associated with the legacy spent fuels.

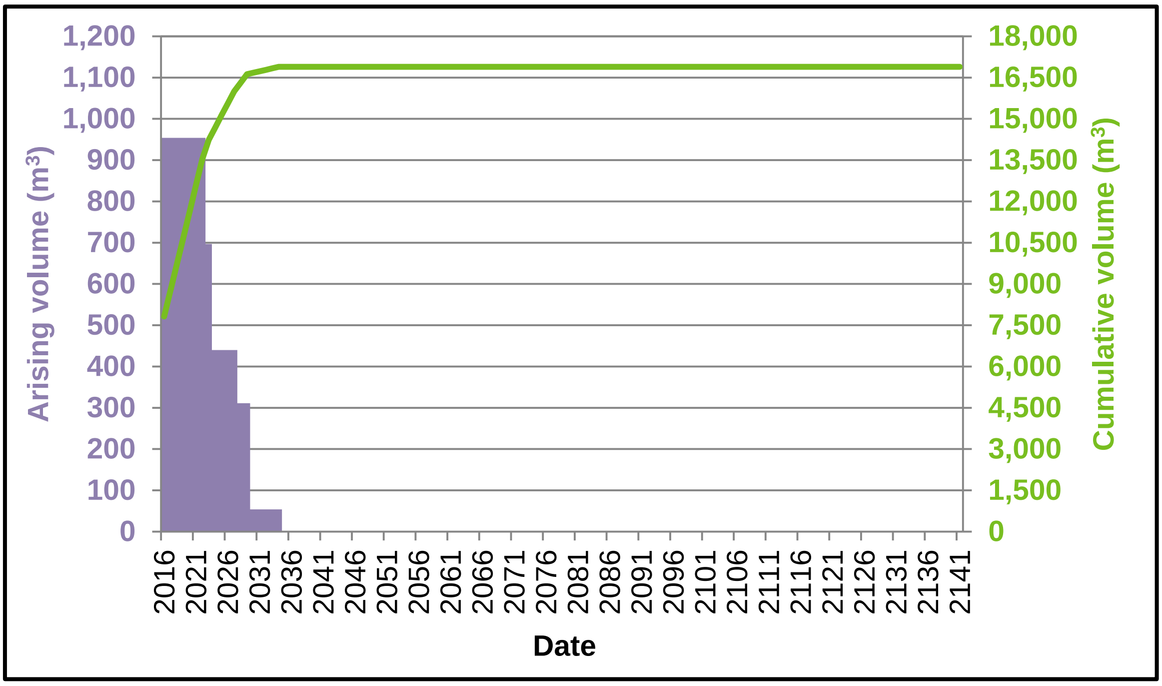
Table B16 The number of disposal units and volumes associated with each container type in the legacy spent fuels waste group

Disposal container	No. disposal units [-]	Volume [m^3]		
		Stored	Conditioned	Packaged
AGR SF	2,670	2,360	2,360	11,200
Magnox SF	859	1,030	1,030	3,490
PFR SF	19	10.9	10.9	48.7
PWR SF	572	426	426	2,160
Irradiated submarine fuel	Not quantified			
Total	4,120	3,830	3,830	16,900

B8.2 Disposal units

This waste group has 4,120 disposal units associated with it. All legacy spent fuels are assumed to be packaged in copper disposal containers. For PWR SF, four assemblies are assumed to be disposed of in a disposal container, while for PFR SF it is seven assemblies in a disposal container. Twenty-six Magnox SF elements are assumed to be packaged into a canister, with three canisters in a disposal container. It is envisaged that the AGR SF assemblies will be dismantled first. The graphite sleeves, support grids, braces, etc will be processed separately as ILW; the remaining fuel pins will be consolidated into bundles, with each bundle being contained within a slotted can. It is assumed that a total of sixteen slotted cans (equivalent to the fuel pins from 48 AGR fuel elements) will be packaged in a single disposal container.

Figure B8 The arisings and total packaged volume profiles for legacy spent fuels



B8.3 Activities

The activity of this waste group at 2040 is estimated to be 66,100,000 TBq. By 2200, the activity is estimated to be 2,730,000 TBq. The quantity of AGR SF is greater than that of the other fuel types and it would therefore be expected that it has the highest activity associated with it; this is seen to be the case in Table B17. The biggest contributor to the total activity at 2040 is Cs-137 (and its short-lived daughter Ba-137m). At 2200, the biggest contributor to the total activity is Am-241.

The activities of the priority 1 radionuclides are presented in Table B18. Since all of the legacy spent fuels have arisen by 2035, any increases in radionuclide activities will be a result of ingrowth (eg Np-237 is a daughter of Am-241, which is itself a daughter of Pu-241).

Table B17 The activity associated with each of the legacy SFs at 2040 and 2200

Fuel type	Activity at 2040 [TBq]	Activity at 2200 [TBq]
AGR SF	49,700,000	2,060,000
Magnox SF	338,000	25,300
PWR SF	15,800,000	605,000
PFR SF	305,000	37,900
Irradiated submarine fuel	Not quantified	

Table B18 The activity of the priority 1 radionuclides in legacy spent fuels at 2040 and 2200

Radionuclide	Activity [TBq]		Radionuclide	Activity [TBq]	
	At 2040	At 2200		At 2040	At 2200
C-14	880	863	Cs-135	154	154
Cl-36	3.54	3.53	Cs-137	15,900,000	403,000
Co-60	234,000	$1.71\ 10^{-4}$	U-233	0.460	0.509
Se-79	15.8	15.8	U-235	3.86	3.87
Kr-85	601,000	19.5	U-238	86.3	86.3
Tc-99	2,010	2,010	Np-237	53.9	85.7
I-129	7.81	7.81			

B8.4 Materials

Appendix C3 presents the materials data for HHGW. The legacy SF waste group is dominated by fuel materials (heavy metal oxide and uranium) and cladding materials (stainless steel, Zircaloy and Magnox).

The containers are assumed to be predominantly copper and cast iron.

B9 New build spent fuels

As the spent fuels from the UK EPR and AP1000 are similar in terms of their size (it is assumed that a common disposal container will be used for the two) and since their burn-ups are assumed to be the same (65 GWd/tU), the two are included together in this waste group and are not discussed separately. The two different spent fuels are, however, considered as separate waste streams.

B9.1 Volumes

By the time that the assumed 16 GW(e) new build programme has finished operating, it is estimated that the total packaged volume[35] will be 39,400 m^3. Table B19 shows that there will be no conditioning for the SFs, while Figure B9 shows the arisings and total packaged volume profiles for the new build SFs. The gradual increase and decrease in arisings is associated with the assumed staggered start for the new build reactors (see Table 1) and the different step sizes in the arisings profile are associated with the different reactor types.

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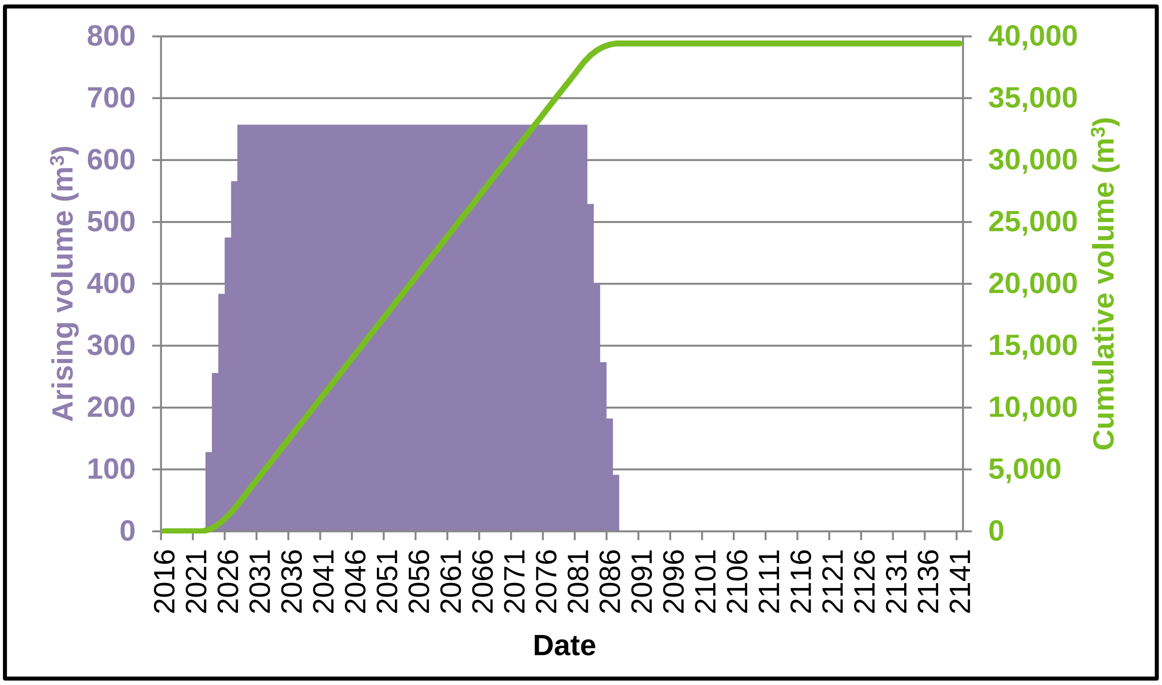
[35] It is noted that this is based on the assumption that the 16 GW(e) will comprise 6 UK EPRs and 6 AP1000s Potential changes to the size and composition of a new build programme are considered in an alternative scenario [8,5].

Table B19 The number of disposal units and volumes associated with each container type in the new build SFs waste group

Disposal container	No. disposal units [-]	Volume [m^3]		
		Stored	Conditioned	Packaged
New build SF	8,940	5,890	5,890	39,400

Figure B9 The arisings and total packaged volume profiles for the new build SFs



B9.2 Disposal units

There are 8,940 disposal units associated with this waste group. For UK EPR and AP1000 spent fuels, three assemblies are assumed to be disposed of in a single disposal container.

B9.3 Activities

At 2040, the activity associated with the new build spent fuels has been estimated to be 127,000,000 TBq; by 2200, this has fallen to 19,000,000 TBq as a result of the decay of the short-lived radionuclides such as Co-60 and Cs-137. Although the activity has fallen significantly in this period, Figure B9 shows that approximately 75% of the waste arose after 2040. At both 2040 and 2200, the biggest contributor to the total activity is Cs-137 (and its short-lived daughter Ba-137m).

The activities associated with the priority 1 radionuclides are presented in Table B20. As would be expected, the longer lived radionuclides (such as C-14) show an increase by a factor of approximately three, consistent with around 25% of the waste having arisen by 2040.

Table B20 The activity of the priority 1 radionuclides in the new build SFs at 2040 and 2200

Radionuclide	Activity [TBq]		Radionuclide	Activity [TBq]	
	At 2040	At 2200		At 2040	At 2200
C-14	536	2150	Cs-135	126	515
Cl-36	18.6	71.7	Cs-137	22,100,000	4,130,000
Co-60	271,000	0.114	U-233	$2.62\ 10^{-2}$	0.381
Se-79	15.1	61.6	U-235	1.55	6.24
Kr-85	1,230,000	1,190	U-238	39.9	163
Tc-99	3,170	12,900	Np-237	93.5	517
I-129	7.72	31.3			

B9.4 Materials

Appendix C3 presents the materials data for HHGW. The new build SF waste group is dominated by heavy metal oxide (ie the fuel) and zircaloy (ie the cladding).

The containers are assumed to be copper and cast iron.

B10 Mixed oxide spent fuel

The assumptions regarding MOX are detailed in Section 2.1.2. It is assumed that the MOX is irradiated to 50 GWd/tU and that the unirradiated fuel contains 8% plutonium. The MOX is assumed to be packaged with one SF assembly in a disposal container; this leads to the package numbers and volumes presented in Table B21.

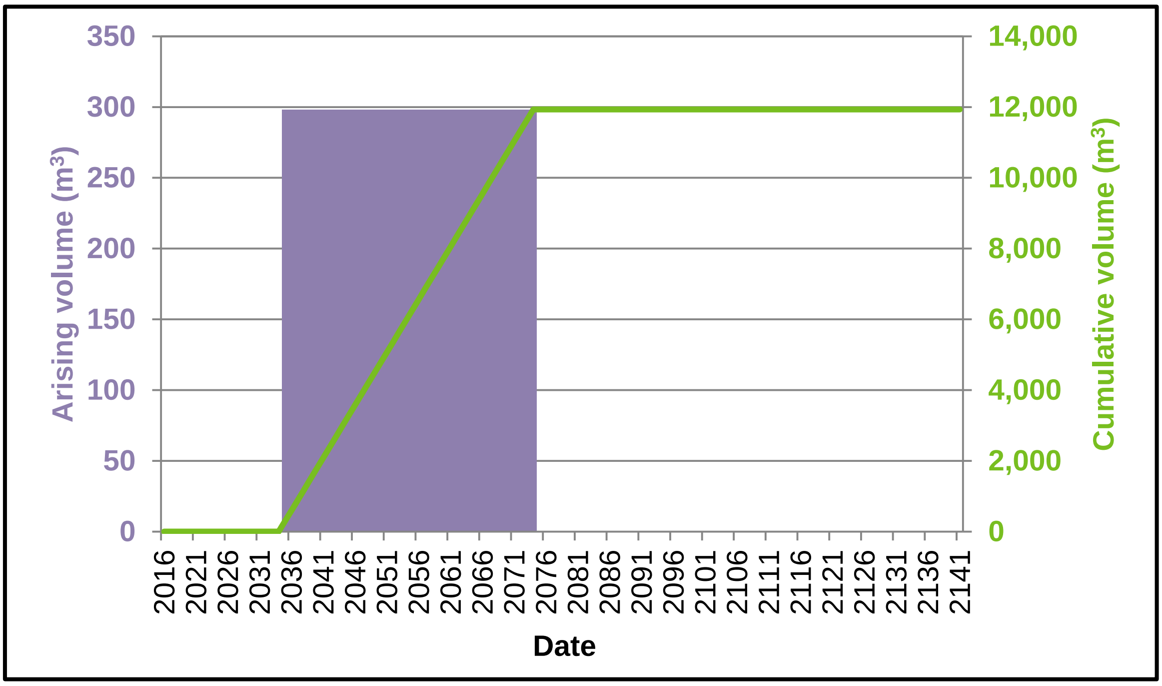
B10.1 Volumes

The MOX SF is assumed to arise evenly over a 40 year period starting in 2035, and this can be seen in Figure B10. The packaged volume of the waste is assumed to be 11,900 m^3. As can be seen In Table B21, the MOX SF is not conditioned.

Table B21 The number of disposal units and volumes associated with each container type in the MOX SF waste group

Disposal container	No. disposal units [-]	Volume [m^3]		
		Stored	Conditioned	Packaged
MOX SF	2,710	594	594	11,900

Figure B10 The arisings and total packaged volume profiles for MOX SF



B10.2 Disposal units

There are 2,710 disposal units associated with this waste group.

B10.3 Activities

The total activity of the MOX SF at 2040 has been estimated to be 14,900,000 TBq. However, only one eighth of the MOX SF has arisen by this point. Despite the arisings, the activity by 2200 has fallen to 3,700,000 TBq. At 2040 the biggest contributor to the total activity is Pu-241; by 2200, the biggest contributor is its daughter Am-241.

The activities of the priority 1 radionuclides are shown in. **Table B22** The activities of shorter-lived radionuclides, such as Co-60 and Cs-137 have fallen, while the activities of the longer-lived radionuclides, such has U-238 and C-14, have increased by a factor of approximately seven, consistent with the increase in the volume of SF between 2040 and 2200. The activity of Np-237 has increased by a very large factor (nearly 100); this is because of its ingrowth as a daughter of Am-241, which is itself a daughter of Pu-241.

Table B22 The activity of the priority 1 radionuclides in MOX SF at 2040 and 2200

Radionuclide	Activity [TBq]		Radionuclide	Activity [TBq]	
	At 2040	At 2200		At 2040	At 2200
C-14	29.8	234	Cs-135	10.5	83.8
Cl-36	0.192	1.54	Cs-137	996,000	312,000
Co-60	125,000	$1.89\ 10^{-2}$	U-233	$3.63\ 10^{-2}$	0.318
Se-79	0.535	4.28	U-235	$1.68\ 10^{-2}$	0.147
Kr-85	39,700	41.4	U-238	2.00	16.0
Tc-99	130	1,040	Np-237	0.929	88.3
I-129	0.410	3.28			

B10.4 Materials

Appendix C3 presents the materials data for HHGW. The MOX SF waste group is dominated by heavy metal oxide (ie the fuel) and zircaloy (ie the cladding).

The containers are assumed to be copper and cast iron.

B11 Highly enriched uranium

B11.1 Volumes

The 2016 IGD includes 22.9tU HEU. This estimate includes the MOD stockpile of 21.9tU HEU given in the 1998 Strategic Defence Review [27]. As noted in Section 2.3.2, it is possible that this stockpile has reduced, or will reduce further, as a result of its use in the production of submarine fuel. Table B23 shows the volume of the HEU and the number of disposal containers. It can be seen that the packaged volume of HEU in the 2016 IGD is 2,470 m^3; this is based on the can-in-canister approach to packaging. No further arisings of HEU are anticipated and therefore no plot of arisings is presented.

Table B23 The number of disposal units and volumes associated with each container type in the HEU waste group

Disposal container	No. disposal units [-]	Volume [m^3]		
		Stored	Conditioned	Packaged
HEU / Pu	780	2.37	694	2,470

B11.2 Disposal units

There are 780 disposal units associated with this waste group; this is based on the can-in-canister approach to packaging.

B11.3 Activities

The total activity of the HEU at 2040 is 53.6 TBq, and this has risen to 53.8 TBq at 2200 as a result of the ingrowth of daughter radionuclides. The dominant contribution to the activity is U-234 (50.1 TBq), which is a shorter lived ($t_{1/2}$ = 2.46 10^5 years) isotope of uranium than either U-235 (7.04 10^8 years) or U-238 (4.47 10^9 years). HEU has very few impurities and as a result, the activity at 2040 results almost entirely from uranium isotopes. Similarly to the DNLEU, an increase in activity is observed with time, resulting from the ingrowth of the daughters.

B11.4 Materials

Appendix C3 presents the materials data for HHGW. The HEU waste group is dominated by stainless steel (ie cans / canister containing the HEU) and glass (ie the encapsulating matrix). Heavy metal oxide is only a small part of the mass.

The containers are assumed to be copper and cast iron.

B12 Plutonium

B12.1 Volumes

The 2016 IGD reports 5.75 tHM of plutonium (that plutonium which is not suitable for the manufacture of MOX fuel to be irradiated in a reactor). The volume associated with this plutonium is presented in Table B24. The total packaged volume is estimated to be 620 m^3; this is based on the can-in-canister approach to packaging. It is assumed that there will be no future arisings of Pu and therefore no plot of arisings is presented.

Table B24 The number of disposal units and volumes associated with each container type in the plutonium waste group

Waste container	No. disposal units [-]	Volume [m^3]		
		Stored	Conditioned	Packaged
HEU / Pu	196	0.567	174	620

B12.2 Disposal units

There are 196 disposal units associated with this waste group.

B12.3 Activities

The total activity of the plutonium at 2040 has been estimated to be 62,000 TBq and this has fallen to 43,700 TBq by 2200. The biggest contributor to the total activity at both 2040 and 2200 is Am-241 which is the daughter of Pu-241. The activities of the priority 1 radionuclides are presented in **Table B25**.

Table B25 The activity of the priority 1 radionuclides in plutonium at 2040 and 2200

Radionuclide	Activity [TBq]		Radionuclide	Activity [TBq]	
	At 2040	At 2200		At 2040	At 2200
C-14	$6.24\ 10^{-8}$	$6.12\ 10^{-8}$	Cs-135	$3.05\ 10^{-8}$	$3.05\ 10^{-8}$
Cl-36	$2.39\ 10^{-10}$	$2.39\ 10^{-10}$	Cs-137	$4.99\ 10^{-4}$	$1.26\ 10^{-5}$
Co-60	$3.48\ 10^{-10}$	$2.54\ 10^{-19}$	U-233	$5.47\ 10^{-5}$	$6.26\ 10^{-4}$
Se-79	$1.31\ 10^{-8}$	$1.31\ 10^{-8}$	U-235	$8.30\ 10^{-4}$	$2.48\ 10^{-3}$
Kr-85	$1.61\ 10^{-6}$	$5.22\ 10^{-11}$	U-238	$3.47\ 10^{-6}$	$3.54\ 10^{-6}$
Tc-99	$4.51\ 10^{-7}$	$4.51\ 10^{-7}$	Np-237	0.377	1.23
I-129	$9.51\ 10^{-10}$	$9.51\ 10^{-10}$			

B12.4 Materials

Appendix C3 presents the materials data for HHGW. The plutonium waste group is dominated by stainless steel (ie cans / canister containing the Pu) and glass (ie the encapsulating matrix). Heavy metal oxide is only a small part of the mass.

The containers are assumed to be copper and cast iron.

References

B1 Radioactive Waste Management, *Geological Disposal: The 2013 Derived Inventory*, DSSC/403/01, December 2016.

Appendix C – Material Summary tables

Appendix C presents materials data as follows:

- Table C1 The number of disposal units, packaged volume and activity in each waste group
- Table C2 The number of waste packages and disposal units for each waste container type, presented by waste group. (The conditioned and packaged volumes are also shown)
- Table C3 The metals in the low-heat-generating wastes bulk materials. (Priority materials are highlighted)
- Table C4 The organics in the low-heat-generating wastes bulk materials. (Priority materials are highlighted)
- Table C5 The inorganics in the low-heat-generating wastes bulk materials. (Priority materials are highlighted)
- Table C6 The bulk materials in the LHGW capping and conditioning materials
- Table C7 The bulk materials in LHGW containers. (Priority materials are highlighted)
- Table C8 The HHGW bulk materials. (Priority materials are highlighted)
- Table C9 The bulk materials in HHGW containers. (Priority materials are highlighted)

C1 Waste group disposal units, volumes and activities

Table C1 The number of disposal units, packaged volume and activity in each waste group

Waste group	No. disposal units	Packaged Volume [m3]	Activity at 2200 [TBq]
Legacy SILW / SLLW	5,403	99,300	13,800
Legacy UILW / ULLW	108,732	329,000	372,000
RSCs	966	2,730	1,110
DNLEU	12,302	191,000	9,560
NB SILW	10,140	18,900	154
NB UILW	8,227	22,100	793,000
HLW	2,549	9,860	1,200,000
Legacy SF	4,121	16,900	2,730,000
NB SF	8,941	39,400	19,000,000
MOX SF	2,707	11,900	3,700,000
HEU	780	2,470	53.8
Pu	196	620	43,700
Total	165,287	744,000	27,900,000

Table C2 The number of waste packages and disposal units for each waste container type, presented by waste group. (The conditioned and packaged volumes are also shown)

Waste container	No. packages	No. disposal units	Conditioned volume [m^3]	Packaged volume [m^3]
SILW / SLLW				
4m box (0 mm concrete)	2,734	2,734	51,600	54,700
4m box (100 mm concrete)	1,286	1,226	17,500	24,500
4m box (200 mm concrete)	363	363	3,950	7,250
6 m^3 concrete box (high density)	170	170	923	2,000
6 m^3 concrete box (low density)	910	910	5,270	10,800
Total SILW / SLLW	5,403	5,403	79,300	99,300
UILW / ULLW				

3 m³ box	4,434	4,434	11,800	14,500
3 m³ box (square corners)	689	688	1,930	2,480
3 m³ drum	545	545	1,220	1,420
3 m³ Sellafield box	54,579	54,579	148,000	180,000
3 m³ Sellafield Enhanced box	16,063	16,063	34,500	53,000
500 litre drum	98,606	24,652	45,500	56,300
Beta/gamma box	1,381	1,381	4,830	6,490
Enhanced 500 litre drum (basket)	24,727	6,182	12,500	14,100
Enhanced 500 litre drum (pre-cast)	821	206	334	469
Total UILW / ULLW	201,845	108,731	260,000	329,000
RSCs				
DCIC Cubical (Type 6)	354	354	883	1,920
500 l RS drum (0 mm Pb)	478	478	257	630
500 l RS drum (20 mm Pb)	54	54	22.8	70.2
500 l RS drum (30 mm Pb)	16	16	5.80	20.6
500 l RS drum (50 mm Pb)	8	8	3.23	9.87
500 l RS drum (80 mm Pb)	3	3	0.697	3.77
500 l RS drum (90 mm Pb)	38	38	8.38	49.9
500 l RS drum (120 mm Pb)	15	15	2.47	19.6
Total RSC	966	966	1,180	2,730
DNLEU				
500 litre drum (DNLEU)	23,874	5,969	11,200	13,600
Uranium TDC (2.1m ht)	460	460	8,630	11,700
Uranium TDC (2.3m ht)	4,427	4,427	87,800	123,000
Uranium TDC (2.4m ht)	1,446	1,446	31,700	42,000
Total DNLEU	30,207	12,302	139,000	191,000
New build SILW				
1 m³ concrete drum (0 mm steel)	1,800	1,800	1,590	3,600
1 m³ concrete drum (40 mm steel)	2,880	2,880	1,790	5,760
1 m³ concrete drum (70 mm steel)	2,160	2,160	1,100	4,320

4m box (100mm concrete)	60	60	858	1,200
500 l concrete drum (40 mm steel)	3,240	3,240	942	4,000
Total new build SILW	10,140	10,140	6,280	18,900
New build UILW				
3 m³ box	961	961	2,550	3,140
3 m³ drum	7,266	7,266	16,200	19,000
Total new build UILW	8,227	8,227	18,800	22,100
HLW				
HLW Disposal Container	2,549	2,549	1,500	9,860
Legacy SF				
AGR SF Disposal Container AGR	2,671	2,671	2,360	11,200
Magnox SF Disposal Container	859	859	1,030	3,490
PFR SF Disposal Container	19	19	10.9	48.7
PWR SF Disposal Container	572	572	426	2,160
Total legacy SF	4,121	4,121	3,830	16,900
New build SF				
New build SF Disposal Container	8,941	8,941	5,890	39,400
MOX SF				
MOX SF Disposal Container	2,707	2,707	594	11,900
HEU				
Pu/HEU Disposal Container	780	780	694	2,470
Pu				
Pu/HEU Disposal Container	196	196	174	620

C2 LHGW Waste group materials

Table C3 The metals in the low-heat-generating wastes bulk materials. (Priority materials are highlighted)

	Material	Total mass [t]					
		SILW / SLLW	UILW / ULLW	RSC	DNLEU	NB SILW	NB UILW
Metals	Aluminium (and alloys)	25.1	1,700	2.89	0	0	0
	Beryllium	11.2	20.5	$2.91\ 10^{-3}$	0	0	0
	Cadmium	0.186	4.60	0	0	0	0
	Copper (and alloys)	13.2	278	0.214	0	0	0
	Lead	3.10	802	0.143	0	0	0
	Magnox	321	5,810	32.4	0	0	0
	Mercury	0	3.18	$2.91\ 10^{-3}$	0	0	0
	Nickel (and alloys)	12.8	242	2.91	0	0	0
	Other ferrous metals	14,500	39,100	445	14,100	1,080	1,840
	Stainless steel	3,210	28,000	52.3	3,430	517	2,290
	Uranium	$8.20\ 10^{-2}$	957	0	0	0	0
	Zinc	0	68.9	0.101	0	0	0
	Zircaloy	30.6	1,260	16.3	0	0	0
	Other metals	25.7	187	0.584	0	0	0
	Total metals	18,200	78,400	553	17,500	1,600	4,130

Table C4 The organics in the low-heat-generating wastes bulk materials. (Priority materials are highlighted)

	Material	Total mass [t]					
		SILW / SLLW	UILW / ULLW	RSC	DNLEU	NB SILW	NB UILW
Organics	Cellulosics	11.9	2,130	6.78	0	15.8	0
	Halogenated Plastics	2.03	3,600	4.84	0	25.9	0
	Ion exchange resins	137	112	111	0	1,080	2,030
	Non-halogenated plastics	278	1,710	2.05	71.0	116	2.72
	Rubbers	0.218	1,690	1.14	0	6.57	$5.83\ 10^{-2}$
	Other organics	5.85	451	11.3	0	7.20	0
	Total organics	435	9,690	137	71.0	1,250	2,030

Table C5 The inorganics in the low-heat-generating wastes bulk materials. (Priority materials are highlighted)

	Material	Total mass [t]					
		SILW / SLLW	UILW / ULLW	RSC	DNLEU	NB SILW	NB UILW
Other Materials	Asbestos	0.300	309	1.60	0	0	0
	Graphite	63,100	15,000	277	0	0	0
	Aqueous liquids	82.1	11,900	80.4	0	37.0	2.66
	Cementitious material	1,730	53,300	8.72	0	0	0
	Desiccants	$8.20\ 10^{-2}$	685	37.2	0	0	0
	Glass / ceramic	9.77	300	0.493	0	12.6	0.389
	Heavy Metal Oxide	0	0	0	254,000	0	0
	Ion exchange materials	193	2,520	24.9	0	0	2,030
	Rubble	247	2,630	84.0	0	1.44	0
	Sand	65.2	173	72.0	0	0	0
	Sludge / flocs	88.0	21,200	220	0	432	0
	Soil	0	5.41	$4.05\ 10^{-2}$	0	0	0
	Other inorganics	0.444	344	12.2	0	0	0
	Total Other Materials	65,500	108,000	819	254,000	483	2,030
	Unspecified	354	1,300	29.8	2.37	0	0

Table C6 The bulk materials in the LHGW capping and conditioning materials

	Material[36]	Total mass [t]					
		SILW / SLLW	UILW / ULLW	RSC	DNLEU	NB SILW	NB UILW
Conditioning materials	Stainless steel	0	0	0	239	0	0
	OPC[37]	5,220	38,800	0	15,600	532	2,160
	BFS or PFA[38]	15,700	137,000	0	36,300	1,810	15,800
	Polymer	82	136	0	0	849	0
	Water	8,530	71,800	0	21,400	955	7,340
	Total conditioning materials	29,500	248,000	0	73,500	4,140	25,300
Capping materials	OPC	0	7,040	0	457	0	531
	PFA	0	21,100	0	1,370	0	1,590
	Water	0	4,930	0	320	0	372
	Iron shot concrete	22,500	0	0	0	271	0
	Total capping materials	22,500	33,100	0	2,150	271	2,500

36 All cementitious materials are assumed to contain 0.5 wt% superplasticiser.

37 Ordinary Portland cement.

38 Blast furnace slag or pulverised fuel ash.

Table C7 The bulk materials in LHGW containers. (Priority materials are highlighted)

	Material	Total mass [t]					
		SILW / SLLW	UILW / ULLW	RSC	DNLEU	NB SILW	NB UILW
Metals	Stainless steel[39]	21,600	82,500	0	44,300	300	3,630
	Lead	0	0	238	0	0	0
	Carbon steel	755	2,760	0	0	13,300	0
	Cast Iron	0	0	9,960	0	0	0
	Total metals	22,400	85,300	10,200	44,300	13,600	3,630
Other materials	Concrete[40]	21,700	50,600	0	0	750	0
	Reinforced concrete[40]	12,100	0	0	0	22,700	0
	Magnetite concrete[40]	4,280	0	0	0	0	0
	Total other materials	38,000	50,600	0	0	23,500	0

39 For UILW / ULLW there is an additional mass of 17,200t and 4,180t for DNLEU due to 4 500 l drums being disposed of together in a stainless steel stillage of mass 0.7t.

40 All cementitious materials are assumed to contain 0.5 wt% superplasticiser

C3 HHGW waste group materials

Table C8 The HHGW bulk materials. (Priority materials are highlighted)

	Material	Total mass [t][41]					
		HLW	Legacy SF	NB SF	MOX SF	HEU	Pu
Metals	Magnox	0	137	0	0	0	0
	Stainless steel	651	1,620	391	39.5	1,820	458
	Uranium	0	760	0	0	0	0
	Zircaloy	0	269	4,280	438	0	0
	Nickel (and alloys)	20.6	18.1	126	11.8	0	0
	Total metals	672	2,800	4,800	490	1,820	458
Others	Heavy metal oxide	0	7,440	16,200	1,660	26.0	6.52
	Glass / ceramic	3,020	42.9	15.6	1.61	1,220	306
	Total others	3,020	7,490	16,200	1,660	1,250	312

41 For HLW, HEU and plutonium, the mass includes the glass conditioning matrix and the stainless steel container. SFs are packaged without any conditioning matrix.

Table C9 The bulk materials in HHGW containers. (Priority materials are highlighted)

	Material	Total mass [t]					
		HLW	Legacy SF	NB SF	MOX SF	HEU	Pu
Metals	Copper	18,900	32,000	73,600	22,300	4,850	1,220
	Carbon steel	2,700	811	0	0	0	0
	Cast Iron	40,200	65,100	178,000	63,100	8,610	2,160
	Total metals	61,800	98,000	251,000	85,400	13,500	3,380

Certificate No LRQ 4008580

Radioactive Waste Management Limited
Building 587
Curie Avenue
Harwell Oxford
Didcot
Oxfordshire OX11 0RH

t +44 (0)1925 802820
f +44 (0)1925 802932
w www.nda.gov.uk/rwm