Radioactive Waste Management

NDA Report no. DSSC/403/01

Geological Disposal

Derived Inventory Report

December 2016

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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 Government's 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 Nuclear Decommissioning Authority (NDA), through Radioactive Waste Management Limited (RWM) is responsible for implementing UK Government policy for long-term management of higher activity radioactive wastes. The UK Government's framework for 'Implementing Geological Disposal' is set out in the 2014 Implementing Geological Disposal White Paper and defines the inventory for disposal in a geological disposal facility (GDF) in terms of types of higher activity radioactive wastes (and nuclear material that could be declared as waste).

In order to support the implementation of geological disposal RWM has developed a quantified description of this inventory called the 'Derived Inventory'. This report details the methodologies and assumptions that have been used to quantify the inventory for disposal in a GDF and the results of this work. The 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 GDF design and assessment work to support the implementation process.

The development of the Derived Inventory has been achieved through a review of RWM's requirements, and an analysis of the 2013 UK Radioactive Waste Inventory (UK RWI) data and other data sources. A methodology for enhancing the data has been applied, and an audit trail maintained that provides transparency and justification for all data modifications. Enhancements have focused on those materials and radionuclides identified as priorities for the assessment work.

The 2013 Derived Inventory provides the volumes and radioactivities of higher activity radioactive wastes, spent fuels and other nuclear materials considered in the planning assumptions for the GDF. Data are presented for High Level Waste, Intermediate Level Waste, some Low Level Waste unsuitable for near-surface disposal, spent fuels, depleted natural and low-enriched uranium, highly enriched uranium and plutonium.

In addition, the inventory for disposal in a GDF is broken down into more detailed waste groups. The waste groups have been defined by RWM to distinguish between different types of waste for RWM's design and assessment studies and to reflect the key differences in time of arising, waste packaging and assumed emplacement in the GDF.

It is not anticipated that, as component parts of the inventory for disposal in a GDF, the categories of wastes and materials listed in the 2014 White Paper will change significantly. The quantities of wastes and materials are, however, subject to change due to a number of factors, including improvements to the estimates of waste that will arise from planned operations and decommissioning programmes. The Derived Inventory is therefore updated periodically to take into account updates to source information, in particular the UK RWI. The 2013 Derived Inventory described in this report provides an update to the 2010 Derived Inventory.

List of Contents

Preface iii

Executive Summary v

1 Introduction 1

1.1 The generic Disposal System Safety Case 1

1.2 Introduction to the derived inventory 3

1.3 Objective 3

1.4 Scope 3

1.5 Document structure 7

2 Assumptions 9

2.1 Defence 11

2.2 Scottish wastes 12

2.3 New build 12

2.4 Mixed oxide SF 13

2.5 Other assumptions 14

3 Data review and enhancement methodology 17

3.1 Review of priority materials and radionuclides 17

3.2 Approach to data enhancement 17

3.3 Data enhancement for UK RWI wastes 20

3.4 Data enhancement for legacy SFs 20

3.5 Uranium and plutonium enhancements 21

3.6 Wastes not considered in the 2013 UK RWI 21

3.7 Gas generation data 22

3.8 Conditioning and capping materials 22

4 Packaging assumptions 23

4.1 Review of package assignments 23

4.2 HLW and SFs 24

4.3 ILW and LLW 24

4.4 Plutonium and uranium 25

5 Inventory for disposal: summary 27

6 Inventory for disposal: waste groups 31

6.1 Shielded legacy wastes (ILW and LLW) 33
6.2 Unshielded legacy wastes (ILW and LLW) 35
6.3 Unshielded new build ILW 38
6.4 Shielded new build ILW 40
6.5 DNLEU 42
6.6 Robust shielded ILW containers 44
6.7 HLW 46
6.8 Legacy SFs 48
6.9 New build SFs 51
6.10 MOX SF 53
6.11 Highly enriched uranium 55
6.12 Plutonium 56
6.13 Comparison of waste groups 57

7 Further potential enhancements 61

7.1 Legacy ILW and LLW 61
7.2 Legacy HLW 63
7.3 Legacy SFs 63
7.4 Uranium and plutonium 63
7.5 New build reactors 63
7.6 Groundwater pollutants 64
7.7 Superplasticisers 64

References 65

Glossary 69

Appendix A Data Enhancement 73

A1 Priority materials 73

A2 Data enhancement for HLW, ILW and LLW 77

A2.1 Bulk material composition 77
A2.2 Elemental composition 80
A2.3 Radionuclide composition 81

A3 Data enhancement for SFs 83

A3.1 AGR SF 83

A3.2 Sizewell B SF 84

A3.3 Exotic SFs 85

A3.4 Metallic SFs 85

A4 Uranium and plutonium 87

A4.1 Uranium 87

A4.2 Plutonium 88

A5 New build 90

A5.1 ILW 90

A5.2 SFs 91

A6 MOX 94

A6.1 MOX SF 94

A7 Gas generation data 95

A7.1 Metal geometry data 95

A7.2 Breakdown of H3 and C14 by material type 95

A8 Conditioning and capping materials 100

A8.1 Legacy ILW and LLW conditioning materials 100

A8.2 Legacy ILW and LLW capping materials 100

Appendix A References 103

Appendix B Waste Packaging 105

B1 Waste packaging rules 105

B1.1 Legacy ILW and LLW waste containers 105

B1.2 Waste container review 108

B1.3 New Build ILW 114

B1.4 Verification of ILW and LLW waste and transport container allocations 115

B2 Containers for nuclear materials 117

B2.1 Containers for SFs, HLW, plutonium and highly enriched uranium 117

B2.2 DNLEU 122

Appendix B References 125

Appendix C Waste package data 127

C1.1 Waste package materials 127

C1.2 Waste package numbers 131

Appendix D Results of enhancements **133**

D1 Comparison of UK RWI waste streams **133**

Appendix E Materials data **139**

E1 Bulk materials data by waste group **139**

E2 Elemental composition data **146**

E3 Gas generation data **166**

E3.1 Metals geometry data 166

E3.2 H3 and C14 by material type 167

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 consent-based 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.

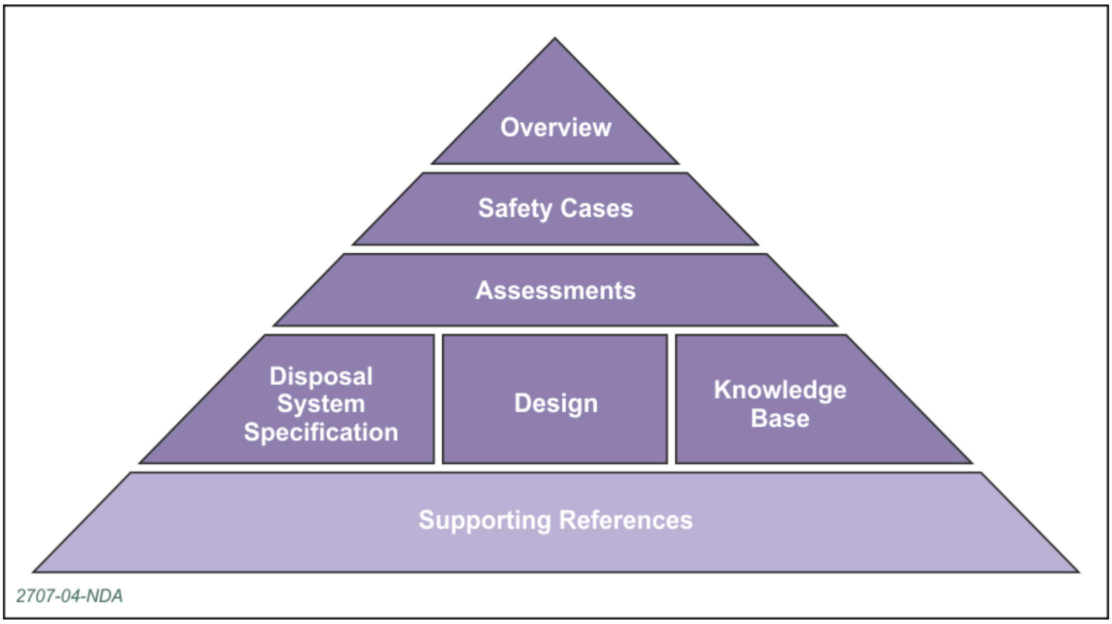
High level information on the inventory for disposal, the illustrative disposal concepts and other aspects of the disposal system is collated in a technical background document (the Technical Background) [3] that supports this generic Disposal System Safety Case.

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 derived inventory

This document is the 2013 Derived Inventory and presents the detailed quantitative inventory for disposal in a GDF that is required for RWM's designs and assessments.

The generic DSSC was previously published in 2010. There are now a number of drivers for updating the safety case as an entire suite of documents, most notably the availability of an updated inventory for disposal.

This document[2] updates and replaces the 2007 Derived Inventory [4], which was published as part of the 2010 generic DSSC suite and the 2010 Derived Inventory [5, 6], which was incorporated into the 2010 DSSC [7]. This issue includes the following improvements:

- it is based on the 2014 UK Government definition of the inventory for disposal in a GDF [2]
- it is based on data from the 2013 UK radioactive waste inventory (UK RWI) [8]
- it includes a 16 GW(e) new build programme
- it reflects Government's preferred policy on the management of plutonium [9]
- it reflects Scottish Government's policy for the management of higher activity radioactive waste [10]

These differences and other features of the 2013 Derived Inventory are discussed further in Section 1.4. 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 GDF design and assessment work to support the process of implementing geological disposal.

1.3 Objective

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

The information presented in the derived inventory includes the volumes, physical and chemical composition, and activities of conditioned wastes and materials, and details of the containers in which they are assumed to be placed for disposal.

Production of the derived inventory involves reviewing and enhancing the 2013 UK RWI and other publicly available data. For the purposes of this work, 'review' is defined as the process of identifying omissions, differences and inconsistencies within the 2013 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 2013 UK RWI.

1.4 Scope

1.4.1 Consistency with Government definition of inventory for disposal

The 2014 Implementing Geological Disposal White Paper sets out the inventory for disposal in terms of waste and material types as follows:

> *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:*

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[2] This is the second iteration of the 2013 derived inventory report; it updates and supersedes the original publication and contains some minor corrections and updated packaging assumptions for DNLEU.

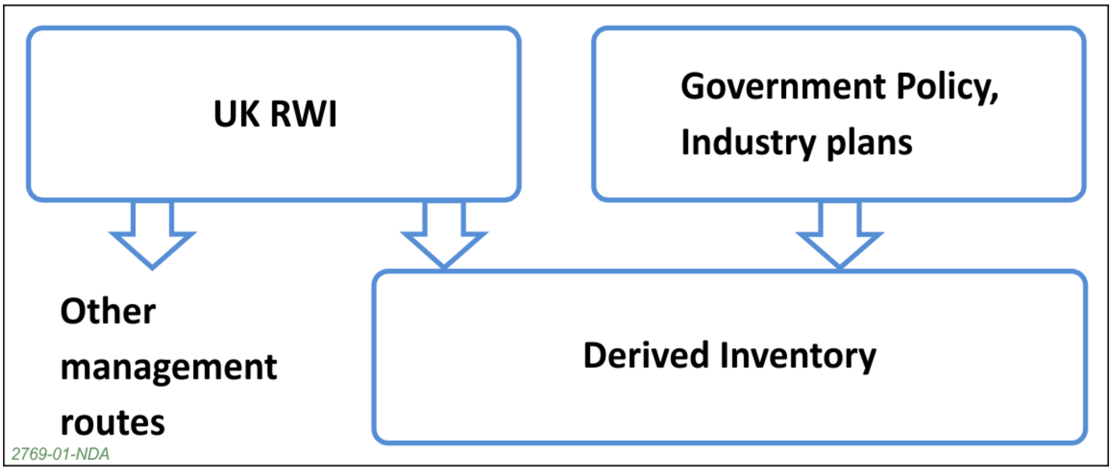
- *HLW arising from the reprocessing of spent nuclear fuel at Sellafield;*
- *ILW arising from existing nuclear licensed sites, and defence, medical, industrial and educational activities;*
- *The small proportion of LLW that is not suitable for disposal in the national Low Level Waste Repository;*
- *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 Consistency with the 2013 UK RWI

The Government and the Nuclear Decommissioning Authority (NDA) periodically publish an inventory of all radioactive waste in the UK: the UK RWI. ‘All radioactive waste’ includes HLW, ILW, LLW, very Low Level Waste (VLLW), and LLW held in Vaults 8 and 9 at the Low Level Waste Repository (LLWR), which is currently classed as stored. This inventory provides a reference source of information for Government and its agencies, and others with a role or interest in the management of radioactive waste. The most recently published iteration, the 2013 UK RWI, contains information on radioactive wastes in the UK that existed at 1st April 2013 and those that were projected to arise after that date. The UK RWI only considers stocks and arisings of waste from existing sources, often referred to as legacy wastes.

Only the specific types of higher activity radioactive waste (and nuclear materials that could be declared as waste) identified as being part of the inventory for disposal are included; ILW that is expected to be managed as LLW will continue to be included until incineration, recycling or disposal routes other than geological disposal are authorised. The relationship between the 2013 Derived Inventory and the UK RWI is illustrated in Figure 2.

Figure 2 The relationship between the UK RWI and the Derived Inventory



1.4.3 Scottish Government HAW policy

The Scottish Government's policy is for the higher activity waste (HAW) arising in Scotland to be managed in near-surface facilities (see Section 2.2 for further details). Wastes that will be managed under the Scottish Government's policy for HAW are not included in the inventory for disposal.

1.4.4 New build

The Derived Inventory includes waste and spent fuel from a 16 GW(e) new build programme and assumes (in line with discussions with the NDA and new build operators) that this will be uranium oxide fuel. The Implementing Geological Disposal White Paper states (see paragraph 7.41) that 16 GW(e) is not a Government target and the Government is supportive of industry bringing forward plans for further development in the future.

1.4.5 Management of separated plutonium

In 2011, Government published a consultation response on the long-term management of UK-owned separated civil plutonium, which concluded that [9]:

> *The UK Government has concluded that for nuclear security reasons the preferred policy for managing the vast majority of UK civil separated plutonium is reuse and it therefore should be converted to MOX fuel for use in civil nuclear reactors. Any remaining plutonium whose condition is such that it cannot be converted into MOX will be immobilised and treated as waste for disposal.*

In line with Government's preferred policy for long term management, the 2013 Derived Inventory assumes that the plutonium inventory will be reused in the form of mixed oxide (MOX) fuel[3]. However, it is noted that the UK Government has not made any decision on the fate of the UK's plutonium stocks, and that the NDA's Position Paper 'Progress on approaches to the management of separated plutonium' [11] identified CANDU and PRISM reactors as credible options for the re-use of plutonium.

The policy for re-using plutonium will only proceed when Government is confident that it could be implemented safely, securely and in a way that offers value for money. For the 2013 Derived Inventory, MOX SF is assumed to be additional to SFs from the defined amount of 16 GW(e) of new build.

1.4.6 Conditioning and packaging of DNLEU

The packaging assumptions for Magnox depleted uranium and depleted uranium tails are based on the preferred options that were identified by RWM's integrated project on uranium [12]. These packaging assumptions are detailed in Section 4.4 and Appendix B2.2.

1.4.7 Waste groups

The Derived Inventory is updated periodically, in line with updates to the UK RWI. The last update was the 2010 Derived Inventory, which was considered to be a 'light' update as it did not include a comprehensive review and enhancement process. The last full issue was the 2007 Derived Inventory and the way that the inventory information is presented has changed for the 2013 Derived Inventory.

The 2013 Derived Inventory presents the inventory for disposal in broad waste categories (in Section 5) and also in a more detailed breakdown of waste groups (see Section 6). The waste groups have been defined by RWM to distinguish between different types of waste for RWM's design and assessment studies and to reflect the key differences in time of arising, waste packaging and assumed emplacement in the GDF.

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[3] Further details of the assumptions made for MOX SF are presented in Section 2.4.

1.4.8 Radionuclides included

Only a subset of the known radionuclides will be present in significant quantities in radioactive waste and, of those present, only a limited number will have relevance to the long-term safe management of the waste. Accordingly, it has been recognised that it is not necessary to record information on all known radionuclides in order to demonstrate the long-term safe management of the wastes.

Nirex determined the radionuclides that are relevant to safety in the transport, operational, and post-closure phases of the GDF's operation [13]. Following the assessment, 112 radionuclides were identified as relevant to geological disposal, and data on each of these are reported in the UK RWI. The derived inventory contains information on all 112 of the 'relevant radionuclides'.

When reporting total activities, the 2007 and 2010 Derived Inventories did not include the contributions of the short-lived daughters[4] of the radionuclides that are quantified by the waste producers. In the 2013 Derived Inventory, the reported total activities include the contributions from the short-lived daughters. Where activities are reported for specific radionuclides, the contributions of any short-lived daughters are not included.

1.4.9 Precision

RWM stores inventory data to the level of precision that the waste producers provide in the UK RWI, or to the level of precision that it is calculated. The results of any calculations by RWM that involve this data are done to a high level of precision. However, RWM recognises that the data are not known to a high level of precision. Where possible, data in this report are presented to three significant figures, which is considered to provide an appropriate quantification of the inventory data. In some cases the data are not available, or are not specified, to three significant figures (eg the assumed burn-ups of SFs); in these cases, the data are presented to the level of precision to which they are known.

As a result of the rounding, some tables will show totals that may not represent the sum of the rounded data that is 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.

1.4.10 Uncertainty

In addition to a 'Reference Case' inventory, the 2007 and 2010 Derived Inventories included an 'Upper Inventory' that was compiled to allow the implications of uncertainty to be explored in RWM's design and safety and environmental assessment work. The 'Upper Inventory' was not intended to be a maximum estimate or to set out the largest inventory that could be safely disposed of in the GDF.

Exploring the sensitivity of the inventory to uncertainties or alternative assumptions is excluded from the scope of this report. A companion report [14] explores the impact of uncertainties and alternative assumptions.

1.4.11 Hazardous substances and non-hazardous pollutants

RWM uses the UK RWI as the basis for producing its Derived Inventory and at present the UK RWI contains little information on hazardous substances and non-hazardous pollutants. Therefore the 2013 Derived Inventory does not specifically quantify hazardous substances and non-hazardous pollutants and the uncertainty associated with them is not explored further in this report. As a consequence of this RWM's safety cases do not provide detailed quantified assessments of the safety and environmental impacts of hazardous substances and non-hazardous pollutants.

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[4] 'Short-lived daughters' are defined in this context as having a half-life of less than 10 days.

RWM is currently working with the NDA, LLWR and waste producers to ensure that more information on hazardous substances and non-hazardous pollutants is available in future iterations of the UK RWI and this can then be incorporated into RWM's Derived Inventory and safety cases. Details of RWM's planned work in this area are provided in the Science and Technology Plan [15].

The Environment Agency and the office for nuclear regulation are formally tracking RWM's development of work in this area through a regulatory observation[5] [16].

1.4.12 Detailed differences relative to the 2013 UK RWI

In addition to the additions discussed above, several other changes are made to the UK RWI data, and these are:

- waste container allocations are reviewed (and, where necessary, revised) to ensure that the waste is packaged in a form that is suitable for its safe management, including storage, transport, underground emplacement and potential disposal
- detailed information on the chemical composition, radionuclide activities and packaging of SFs, uranium and plutonium need to be included
- information must be provided at the waste package level rather than the waste stream level (as in the UK RWI)
- all waste streams must have package types assigned (this is not always the case in the UK RWI as conditioning processes have not been finalised)
- material component values with 'less than' prefixes must be revised to avoid potentially significant mass overestimates from summing these values
- nuclear materials associated with UK defence activities need to be included

1.5 Document structure

The remainder of this report is structured as follows:

- Section 2 details the assumptions that have been made in producing the inventory for disposal
- Section 3 describes the enhancement methodology for producing the inventory for disposal
- Section 4 provides an overview of the packaging assumptions
- Section 5 provides a summary of the inventory for disposal
- Section 6 presents the inventory for disposal in terms of the different waste groups
- Section 7 discusses areas for potential further improvements to the inventory for disposal

In addition, there are five appendices, which contain further details:

- Appendix A gives the detailed methodology for the enhancement work
- Appendix B presents the waste packaging assumptions
- Appendix C presents waste package data
- Appendix D details the results of the enhancements to the UK RWI data

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[5] A Regulatory Observation is a regulatory finding that cannot (or is inappropriate to) be resolved in the current context, because it requires further investigation or information to resolve it that can only be obtained or achieved at a later stage in the GDF programme (for example, in a site-specific context). However, this might not preclude RWM starting work to progress its resolution.

- Appendix E provides detailed materials data, including bulk materials, elemental composition and data for the gas pathway analysis

2 Assumptions

The 2013 Derived Inventory has been compiled using data sourced predominantly from the 2013 UK RWI. The data presented in the UK RWI for future waste arisings are projections made by the organisations that operate the sites where radioactive waste is generated. The projections are based on assumptions as to the nature, scale and timing of future operations and activities. For the 2013 UK RWI, these projections represent planning assumptions at 1st April 2013, which have been constructed for the purpose of preparing data.

The UK RWI does not include arisings profiles or radionuclide inventories for the SFs or the wastes from new build. As a result, additional assumptions need to be made. Table 1 presents the assumptions broken down by waste and material category while Table 2 presents the assumptions broken down by sector. Details of other high level assumptions are given in Sections 2.1 to 2.5.

Table 1 Key assumptions for each waste and material category

Waste / material type	2013 Derived Inventory[6]
HLW[7]	All 2013 UK RWI HLW from reprocessing 55,000 tU Magnox SF and 5,000 tU Advanced gas-cooled reactor (AGR) SF
ILW	All 2013 UK RWI ILW, excluding those wastes with an established management strategy of incineration, recycling or near surface disposal ILW from a 16 GW(e) new build programme
LLW	2013 UK RWI LLW reported as unsuitable for near surface disposal
SFs	4,500 tU AGR SF 1,050 tU Sizewell B Pressurised Water Reactor (PWR) SF 740 tU metallic SF 10 tHM exotic SF 8,260 tU UK European Pressurized Reactor (UK EPR) SF (PWR new build) 6,030 tU AP1000 SF (PWR new build) 1,460 tHM MOX SF (includes fuel made from 7.6 t of defence Pu) Irradiated submarine fuel (not quantified)
DNLEU	170,000 tU from civil fuel enrichment and civil SFs reprocessing 15,000 tU from defence programmes
HEU	1.0 tU from civil programmes 21.9 tU from defence programmes
Plutonium	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)

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[6] Excludes wastes managed under the Scottish Government's Policy for HAW.

[7] 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 2.5.

Table 2 The assumptions for the 2013 Derived Inventory

Sector	Assumptions[8]
Civil nuclear power stations[9]	Wylfa shuts down in 2014 Sizewell B shuts down in 2035 AGRs: Shuts down in 2018: Dungeness B Shuts down in 2019: Heysham 1, Hartlepool Shuts down in 2023: Hinkley Point B, Hunterston B, Heysham 2, Torness Deferral of Magnox and AGR reactor final stage decommissioning for up to about 85 years after shutdown; all decommissioning complete by 2118 Prompt decommissioning of Sizewell B PWR station (completed by 2053) New build programme of 16 GW(e) comprising 6 UK EPRs and 6 AP1000s
Plutonium	95% of civil (and all Ministry of Defence (MOD)) Pu re-used as MOX fuel 5% of civil Pu treated as waste
Fuel fabrication	Uranium dioxide (UO_2) manufacturing continues until 2023
Uranium enrichment	Continues to 2023
Spent fuel reprocessing	Magnox fuel reprocessing continues until 2017 (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 2120 4,500 tU AGR SF is not reprocessed Sizewell B SF, new build SFs and MOX SF are not reprocessed
Research & Development	Joint European Torus operates until 2018 All former UK Atomic Energy Authority facilities (including Windscale Piles 1 & 2) are fully decommissioned by 2050
Defence	A continuing nuclear defence capability (waste estimated to 2060) A continuing nuclear powered submarine programme (waste estimated to 2070)
Medical & industrial sources	The medical uses of radioactivity continue Arisings estimated to 2040

It is recognised in the 2013 UK RWI that projections made at a particular date may need to be amended as plans and arrangements are developed or changed for commercial, policy or funding reasons, or if improved data become available. Revisions can affect either or

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[8] Excludes wastes managed under the Scottish Government's Policy for HAW.

[9] Since this work was carried out, the operational lifetimes have been extended as follows: Wylfa has been extended by one year Dungeness B by 10 years, Heysham 1 and Hartlepool by 5 years, and Heysham 2 and Torness by 7 years. The inventory has not been updated and uncertainties associated with the lifetimes of existing reactors are be explored in RWM's inventory scenarios report.

both of the quantity and timing of future arisings. For example, for the purposes of producing the 2013 Derived Inventory, it is assumed that the nuclear new build programme is composed of six AP1000s and six UK EPRs. The GE-Hitachi UK Advanced Boiling Water Reactor (UK ABWR), which is currently progressing through the Generic Design Assessment process and is proposed for Horizon Nuclear Power's sites at Wylfa and Oldbury, is not currently considered (this is discussed further in Section 2.3). The Derived Inventory has assumptions that reflect the best available information and data. If more information and / or data are available for the next iteration of the Derived Inventory, then these assumptions will be revised.

2.1 Defence

2.1.1 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 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 PWR) SFs
- new build SFs
- 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.

2.1.2 Uranium

The 1998 Strategic Defence Review [17] 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 the GDF but for the purposes of developing the 2013 Derived Inventory and informing assumptions of the inventory to be disposed of, HEU is assumed to be immobilised in a titanate-based ceramic that contains 11.9% HEU dioxide by mass, and which is then 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 Derived Inventory, 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.

2.1.3 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.

In December 2011 the Government proposed a preliminary policy view [9] to pursue re-use of plutonium as MOX fuel, converting the vast majority of the UK civil separated plutonium into fuel for use in civil nuclear reactors. Any remaining plutonium, whose condition is such that it could not be converted into MOX fuel suitable for a reactor, would be immobilised and treated as waste for disposal. 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 (115 t). For the purposes of developing the 2013 Derived Inventory, the MoD's stocks of plutonium are assumed to be 7.6 t of plutonium [17] 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.

2.2 Scottish wastes

The Scottish Government's policy is for the HAW arising in Scotland to be managed in near-surface facilities[10] [10]. Scottish Government's higher activity waste policy defines higher activity radioactive wastes as follows:

> *2.03.02 For the purposes of this policy the term higher activity radioactive waste means:*
>
> - *Radioactive waste defined in current UK categorisations as Intermediate Level Waste (ILW).*
> - *Intermediate Level Waste is waste which has radioactivity levels exceeding the upper boundaries for Low Level Waste and which does not generate enough heat for this to need to be taken into account in the design of treatment or storage facilities.*
>
> *2.03.03 The policy also applies to waste which is not higher activity radioactive waste as defined in paragraph 2.03.02. This is waste for which the most appropriate long-term management option may be the same as that for higher activity radioactive waste. This includes:*
>
> - *Certain wastes categorised as Low Level Waste (LLW), which by their nature are not currently suitable for disposal in existing LLW facilities as, for example, they may be longer-lived waste.*
> - *LLW is as defined in the March 2007 LLW Policy [18].*

Waste that is covered by the Scottish Government's policy[11] is, therefore, excluded from the 2013 Derived Inventory.

2.3 New build

Before a new nuclear reactor can be built in the UK, its design must be approved by the regulators through the generic design assessment (GDA) process[12] [19]. This allows the

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[10] 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 [10].

[11] 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.

[12] GDA is a joint process between the Office for Nuclear Regulation and the Environment Agency. Natural Resources Wales, the environmental regulator in Wales since April 2013, is also participating in GDA with the other two regulators and will be leading on engagement with people in Wales.

regulators to assess the safety, security and environmental implications of new reactor designs, separately from applications to build them at specific sites.

An important aspect of the GDA process is the consideration of the disposability of the higher activity solid radioactive wastes and SF that would be generated through reactor operation and decommissioning. Consequently, the regulators have indicated that as part of the GDA process, the requesting party should seek advice from the NDA to provide assurances that adequate consideration is being given to the disposability of any radioactive waste that will be produced by a power station based on the generic design [20]. As a result, the inventory of waste that would require disposal in the GDF is estimated as part of the GDA process.

At present, only EdF / Areva's UK EPR reactor has completed the GDA process. Inventory information for both the UK EPR and the AP1000 was produced for the GDA reports [21, 22]. Hitachi-GE has also begun the GDA process for their UK ABWR. However, the process has not reached the stage where inventory information has been published. As a result, for the purposes of the 2013 Derived Inventory, the new build programme is assumed to be composed of an equal number of UK EPRs and AP1000s that become operational over the timescales shown in Table 3.

Table 3 The number of reactors that become operational in each year

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

For the purposes of the 2013 Derived Inventory, the new build programme is assumed to be approximately 16 GW(e) and this is assumed to be achieved through having 6 AP1000s (each producing 1.14 GW(e)) and 6 UK EPRs (each producing 1.6 GW(e)). All of the new build reactors are assumed to be operational for 60 years.

2.4 Mixed oxide SF

In December 2011, the UK Government set out its preferred policy for the long-term management of plutonium – that it should be re-used in the form of mixed oxide fuel[13]. However, only when the UK Government is satisfied that this 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. Hence, for the purposes of the 2013 Derived Inventory, RWM considers it appropriate to decouple the new build programme from the MOX assumptions. As such, the MOX SF is considered as an addition to the SFs from new build. However, no nuclear power plant, MOX manufacturing plant or UO_2 fuel is assumed to be associated with the MOX SF.

The only time constraint regarding when MOX fuel could be burned is that it is not assumed to start before the MOX fuel could realistically be manufactured. In discussions with NDA Strategy, RWM has decided 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.

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[13] It is noted that the UK Government has not made any decision on the fate of the UK's plutonium stocks, and that the NDA's Position Paper [11] identified CANDU and PRISM reactors as credible options for the re-use of plutonium.

There is potential for the quantity of plutonium (and therefore MOX SF) to change and the two principal reasons for this, both of which are uncertain, are:

- the assumption is based on predictions of the final reprocessing outturn
- Government policy allows the UK to take title to overseas plutonium under commercial terms (see paragraph 1.8 of [9])

The fraction of the plutonium that will be suitable for manufacture into MOX fuel is also difficult to quantify. In discussions with NDA Strategy, it was decided 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.

2.5 Other assumptions

The containers that are used for the disposal of the waste can have a significant impact on the packaged volume of waste that needs to be disposed of. There are new families of waste containers in the 2013 Derived Inventory: 500 l robust shielded (RS) drums and 3 m^3 RS drums, 1 m^3 and 500 l concrete drums, and redesigned disposal containers for HLW and SFs. All of these new waste containers will be included in an update to RWM's Disposal System Technical Specification (DSTS)[14].

- The 2013 Derived Inventory includes: 3 m^3 RS boxes, which are cuboidal; and 500 l RS drums, which are cylindrical and can be used with optional additional lead shielding inserts of different thicknesses. These waste containers have been specified for several Magnox waste streams and a single waste stream at Sizewell B.
- 1 m^3 and 500 l concrete drums are assumed to be used for operational wastes arising from the new build UK EPRs. Both can be used with additional carbon steel shielding inserts of varying thicknesses.
- The assumed disposal containers for HLW and SFs, which are used for the purposes of RWM's generic design and assessments work, have been redesigned so that they have a diameter of 1,050 mm. The revised designs allow for 50% more HLW and 100% more AGR SF to be held in a single disposal container. Illustrative designs have also been developed for disposal containers for other nuclear materials.

The 2013 UK RWI includes 42 ILW streams that waste producers expect to manage as LLW through near-surface disposal by using radioactive decay storage and / or decontamination processes. 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 have been excluded from the 2013 Derived Inventory. As a result, the 2013 Derived Inventory does not include the following ILW streams:

- 1B04 ILW containing tritium excluding free liquid (incinerated)
- 1B11 ILW containing tritium free liquid (incinerated)

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 2013 Derived Inventory includes LLW in the 2013 UK RWI identified as unsuitable for consignment to the Low Level Waste Repository (LLWR) and which is not being treated by incineration or being recycled. The 2013 UK RWI includes six LLW streams unsuitable for near-surface disposal that are being treated by incineration or are recycled:

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[14] New waste packages are subject to RWM's change management process.

- 2A30, 2D30, 5H307, 7A34 (Oils)
- 7A37 (Contaminated mercury)
- 7A32 (Closed sources)

Any 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 2013 Derived Inventory) and are not included in the 2013 Derived Inventory.

A proportion of the waste from THORP and the Magnox reprocessing plant at Sellafield results from the reprocessing of overseas SFs. 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' SFs. The HLW is smaller in volume but equivalent to the ILW and LLW in radiological terms. The Derived Inventory 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 in the 2013 Derived Inventory).

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

3 Data review and enhancement methodology

The 2013 Derived Inventory uses the data from the 2013 UK RWI as its basis. However, this data needs to be reviewed and, where necessary, 'enhanced'. There are a number of reasons for enhancing the UK RWI data; examples include:

- the material breakdown may be incomplete (ie the waste stream's mass is not all assigned to material types)
- material grades and types may not be assigned to bulk materials
- waste streams may not have a package type specified
- the package types specified for a waste stream may not provide sufficient shielding
- radionuclide data may not be present (eg for SFs, plutonium and uranium)
- other publicly available information may be considered to be better underpinned than the inventory submissions (eg data from sampling programmes)

In addition to enhancing the UK RWI data, new data have to be added to account for wastes from a new build programme, nuclear materials arising from UK defence activities and SFs from a new build programme and the re-use of plutonium as MOX fuel.

3.1 Review of priority materials and radionuclides

The 2010 Derived Inventory was a 'light' update that did not include a comprehensive review and enhancement process. The 2007 Derived Inventory was the last 'full' update and as part of this exercise, the materials and radionuclides that were considered to be most important for the GDF and for RWM's generic safety cases were identified, and priority scores assigned. As part of the 2013 Derived Inventory exercise, these lists, and the associated priority scores, were updated; Appendix A1 records the revised priority materials, radionuclides, and scores.

The priority scores have been used to determine the level of focus allocated to the enhancement of data. It should be noted that the priority scores take no account of the coverage and quality of data in the 2013 UK RWI, or whether a credible means of improving the data within the work programme constraints is available.

There are areas that were not considered as part of the 2007 Derived Inventory that have more recently been identified as requiring enhancements: superplasticisers, plasticisers and groundwater pollutants.

3.2 Approach to data enhancement

The starting point for the review and enhancement work is the data in the 2013 UK RWI. Enhancements are focussed where mass and activity data are unspecified and on those material and radionuclide components identified as a priority (see Appendix A1). The review and enhancement methodology is based on that used in the production of the 2007 Derived Inventory, which was peer reviewed[15]. The issues that were identified in the peer review, and were not addressed in the 2007 Derived Inventory, were added to the RWM issues register [23]. As a result of addressing these issues, some elements of the methodology have been refined.

The enhancements that are made are documented in 'audit trail spreadsheets', with different spreadsheets for different parameters. Information is provided in these spreadsheets on a waste stream basis: 2013 UK RWI data and enhanced data are included, along with an optional comment to explain the reason for any enhancements.

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[15] Enhancement of material and radionuclide compositions was not undertaken for the 2010 Derived Inventory.

3.2.1 Material composition enhancements

Materials data required for the 2013 Derived Inventory comprises:

- material component masses of the waste
- the make-up and masses of any waste, conditioning, capping and container materials
- the material masses of waste disposal containers

The Derived Inventory considers (and investigates) material composition on two levels:

- bulk materials: the bulk materials that make up the wastes, conditioning and capping materials and disposal containers
- elemental: the specifications, grades, types and proprietary names of materials that allow the elemental quantities of the bulk materials to be derived

A substantial database of elemental compositions for a range of materials that make up the component parts of a waste package (waste, conditioning matrix, capping matrix and container) was compiled for the 2007 Derived Inventory and has been extended for the 2013 Derived Inventory. This database comprises probability density function data for various steels, other metals, uranium and UO_2. This data includes mean, upper and lower uncertainty estimates of elemental precursors. The upper and lower uncertainty estimates represent 95% and 5% levels on the cumulative distribution.

Where no data were available for specific elements (most often minor components), the reported concentrations of these in the Earth's crust have been used as a basis for calculation. Upper uncertainty estimates are reported as 100 times the Earth's crustal abundance, but with a set maximum value (typically 1,000 ppm). Lower uncertainty estimates are reported as 100 times lower than the upper uncertainty values.

The mean material compositions have not been enhanced by the addition of Earth's crustal abundance data because it is more than likely that to do so would significantly overestimate the mass of many minor elemental components. This has resulted in some elements having no value for the mean concentration but values for the upper and lower uncertainty estimates. This can lead to the best estimate value for an element in the elemental composition tables in Appendix E2 being less than the value for the lower uncertainty.

Material grades and types are assigned to the bulk materials. Elemental compositions / specifications for these grades and types are then used with the material masses to derive elemental masses.

3.2.2 Radionuclide composition enhancements

Radionuclide enhancement work is limited to the 37 priority radionuclides that are significant or potentially significant for RWM's safety cases (see Appendix A1). The enhancements have focussed on the more significant gaps in activities (ie for each radionuclide those waste streams likely to have higher activity). Smaller volume waste streams that will not make any significant contribution to the radionuclide totals have not been considered.

3.2.3 Other enhancements

Superplasticisers are commonly used in the construction industry to improve the properties of cement and concrete. It is known that superplasticisers have been used in the packaging of some wastes, and it is assumed that they will have been used in the construction of legacy plant, some of which will be disposed of to the GDF. The chemical composition of superplasticisers means that they could complex with actinides and potentially increase their solubility. Therefore, the effect of superplasticisers on the behaviour of radionuclides is an area that requires consideration by RWM.

Future use of superplasticisers in waste containers, and capping and conditioning materials, will be subject to disposability assessments. Based on information available at the time of assessment, the use of superplasticisers may not be endorsed. Also, the use of superplasticisers may not be required for the vast majority of conditioning and capping materials.

For the purposes of the 2013 Derived Inventory, a conservative assumption that all cementitious materials (ie cement and concrete in wastes; cement encapsulating and capping grouts; and concrete containers) contain 0.5 wt% superplasticiser is applied. Although this assumption is thought to be bounding, the total mass of superplasticisers is not quantified in the Derived Inventory and further work in this area is planned (see, for example, Tasks 757 (Testing and Selection of Candidate Superplasticisers) and 759 (Review of Potential Superplasticiser Inventory in Decommissioned Building Materials) in RWM's Science and Technology Plan [15]). RWM's current understanding of superplasticisers is summarised in reference [24].

Flexible Polyvinyl Chloride (PVC) can contain high levels of plasticisers, which diffuse from the polymer. This may be accelerated under the influence of heat, ionising radiation and at high pH. Plasticisers have the potential to form Non-Aqueous Phase Liquids (NAPLs) and their eventual degradation products are uncertain. There is currently some uncertainty about their impact on radionuclide behaviour. As a result, plasticisers in wastes need to be quantified in order to bound their impact on the migration of radionuclides from the GDF. PVC is expected to be the dominant source of such plasticisers in the ILW inventory.

Plasticisers in PVC were not included in the 2007 Derived Inventory. Based on a review of plasticisers in PVC [25], a range of 30 – 40 wt% of diethylhexyl phthalate ($C_{24}H_{38}O_4$) has been used for all PVC in the 2013 Derived Inventory. Diethylhexyl phthalate is the most commonly used plasticiser in PVC flexible film, which is the predominant form of PVC in radioactive wastes.

The 2013 UK RWI does record the presence of a small number of non-radiological substances in some waste streams. However, groundwater pollutants require further consideration as the legislation regarding the protection of groundwater from the introduction of hazardous substances and non-hazardous pollutants changed in 2010 when The Environmental Permitting (England and Wales) Regulations 2010 [26] came into force. This new legislation gives effect to certain provisions of Directive 2000/60/EC (Water Framework Directive) [27] and Directive 2006/118/EC (Groundwater Daughter Directive) [28] in England and Wales. It is noted that the legislation governing Scotland [29] and Northern Ireland [30] is different to that governing England and Wales.

Because the information on groundwater pollutants that is contained within the 2013 UK RWI is limited, no attempt has been made to enhance this data for the 2013 Derived Inventory. The NDA, LLWR and RWM are in discussions with waste producers regarding the inclusion of greater detail on the groundwater pollutants present in the waste in the next iteration of the UK RWI.

If complexing agents are present in the GDF, they could form complexes with the contaminants that are present. Contaminants present in a complexed form have different effective solubility limits and sorption coefficients when compared with the uncomplexed contaminants. In order to better understand the transport of the contaminants, it is necessary for RWM to know which complexants are present and in what quantities. RWM's current understanding of complexants is summarised in reference [24].

About 1 tonne of complexants is quantified in the 2013 UK RWI. Although there is information indicating that additional quantities are present in some wastes, this information is insufficient to determine the types and quantities. RWM is undertaking work to assess the disposability of materials used to fix and remove radioactive waste contamination (see reference [15]). Once this is completed, it may be necessary to add certain complexants to the list of priority materials.

3.3 Data enhancement for UK RWI wastes

The 2013 UK RWI provides detailed composition data for HLW, ILW and LLW streams and, for these waste categories, a common review and enhancement methodology is adopted. A detailed description of the methodology is contained in Appendix A2 and a brief summary is provided below.

Bulk materials

The data from the UK RWI is supplemented by reviewing the supporting descriptive text to identify any additional information. Where the mass of the waste is not accounted for by the bulk materials, comparison with similar waste streams in the 2013 UK RWI is used to enhance the data, with the aim of assigning greater than 99% of the waste mass to bulk materials.

Priority materials are enhanced by comparing the 2013 UK RWI descriptive data with that from the 2007 UK RWI. Where the two descriptions are the same, the enhancements from the 2007 Derived Inventory can be used; where the descriptions differ, or the waste streams are new for the 2013 UK RWI, further investigation is required in order to assign the materials.

Elemental composition

Material grades are allocated to steels, other metals, alloys and other proprietary material types, such as ion exchange resins based on: the data reported in the 2013 UK RWI; the 2007 Derived Inventory enhancements; and additional information available to RWM. If the material grades are not specified by the waste producers, then the materials are assigned grades in the same relative proportions as major contributing streams where grades are reported.

Radionuclide data

Priority radionuclides have been enhanced by first incorporating enhancements from the 2007 Derived Inventory that remain valid. Other gaps have been filled by fingerprinting (selecting a surrogate 2013 UK RWI waste stream that is known to have similar radionuclide properties and factoring activity values using a marker nuclide or total activity). Finally, if a radionuclide is identified as being present in significant quantities but not determined, an activity is derived through comparison with a waste stream that is expected to have a similar radionuclide fingerprint.

3.4 Data enhancement for legacy SFs

The 2013 UK RWI only reports masses for SFs, uranium and plutonium; there are no material, chemical or radionuclide composition data. For these waste categories, materials composition data have been compiled using the most robust information from other published sources and from supporting calculations.

The radionuclide inventories of SFs are calculated based on the parameters given in Table 4. The two enrichments of the ‘robust fuel’ [31] are considered for future arisings of AGR SF. Full details of the calculations and of the materials compositions assumed for the fuels are presented in Appendix A3.

Table 4 Parameters used to calculate the radionuclide inventories of SFs

Fuel	Burn-up (GWd/tHM)	Enrichment (%)	Cooling times (yrs)
AGR stocks	28	2.9	6
AGR arisings [16]	33	3.2 / 3.78	1
Sizewell B stocks	45	4.2	8
Sizewell B arisings	55	4.4	1
PFR stocks	189	(Pu) 29.5	19
Legacy ponds stocks	4.1	0.71	36

3.5 Uranium and plutonium enhancements

The 2007 Derived Inventory peer review noted that trace impurities in uranium materials had not been accounted for; this issue has been addressed in the 2013 Derived Inventory. However, plutonium and HEU continue to be reported without impurities as no definitive data are currently available to RWM. The decontamination factors associated with the reprocessing plant are used to determine the radionuclide impurities.

Full details of the enhancement methodology for uranium and plutonium are presented in Appendix A4.

3.6 Wastes not considered in the 2013 UK RWI

There are two sources of waste that are not considered in the UK RWI: new build and MOX. A summary of the enhancement methodology for these wastes is provided below and full details are provided in Appendices A5 and A6.

Inventory information for the AP1000 and the UK EPR has been taken from the GDA reports [21, 32, 22, 33] and (in the case of the UK EPR) from the Pre-Construction Safety Reports (PCSRs) [34, 35]. These documents have provided the information for the material compositions; where no information was available, materials have been assigned based on comparison with similar Sizewell B wastes. Radionuclide inventories are taken from the GDA reports.

In the case of MOX, only SF is considered. Because of the similarities between the fuel for the UK EPR and the AP1000, and because the Government's preliminary preferred option for plutonium is re-use as MOX in a light water reactor (LWR) [9], the parameters for the fuel and assembly have been based on the UK EPR and AP1000. The height of the fuel assembly is also assumed to be similar when considering initial design work for the disposal container. The parameters for the MOX and new build SFs are presented in Table 5.

Table 5 Parameters for New build and MOX SFs

Fuel	Burn-up (GWd/tHM)	Enrichment (%)	Cooling times (yrs)
AP1000 arisings	65	5	1
UK EPR arisings	65	4.5	1
MOX	50	(Pu) 8	1

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[16] The two enrichments for the robust fuel [31] are assumed to be used in equal amounts.

3.7 Gas generation data

A feature of radioactive wastes is that they contain materials that produce gas when they corrode, degrade or interact with radiation (RWM's current understanding of gas generation and migration processes during periods before and after closure of the GDF is summarised in reference [36]). Thus, gas is generated by corrosion of metals, degradation of organic wastes (particularly cellulose) and by radiolysis. The most important gases volumetrically are hydrogen, carbon dioxide and methane and a small proportion of the generated gas can be radioactive, containing H3 and C14. In order for RWM to carry out performance assessment calculations, mass and geometry information for reactive metals (such as Magnox, aluminium and uranium) and less reactive metals (such as stainless and mild steels and Zircaloy) are required. This is done by representing the metals in waste streams as plates or spheres and assigning a thickness / radius. In addition, the H3 and C14 associated with the gas generating materials are determined.

The detailed methodology for producing the gas generation data is described in Appendix A7.

3.8 Conditioning and capping materials

Conditioning and capping materials are discussed in detail in Appendix A8 and a brief summary is provided below.

ILW and LLW

For waste streams that are encapsulated in a cementitious matrix, the volume of conditioning grout is determined by subtracting the waste loading volume from the waste container payload volume. In the case of 500 l RS drums and 3 m^3 RS boxes, no encapsulation is included. For other waste streams, the volume of grout will be based on a surrogate stream. The volume of capping grout assigned to each waste stream is determined by the type of waste container.

HLW

HLW is immobilised in a borosilicate glass. The 2013 UK RWI contains information on the make-up of the glass and the proportions of glass and waste in the vitrified product.

HEU and plutonium

Consistent with the 2007 Derived Inventory, HEU and plutonium residues are assumed to be immobilised in a ceramic matrix and loaded into stainless steel cans, which in turn are encapsulated in glass within a large steel canister.

DNLEU

Consistent with the 2007 Derived Inventory, all miscellaneous DNLEU and 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

MDU and depleted uranium tails (irradiated and unirradiated) are assumed to be disposed of in the form of oxide powders (UO_3 and U_3O_8 respectively) using storage containers with a stainless steel overpack. The storage containers are immobilised within a transport disposal container using a mixture of BFS/PFA/OPC encapsulant.

SF

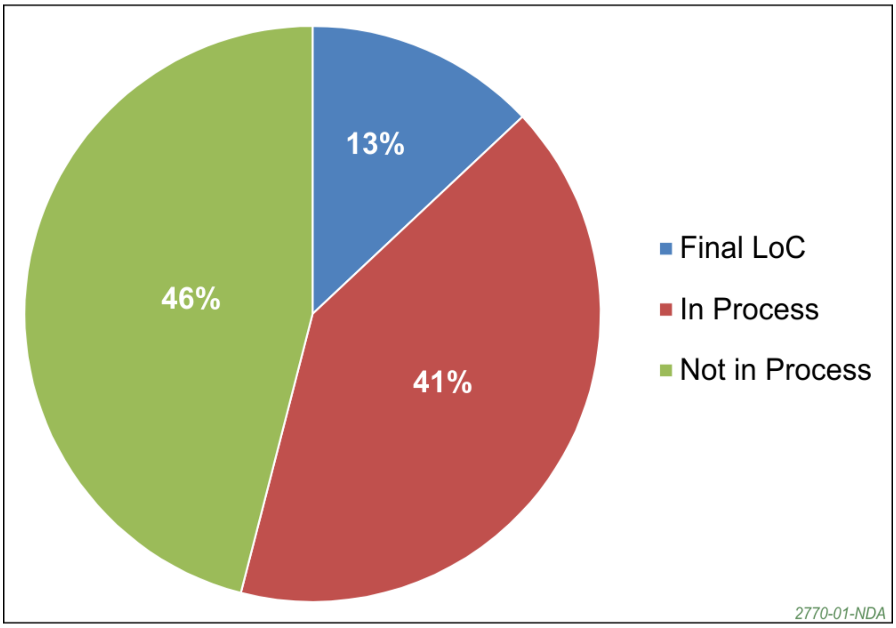
SFs are assumed to be disposed of unencapsulated.

4 Packaging assumptions

In order for a waste stream to be disposed of, it must complete RWM's disposability assessment process. Figure 3 shows the fraction of the waste that is in the disposability assessment process and that which has completed the process and therefore has a final Letter of Compliance. At present, around 13% of the ILW (by conditioned volume) has completed this process, and a further 41% is currently within the process[17]. The waste packages that are specified by the waste producers (and that have been used in the Derived Inventory) are, therefore, subject to change.

In preparing the Derived Inventory, RWM reviews the waste packages that the waste producers have assigned to the ILW and LLW that is not yet packaged; this may result in the waste containers being reassigned for some waste streams. Section 4.1 presents an overview of the packaging review process, and Sections 4.2 to 4.4 give an overview of the packages used for different waste categories.

Figure 3 The fraction of the ILW (by conditioned volume) that: has a final Letter of Compliance; is in the disposability assessment process; or is not in the disposability assessment process



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 discussed as part of RWM's inventory scenarios study [14].

4.1 Review of package assignments

Waste container allocations in the 2013 UK RWI have been subject to further consideration:

- where the waste container has not been specified
- where RWM has thought it necessary to review the waste container type
- where a non-standard container is specified and this might be overpacked
- where a waste stream has been allocated more than one container type

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[17] Data complete to March 2013; volumes based on the 2010 UK RWI.

- where the 2007 Derived Inventory peer review identified the stream as having a container inconsistent with the packaging rules

A further verification of the waste package types 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 package is assigned. The detailed methodology for this review and verification of waste packages is presented in Appendix B and has resulted in some waste streams being assigned alternative packages.

4.2 HLW and SFs

RWM has defined illustrative geological disposal concept examples for HLW and SFs in a range of potentially suitable UK geological environments[18] [37]. Detailed design work has been carried out for the disposal containers for HLW, AGR SF and PWR SF [38]. 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 [39]
- Variant 2: a disposal container designed for a lower strength sedimentary host rock and based on NAGRA's mild steel disposal canister concept [40]

For the purposes of quantifying the packaged volumes and material masses of the inventory for disposal, it is assumed that the Variant 1 disposal container is used. The differences between the two variants of the disposal container, in terms of the information presented in this report, are the container materials masses and the elemental compositions.

The inventory for disposal includes other types of SFs: exotic SFs, new build SFs, MOX SF and metallic SFs. The packaging assumptions for these other SFs are assumed to be similar to those for the AGR and PWR SF, ie a copper container with a cast iron insert (see Appendix B2.1 for further details).

4.3 ILW and LLW

RWM's illustrative geological disposal concepts are based on three general waste package types: unshielded, shielded and robust shielded packages. Two new families of shielded waste containers have been introduced since the 2010 Derived Inventory, and these are detailed below.

- 500 l RS drums and 3 m^3 RS boxes[19] have been assigned (by waste producers) to a number of waste streams in the 2013 UK RWI. Two types are considered: 3 m^3 RS boxes, which are cuboidal; and 500 l RS drums, which are cylindrical and can be used with optional additional lead shielding inserts of different thicknesses.
- 500 l and 1 m^3 concrete drums are assumed to be used for operational wastes arising from the new build UK EPRs. Both can be used with additional carbon steel shielding inserts of varying thicknesses.

The range of ILW disposal containers comprises unshielded containers, which would be transported in a Standard Waste Transport Container (SWTC), and shielded containers that are both waste and transport packages.

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

[19] On the waste stream datasheets that waste producers have submitted, the 500 l RS drum is sometimes referred to as a MOSAIK or a Type II ductile cast iron container; the 3 m^3 RS box is sometimes referred to as a Type VI ductile cast iron container. The two are sometimes collectively referred to as ductile cast iron containers.

Detailed properties of the legacy ILW and LLW containers can be found in Table B2 and those of the new build waste containers can be found in Table B11.

4.4 Plutonium and uranium

HEU and plutonium

The can-in-canister concept [4] is assumed for HEU and the plutonium residues (that plutonium which is not suitable for fabrication into MOX). In this concept, the waste would be 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.

DNLEU

The 2007 and 2010 Derived Inventories assumed that all DNLEU would be converted into a U_3O_8 powder, which would be mixed with a PFA / OPC encapsulant and repackaged into 500 l drums for disposal. These packaging assumptions are consistent with those that were adopted in previous calculations of packaged volumes of DNLEU by Nirex and the Committee on Radioactive Waste Management [41, 42], and were considered in the 2010 generic DSSC [43].

Based on the preferred options identified by RWM's uranium integrated project team [12], the 2013 Derived Inventory adopts revised packaging assumptions for DNLEU that is less than 1% enriched in U-235 (ie Magnox depleted uranium (MDU) and depleted uranium tails). RWM has not revised the packaging assumptions for the remaining DNLEU (THORP product uranium (TPU), miscellaneous DNLEU and depleted uranium from defence enrichment, for which no data were available).

The revised packaging assumptions for MDU and depleted uranium tails are that:

- the current / planned wasteform for storage would be used for disposal (ie unencapsulated UO_3 and U_3O_8 powders)
- the powders would not be repackaged, ie they will remain in their current / planned storage containers[20]:
    - depleted uranium tails (U_3O_8 powder) in mild steel DV-70s
    - older MDU (UO_3 powder) in mild steel 200 l drums that have been overpacked in large (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 ~500 l drums for older MDU
    - 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

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[20] There is a degree of uncertainty in the future packaging of uranium. RWM has currently assumed that the quantity of uranium per container is at the lower end of the possible range. These packaging assumptions are not optimised and may be revised in a future inventory.

5 Inventory for disposal: summary

The impact of the enhancements on the legacy wastes contained in the UK RWI is presented in Appendix D and a summary of the enhanced inventory is presented in this section.

The inventory can be broken down into six broad waste categories: LLW, ILW, HLW, uranium, plutonium and SFs. Total volumes are presented for the different waste categories in their stored, conditioned and packaged forms in Table 6. Also presented are the activities at 2040 and 2200 (ie the assumed dates for the start of GDF operations and closure).

It is clear that the volume of the waste is dominated by the ILW and uranium, and that the proportion of the volume that is attributable to SFs and HLW increases significantly once packaging is taken into account. The relative proportions of packaged volume attributable to each waste category are shown in Figure 4, which illustrates the significant contribution of the ILW to the overall volume.

Table 6 The stored, conditioned and packaged volumes in each waste category. Also shown is the activity at 2040 and 2200

Waste category	Stored volume (m^3)	Conditioned volume (m^3)	Packaged volume (m^3)	Activity (TBq)	
				2040	2200
HLW	1,410	1,410	9,290	35,200,000	1,090,000
ILW	267,000	353,000	456,000	1,930,000	1,170,000
LLW	9,330	11,100	11,800	0.908	2.48
Pu	0.567	174	620	62,000	43,700
SFs	9,850	9,850	66,100	194,000,000	25,000,000
U	111,000	161,000	222,000	8,430	8,430
Total	399,000	536,000	764,000	231,000,000	27,300,000

At 2040, the activity of the wastes is dominated by that of the SFs and HLW, with the total activity standing at 231,000,000 TBq. However, by 2200 the activity has fallen by nearly an order of magnitude, despite the fact that more SFs and wastes have arisen in this period. The reason for this significant drop in activity in a short space of time is that the shorter lived radionuclides have decayed. Figure 4 shows the activity at 2200 broken down by waste category. The dominance of the contribution from the SFs is clear. The LLW, plutonium and uranium between them contribute approximately 0.2% of the total activity.

Figure 5 shows the evolution of the activity of the wastes and materials[21]. The total activity increases initially as a result of SFs arising from legacy reactors, and the assumed arisings of MOX and new build SFs. Sharp changes in the activities of the LLW and the ILW can also be seen, and these are a result of final site clearance at reactor sites. In addition, the shorter lived radionuclides, which contribute significantly to the total activity, decay quickly and a large drop in the total activity is observed shortly after the waste has arisen. Unlike

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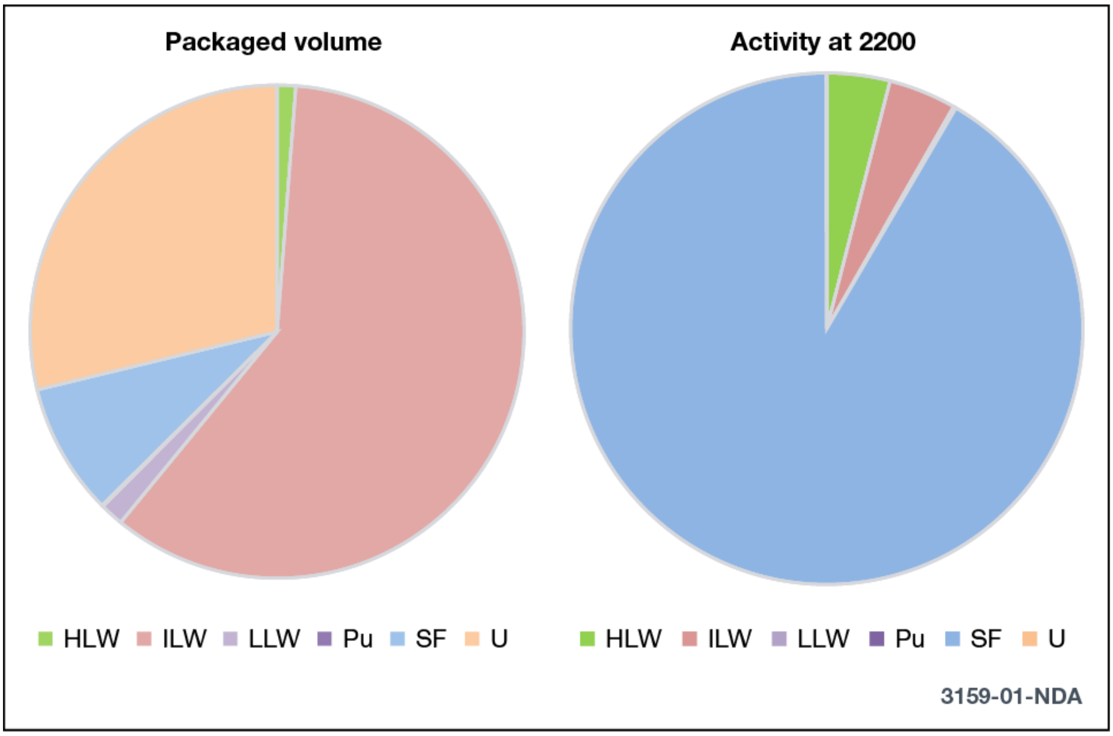
[21] Whilst the data are presented to 10^8 years after GDF operations start, the physical processes of decay and ingrowth are well understood and presenting the data over this timescale illustrates the long-term evolution of the DNLEU.

the other wastes, the activity of the uranium is seen to grow with time due to the ingrowth of daughter radionuclides[22].

The SFs make the most significant contribution to the total activity until around 1,000,000 years. At this point, the uranium becomes the biggest single contributor to the total activity. As a result of the long lived nature of the uranium isotopes (specifically U238 and U235), the total activity of the inventory changes very slowly with time after one million years, when compared to the earlier phases of its evolution.

As discussed in Section 3.1, priority radionuclides and materials were identified and priority scores assigned. Activities for those radionuclides that were assigned a priority of 1 (the highest priority) are reported in Table 7 at 2040 and 2200. A number of radionuclides (those with long half-lives) show an increase in activity between 2040 and 2200; this is because more waste containing these radionuclides has arisen. There are also a number of shorter lived radionuclides that were assigned a priority of 1, for example Co60 (half-life 5.3 years) and Cs137 (half-life 30.2 years). As would be expected, the shorter lived radionuclides show a significant drop in activity between 2040 and 2200.

Figure 4 **The packaged volume and activity broken down by waste category**



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[22] Uranium is refined, and its daughters removed, in the country in which it is mined. As a result, the daughter radionuclides were not present when the uranium arrived in the UK. Because U238 (which is the main constituent of the uranium) has such a long half-life, it takes a long time for the daughter radionuclides to grow back in.

Figure 5 **The activity of the different waste categories as a function of time after GDF operations start in 2040**

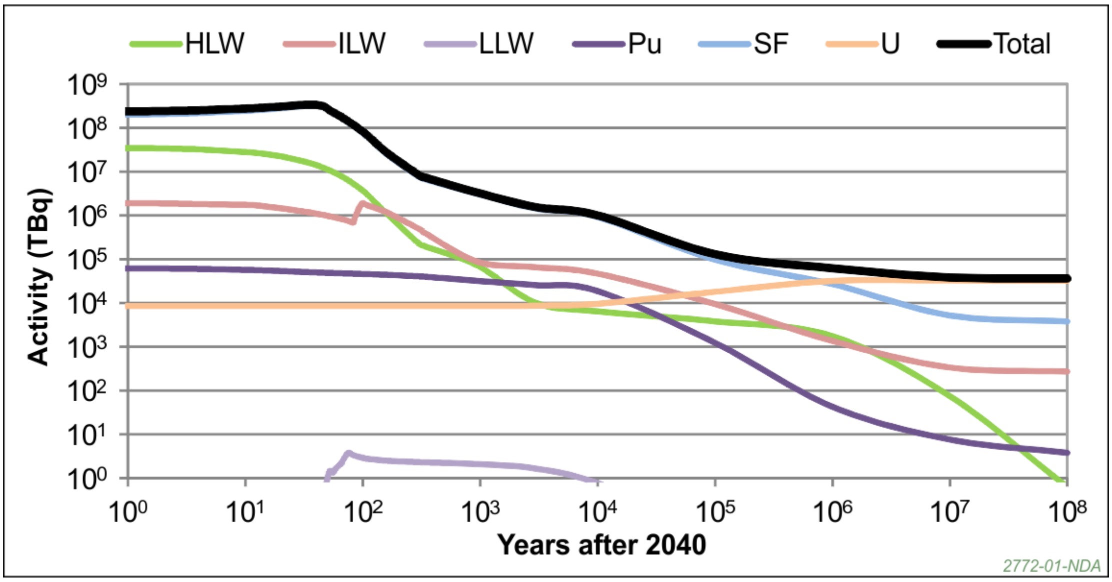

Table 7 **The activity of the priority 1 radionuclides at 2040 and 2200**

Radionuclide	2040 activity (TBq)	2200 activity (TBq)	Radionuclide	2040 activity (TBq)	2200 activity (TBq)
C14	2,080	17,600	Cs135	456	919
Cl36	31.9	114	Cs137	46,500,000	5,040,000
Co60	623,000	2.12	U233	1.6	2.51
Se79	46.2	96.8	U235	48.9	53.8
Kr85	1,700,000	1,250	U238	2,420	2,560
Tc99	8,460	19,100	Np237	282	837
I129	15.5	42.1			

6 Inventory for disposal: waste groups

Previous Derived Inventories have presented the inventory in terms of waste category (eg LLW, ILW, etc). However, for the 2013 Derived Inventory information is presented in waste groups in order to support RWM's design and assessments work. Waste groups have been chosen to reflect the key differences in time of arising, waste packaging and assumed emplacement in the GDF.

RWM's generic disposal facility designs [44] recognise the different packaging and disposal processes for different types of waste with LLW, ILW and DNLEU disposed of in a low-heat generating disposal area; HLW, SFs, plutonium and HEU would be disposed of in a separate high-heat generating disposal area[23]. The disposal of high-heat-generating wastes (HHGW) and low-heat-generating wastes (LHGW) in separate areas of the same facility is referred to as co-location.

Within the two areas, the wastes are further partitioned: in the LHGW area, DNLEU, 500 l RS drums and 3 m^3 RS boxes, shielded wastes (excluding the 500 l RS drums and 3 m^3 RS boxes) and unshielded wastes are disposed of in separate vaults; in the HHGW area, SFs are grouped together, separate from HEU and plutonium. The different characteristics of the SFs influence the way that they are assessed and in order to provide information to RWM's assessments team, the legacy SFs are sub-divided into the different fuel types.

Presenting the inventory in a modular fashion will allow the different components to be identified, and their contribution assessed. For this reason, the waste groups are broken down by source so that, for example, the envisaged contribution of a 16 GW(e) new build programme can be easily identified. Three sources have been chosen:

- **legacy:** this includes wastes and materials that already exist or that will arise in the future as a result of the operation of existing nuclear facilities. Legacy wastes and materials arise (or have arisen) from:
    - the operation of the Sizewell B reactor, the AGRs and Magnox reactors
    - the UK's nuclear research and development programme
    - the enrichment of uranium and manufacture of fuel
    - the reprocessing of spent nuclear fuel
    - defence operations
    - medical and industrial sources (though this is a very small component)
- **new build:** this includes wastes (ILW) and SFs from a proposed new build programme of 16 GW(e)
- **MOX:** at this stage only SF is included; this does not displace fuel from the new build programme and does not have any additional UO_2 fuel associated with it

The result of the above divisions of the inventory is shown in Table 8.

For each of the waste groups, results are presented for the following key areas:

- volumes and package numbers
- activities of key radionuclides
- materials data
- in the case of LHGW gas pathway analysis data

Data for the gas pathway analysis are presented in Appendix E3.

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[23] It is noted that HEU does not generate significant heat; it is included in the high-heat generating area as its disposal concept is very similar to that of the high heat generating wastes.

Table 8 The waste groups used for the presentation of the inventory for disposal in a GDF

	Waste groups	Subdivision
LHGW	Shielded Legacy LLW and ILW	
	Unshielded Legacy LLW and ILW	
	500 l RS drums and 3 m^3 RS boxes	
	DNLEU	
	Shielded new build ILW	
	Unshielded new build ILW	
HHGW	HLW	
	Plutonium	
	HEU	
	Legacy SFs	AGR
		Exotic
		Metallic
		Sizewell B PWR
	New build SFs	
	MOX SF	

6.1 Shielded legacy wastes (ILW and LLW)

6.1.1 Volumes and package numbers

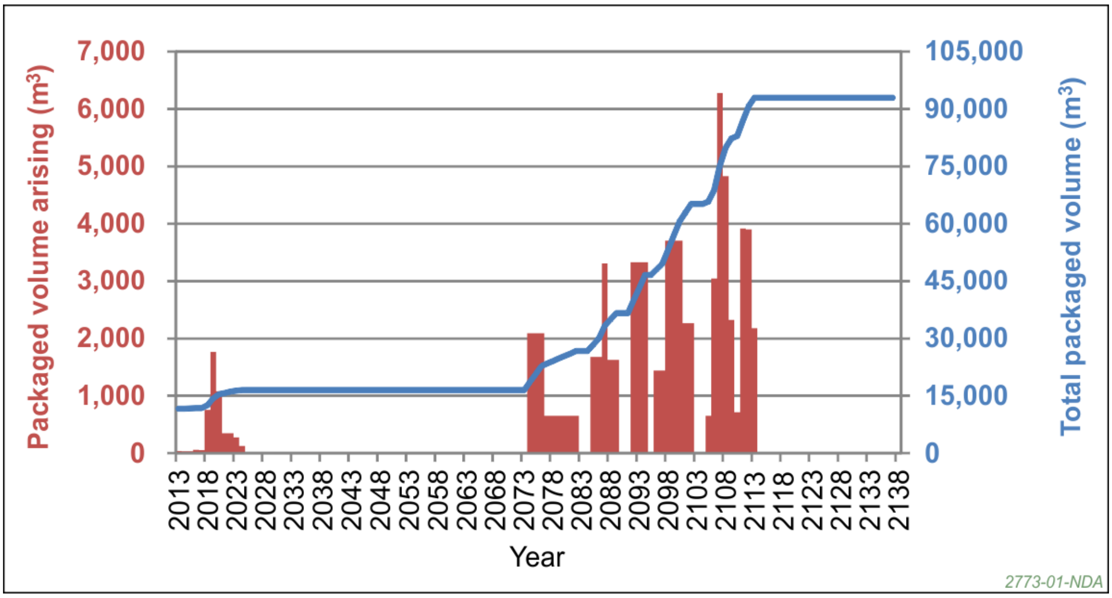
The legacy shielded ILW and LLW (SILW / SLLW) waste group does not include 500 l RS drums or 3 m^3 RS boxes as these are dealt with in a separate waste group. All other SILW / SLLW waste containers are included in this waste group.

By the time all of this waste group has arisen in 2113, the packaged volume is estimated to be 93,000 m^3. The stored, conditioned and packaged volumes associated with each of the SILW / SLLW waste container types is shown in Table 9 along with the number of waste packages. It is noted that some of the waste containers have variable levels of internal shielding and that the 6 m^3 concrete box has standard and high density (SD and HD) variants. Figure 6 shows the arisings and total packaged volume of SILW / SLLW plotted against date. The majority of the SILW arises after 2073, with the step changes in the arisings after that date being a result of individual power stations entering their final site clearance phase.

Table 9 The number of packages and volumes associated with each SILW / SLLW waste container type (data rounded to three significant figures)

Waste container	Number of packages	Volume (m^3)		
		Stored	Conditioned	Packaged
2 m box (100 mm concrete)	75	163	334	758
4 m box (0 mm concrete)	2,760	44,500	52,100	55,300
4 m box (100 mm concrete)	1,190	14,300	17,100	23,900
4 m box (200 mm concrete)	399	2,090	4,350	7,990
6 m^3 concrete box (HD)	96	43.9	544	1,130
6 m^3 concrete box (SD)	330	1,130	1,900	3,910
Total	4,850	62,200	76,300	93,000

Figure 6 The arising and total packaged volume profiles for SILW / SLLW



6.1.2 Activities

The total activity of the SILW / SLLW at 2040 is estimated to be 36,800 TBq and despite the fact that the majority of the waste (by volume) arises after this, the activity at 2200 has fallen to 15,900 TBq. The activity associated with the priority 1 radionuclides is shown in Table 10. As might be expected, the activity associated with shorter lived radionuclides (eg Co60) has fallen between 2040 and 2200. The activity associated with the longer lived radionuclides, such as C14 and Cl36 has increased as more waste containing these radionuclides has arisen.

Table 10 The activity of the priority 1 radionuclides in SILW / SLLW at 2040 and 2200 (data rounded to three significant figures)

Radionuclide	2040 activity (TBq)	2200 activity (TBq)	Radionuclide	2040 activity (TBq)	2200 activity (TBq)
C14	70.8	6,400	Cs135	$4.81\ 10^{-2}$	$4.81\ 10^{-2}$
Cl36	0.260	26.0	Cs137	148	3.75
Co60	3,140	$7.69\ 10^{-6}$	U233	$5.96\ 10^{-2}$	$5.96\ 10^{-2}$
Se79	$3.30\ 10^{-4}$	$3.30\ 10^{-4}$	U235	$1.91\ 10^{-4}$	$1.91\ 10^{-4}$
Kr85	0.779	$2.53\ 10^{-5}$	U238	$2.99\ 10^{-3}$	$2.99\ 10^{-3}$
Tc99	$9.89\ 10^{-2}$	0.301	Np237	$2.84\ 10^{-2}$	$2.87\ 10^{-2}$
I129	$2.06\ 10^{-5}$	$2.06\ 10^{-5}$			

6.1.3 Materials data

Three sets of data are presented for the legacy SILW / SLLW bulk materials:

- data for bulk materials in the waste are presented in Table E1
- data for bulk materials in the capping and conditioning materials are presented in Table E2
- data for bulk materials in the waste containers are presented in Table E3

Based on the data in Table D2, it would be expected that the SILW / SLLW metal mass in the bulk materials is dominated by stainless steel and other ferrous metals, and this is seen to be the case. The inorganic bulk materials are dominated by core graphite from the decommissioning of the AGR and Magnox reactors.

As would be expected, the conditioning materials are dominated by the components of a cementitious conditioning matrix, while the capping materials are dominated by the iron-shot concrete that is used in 2 m and 4 m boxes. The container materials are dominated by stainless steel and concrete.

Elemental composition data for the wastes, capping, conditioning and packaging materials in the legacy SILW / SLLW waste group are presented in Table E6.

6.2 Unshielded legacy wastes (ILW and LLW)

6.2.1 Volumes and package numbers

On the 1st April 2013, the packaged volume of legacy UILW and ULLW was 117,000 m^3; by the time all of this waste group has arisen in 2119, the packaged volume is estimated to be 327,000 m^3. The stored, conditioned and packaged volumes associated with each of the UILW / ULLW waste container types is shown in Table 11 along with the number of waste packages. Figure 7 shows the arisings and total packaged volume of UILW / ULLW plotted against date.

It can be seen that the UILW / ULLW arises continuously; this is because the waste arising as a result of decommissioning at Sellafield is expected to continue throughout the period during which the Magnox and AGR stations are in their Care & Maintenance phase. Legacy UILW / ULLW ceases to arise after 2118, when the decommissioning of all of the legacy facilities is forecast to be complete. Large spikes, for example, at 2045 are associated with specific events (in this case a large volume of Magnox pond furniture arising). The broader peak from 2108 to 2111 is associated (predominantly) with the graphite at Calder Hall.

Table 11 The number of packages and volumes associated with each UILW / ULLW waste container type (data rounded to three significant figures)

Waste container	Number of packages	Volume (m^3)		
		Stored	Conditioned	Packaged
3 m^3 box (side lifting)	4,770	13,600	12,700	15,600
3 m^3 box (corner lifting)	403	146	1,120	1,450
3 m^3 drum	563	825	1,260	1,470
3 m^3 Sellafield box[24]	54,300	50,000	147,000	179,000
3 m^3 Enhanced Sellafield box[24]	16,300	19,100	35,100	53,900
MBGWS box	1,510	5,150	5,270	7,070
500 l drum	91,800	46,900	42,800	52,400
Enhanced 500 l drum (with basket)[25]	26,100	66,900	13,200	14,900
Enhanced 500 l drum (pre-cast)[25]	893	319	363	510
Total	197,000	203,000	259,000	327,000

6.2.2 Activities

The total activity of the legacy UILW / ULLW at 2040 is estimated to be 1,890,000 TBq and despite the fact that the majority of the waste (by volume) arises after this, the activity at 2200 has fallen to 355,000 TBq. The activity associated with the priority 1 radionuclides is shown in Table 12. As might be expected, the activity associated with shorter lived radionuclides (eg Co60) has fallen. The activity associated with the longer lived

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[24] The 3 m^3 Sellafield box and the 3 m^3 Sellafield Enhanced box are instances of the 3 m^3 box (corner lifting).

[25] The Enhanced 500 l drum (with basket) and the Enhanced 500 l drum (pre-cast) are instances of the 500 l drum.

radionuclides, such as C14 and Cl36 has increased as more waste containing these radionuclides has arisen.

Figure 7 **The arising and total packaged volume profiles for UILW / ULLW**

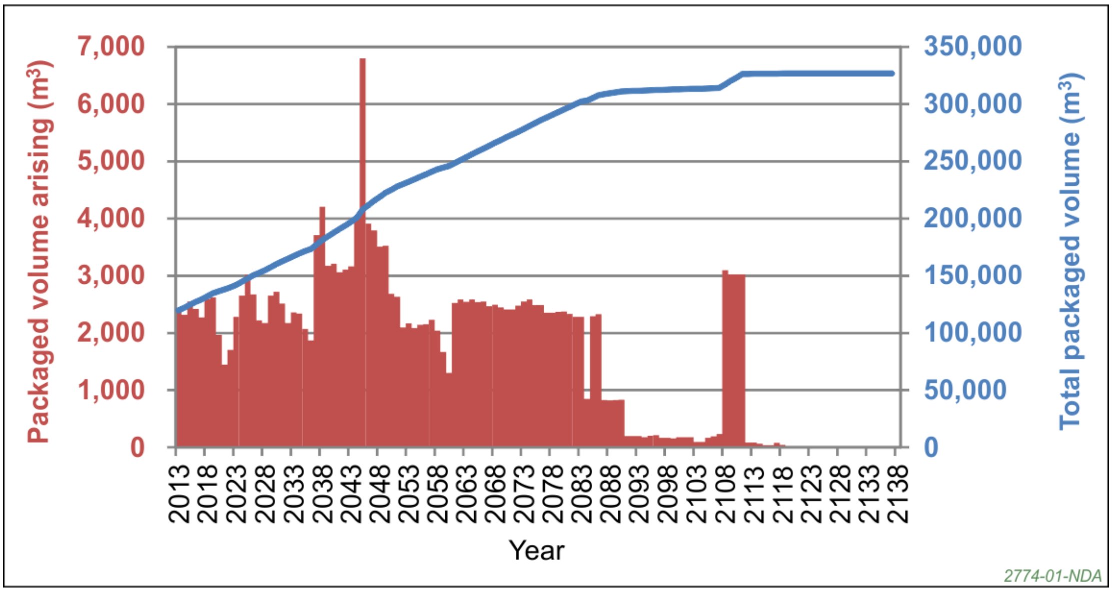


Table 12 **The activity of the priority 1 radionuclides in UILW / ULLW at 2040 and 2200 (data rounded to three significant figures)**

Radionuclide	2040 activity (TBq)	2200 activity (TBq)	Radionuclide	2040 activity (TBq)	2200 activity (TBq)
C14	672	1,350	Cs135	7.60	7.64
Cl36	8.04	9.44	Cs137	315,000	8,120
Co60	43,600	$2.69\ 10^{-3}$	U233	1.04	1.14
Se79	0.384	0.387	U235	0.567	0.591
Kr85	778	$2.53\ 10^{-2}$	U238	18.1	18.6
Tc99	916	917	Np237	108	110
I129	0.620	0.621			

6.2.3 Materials data

Three sets of data are presented for the legacy UILW / ULLW bulk materials:

- data for bulk materials in the waste are presented in Table E1
- data for bulk materials in the capping and conditioning materials are presented in Table E2
- data for bulk materials in the waste containers are presented in Table E3

The UILW / ULLW metal mass in the bulk materials is dominated by stainless steel and other ferrous metals. The inorganic bulk materials are dominated by cement / concrete / sand (the main contribution is from the conditioning grout of those streams that are already conditioned, though decommissioning of plant also makes a significant contribution), sludge / floc and core graphite from the decommissioning of the AGR and Magnox reactors.

As would be expected, the conditioning and capping materials are dominated by the components of a cementitious conditioning and capping material. The container materials are dominated by stainless steel and concrete.

Elemental composition data for the wastes, capping, conditioning and packaging materials in the legacy UILW / ULLW waste group are presented in Table E7.

6.3 Unshielded new build ILW

6.3.1 Volumes and package numbers

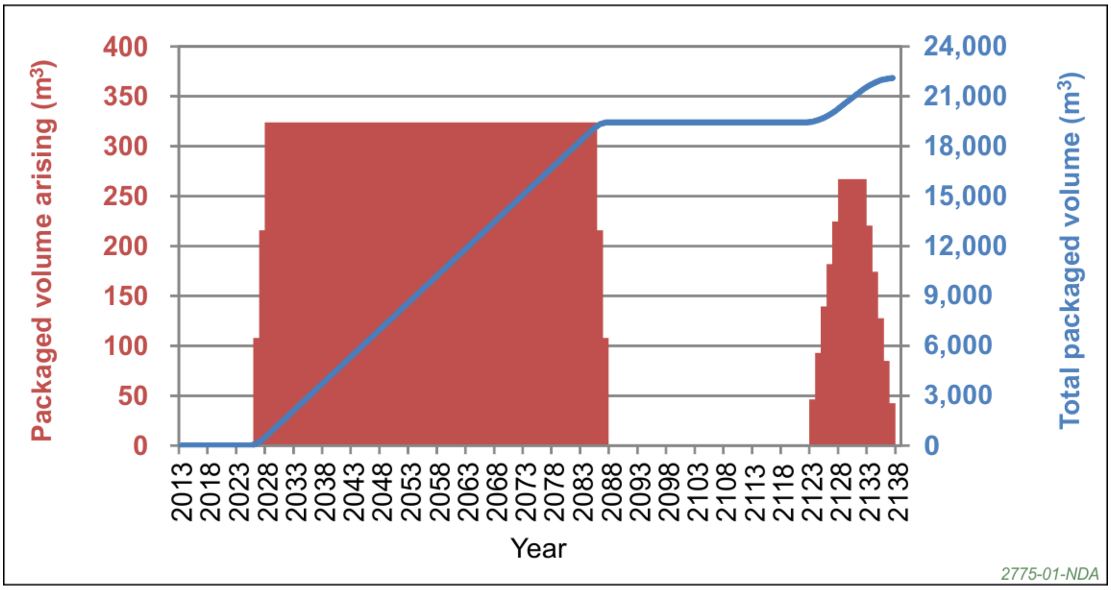
By the time the assumed 16 GW(e) new build programme has been operated and decommissioned, it is estimated that it will have produced 22,100 m^3 of UILW. Appendix A5.1 contains details of the assumptions that have been made in arriving at this estimate. The stored, conditioned and packaged volumes associated with each of the waste container types are shown in Table 13 along with the number of waste packages.

Figure 8 shows the arisings and total packaged volume of new build UILW 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 3).

Table 13 The number of packages and volumes associated with each new build UILW waste container type (data rounded to three significant figures)

Waste container	Number of packages	Volume (m^3)		
		Stored	Conditioned	Packaged
3 m^3 box (side lifting)	960	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 8 The arising and total packaged volume profiles for new build UILW



6.3.2 Activities

The total activity of the new build UILW at 2040 is estimated to be 875 TBq at 2040. 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 793,000 TBq. The activity associated with the priority 1 radionuclides is shown in Table 14. As might be expected, the activity associated with short-lived radionuclides (eg Co60) has fallen. The activity associated with the longer lived radionuclides, such as C14 and Cl36, has increased as more waste containing these radionuclides has arisen.

Table 14 The activity of the priority 1 radionuclides in new build UILW at 2040 and 2200 (data rounded to three significant figures)

Radionuclide	2040 activity (TBq)	2200 activity (TBq)	Radionuclide	2040 activity (TBq)	2200 activity (TBq)
C14	0.697	$6.67\ 10^{3}$	Cs135	$1.92\ 10^{-3}$	$1.58\ 10^{-2}$
Cl36	$2.16\ 10^{-3}$	0.618	Cs137	308	101
Co60	32.9	1.98	U233	$5.86\ 10^{-7}$	0.114
Se79	$1.61\ 10^{-4}$	0.428	U235	$1.39\ 10^{-6}$	$1.07\ 10^{-5}$
Kr85	0	0.261	U238	$3.72\ 10^{-5}$	$1.73\ 10^{-4}$
Tc99	0.123	32.1	Np237	$6.83\ 10^{-5}$	$6.55\ 10^{-4}$
I129	$3.57\ 10^{-2}$	0.165			

6.3.3 Materials data

Three sets of data are presented for the new build UILW bulk materials:

- data for bulk materials in the waste are presented in Table E1
- data for bulk materials in the capping and conditioning materials are presented in Table E2
- data for bulk materials in the waste containers are presented in Table E3

The bulk materials in the new build UILW are dominated by the organic ion exchange resins and the ion exchange materials. The conditioning and capping materials are dominated by the components of a cementitious capping / conditioning matrix and the container material is stainless steel.

Elemental composition data for the wastes, capping, conditioning and packaging materials in the new build UILW waste group are presented in Table E8.

6.4 Shielded new build ILW

6.4.1 Volumes and package numbers

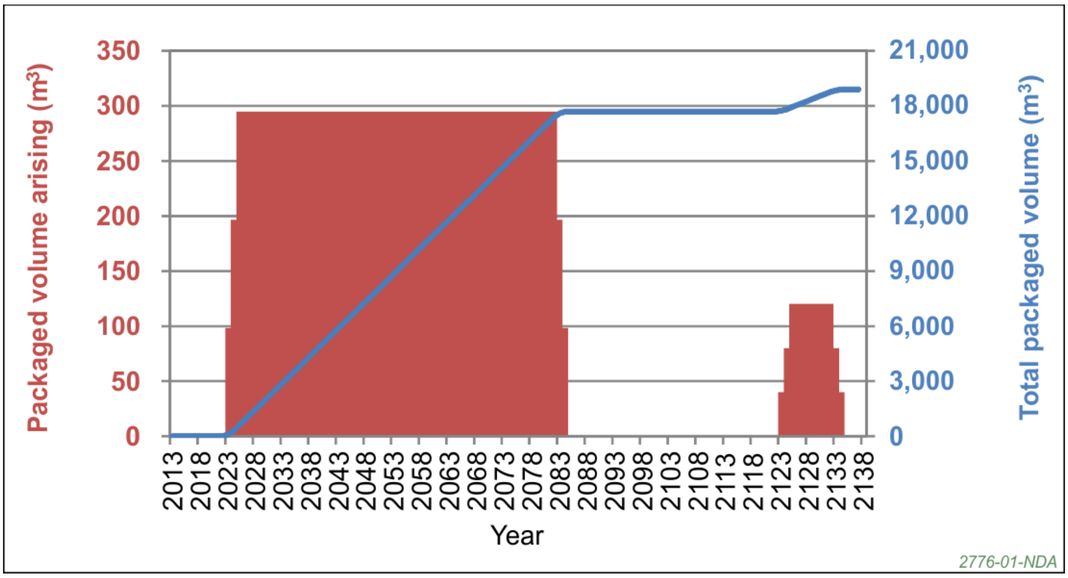
By the time the assumed 16 GW(e) new build programme has been operated and decommissioned, it is estimated that it will have produced 18,900 m^3 of SILW. The stored, conditioned and packaged volumes associated with each of the waste container types are shown in Table 15 along with the number of waste packages.

Figure 9 shows the arisings and total packaged volume of SILW 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 3).

Table 15 The number of packages and volumes associated with each new build SILW waste container type (data rounded to three significant figures)

Waste container	Number of packages	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

Figure 9 The arising and total packaged volume profiles for new build SILW



6.4.2 Activities

The total activity of the new build SILW at 2040 is estimated to be 197 TBq at 2040. 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 would be 154 TBq. The activity associated with the priority 1 radionuclides is shown in Table 16. As might be expected, the activity associated with shorter lived radionuclides (eg Co60) has fallen. The activity associated with the longer lived radionuclides, such as C14 and Cl36 can be seen to increase as more waste containing these radionuclides arises.

Table 16 The activity of the priority 1 radionuclides in new build SILW at 2040 and 2200 (data rounded to three significant figures)

Radionuclide	2040 activity (TBq)	2200 activity (TBq)	Radionuclide	2040 activity (TBq)	2200 activity (TBq)
C14	1.42	5.44	Cs135	$1.08\ 10^{-4}$	$4.06\ 10^{-4}$
Cl36	$3.59\ 10^{-4}$	$1.53\ 10^{-3}$	Cs137	19.3	3.28
Co60	46.4	$3.68\ 10^{-4}$	U233	$1.59\ 10^{-9}$	$1.81\ 10^{-5}$
Se79	$4.06\ 10^{-4}$	$1.65\ 10^{-3}$	U235	$4.22\ 10^{-7}$	$1.59\ 10^{-6}$
Kr85	-	$7.91\ 10^{-5}$	U238	$1.04\ 10^{-5}$	$3.91\ 10^{-5}$
Tc99	$1.73\ 10^{-3}$	$1.57\ 10^{-2}$	Np237	$2.40\ 10^{-5}$	$1.16\ 10^{-4}$
I129	$2.31\ 10^{-5}$	$8.67\ 10^{-5}$			

6.4.3 Materials data

Three sets of data are presented for the new build SILW bulk materials:

- data for bulk materials in the waste are presented in Table E1
- data for bulk materials in the capping and conditioning materials are presented in Table E2
- data for bulk materials in the waste containers are presented in Table E3

The bulk materials in the new build SILW are dominated by the organic ion exchange resins, stainless steel and sludge / flocs. The conditioning and capping materials are dominated by the components of a cementitious capping / conditioning materials and the container materials are steels and concrete.

Elemental composition data for the wastes, capping, conditioning and packaging materials in the new build SILW waste group are presented in Table E9.

6.5 DNLEU

The DNLEU in the inventory arises from a number of different sources; Table 17 shows the DNLEU waste streams and the quantity (in tU) of uranium associated with each. The packaging assumptions for the DNLEU are presented in Section 4.4 and the package types associated with the DNLEU categories are presented in Table 17.

Table 17 Breakdown of the DNLEU by source

DNLEU category	Quantity (tU)	Waste container
Magnox depleted uranium (MDU)	23,100	TDC (2.4 m high)
Magnox depleted uranium (MDU)	14,900	TDC (2.1 m high)
THORP product uranium (TPU)	5,000	500 l drum (DNLEU)
DU tails (unirradiated)	108,500	TDC (2.3 m high)
DU tails (irradiated)	15,500	TDC (2.3 m high)
Miscellaneous DNLEU	3,000	500 l drum (DNLEU)
DU from defence enrichment	15,000	500 l drum (DNLEU)

6.5.1 Volumes and package numbers

By the time that all of the DNLEU has arisen, the final packaged volume is estimated to be 217,000 m^3. The majority of the arisings will come from the enrichment activities at Capenhurst and the reprocessing of Magnox and oxide SFs. Since these operations are assumed to finish in 2023, the arisings of DNLEU cease at this point. This can be seen in Figure 10, which shows the arisings and total packaged volume of the DNLEU plotted against the date. Table 18 shows the packaged volumes and numbers of packages associated with the DNLEU.

Figure 10 The arising and total packaged volume profiles for DNLEU

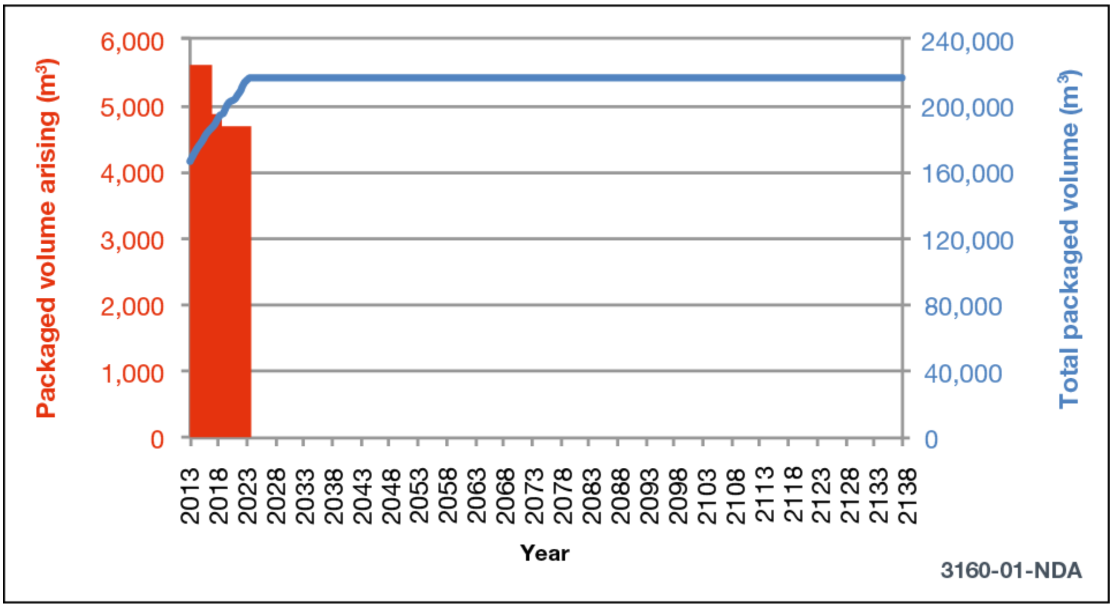


Table 18 The number of packages and volumes associated with each DNLEU waste container type (data rounded to three significant figures)

Waste container	Number of packages	Volume (m^3)		
		Stored	Conditioned	Packaged
500 l drum (DNLEU)	23,800	3,270	11,200	13,600
Uranium TDC (2.1m ht)	581	8,250	10,900	14,800
Uranium TDC (2.3m ht)	3,780	58,400	75,000	105,000
Uranium TDC (2.4m ht)	2,890	41,200	63,300	83,800
Total	31,000	111,000	160,000	217,000

6.5.2 Activities

DNLEU has very low quantities of impurities and is predominantly composed of U238. The activity of the DNLEU is dominated by that of the U238 and its daughters (Th234, half-life 24.1 days and Pa234m, half-life 1.17 minutes). Since the half-life of U238 is very long, the total activity associated with the DNLEU does not change significantly between 2040 and 2200. Instead, it remains relatively constant at 8,370 TBq. The activities of the priority 1 radionuclides in the DNLEU are shown at 2040 and 2200 in Table 19. Unlike other waste groups, the activity associated with the DNLEU increases with time as a result of the ingrowth of daughters. Figure 5 illustrates this feature.

Table 19 The activity of the priority 1 radionuclides in DNLEU at 2040 and 2200 (data rounded to three significant figures)

Radionuclide	2040 activity (TBq)	2200 activity (TBq)	Radionuclide	2040 activity (TBq)	2200 activity (TBq)
C14	$6.79\ 10^{-10}$	$6.66\ 10^{-10}$	Cs135	$2.41\ 10^{-8}$	$2.41\ 10^{-8}$
Cl36	0	0	Cs137	$1.98\ 10^{-3}$	$5.02\ 10^{-5}$
Co60	$1.62\ 10^{-20}$	$1.19\ 10^{-29}$	U233	$1.60\ 10^{-3}$	$1.61\ 10^{-3}$
Se79	$1.78\ 10^{-9}$	$1.78\ 10^{-9}$	U235	41.8	41.8
Kr85	0	0	U238	2,290	2,290
Tc99	0.645	0.645	Np237	$1.66\ 10^{-2}$	$1.66\ 10^{-2}$
I129	$1.60\ 10^{-9}$	$1.60\ 10^{-9}$			

6.5.3 Materials data

Three sets of data are presented for the DNLEU bulk materials:

- data for bulk materials in the waste are presented in Table E1
- data for bulk materials in the capping and conditioning materials are presented in Table E2
- data for bulk materials in the waste containers are presented in Table E3

The bulk material for DNLEU is heavy metal oxide. The conditioning and capping materials are cementitious, and the container material is stainless steel.

Elemental composition data for the wastes, capping, conditioning and packaging materials in the DNLEU waste group are presented in Table E10.

6.6 Robust shielded ILW containers

6.6.1 Volumes and package numbers

The 500 l RS drum and the 3 m^3 RS box are both robust shielded ILW containers (abbreviated to RSCs); they are considered together here as the RSC waste group since this is how they will be managed in RWM's design and assessments work. 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 Derived Inventory. The numbers of each type of RSC are shown in Table 20, which also includes the volume associated with the waste and the waste packages.

When all of the waste has been loaded into the RSCs, its total packaged volume is estimated to be 7,280 m^3. Figure 11 shows the arisings of the RSC waste streams. With the exception of a single Sizewell B waste stream (3S12), all RSC streams are associated with Magnox reactor wastes. All Magnox stations are assumed to be in Care and Maintenance by 2028, and the reason the RSC arisings continue past this point is that there is still waste arising in stream 3S12.

Table 20 The number of packages and volumes associated with each RSC waste container type (data rounded to three significant figures)

Waste package	Number of packages	Volume (m^3)		
		Stored	Conditioned	Packaged
3 m^3 RS box	1,040	2,360	2,920	5,650
500 l RS drum (0 mm Pb)	683	309	335	901
500 l RS drum (20 mm Pb)	370	128	149	488
500 l RS drum (30 mm Pb)	146	40.2	54.3	193
500 l RS drum (60 mm Pb)	2	0.40	0.444	2.02
500 l RS drum (80 mm Pb)	1	6 10^{-2}	6.68 10^{-2}	0.362
500 l RS drum (90 mm Pb)	6	1.03	1.14	6.8
500 l RS drum (120 mm Pb)	28	4.09	4.56	36.2
Total	2,280	2,840	3,460	7,280

6.6.2 Activities

The total activity in the RSC waste group is estimated to be 5,350 TBq at 2040 and this has decayed to 1,180 TBq by 2200. As there are no RSC arisings between 2040 and 2200, the change is solely a result of decay (and ingrowth). Table 21 shows the activity of the priority 1 radionuclides that are associated with the RSCs at 2040 and 2200.

Figure 11 The arising and total packaged volume profiles for the RSCs

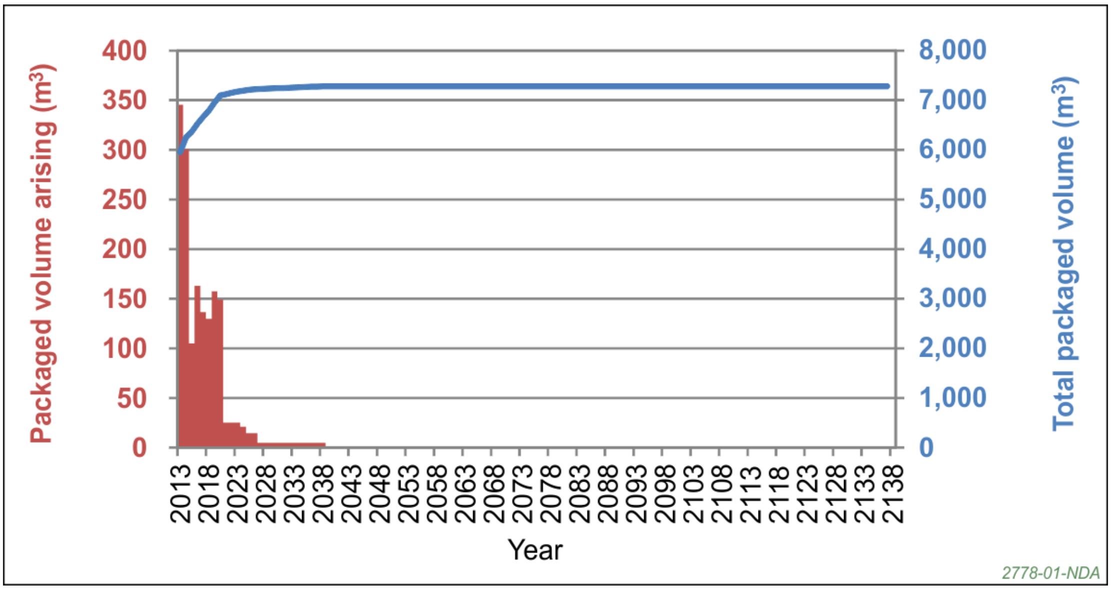


Table 21 The activity of the priority 1 radionuclides in RSCs at 2040 and 2200 (data rounded to three significant figures)

Radionuclide	2040 activity (TBq)	2200 activity (TBq)	Radionuclide	2040 activity (TBq)	2200 activity (TBq)
C14	7.58	7.43	Cs135	7.73 10^{-3}	7.73 10^{-3}
Cl36	0.446	0.446	Cs137	832	21.1
Co60	23.9	1.74 10^{-8}	U233	1.70 10^{-4}	1.80 10^{-4}
Se79	1.39 10^{-4}	1.39 10^{-4}	U235	5.19 10^{-4}	5.20 10^{-4}
Kr85	0.204	6.6 10^{-6}	U238	3.93 10^{-2}	3.93 10^{-2}
Tc99	7.82 10^{-2}	7.82 10^{-2}	Np237	1.42 10^{-2}	1.48 10^{-2}
I129	4.57 10^{-4}	4.57 10^{-4}			

6.6.3 Materials data

Three sets of data are presented for the RSC bulk materials:

- data for bulk materials in the waste are presented in Table E1
- data for bulk materials in the capping and conditioning materials are presented in Table E2
- data for bulk materials in the waste containers are presented in Table E3

The metals in the RSC waste are dominated by stainless steel and other ferrous metals. The organic components are predominantly organic ion exchange resins and the other materials are dominated by graphite, rubble and sludge / flocs. There is no conditioning or capping for RSCs and, as expected, the container materials are cast iron and lead (from the shielding inserts).

Elemental composition data for the wastes, capping, conditioning and packaging materials in the RSC waste group are presented in Table E11.

6.7 HLW

6.7.1 Volumes and package numbers

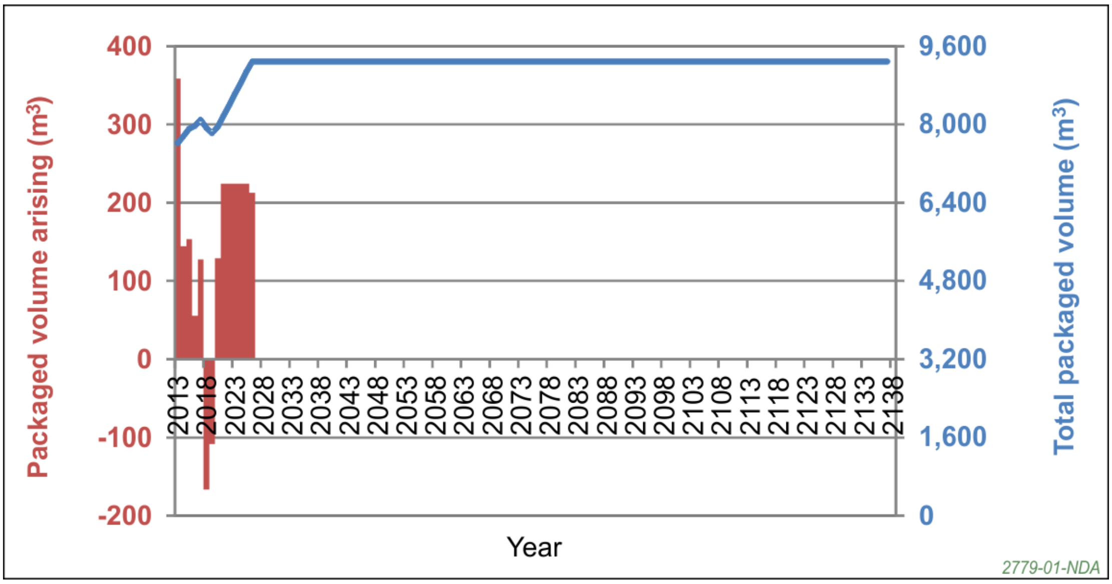
Once all of the HLW has arisen, it is estimated that the packaged volume will be 9,290 m^3. The arisings come from the reprocessing of Magnox and oxide SFs at Sellafield and the post operational clean out of the vitrification plant facilities. These operations are anticipated to finish in 2026 and the arisings of HLW will cease at this point. This can be seen in Figure 12, which shows the arisings and total packaged volume of the HLW plotted against the date. Table 22 shows the 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 SFs. 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. The return of HLW to overseas reprocessing customers is clearly visible in Figure 12, which shows negative arisings to account for the exports.

Table 22 The number of packages and volumes associated with the HLW (data rounded to three significant figures)

Waste container	Number of packages	Volume (m^3)		
		Stored	Conditioned	Packaged
HLW Disposal Container	2,400	1,410	1,410	9,290

Figure 12 The arising and total packaged volume profiles for HLW



6.7.2 Activities

At 2040, the activity of the HLW is estimated to be 35,200,000 TBq and this has decayed to 1,090,000 TBq by 2200. Since all of the waste has arisen by 2040, any increases in activity of specific radionuclides (for example Np237, which is a daughter of Am241) will be a result of ingrowth. The activities of the priority 1 radionuclides in HLW are shown at 2040 and 2200 in Table 23.

Table 23 The activity of the priority 1 radionuclides in HLW at 2040 and 2200 (data rounded to three significant figures)

Radionuclide	2040 activity (TBq)	2200 activity (TBq)	Radionuclide	2040 activity (TBq)	2200 activity (TBq)
C14	0	0	Cs135	183	183
Cl36	1.29	1.29	Cs137	10,400,000	262,000
Co60	408	$2.98\ 10^{-7}$	U233	$4.97\ 10^{-3}$	$3.14\ 10^{-2}$
Se79	16.7	16.7	U235	$9.43\ 10^{-4}$	$9.81\ 10^{-4}$
Kr85	0	0	U238	$2.61\ 10^{-2}$	$2.61\ 10^{-2}$
Tc99	2,470	2,460	Np237	31.0	44.2
I129	$8.78\ 10^{-2}$	$8.78\ 10^{-2}$			

6.7.3 Materials data

Two sets of data are presented for the HLW bulk materials:

- data for bulk materials in the waste are presented in Table E4
- data for bulk materials in the waste containers are presented in Table E5

The mass of the HLW is dominated by that of the borosilicate glass, which includes the mass of the waste oxide that it encapsulates.

Elemental composition data for the wastes, capping, conditioning and packaging materials in the HLW waste group are presented in Table E12.

6.8 Legacy SFs

There are various types of SF that have arisen (or are arising) from commercial and research reactors in the UK and this leads to SFs with different characteristics. These differences are important to RWM's safety cases and data are therefore presented for each of the individual types of SF. The types of SF considered here are:

- SF arising from the AGR fleet that will not be reprocessed
- SF arising from the Sizewell B PWR
- metallic SFs includes only that fuel which will be recovered from Sellafield legacy ponds (and is assumed to be low burn-up Magnox SF)
- exotic SFs. The NDA manages non-standard fuels, commonly referred to as exotics. Although the quantity is small when compared to other SFs (eg AGR and PWR), exotics present their own particular management challenges as a result of their diverse properties. PFR SF is a major component of this category and is the only type of exotic SF modelled in the 2013 Derived Inventory.

6.8.1 Volumes and package numbers

When all of the legacy SFs have been packaged for disposal, they are estimated to have a packaged volume of 14,800 m^3. The arisings come from the operations of AGR stations, Sizewell B PWR and Wylfa (which is assumed to shut down in 2014). These reactors will all be shut down by 2035 and the arisings of legacy SFs will cease at this point. This can be seen in Figure 13, which shows the arisings and total packaged volume of the SFs plotted against the date. Table 24 shows the packaged volumes and numbers of packages associated with the SFs.

Table 24 The number of packages and volumes associated with each SF container type (data rounded to three significant figures)

Waste container	Number of packages	Volume (m^3)		
		Stored	Conditioned	Packaged
AGR SF disposal container	2,190	1,930	1,930	9,160
Magnox disposal container[26]	836	999	999	3,390
PFR SF disposal container[27]	19	10.9	10.9	48.7
PWR SF disposal container	572	425	425	2,160
Total	3,610	3,370	3,370	14,800

6.8.2 Activities

The activities of the priority 1 radionuclides in legacy SFs and the total activity (including all radionuclides, not just those that are priority 1) at 2040 are presented in Table 25 and equivalent information at 2200 is presented in Table 26. Since all of the waste has arisen by 2040, any increases in activity of specific radionuclides (for example Np237, which is a daughter of Am241) will be a result of ingrowth. The quantity of AGR SF (4,500 tU) is greater than that of the other fuel types (1,050 tU PWR SF; 740 tU metallic SFs; and

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[26] As the metallic SFs are assumed to be Magnox, they are packaged in a Magnox disposal container.

[27] The only component of the exotic SFs that is considered in the 2013 Derived Inventory is PFR SF, hence the use of PFR SF disposal containers.

10 tHM exotic SFs) and it is therefore expected that it has the highest activity associated with it.

Figure 13 The packaged volume arising profile for legacy SFs

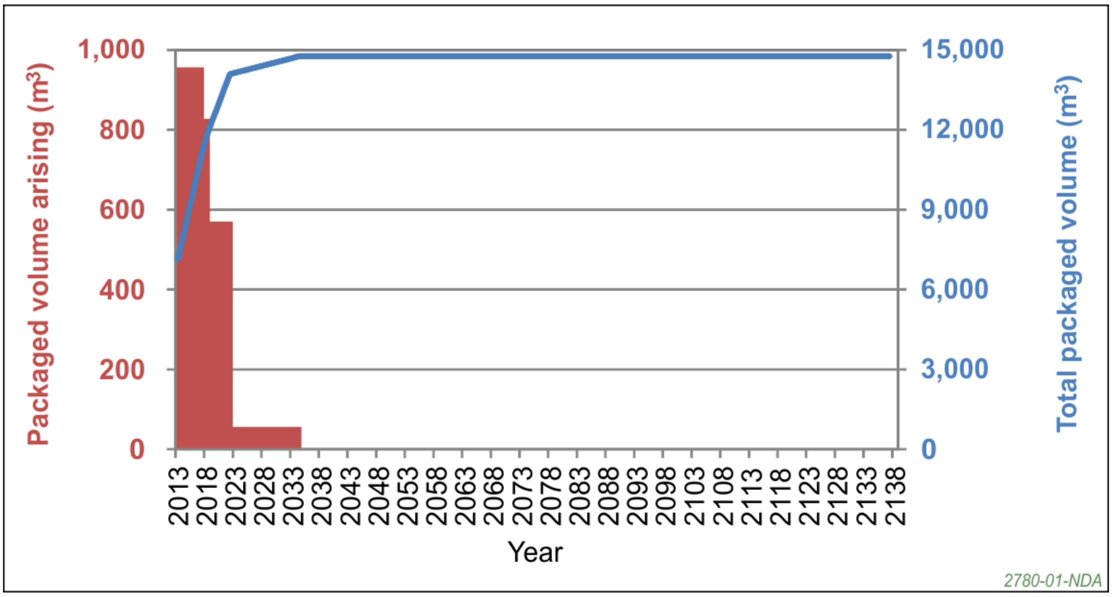


Table 25 The activity of the priority 1 radionuclides in the legacy SFs and the total activity of the legacy SFs at 2040 (data rounded to three significant figures)

Radionuclide	Activity (TBq) at 2040			
	AGR SF	Metallic SF	Exotic SF	PWR SF
C14	523	48.2	6.55	184
Cl36	1.97	2.91 10^{-2}	7.13 10^{-4}	1.09
Co60	48,400	2.25	64.2	132,000
Se79	9.55	0.126	8.12 10^{-2}	3.69
Kr85	285,000	603	690	139,000
Tc99	936	50.2	28.6	763
I129	4.84	0.106	8.13 10^{-2}	1.61
Cs135	95.7	2.29	3.25	28.6
Cs137	8,850,000	82,000	76,100	3,690,000
U233	0.170	0.036	4.87 10^{-3}	0.211
U235	2.45	0.236	1.17 10^{-3}	0.556
U238	53.1	9.10	7.3 10^{-2}	12.0
Np237	26.0	0.491	0.387	21.0
Total	35,800,000	329,000	305,000	15,900,000

Table 26 **The activity of the priority 1 radionuclides in the legacy SFs and the total activity of the legacy SFs at 2200 (data rounded to three significant figures)**

Radionuclide	Activity (TBq) at 2200			
	AGR SF	Metallic SF	Exotic SF	PWR SF
C14	513	47.3	6.42	180
Cl36	1.97	$2.91\ 10^{-2}$	$7.12\ 10^{-4}$	1.09
Co60	$3.53\ 10^{-5}$	$1.65\ 10^{-9}$	$4.69\ 10^{-8}$	$9.61\ 10^{-5}$
Se79	9.55	0.126	$8.12\ 10^{-2}$	3.69
Kr85	9.24	0.0196	$2.24\ 10^{-2}$	4.52
Tc99	936	50.2	28.6	763
I129	4.84	0.106	$8.13\ 10^{-2}$	1.61
Cs135	95.7	2.29	3.25	28.6
Cs137	224,000	2,080	1,930	93,500
U233	0.194	$3.64\ 10^{-2}$	$5.44\ 10^{-3}$	0.229
U235	2.46	0.236	$1.55\ 10^{-3}$	0.559
U238	53.1	9.10	$7.30\ 10^{-2}$	12.0
Np237	42.7	0.927	1.25	31.1
Total	1,580,000	24,600	37,900	609,000

6.8.3 Materials data

Two sets of data are presented for the legacy SFs bulk materials:

- data for bulk materials in the waste are presented in Table E4
- data for bulk materials in the waste containers are presented in Table E5

The mass of the legacy SFs is dominated by that of the heavy metal oxide (and in the case of metallic SFs, uranium) and stainless steel (ie the fuel and the cladding / assembly materials).

Elemental composition data for the wastes, capping, conditioning and packaging materials in the legacy SFs waste group are presented in Table E13.

6.9 New build SFs

As the SFs from the UK EPR and the 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 SFs are, however, considered as separate waste streams.

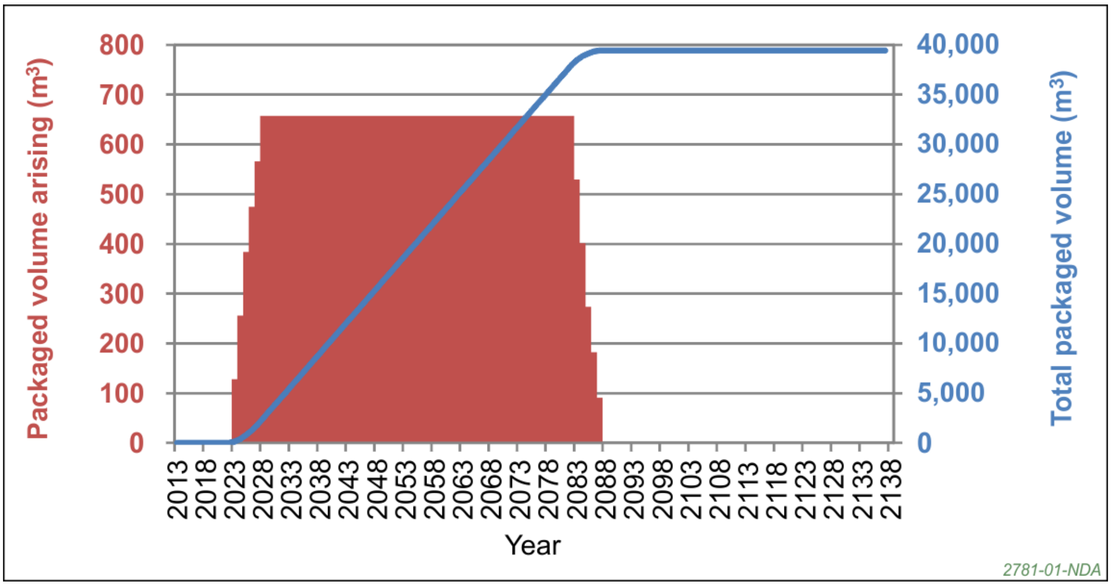
6.9.1 Volumes and package numbers

By the time the assumed 16 GW(e) new build programme has finished operating, it is estimated that the total packaged volume of SFs[28] will be 39,400 m^3. Table 27 shows the packaged volumes and numbers of packages associated with the SFs. It is noted that there is no conditioning for the SFs. Figure 14 shows the arisings and total packaged volume profiles for the new build SFs. The gradual increase and decrease in arisings is associated with the new power stations becoming operational / shutting down (see Table 3 for the assumed timetable) and the different step sizes in the arisings profile are associated with the different reactor types.

Table 27 The number of packages and volumes associated with the new build SFs (data rounded to three significant figures)

Waste container	Number of packages	Volume (m^3)		
		Stored	Conditioned	Packaged
New build SF disposal container	8,940	5,890	5,890	39,400

Figure 14 The packaged volume arising profile for new build SFs



6.9.2 Activities

At 2040, the total activity associated with the new build SFs 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 Co60 and Cs137. Although the activity has fallen significantly in this period, Figure 14 shows that a significant fraction of the waste

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[28] It is noted that this is based on the assumption that the 16 GW(e) will comprise 6 UK EPRs and 6 AP1000s. However, as the new build programme will likely include the UK ABWR, this assumption will need to be revised once inventory information for the UK ABWR is available.

(approximately 75%) arose after 2040. The activities associated with the priority 1 radionuclides are shown in Table 28. As would be expected, the longer lived radionuclides (such as C14) show an increase of approximately a factor of three, consistent with around 25% of the waste having arisen by 2040.

Table 28 **The activity of the priority 1 radionuclides in new build SF at 2040 and 2200 (data rounded to three significant figures)**

Radionuclide	2040 activity (TBq)	2200 activity (TBq)	Radionuclide	2040 activity (TBq)	2200 activity (TBq)
C14	536	2,150	Cs135	126	515
Cl36	18.6	71.7	Cs137	22,100,000	4,130,000
Co60	271,000	0.114	U233	0.0262	0.381
Se79	15.1	61.6	U235	1.55	6.24
Kr85	1,230,000	1,190	U238	39.9	163
Tc99	3,170	12,900	Np237	93.5	517
I129	7.72	31.3			

6.9.3 Materials data

Two sets of data are presented for the new build SFs bulk materials:

- data for bulk materials in the waste are presented in Table E4
- data for bulk materials in the waste containers are presented in Table E5

The mass of the new build SFs is dominated by that of the heavy metal oxide and zircaloy (ie the fuel and the cladding / assembly materials).

Elemental composition data for the wastes, capping, conditioning and packaging materials in the new build SFs waste group are presented in Table E14.

6.10 MOX SF

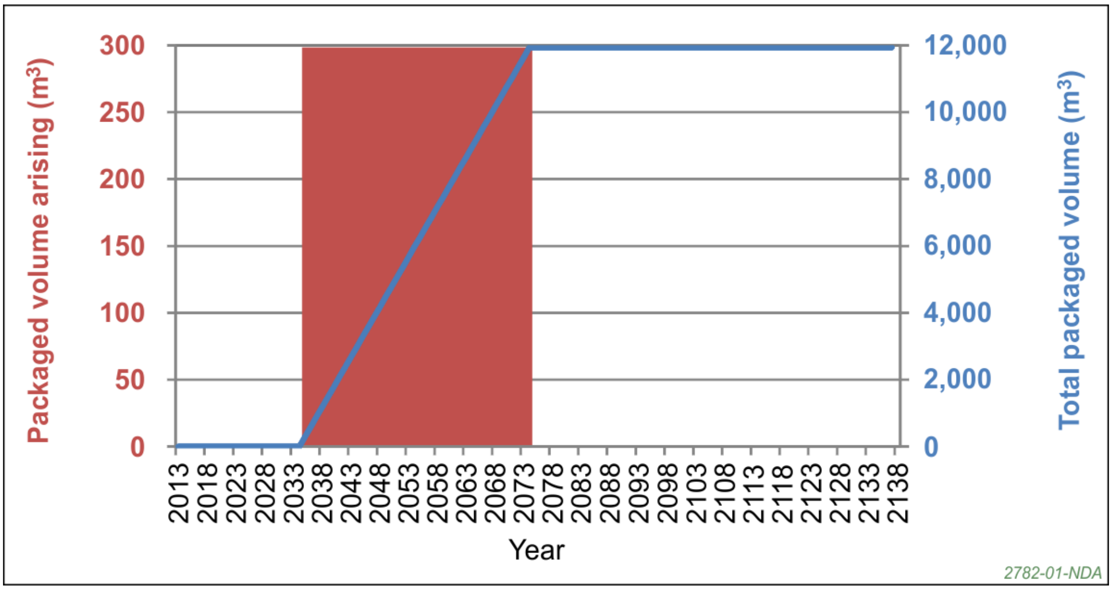
6.10.1 Volumes and package numbers

The assumptions regarding MOX are detailed in Section 2.4. It is assumed that the MOX is irradiated to 50 GWd/tU, and that the unirradiated fuel contains 8% plutonium. Since the quantity of plutonium is known, this allows the number of SF assemblies to be calculated (2,710). The MOX is assumed to be packaged with one SF assembly in a disposal container and this leads to the package numbers and waste volumes given in Table 29. The arisings are assumed to be evenly distributed over a 40 year period, starting in 2035, and this is seen in Figure 15, which also shows the cumulative packaged volume.

Table 29 The number of packages and volumes associated with the MOX SF (data rounded to three significant figures)

Waste container	Number of packages	Volume (m^3)		
		Stored	Conditioned	Packaged
MOX SF disposal container	2,710	594	594	11,900

Figure 15 The packaged volume arising profile for MOX SF



6.10.2 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 at this point. Despite the arisings, the activity by 2200 has fallen to 3,700,000 TBq. The activities of the priority 1 radionuclides are shown in Table 30. The activities of shorter lived radionuclides, such as Co60 and Cs137 have fallen, while the activities of the longer lived radionuclides, such as U238 and C14 have increased by a factor of approximately seven, consistent with the increase in the volume of SF between 2040 and 2200. The activity of Np237 has increased by a very large factor (nearly 100); this is because of its ingrowth (as a daughter of Am241, which is itself a daughter of Pu241).

Table 30 **The activity of the priority 1 radionuclides in MOX SF at 2040 and 2200 (data rounded to three significant figures)**

Radionuclide	2040 activity (TBq)	2200 activity (TBq)	Radionuclide	2040 activity (TBq)	2200 activity (TBq)
C14	29.8	234	Cs135	10.5	83.8
Cl36	0.192	1.54	Cs137	996,000	312,000
Co60	125,000	$1.89\ 10^{-2}$	U233	$3.63\ 10^{-2}$	0.318
Se79	0.535	4.28	U235	$1.68\ 10^{-2}$	0.147
Kr85	39,700	41.4	U238	2.00	16.0
Tc99	130	1,040	Np237	0.929	88.3
I129	0.410	3.28			

6.10.3 Materials data

Two sets of data are presented for the MOX SF bulk materials:

- data for bulk materials in the waste are presented in Table E4
- data for bulk materials in the waste containers are presented in Table E5

The mass of the MOX SF is dominated by that of the heavy metal oxide and Zircaloy (ie the fuel and the cladding / assembly materials).

Elemental composition data for the wastes, capping, conditioning and packaging materials in the MOX SF waste group are presented in Table E15.

6.11 Highly enriched uranium

6.11.1 Volumes and package numbers

The Derived Inventory reports 22.9 tU of HEU, of which, 21.9 tU is from the UK's defence programme. As noted in Section 2.1.2, it is possible that this stockpile has reduced, or will reduce further, as a result of its use in the production of submarine fuel. The number of disposal containers and packaged volumes associated with the HEU in the Derived Inventory are shown in Table 31. It is assumed that there will be no future arisings of HEU and therefore no plot of arisings is presented.

Table 31 The number of packages and volumes associated with the HEU (data rounded to three significant figures)

Waste container	Number of packages	Volume (m^3)		
		Stored	Conditioned	Packaged
HEU / Pu Disposal Container	780	2.37	694	2,470

6.11.2 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 U234, which is a shorter lived isotope of uranium (2.46 10^5 years) than either U235 (7.04 10^8 years) or U238 (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.

6.11.3 Materials data

Two sets of data are presented for the HEU bulk materials:

- data for bulk materials in the waste are presented in Table E4
- data for bulk materials in the waste containers are presented in Table E5

The mass of the HEU is dominated by that of the glass and stainless steel that is used to encapsulate the ceramic pucks.

Elemental composition data for the wastes, capping, conditioning and packaging materials in the HEU waste group are presented in Table E16.

6.12 Plutonium

6.12.1 Volumes and package numbers

The Derived Inventory reports 5.75 t of plutonium residues (that plutonium which is not suitable for the manufacture of MOX fuel to be irradiated in a reactor). The number of disposal containers and packaged volumes associated with the plutonium residues in the Derived Inventory are shown in Table 32. It is assumed that there will be no future arisings of plutonium and therefore no plot of arisings is presented.

Table 32 The number of packages and volumes associated with the plutonium (data rounded to three significant figures)

Waste container	Number of packages	Volume (m^3)		
		Stored	Conditioned	Packaged
HEU / Pu Disposal Container	196	0.567	174	620

6.12.2 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 activities of the priority 1 radionuclides are presented in Table 33. The dominant contribution to the total activity comes from the plutonium isotopes and Am241, which is the daughter of Pu241.

Table 33 The activity of the priority 1 radionuclides in the plutonium at 2040 and 2200 (data rounded to three significant figures)

Radionuclide	2040 activity (TBq)	2200 activity (TBq)	Radionuclide	2040 activity (TBq)	2200 activity (TBq)
C14	$6.24\ 10^{-8}$	$6.12\ 10^{-8}$	Cs135	$3.05\ 10^{-8}$	$3.05\ 10^{-8}$
Cl36	$2.39\ 10^{-10}$	$2.39\ 10^{-10}$	Cs137	$4.99\ 10^{-4}$	$1.26\ 10^{-5}$
Co60	$3.48\ 10^{-10}$	$2.54\ 10^{-19}$	U233	$5.47\ 10^{-5}$	$6.26\ 10^{-4}$
Se79	$1.31\ 10^{-8}$	$1.31\ 10^{-8}$	U235	$8.30\ 10^{-4}$	$2.48\ 10^{-3}$
Kr85	$1.61\ 10^{-6}$	$5.22\ 10^{-11}$	U238	$3.47\ 10^{-6}$	$3.54\ 10^{-6}$
Tc99	$4.51\ 10^{-7}$	$4.51\ 10^{-7}$	Np237	0.377	1.23
I129	$9.51\ 10^{-10}$	$9.51\ 10^{-10}$			

6.12.3 Materials data

Two sets of data are presented for the plutonium bulk materials:

- data for bulk materials in the waste are presented in Table E4
- data for bulk materials in the waste containers are presented in Table E5

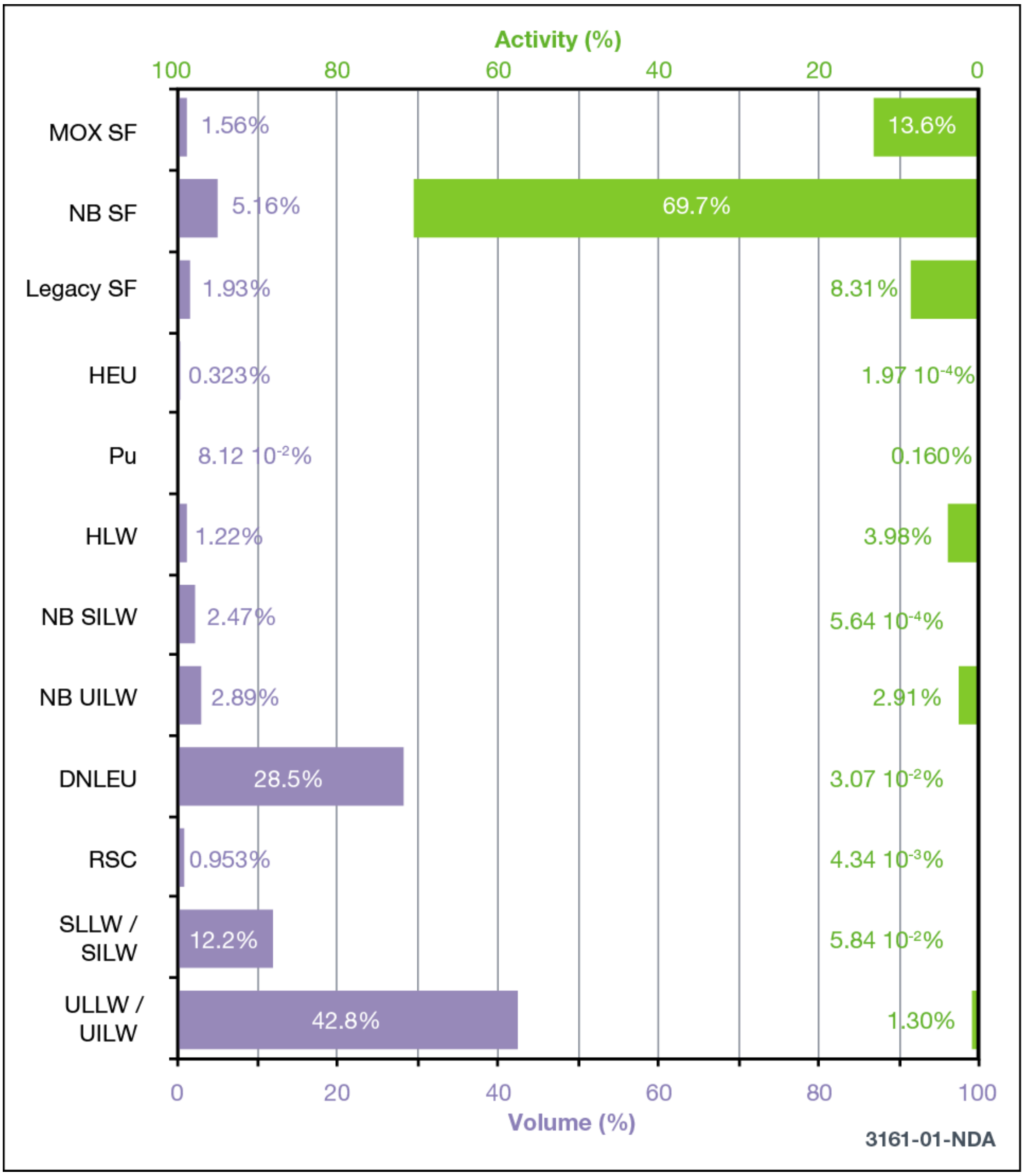
The mass of the plutonium is dominated by that of the glass and stainless steel that is used to encapsulate the ceramic pucks.

Elemental composition data for the wastes, capping, conditioning and packaging materials in the plutonium waste group are presented in Table E17.

6.13 Comparison of waste groups

The contribution that each waste group makes to the total activity (at 2200) and total packaged volume is presented in Figure 16. It is clear that the packaged volume is dominated by the legacy ILW (SILW / SLLW, UILW / ULLW and RSCs) and DNLEU. Unlike the packaged volume, the activity of the wastes is time dependent. It is seen in Figure 16 that at 2200 the activity is dominated by the SFs from the new build programme, with another significant contribution from the MOX SF. Indeed, at 2200, the activity from the new build ILW and SFs contributes 72.6% of the total activity.

Figure 16 A comparison of the fraction of the activity (at 2200) and volume associated with each waste group. New build has been abbreviated as NB



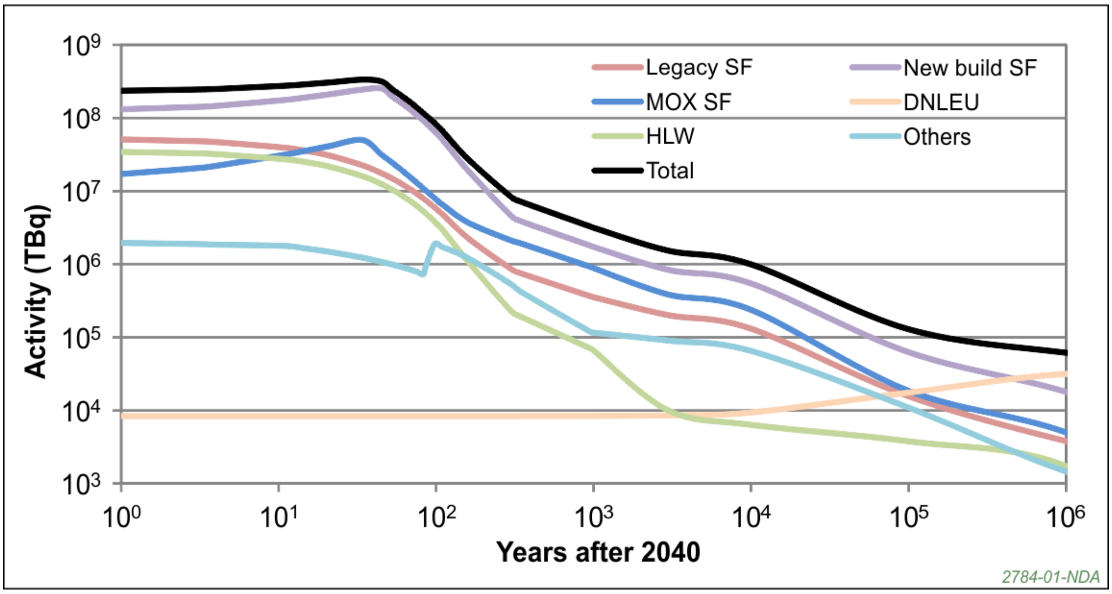
A significant portion of the activity from SFs is from the decay of relatively short-lived radionuclides. In this work, it was assumed that: all of the Magnox reactors are shut down by 2014; the AGR fleet is shut down by 2023 and Sizewell B is shut down in 2035. It is noted that since this work was carried out some reactors have had their lifetimes extended.

By comparison, the SFs from the new build programme continue to arise until 2088. As a result, the SFs from the new build programme have had less time to cool than the legacy SFs and would be expected to be more active at 2200 (as shown in Figure 16). Figure 17 shows that the activity associated with the new build SFs always exceeds that associated with the legacy SFs.

Figure 17 shows the evolution of the activity of the various different waste groups as a function of time (all ILW / LLW waste groups, HEU and plutonium have been grouped together as they only make a minor contribution to the total activity at any point in time). The activity of the MOX and new build SFs are seen to increase initially as the fuel continues to arise after 2040. A spike in the ‘Others’ category is primarily associated with the onset of final site clearance at the various reactor sites.

As was seen in Figure 5, the activity of the SFs dominates initially, but after around one million years, it is the DNLEU that makes the largest contribution to the total activity. The DNLEU and HEU are the only waste groups for which the activity increases with time, and this is a result of the ingrowth of daughter radionuclides.

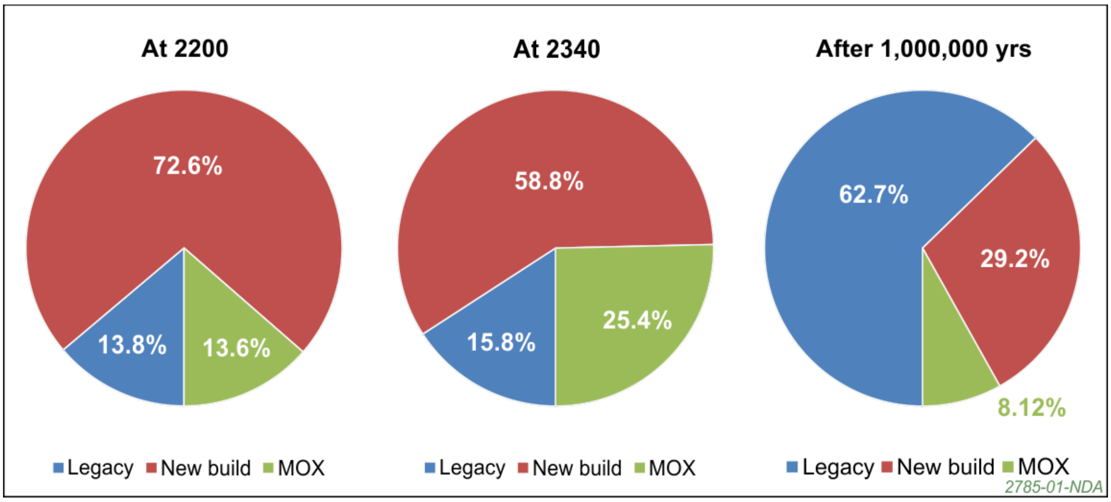
Figure 17 The activity of the different waste groups as a function of time after the GDF is assumed to open (in 2040). HEU, plutonium and all ILW / LLW waste groups have been grouped into ‘Others’



As was discussed in Section 6, there are three sources that the wastes and nuclear materials can be split into: legacy, new build, and MOX. Figure 18 shows the fraction of the total activity that is attributable to each of the three sources at three different times: at 2200, when the GDF is assumed to be closed; at 2340, when the activity associated with the shorter lived radionuclides has reduced; and 1,000,000 years after the GDF is assumed to open, when the activity of the DNLEU begins to dominate.

At 2200, it is the activity of the 16 GW(e) new build programme that dominates and it accounts for nearly three quarters of the total activity, with legacy wastes and MOX each contributing approximately half of the remaining activity. By 2340, the shorter lived radionuclides that dominated the total activity at earlier times have decayed and reduced the proportion of the total activity from the 16 GW(e) new build programme to approximately 60% of the total. After 1,000,000 years, it is the long-lived radionuclides that dominate the total activity and, as can be seen in Figure 17, it is the DNLEU that dominates. The 16 GW(e) new build programme wastes and SFs contribute 29.2% of the total activity at this point, while the contribution of MOX is only 8.11%. The remainder (approximately 60%) is attributable to the legacy wastes and materials.

Figure 18 **The fraction of the activity that is attributable to waste and materials and SFs from new build, MOX and legacy sources at 2200, at 2340 and 1,000,000 years after the GDF opens**



The wastes that will be disposed of in the GDF come from a variety of different industries, and Figure 19 shows a breakdown of the packaged volume of the wastes in the 2013 Derived Inventory by industry. The following industries are included:

- **fuel fabrication and enrichment**, which includes activities carried out at Springfields and Capenhurst
- **commercial reactor operation**, which includes all Magnox and AGR stations, as well as Sizewell B
- **new build commercial reactor operation**, ie the assumed 16 GW(e) new build programme
- **MOX SF**
- **Sellafield**, which includes wastes from reprocessing and other activities at Sellafield[29]
- **nuclear energy research and development**, which includes activities at Harwell, Windscale, Winfrith, Culham and Berkeley Centre
- **defence**, which includes activities at sites throughout the UK supporting the MoD
- **medical and industrial**, which includes the waste from the activities of GE Healthcare Ltd at Amersham and Cardiff, the LLWR and minor waste producers

The contribution of the ‘Medical and Industrial’ industry 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 the fuel cycle activities and reactor operation.

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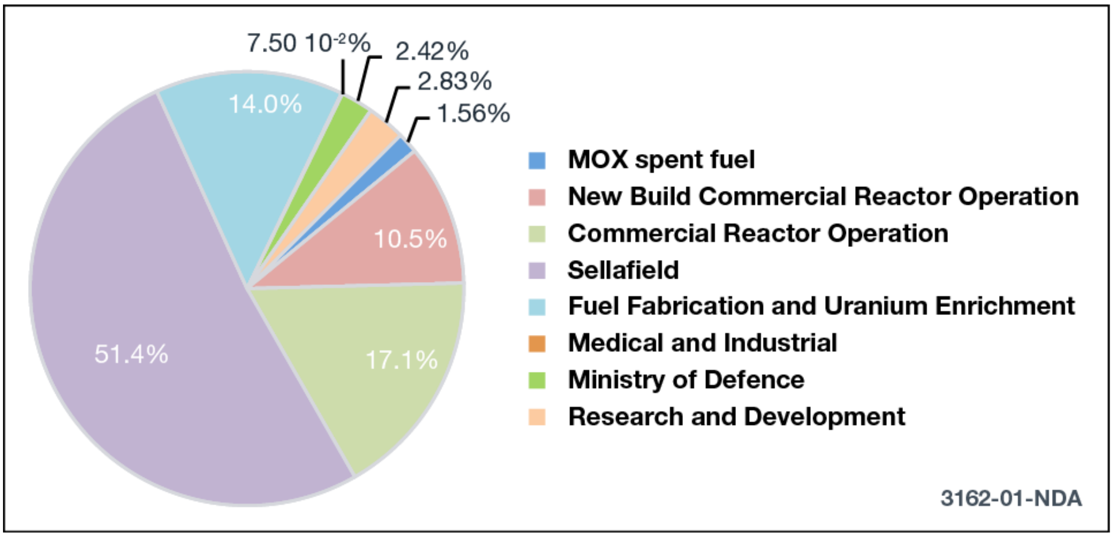
[29] Only wastes from the historically separate licensed sites of Windscale and Calder Hall are excluded; these wastes are included in the ‘nuclear energy research and development’ and ‘commercial reactor operation’ industries, respectively.

Figure 19 A breakdown of the packaged volume of the 2013 Derived Inventory wastes by industry



The numbers of disposal units in each waste group is presented in Table 34. It is noted that four 500 l drums are disposed of together in a stillage and that this is a single disposal unit. A full breakdown of the waste containers and disposal units is provided in Table C4.

Table 34 The number of disposal units, packaged volume and activity in each waste group (data rounded to three significant figures).

Waste group	No. disposal units	Packaged Volume (m^3)	Activity (TBq) at 2200
Legacy SILW / SLLW	4,850	93,000	15,900
Legacy UILW / ULLW	108,000	327,000	355,000
New build UILW	8,230	22,100	793,000
New build SILW	10,100	18,900	154
DNLEU	13,200	217,000	8,370
RSC	2,280	7,280	1,180
HLW	2,400	9,290	1,090,000
Legacy SF (AGR)	2,190	9,160	1,580,000
Legacy SF (PWR)	572	2,160	609,000
Legacy SF (metallic)	836	3,390	24,600
Legacy SF (exotic)	19	48.7	37,900
New build SFs	8,940	39,400	19,000,000
MOX SF	2,710	11,900	3,700,000
HEU	780	2,470	53.8
Pu	196	620	43,700
Total	165,000	764,000	27,300,000

7 Further potential enhancements

The Derived Inventory enhancement process is based on the information needs of RWM users (ie for generic designs and assessments, as described in Section 3). This section describes where enhancements have not been possible. The need for these enhancements in the future will be considered as part of the iterative process of disposal system development when generic designs and assessments are updated to be based on the 2013 Derived Inventory.

7.1 Legacy ILW and LLW

It is only where a robust basis for data enhancement is believed to exist that modified 2013 UK RWI data values have been used in the 2013 Derived Inventory. Where a robust basis was not identified, because of data constraints, no modifications were made. It is the inventory areas for which no enhancements have been made that are discussed here.

7.1.1 Material composition

In general, there are six areas where a robust basis for enhancement could not be established for waste materials.

1. A proportion of the waste stream mass could not be assigned to any specific bulk material component because insufficient data were available. However, this mass is only 1,020 t, representing <0.4% of the total mass of legacy ILW and LLW.
2. A material category is quantified (eg ‘other metals’) but no information is available for assigning the mass to specific material components. In particular, there are priority materials for which data have not been provided. The material categories are listed below (with priority materials in brackets):
    - halogenated plastics (PVC)
    - non-halogenated plastics (polyethylene and polypropylene)
    - cellulose (paper / cotton and wood)
    - other organics (NAPLs)
3. Where a priority material is reported as being present in the waste, but there is no information on the quantity. These priority materials are listed below:
    - borates
    - eutectics
    - ammonium species
    - potassium hydroxide
4. Priority materials that are not reported in any waste stream in the 2013 UK RWI (currently only selenates)
5. There is insufficient information to quantify the small amounts of complexants in wastes. RWM is undertaking work to assess the disposability of materials used to fix and remove radioactive waste contamination. Once this is completed, it may be necessary to add certain complexants to the list of priority materials.
6. The compilation of metal geometry information for waste components is constrained by the lack of data on metal thickness and shapes. Assignments for historic wastes are based on work carried out for the 2004 UK RWI. Assignments for new streams are based on the data for similar wastes.

7.1.2 Radionuclide activity

There are a range of issues relating to radionuclide activities in waste streams and these can be categorised as follows.

- 2013 UK RWI data for Sellafield Magnox Swarf Storage Silos (MSSS) streams are historic: there has been no substantive change to the data, including that for the Magnox and uranium[30] fractions, since the 1998 UK RWI. Ahead of planned waste retrieval operations in the MSSS, Sellafield Ltd has commissioned a characterisation study of silos based on extensive analysis of historical records. This covers the physical / chemical contents and the radionuclide inventory. At the time of compiling the 2013 Derived Inventory, the results of the study were not available. A re-evaluated MSSS inventory should give greater confidence in the quantities of reactive metals, other species and radionuclide activities for disposal to the GDF.
- As part of their UK RWI submissions, waste producers are asked to provide an uncertainty for each radionuclide. ‘Band E’, which denotes uncertainty of a factor of 1,000 in the specific activity, remains for some streams. There has been an initiative for the past few UK RWIs to eliminate Band E by requesting that waste producers reduce the level of uncertainty. No suitable method for enhancement could be established for these waste streams. In addition:
  - there are a small number of uncertainty bands which therefore can provide only a crude estimate of the uncertainty
  - it is recognised that, in general, reporting of uncertainty bands is overly conservative, and therefore gives much greater uncertainties in activities than are likely in reality
  - waste producers could be encouraged to justify or reassess the uncertainties for key waste streams that contribute to total radionuclide activities, and RWM is already pursuing this in collaboration with LLWR and the NDA
- The 2013 Derived Inventory contains 566 waste streams and of these, nine contain a Code 7 (Present in significant quantities but not determined) on one or more radionuclides. Of these nine streams, two have been enhanced such that the number of instances of Code 7 has been reduced. It is not anticipated that the remaining Code 7s will significantly affect the total activity of any radionuclides within the 2013 Derived Inventory.
- Apparent anomalies in uranium isotope ratios were identified during the data review exercise. In some cases, these anomalies were a result of either U235 or U238 not being quantified. Where these anomalies are considered significant, they have been addressed. However, in most cases the waste stream has a very low uranium content, and hence the data were left unchanged.
- Apparent anomalies in plutonium isotope ratios were also identified. Where these are considered significant they have been addressed. As for uranium, in some cases the waste stream has a very low plutonium content, and hence the data were left unchanged.
- Of those waste streams considered for data enhancement, there are 53 where priority radionuclides could not be quantified because no surrogate stream or method of enhancement was identified. However, these streams have relatively low total activities and are expected to have low concentrations of the unquantified priority radionuclides. The impact on the total radionuclide activities in the 2013 Derived Inventory is thought to be less than 0.1% for any given radionuclide and this will be bounded by the uncertainties that RWM has considered in the alternative scenarios report [14].

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[30] These metals will have continued to corrode in the water filled compartments.

7.2 Legacy HLW

Volumes of vitrified HLW from Post-Operational Clean-Out (stream 2F38/C) are initial estimates only and subject to an order of magnitude level of uncertainty.

There are no outstanding issues concerning the material composition of HLW. All HLW streams are well characterised in the 2013 UK RWI and no significant gaps or anomalies have been identified in the data. The 2013 UK RWI quantifies specific activities for all priority radionuclides apart from H3, C14 and Kr85, which are reported as Code 8 (not expected to be present in significant quantity).

For stream 2F38/C, radionuclide activities of insoluble fission product residues have the same level of uncertainty as packaged volumes.

7.3 Legacy SFs

7.3.1 Material composition

No publicly available information was identified that could be used as the basis for material and radionuclide compositions for Legacy Ponds Fuel (stream M2D300) in the 2013 Derived Inventory. For the purposes of the 2013 Derived Inventory, the composition (and packaging assumptions) is taken to be that of Magnox SF, which is likely to be a major component, with a lower burn-up than current commercial SFs.

PFR SF (M5B100) is made up of a variety of intact sub-assemblies and separate fuel pins. Some fuel is clad in a stainless steel wrapper and some in a Nimonic wrapper. Currently, there is insufficient data to determine the overall material composition.

The material components for AGR and PWR SF are much better characterised. A number of assumptions have been made in compiling radionuclide activity data for the 2013 Derived Inventory. Assumptions have been based on the best available data. If a comprehensive record of fuel compositions, enrichment levels and burn-ups were available, improved quality data could be generated.

No upper and lower uncertainty bands have been derived for the radionuclide activity data. To do so would have required further information, analysis and calculation.

7.4 Uranium and plutonium

No publicly available information has been identified regarding the level of chemical and radionuclide impurities in the plutonium residues unsuitable for MOX fuel production (stream MPu001).

The masses of the DNLEU streams are based on the limited amount of information published in the 2013 UK RWI and other sources. Definitive information on masses of the different streams, the range of isotope ratios, and chemical and radionuclide impurities, remains to be incorporated into the Derived Inventory.

Whilst the packaging assumptions for MDU and depleted uranium tails have been updated, the packaging assumptions for other DNLEU waste streams have not. It is acknowledged that the packaging assumptions for these other DNLEU streams have not been optimised.

Similarly, the concepts assumed for HEU and plutonium are thought to be non-optimal. However, until further work that justifies an alternative assumption has been completed, the can-in-canister approach remains the reference packaging assumption.

7.5 New build reactors

The 2013 UK RWI does not contain information on wastes and SFs that might arise from new build reactors. Hence, 2013 Derived Inventory data have been compiled using data from the GDA process and the UK EPR and Hinkley Point C PCSRs.

Improvements in material and radionuclide characteristics could be made to the Derived Inventory once more data for new build reactors are made publicly available by reactor designers / vendors and prospective operators.

One specific area for improvement is information on the quantities of redundant non-fuel core components (eg rod cluster control assemblies and thimble plugs) and whether these will be managed as ILW or disposed of with the SF assemblies. Such information was not available at the time of compiling the 2013 Derived Inventory so these wastes have not been considered.

Furthermore, the Derived Inventory makes no allowance for the potential for depleted uranium arising in the UK from uranium enrichment that is part of the manufacturing process for new build reactor fuel.

7.6 Groundwater pollutants

The legislation regarding the protection of groundwater from the introduction of pollutants changed in 2010 when The Environmental Permitting (England and Wales) Regulations 2010 [26] came into force. This gives effect to certain provisions of Directive 2000/60/EC (Water Framework Directive) [27] and Directive 2006/118/EC (Groundwater Daughter Directive) [28] in England and Wales. It is noted that the legislation governing Scotland [29] and Northern Ireland [30] is different to that governing England and Wales.

The 2010 Regulations 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 of the controls it will have in place to prevent and limit (respectively) inputs of these substances to groundwater.

The UK RWI does not currently provide sufficient information to satisfy this requirement and RWM is currently working with the NDA, LLWR and waste producers to ensure that more information is available in the next iteration of the UK RWI; this will then be incorporated into the next iteration of the Derived Inventory.

7.7 Superplasticisers

The 2013 Derived Inventory assumes that Superplasticisers comprise 0.5 wt% of all cementitious materials. This assumption is thought to be bounding. Details of the work that RWM is currently undertaking on superplasticisers are provided in the Science and Technology Plan[15].

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Glossary

'A glossary of terms specific to the generic DSSC can be found in the Technical Background.

Term	Definition
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
DECC	Department of Energy and Climate Change. The responsibilities of DECC were transferred to the Department for Business, Energy and Industrial Strategy in July 2016
Decontamination factor	The amount of contaminant in the feed stream (per unit mass of uranium) / amount of contaminant in the product stream (per unit mass of uranium)
DIQuest	Derived Inventory query and scenarios toolkit
DNLEU	Depleted, natural and low-enriched uranium. Comprises all uranium with the exception of highly enriched uranium
DSSC	Disposal System Safety Case
EPR	EPR is now used by AREVA as a reactor name, it was previously used to mean European Pressurized Reactor and Evolutionary Power Reactor;
FED	Fuel element debris
Fingerprint	A radionuclide fingerprint is an estimate of the anticipated radionuclide mix of a substance. The fingerprinting technique is used in the characterisation of wastes: when the quantity of one radionuclide (or a limited number of radionuclides) in a waste has been measured, the application of a fingerprint is used to infer and quantify the presence of other radionuclides
GDA	Generic design assessment
GDF	Geological disposal facility
Groundwater pollutant	The hazardous substances and non-hazardous pollutants that are prevented from input into the groundwater without a permit by ‘The Environmental Permitting (England and Wales) Regulations 2010’. This legislation gives effect to certain provisions of Directive 2000/60/EC (Water Framework Directive) and Directive 2006/118/EC (Groundwater Daughter Directive) in England and Wales.
GWd/tU	Gigawatt days per tonne of uranium
GW(e)	Gigawatt electrical output
HAW	Higher activity waste
HEU	Highly enriched uranium
HHGW	High heat generating waste

HLW	High Level Waste
IAEA	International Atomic Energy Agency
ILW	Intermediate Level Waste
ISO	International Organisation for Standardisation
Legacy waste	Radioactive waste which already exists or whose arising is committed in future by the operation of an existing nuclear facility
LHGW	Low heat generating waste
LLW	Low Level Waste
LLWR	Low Level Waste Repository
LWR	Light water reactor
MBGWS	Miscellaneous beta gamma waste store
MDU	Magnox depleted uranium
MOD	Ministry of Defence
MOX	Mixed oxide
MSSS	Magnox swarf storage silos
NAPL	Non-aqueous phase liquid
Nuclear material	Fissile material or material that can be used to produce fissile material (ie source material). This includes most isotopes of uranium, plutonium and thorium, together with certain isotopes of neptunium and americium. In the context of the Derived Inventory, this covers uranium and plutonium and spent fuel.
OPC	Ordinary Portland cement
Packaged volume	The packaged waste volume is the displacement volume of a container used to package a wasteform
PCSR	Pre-construction safety report
PFA	Pulverised fuel ash
PFR	Prototype Fast Reactor
PVC	Polyvinyl chloride
PWR	Pressurised water reactor
RS	Robust shielded
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 Intermediated Level Waste
SLLW	Shielded Low Level Waste
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 Disposal Container
tHM	Tonnes of heavy metal
TPU	THORP product uranium
tU	Tonnes of uranium
UILW	Unshielded Intermediate Level Waste
UK ABWR	UK Advanced boiling water reactor
UK RWI	United Kingdom Radioactive Waste Inventory
ULLW	Unshielded Low Level Waste
VLLW	Very Low Level Waste
Wasteform	The waste in the physical and chemical form in which it will be disposed of, including any conditioning media and container furniture (ie in-drum mixing devices, dewatering tubes, etc) but not including the waste container itself or any added inactive capping material
WVP	Waste vitrification plant

Appendix A Data Enhancement

A1 Priority materials

The 2007 Derived Inventory established priority scores for materials and radionuclides in the inventory through discussions with RWM safety case owners and experts in the areas of inventory, wasteform, packaging, transport and criticality. The priority scores reflect the importance of the materials and radionuclides to RWM's safety cases.

The priority scores assigned in the 2007 Derived Inventory were revised through consultation with RWM staff as part of the 2013 Derived Inventory exercise. Table A1 to Table A6 record the revised priority materials and radionuclides and their priority scores. Some materials are not relevant to certain waste types (eg organic items for HLW and SFs). Also, a small number of material and radionuclide priority scores differ for the different waste types. Where different priority scores are associated with different aspects of RWM's work areas or safety cases, the highest priority score is reported.

The priority scores are:

1. Most important
2. More important
3. Important
4. Less important
5. Least important

In the case of the priority radionuclides (Table A6), only those with a priority score of greater than or equal to 3 are listed.

Table A1 Material properties (metals)

Inventory item	Material / compound / element	Priority
Aluminium	Metal & carbides	2
Magnox	Metal & metal carbides	1
Stainless steels / mild steels	Metal & metal carbides	1
Uranium	Metal & carbides	1
Zircaloy	Metal & metal carbides	2

Table A2 Material properties (metallic species)

Inventory item	Material / compound / element	Priority
Aluminium	All chemical forms	3
Antimony	All chemical forms	3
Arsenic	All chemical forms	3
Beryllium	All chemical forms	1
Cadmium	All chemical forms	1
Caesium	All chemical forms	3
Chromium	All chemical forms	1
Cobalt	All chemical forms	3
Copper	All chemical forms	3
Iron	All chemical forms	3
Lead	All chemical forms	1
Magnesium	All chemical forms	1
Manganese	All chemical forms	3
Mercury	All chemical forms	2
Molybdenum	All chemical forms	3
Nickel	All chemical forms	3
Niobium	All chemical forms	3
Plutonium / uranium	Oxide or metal	1
Ruthenium	All chemical forms	3
Selenium	All chemical forms	3
Tin	All chemical forms	3
Uranium	All chemical forms	1
Vanadium	All chemical forms	3
Yttrium	All chemical forms	3
Zinc	All chemical forms	3
Zirconium	All chemical forms	3

Table A3 Material properties (organics)

Inventory item	Material / compound / element	Priority
Cellulose	Paper & cotton; wood	1
Halogenated plastics	PVC	3
Non-halogenated plastics	Polyethylene; polypropylene	1
Organic ion exchange resins	Styrene divinyl benzene based	1
Phenol		3
Plastics (general)		3
Vinyl chloride monomer		3
Volatile organic compound	Toluene; vinyl styrene	3
Other organics	Small organic molecules; hydrocarbon oils; chlorinated solvents (eg trichloroethylene)	1

Table A4 Material properties (inorganic anions)

Inventory item	Material / compound / element	Priority
Borate		3
Fluoride		3
Nitrate		2
Nitrite		1
Phosphate		3
Selenate		3
Sulphate		2

Table A5 Material properties (other species)

Inventory item	Material / compound / element	Priority
Ammonium species		3
Asbestos		5
Eutectics	Barium chloride	5
Ferrocyanates		4
Graphite		1
Non-aqueous phase liquids		3
Potassium hydroxide		5

Table A6 Radionuclide priorities

Radionuclide	Priority	Radionuclide	Priority	Radionuclide	Priority
H3	3	Sn126	2	U236	3
C14	1	I129	1	U238	1
Cl36	1	Cs135	1	Np237	1
Co60	1	Cs137	1	Pu238	2
Ni59	3	Eu152	3	Pu239	2
Ni63	3	Eu154	3	Pu240	2
Se79	1	Ra226	3	Pu241	2
Kr85	1	Th232	3	Pu242	3
Sr90	3	Th234	3	Am241	3
Zr93 / Nb93m	3	Pa231	2	Am242m	3
Nb94	3	U233	1	Cm244	3
Mo93	3	U234	2	Cm248	3
Tc99	1	U235	1		

A2 Data enhancement for HLW, ILW and LLW

A2.1 Bulk material composition

The 2013 UK RWI includes numerical data (in terms of percentage by mass) for the contribution of a number of bulk materials (comprising metals, organics and inorganics) to the total mass of waste; Table A7 lists these materials. It is noted that there is some overlap between these bulk materials (eg Cellulose (total), Cellulose (paper & cotton) and Cellulose (wood)). RWM therefore considers two levels of bulk materials: Level 1 materials, such as Cellulose (total) and Rubber (total); and secondary materials, such as Cellulose (paper & cotton) and Halogenated rubber, which are components of Level 1 materials.

Table A7 Chemical components for which the 2013 UK RWI contains numerical data

Metals	Organics	Inorganics
Aluminium	Cellulose (total)	Aqueous liquids[31]
Beryllium	Cellulose (paper & cotton)	Asbestos
Boral	Cellulose (wood)	Ceramic
Brass	Halogenated plastics	Concrete / cement / sand
Bronze	Ion Exchange resins	Glass
Copper	Non-halogenated plastics (total)	Graphite
Dural	Non-halogenated plastics (condensation polymers)	Ion exchange materials
Inconel	Non-halogenated plastics (others)	Rubble
Lead	Rubber (total)	Sludges and flocs
Magnox	Rubber (Halogenated rubber)	Soil
Monel	Rubber (Non-halogenated rubber)	Other inorganics
Nimonic	Other organics	
Other ferrous metals		
Stainless Steel		
Stellite		
Uranium		
Zinc		
Zircaloy		
Other metals		

The review and enhancement methodology is detailed below.

1. Numerical data for the material components (wt%), prefixes and supporting descriptive data fields for each waste stream are downloaded into spreadsheets (an original copy is retained to allow comparisons following data enhancement).

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[31] Additional to water associated with wet wastes (sludges, flocs and ion exchange materials).

2. Numerical data are supplemented by reviewing the supporting descriptive data fields in the 2013 UK RWI to identify any Level 1 materials not covered in Table A7 (eg desiccants and catalysts). Additional columns are added to the spreadsheet for these materials. All waste streams are screened to capture any Level 1 material components.
3. Waste streams containing ion exchange resins and sludges are reviewed to ensure that free aqueous liquid is not double counted (ie if its percentage by weight is reported separately it is not also reported as part of the percentage by weight of the resin / sludge).
4. Data for waste streams where only total values are given for metal, steel or organics, or where cellulose, plastics or rubbers are not split into their component parts, are analysed. If there are no supporting descriptive data or surrogate waste streams to allow specific data enhancements for these streams, assignments are made based on relative masses of these materials that are quantified in the 2013 UK RWI.
5. Numerical Level 1 material component values of each stream are summed.
6. Waste streams with the greatest unassigned mass are identified. (Most of the unassigned mass in the 2013 UK RWI is associated with a small number of waste streams; the focus of the enhancements is on these waste streams.) Supporting descriptive data fields and comparison with similar waste streams in the 2013 UK RWI are used to enhance the data. The aim is to assign > 99% of the waste mass.
7. Priority materials are enhanced using the following process (see Table A8):
    - incorporate existing enhancements from 2007 Derived Inventory
    - compare 2013 UK RWI and 2007 Derived Inventory material composition descriptive data fields to confirm existing enhancements or to incorporate new or updated data
    - review the descriptive data fields for those waste streams in the 2013 UK RWI that are not in the 2007 Derived Inventory and incorporate any data
8. Any mass not allocated to a specific material remains unassigned.
9. Upper and lower uncertainties in material component masses are calculated by using the upper and lower uncertainty factors on waste stream volumes reported in the 2013 UK RWI[32].

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[32] This is a revised approach that will give estimates of uncertainties that are underpinned by new information from the data providers. For the 2007 Derived Inventory, each material component was assigned as a best estimate, upper and lower uncertainty mass contribution. Uncertainties in material component masses were manifested by use of various prefixes (<, P and TR) on the numerical data.

Table A8 Rules for Level 1 data enhancement of priority materials

Priority materials	Enhancement
Value for ‘Other metals’	Use text fields to assign priority items (See Appendix A1) and list separately
Value for ‘Other organics’	Use text fields to assign priority items (See Appendix A1) and list separately
Non-radiological substances	Use text fields to assign priority items (See Appendix A1) and list separately
Cellulose (amorphous / crystalline split)	If cellulose > 0, assign wood as crystalline and paper / cotton as amorphous
Organic resins (styrene divinylbenzene or phenol)	Assign resin type according to data in the text
Polyvinylchloride (PVC)	If halogenated plastics > 0, use text fields to assign value
Polyethylene / polypropylene	If non-halogenated plastics > 0, use text fields to assign value

The prefix ‘TR’ (present at trace levels) is reported for some material components in the waste streams. The UK RWI conventions define ‘TR’ as in the range 1 – 100 ppm). In the 2007 Derived Inventory the best estimate component composition was assigned a value of 0.001% (ie equivalent to a geometric mean of 10 ppm). A review of the data in the 2013 UK RWI has shown that applying this methodology would only add ~15 tonnes to the total mass of legacy ILW (ie ~0.005%) and no more than 1% to any one material component. Because these impacts are small, and well within the uncertainties on the waste masses, this enhancement has not been made for the 2013 Derived Inventory.

HLW streams are made up of calcined waste oxide in a borosilicate glass matrix within stainless steel waste vitrification plant (WVP) canisters, with the exception of high level contaminated plant items (stream 2F22/C), which comprise Inconel, Uranus 65 and stainless steel in a borosilicate glass matrix within WVP canisters.

The material composition and bulk density of each HLW stream as reported in the 2013 UK RWI were modified to include the mass of the WVP canister. The 2013 UK RWI reports that each WVP canister contains 0.15 m^3 of vitrified HLW with a density of 2.65 t/m^3. Thus the mass of the vitrified product is approximately 400 kg. The mass comprises approximately 100 kg of waste oxide and approximately 300 kg of borosilicate glass.

The composition assumed for the waste oxide is given in Table A9, while the composition of the glass is given in Table A10 from information in the 2013 UK RWI. The WVP canister has a mass of about 85 kg and is manufactured from Type 309 stainless steel.

Table A9 Composition of waste oxide (%)

Species	Mass (%)	Species	Mass (%)	Species	Mass (%)
GeO_2	$9.2\ 10^{-4}$	Rh_2O_3	1.80	CeO_2	8.80
As_2O_3	$2.6\ 10^{-4}$	PdO	4.02	Pr_6O_{11}	3.95
SeO_2	0.202	Ag_2O	0.192	Nd_2O_3	13.3
Rb_2O	1.08	CdO	0.215	Pm_2O_3	0.204
SrO	2.78	In_2O_3	$6.39\ 10^{-3}$	Sm_2O_3	2.65
Y_2O_5	1.64	SnO_2	0.232	Eu_2O_3	0.389
ZrO_2	13.8	Sb_2O_3	$4.12\ 10^{-2}$	Gd_2O_3	0.230
Nb_2O_5	$5.18\ 10^{-5}$	TeO_2	1.31	Tb_2O_3	$6.91\ 10^{-3}$
MoO_3	14.1	Cs_2O	8.37	Dy_2O_3	$2.07\ 10^{-3}$
TcO_2	3.23	BaO	5.03		
RuO_2	7.87	La_2O_3	4.16		

Table A10 Composition of the glass used to vitrify HLW (%)

Material	SiO_2	Na_2O	B_2O_3	Li_2O
Glass	62.9	11.4	23.0	2.7

A2.2 Elemental composition

Material grades and types are assigned to all bulk materials and elemental compositions / specifications for these are then used with the material masses to derive elemental masses. The approach is detailed below.

1. For each material component, order waste streams by their contribution to the total mass of the component.
2. Allocate material grades to steels, other metals and alloys and to proprietary material types such as exchange resins using the following order of preference:
    - data reported in the 2013 UK RWI
    - 2007 Derived Inventory enhancements
    - additional information available to RWM
3. Where the total mass of a material component in a waste stream is made up of a number of different grades (eg stainless steel), assign proportions to each grade.
4. Where specific material grades or types are not reported use the same approach to allocating grades or types as was used in the 2007 Derived Inventory. (For example, where no information is available on the grade of stainless steel it is assigned to 304L and 316 in the same relative proportion as major contributing streams where grades are reported.)
5. Once material grades have been established for all of the components, the elemental masses are determined using the database of elemental compositions.

Issues were raised by the peer review of the 2007 Derived Inventory and have been addressed. Details of these issues are provided below.

- the thorium concentration in stainless steels has been corrected
- other ferrous metals in waste stream 2F22/C (High Level Contaminated Waste) are assigned to the alloy Uranus 65 and an elemental specification for the alloy has been added to the database of material elemental compositions
- waste stream 2S302 (Windscale Pile 1 and Pile 2 Graphite and Aluminium Charge Pans) will be included as a contributor to the calculation of the overall weighted elemental composition of graphite in ILW. A reassessment of waste streams containing graphite and their source formed part of the input to the 2013 Derived Inventory
- the magnesium mass in $Mg(OH)_2$ sludges has been scaled to the source Magnox alloy elemental composition, and the uranium mass in UO_2 has been scaled to the source uranium elemental composition
- an elemental composition for magnetite concrete has been added (this material is used in high density 6 m^3 concrete boxes)

A2.3 Radionuclide composition

The 2013 UK RWI data are the starting point for developing the 2013 Derived Inventory radionuclide compositions for HLW, ILW and LLW streams. The 2013 UK RWI data contain a number of updates that provide more recent and improved quality data.

The review of the data aims to identify issues for enhancement (for example, potential anomalies, missing data, under-reporting). All issues for enhancement are then addressed. The following methodology is used.

1. Limit the review and enhancement work to the 37 priority radionuclides.
2. Identify other additional sources of public domain data (eg reports from RWM's Integrated Project Teams).
3. For each radionuclide order waste streams by contribution and carry out a sanity check to identify if any waste streams have a significantly (order of magnitude) lower or higher activity than would be expected. Make any necessary adjustments[33].
4. Identify gaps in the data for waste streams that do not contribute to radionuclide totals (because activity is not quantified). Filter out gaps for small volume waste streams that contain insignificant activities.
5. Focus enhancement work on the more significant gaps in activities (ie for each radionuclide those waste streams likely to have higher activity). For example, gaps for fission products and actinides in Sellafield waste streams and gaps for activation products in reactor waste streams.
6. Fill gaps by using existing 2007 Derived Inventory enhancements:
    - for waste streams with an unchanged radionuclide composition, use 2007 Derived Inventory values (subject to decay adjustments); and
    - for waste streams with a revised radionuclide composition, factor 2007 Derived Inventory values by selecting a marker (pertinent radionuclide or total).
7. Fill remaining gaps by using 2013 UK RWI fingerprint data:
    - For waste streams with no quantified activity values, select a surrogate waste stream that is expected to have a similar radionuclide fingerprint;

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[33] This was carried out as part of the 2013 UK RWI project and has not been repeated here.

  - For waste streams with only total activity quantified, select a surrogate waste stream that is expected to have a similar radionuclide fingerprint and calculate radionuclide activities by factoring using total activity;
  - For waste streams with an incomplete radionuclide composition, select a surrogate waste stream that is expected to have a similar radionuclide fingerprint and calculate radionuclide activities by factoring using a marker radionuclide.

8. Derive activity values where a radionuclide has a 'Code 7' (present in significant quantities but not determined). Select a surrogate waste stream that is expected to have a similar radionuclide fingerprint and calculate radionuclide activities by factoring using a marker radionuclide.
9. A final sanity check of the radionuclide activity data is carried out. This includes the calculation of total radionuclide activity changes and a review of radionuclide ratios.

A3 Data enhancement for SFs

The 2013 UK RWI only includes masses of legacy SFs. It has been necessary to calculate radionuclide inventories for these fuels; details are provided below and the key parameters are listed in Table A11. The enhancement approach is to use information compiled for the 2007 Derived Inventory that remains valid together with improved radionuclide characterisation data generated specifically for the 2013 Derived Inventory. In the case of SFs, no uncertainty data have been derived; to do so would require considerable analysis and calculation that is beyond the scope of this work.

Table A11 The key parameters used in the calculation of the radionuclide inventories for the various SFs

Fuel	Burn-up (GWd/tHM)	Enrichment (%)	Cooling times (yrs)
AGR stocks	28	2.9	6
AGR arisings[34]	33	3.2 / 3.78	1
Sizewell B stocks	45	4.2	8
Sizewell B arisings	55	4.4	1
Exotic SFs stocks	189	(Pu) 29.5	19
Metallic SFs stocks	4.1	0.71	36

A3.1 AGR SF

Bulk materials

The assumed masses of the materials comprising all AGR fuel components contained within a single disposal container (corresponding to 16 slotted cans holding consolidated fuel bundles) are given in Table A12.

Elemental composition

SF irradiated compositions are used for the UO_2. However, for the fuel cladding, a pre-irradiation elemental composition is used (analysis of the impact of irradiation on fuel cladding and component compositions showed that there are no significant changes in elemental masses).

Radionuclide composition

It is assumed that the SF remaining unreprocessed is that which has been most recently discharged from reactors. Based on details of AGR SF held in stock in the Sellafield ponds, the AGR SF inventory calculations assume a burn-up of 28 GWd/tU and an enrichment of 2.9%. The average cooling time of the stocks (6 years) was chosen.

It is assumed that the arisings can be divided evenly into two enrichments (3.2% and 3.78%) [A1], each with a burn-up of 33 GWd/tU.

The other irradiated components of the AGR SF that are disposed of are shown in Table A12 and these are assumed to be irradiated to 47.4 GWd/tU. The apparent discrepancy between the burn-up assumed for the fuel and that assumed for the other components is considered to be insignificant. In addition, the impurities in the components and fuel are assumed to be present at the maximum permissible level, with the exception of nitrogen in the stainless steel cladding. Nitrogen is an important precursor for C14 and RWM's C14 integrated project team has undertaken work to determine the concentration of the nitrogen

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[34] There are two enrichments for the ‘robust fuel’, which are assumed to be used in equal amounts.

precursor. Based on discussions with members of the C14 integrated project team, the concentration of nitrogen in the stainless steel is assumed to be 100 ppm.

Table A12 AGR SF components per disposal container

Component	Material	Mass (t)
Fuel	UO_2 (U)	2.34 (2.06)
Cladding	Type 20/25/Nb SS	0.282[35]
Sintox discs	Al_2O_3	0.016
Slotted cans	Type 316 stainless steel	0.197

A3.2 Sizewell B SF

Bulk materials

The assumed contents of a disposal container for Sizewell B SF are shown in Table A13. A disposal container houses four SF assemblies.

Elemental composition

As with the AGR SF, the fuel composition is that of irradiated fuel, while the compositions of the cladding and other components are unirradiated values.

Radionuclide composition

Unlike the AGR SF, Sizewell B SF assemblies are assumed to be disposed of intact and it is necessary to include the contribution to the inventory from the non-fuel components of the fuel assembly; these are detailed in Table A13. The stocks of Sizewell B SF are assumed to have a burn-up of 45 GWd/tU, an enrichment of 4.2% and an average cooling time of 8 years. The arisings are assumed to have a burn-up of 55 GWd/tU and an enrichment of 4.4%.

As with the AGR SF, the impurities in the components and fuel are assumed to be present at the maximum permissible level. The components and impurities are assumed to be irradiated to 61 GWd/tU. The apparent discrepancy between the burn-up assumed for the fuel and that assumed for the other components is assumed to be insignificant.

Table A13 Spent Sizewell B fuel components in a disposal container

Component	Material	Mass (t)
Fuel	UO_2 (U)	2.080 (1.834)
Cladding[36]	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[37]	Type 304 SS	$5.04\ 10^{-2}$

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[35] Consistent with the 2007 Derived Inventory, the radionuclide activity used for AGR SF has assumed 0.270 t of cladding.

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

[37] Note that 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.

A3.3 Exotic SFs

The data (including quantities, materials and radionuclide inventory) for exotic SFs are based solely on PFR SF.

Bulk materials

PFR SF comprises intact sub-assemblies and separate fuel pins. The sub-assemblies contain driver fuel and additional breeder material. The driver fuel is a (U, Pu)O_2 solid solution known as mixed oxide (MOX). The plutonium content is typically 25 – 33% plutonium by mass and it is assumed that the PFR fuel is 29.5% plutonium by mass. The breeder material comprises depleted UO_2.

There is considerable variety between individual fuel sub-assemblies. Each sub-assembly contains between 165 and 325 fuel pins, with the number of pins depending on their diameter. From data published by IAEA [A2], the quantity of uranium and plutonium in seven unirradiated sub-assemblies is estimated to be ~600 kgHM. High burn-up results in a significant reduction in the quantity of heavy metals in the fuel after irradiation and therefore it is assumed that a disposal container with seven sub-assemblies would contain ~550 kgHM.

Some fuel sub-assemblies are clad in a stainless steel wrapper, others in a Nimonic wrapper. Similarly, individual fuel pins are clad in stainless steel or Nimonic. Currently there are insufficient detailed data for the PFR sub-assemblies and fuel pins to accurately calculate the quantities of stainless steel and Nimonic. It has been assumed that for each tonne of heavy metal, there is 0.302 t of Nimonic cladding. This is an upper value for sub-assemblies with 325 fuel pins. The total materials mass in a PFR disposal container is shown in Table A14.

Table A14 PFR SF components in a disposal container

Component	Material	Mass (t)
Fuel	UO_2 / PuO_2 (U/Pu)	0.624 (0.550)
Cladding	Nimonic	0.166
SS canisters	Type 304 SS	0.488

Elemental composition

Data from the 2007 Derived Inventory (based on pre-irradiation elemental compositions) are used. The lower mass of PFR SF when compared with the other legacy SFs does not justify developing estimates for irradiated fuel compositions.

Radionuclide composition

Spent PFR fuel assemblies have a wide range of irradiation histories with cumulative burn-ups ranging from 21 GWd/tHM to 230 GWd/tHM [A3]. A burn-up of 189 GWd/tHM has been used when determining the PFR SF inventory.

A3.4 Metallic SFs

Bulk materials

Sufficient information is not currently available to determine the material components of the legacy ponds fuel. To allow some contribution from these fuels in the 2013 Derived Inventory, it is assumed that the composition is the same as that for Magnox SF, which is expected to be the predominant component of the fuel.

Details of the materials and masses of the components contained within a single disposal container (corresponding to 26 intact fuel elements in each of three WVP-type canisters) are given in Table A15. The fuel and cladding data are average values for five fuel element designs that could potentially be packaged rather than reprocessed. The mass of the WVP type canisters is assumed to be 127 kg.

Elemental composition

The elemental composition of the uranium fuel is taken from a radionuclide inventory calculation for Magnox fuel (with a burn-up of 4.1 GWd/tU). A pre-irradiation elemental composition is used for the fuel cladding.

Radionuclide composition

The radionuclide composition of the legacy ponds fuels is calculated based on the irradiation of Magnox fuel (natural uranium) irradiated to 4.1 GWd/tU.

Table A15 Assumed legacy ponds fuel components in a disposal container

Component[38]	Material	Mass (t)
Fuel	Uranium metal	0.886
Cladding[39]	Magnox AL80	0.159
WVP canisters	Type 309 SS	0.381

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[38] 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; and
Dungeness A: total element mass 12.9 kg; uranium mass 11.0 kg.

[39] Mass includes stainless steel sheathed bottom cone (mass unknown).

A4 Uranium and plutonium

A4.1 Uranium

The stored volume of DNLEU in the 2007 Derived Inventory was calculated from the mass of triuranium octoxide (U_3O_8) and its density. This assumption has been used for the miscellaneous DNLEU, TPU and defence DNLEU, which are assumed to be packaged in 500 l drums for the 2013 Derived Inventory. The stored volume of the Magnox Depleted Uranium (MDU) and the depleted uranium tails is based on the volume of the overpacked drums and the DV-70 containers respectively.

Material composition

Uranium is stored in a number of different chemical forms; principally as an oxide or a fluoride. It is assumed that HEU for disposal will be in the form of UO_2, and that DNLEU will be in the form of U_3O_8 or UO_3.

One of the issues identified with the 2007 Derived Inventory noted that trace impurities in uranium materials had not been accounted for. This issue has been addressed as part of the 2013 Derived Inventory enhancement work. The conclusions of the investigations, which were limited to publicly available documentation, are listed below.

- No information has been identified on chemical impurities in HEU. As these are likely to be at very low levels, and therefore of no significance, no impurities are included.
- Based on the specification for U_3O_8 produced in the Tails Management Facility, the uranyl fluoride (UO_2F_2) content of material deconverted from uranium hexafluoride (UF_6) tails derived from unirradiated uranium is assumed to be 4 wt%. This is likely to be a conservative value.
- No information has been identified on the likely chemical composition of the deconverted U_3O_8 product originating from irradiated uranium, but the composition is assumed to be the same as that originating from unirradiated uranium. No published data on the level of technetium has been identified. A nominal value of 0.03 µg/gU is assumed – a measured datum for THORP product uranium (TPU).
- The Magnox depleted uranium (MDU) UO_3 specification for recycled material [A4] provides limits on some contaminants (see Table A16). These are used to derive an improved composition. In the absence of any other published material data, these bounding values are also used for the TPU composition.
- No references have been identified that give information on the trace chemical levels in miscellaneous DNLEU streams. As these are likely to be at very low levels, and therefore of no significance, no assumptions have been made.

Table A16 MDU UO_3 specification

Contaminant	Concentration (µg / gU)
Iron	< 300
Sodium	< 20
Nitrate (as NO_3)	< 8,000
Sulphate (as SO_4)	950 – 1,450

Radionuclide composition

The isotopic composition of uranium and the presence of impurities are different for uranium that has arisen from reprocessing spent fuel and uranium that has arisen from the enrichment of natural uranium. For material separated from irradiated fuel, the determining factors are the reactor type, the initial enrichment of the uranium in the fuel, the discharge burn-up and the decontamination factors during reprocessing.

Small quantities of impurities, including plutonium and fission products, are likely to have been carried over into the MDU and TPU streams during the chemical separation phase of reprocessing. The radioactivities of these impurities are calculated in the same manner as for the 2007 Derived Inventory. That is, mean whole plant decontamination factors are applied to the plant in separating radionuclides during reprocessing. A subsequent period of radioactive decay is applied; this is the estimated average age of material accumulations assuming constant arisings over time.

Published decontamination factors are available for the THORP reprocessing plant only (see Table A17). These factors have also been used for determining radionuclide impurity levels in MDU. Mean decontamination factors have been applied to other radionuclide species by selecting the value for the contaminant that is likely to show a similar chemical behaviour during reprocessing.

Table A17 Uranium decontamination factors (DF) for THORP[40]

Contaminant	Observed DF to UO_3 product	Mean DF
Tc99	$8.17\ 10^{3}$ – $1.16\ 10^{4}$	$9.74\ 10^{3}$
Ru106	$4.32\ 10^{6}$ – $1.33\ 10^{7}$	$7.58\ 10^{6}$
Cs134 + Cs137	$5.66\ 10^{9}$ – $1.38\ 10^{10}$	$8.84\ 10^{9}$
Ce144	$9.36\ 10^{5}$ – $4.96\ 10^{6}$	$2.15\ 10^{6}$
Np237	$3.31\ 10^{4}$ – $6.76\ 10^{4}$	$4.73\ 10^{4}$
Plutonium isotopes	$8.60\ 10^{6}$ – $2.03\ 10^{7}$	$1.32\ 10^{7}$

Depleted uranium tails generated from the use of irradiated MDU in the enrichment process contain the artificial isotopes U232 and U236. The fate of fission products (principally technetium) and transuranics (principally neptunium and plutonium) when MDU was reconverted and re-enriched is complex. For the purposes of the 2013 Derived Inventory, only U236 (0.03% of mass of uranium) and Np237 (1 Bq per gU) are quantified.

Some depleted uranium tails produced from natural, unirradiated UF_6 will also be contaminated with U232 and U236, because in the past they were sometimes collected in emptied (but not washed out) feed cylinders that had previously been used for MDU-derived material, resulting in cross-contamination. The levels of contamination are not known, but are likely to be very low and therefore no estimate has been made for the 2013 Derived Inventory.

A4.2 Plutonium

Material composition

Plutonium is separated from the uranium, transuranic elements and fission products in spent fuel by a process of solvent extraction. The multiple cycles of solvent extraction ensure that the plutonium stream has a high degree of chemical purity. Separated civil plutonium is stored as solid PuO_2 powder and it is assumed that this is the form of the material that would be disposed of.

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[40] Where decontamination factors can be compared with impurity levels in UO_3 product, they have been shown to be consistent.

The only information on impurities and their levels in separated plutonium indicates that uranium, fission products and non-volatile oxides in PuO_2 from spent oxide fuel reprocessing in THORP are present at very low levels. There may also be residual chemical species (eg nitrate) and trace metallic species from the corrosion of process equipment (eg iron and nickel from stainless steel). While contamination as a result of storage is likely to be present in pre-1980 PuO_2, their levels are unknown and are not quantified.

Plutonium therefore continues to be reported without impurities as no definitive data are available.

Radionuclide composition

The isotopic composition of separated plutonium is determined by reactor type, the initial enrichment of uranium in the fuel, the discharge burn-up and the duration of radioactive decay since discharge from the reactor.

The civil plutonium residues unsuitable for MOX fuel production (stream MPu001) are assumed to be older material from Magnox fuel reprocessing. This material has comparatively good isotopic quality (ie less Pu-241). However, there will be a degree of americium from ingrowth during storage. The discharge plutonium isotope composition adopted is based on Magnox fuel with a burn-up of 3 GWd/tU and 1 year cooled. The period of accumulation is assumed to be 1957 – 1961.

Small quantities of uranium and other species are likely to have been carried over into the plutonium stream during the chemical separation phase of SF reprocessing. The radioactivities of these impurities are calculated from typical SF compositions (ie the initial composition of the feed to the chemical separation plant) and reported mean decontamination factors that quantify the performance of the plant [A5]. The following decontamination factors are used:

- uranium (to PuO_2) 10^7
- fission products 3 10^8

A5 New build

The UK RWI does not contain estimated quantities of new build wastes. The source and justification for the use of inventory information on these wastes and SFs are based on the Implementing Geological Disposal White Paper [A6] and are detailed below. Operational and decommissioning wastes are considered separately to SFs. Operational wastes are assumed to arise at a constant rate from reactor start-up to final reactor shut-down. All new build reactor decommissioning wastes are assumed to arise 100 years after start-up [A7, A8] with waste arising over a ten year period (the same period as for the Sizewell B PWR). The arisings of SFs are assumed to be equally distributed over the 60 year lifetime of the reactors.

A5.1 ILW

A5.1.1 UK EPR

Unconditioned volumes and the numbers of disposal containers have been taken from the GDA PCSR [A9]. Unconditioned volumes and the numbers of waste packages for decommissioning waste have been taken from the NDA's GDA disposability assessment report [A7]. Table A18 gives the raw waste volumes and numbers of waste packages for UK EPRs. Conditioned and packaged volumes are derived from the number of disposal packages and the container payload and displacement volumes.

Table A18 Operational and decommissioning ILW quantities for six UK EPRs

Waste stream	Description	Stored volume (m^3)	Waste container	No. of packages
EP01	Ion exchange resin	1,080	1 m^3 concrete drum (40 mm steel)	2,880
EP02	Spent cartridge filters (ILW)	900	1 m^3 concrete drum (70 mm steel)	2,160
EP03	Spent cartridge filters (ILW + LLW)	900	500 l concrete drum (40 mm steel)	3,240
EP04	Operational waste > 2 mSv/hr	360	1 m^3 concrete drum (0 mm steel)	1,080
EP05	Wet sludge	360	1 m^3 concrete drum (0 mm steel)	720
EP301	Decommissioning: reactor vessel	138	4 m box (100 mm concrete)	60
EP302	Decommissioning: Upper and Lower reactor internals	60	3 m^3 box (side lifting)	150
EP303	Decommissioning: Lower reactor internals including heavy shield	108	3 m^3 box (side lifting)	276

A5.1.2 AP1000

Information on the numbers of waste packages and volumes of operational and decommissioning wastes has been taken from the NDA's GDA disposability assessment report [A8]. Table A19 gives the raw waste volumes and numbers of disposal packages for the AP1000 reactors. Conditioned and packaged volumes are derived from the number of disposal packages and the container payload and displacement volumes.

Table A19 Operational and decommissioning ILW quantities for six AP1000s

Waste stream	Description	Stored Volume (m^3)	Waste container	No. of disposal packages
AP01	Primary circuit filters	130	3 m^3 box (side lifting)	144
AP02	Primary resins	3,410	3 m^3 drum	6,120
AP03	Secondary resins	639	3 m^3 drum	1,150
AP301	Decommissioning: ILW steel	120	3 m^3 box (side lifting)	132
AP302	Decommissioning: Pressure vessel	234	3 m^3 box (side lifting)	258

A5.1.3 Radionuclide composition

Radionuclide inventories for the UK EPR and AP1000 have been taken from the GDA disposability assessment reports.

A5.1.4 Material composition

The approach to establishing the material composition of the nuclear new build wastes is:

1. use material components and grades given in the reference documents for the UK EPR [A7, A10] and AP1000 [A8, A11]
2. where information is not available, assume the same compositions as equivalent streams from the Sizewell B PWR

The redundant non-fuel core components (eg rod cluster control assemblies and thimble plugs) were not considered in the GDA work. As a result, no information is available on these components and they are not included in the 2013 Derived Inventory.

A5.2 SFs

Fuel for the new build reactors is assumed to be manufactured from fresh uranium and will be in the form of enriched UO_2[41]. However, the depleted uranium tails that are associated with the manufacture of the fuel are not included in the 2013 Derived Inventory. Instead, it is currently planned that RWM will consider the inclusion of additional depleted uranium in a sensitivity study.

Both the UK EPR and the AP1000 are assumed to discharge fuel with a burn-up of 65 GWd/tU. The radionuclide inventories for the SFs have been taken from the GDA reports and, for simplicity, the total arisings of the SFs are assumed to be equally distributed over the operational lifetime of the reactors. It is assumed that the SFs are disposed of directly, with three SF assemblies in a single disposal container. Based on judicious mixing of the SF assemblies, a storage period lasting until 57 years after the reactor shuts down will be required before the SF can be disposed of[42] [A12].

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[41] It is assumed that AP1000 fuel is enriched to 4.5% and UK EPR fuel to 5%.

[42] It is noted that the calculations assumed a diameter of 900 mm for the disposal container. The revised disposal container design has a larger diameter (1050 mm) and this will reduce the storage period that is required. The host-rock properties will also influence the required storage period.

The PCSR for the proposed Hinkley Point C UK EPR presents the number of SF assemblies for burn-ups of 50 GWd/tU and 65 GWd/tU [A13]. 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. For each UK EPR, the 2013 Derived Inventory includes 870 SF disposal containers.

For the AP1000, the NDA's GDA disposability assessment report estimates 640 disposal containers each containing four fuel assemblies with a burn-up of 65 GWd/tU over a reactor lifetime. However, this is a very conservative estimate[43] and a more realistic inventory of SF has been derived based upon the equivalent data for the UK EPR.

The fuel used for the AP1000 is very similar in geometry and composition to that used in the UK EPR. For a given fuel burn-up the heat output characteristics of the two fuel types would be very similar. Thus, it is found that an AP1000 reactor would generate 620 disposal containers, each containing three SF assemblies[44].

Radionuclide composition

Radionuclide inventories for the UK EPR and AP1000 have been taken from the GDA disposability assessment reports; the inventories include volumes and radionuclide inventories for ILW and SF. It is assumed that the burn-up of the SF is 65 GWd/tU and that the reactor lifetime is 60 years. Arisings for operational streams are split evenly over the lifetime of the reactor.

The material composition of the SF assemblies is given in the GDA disposability assessment reports [A7, A10, A8, A11] and Table A20 and Table A21 show the mass of each of the components that are present in a disposal container (ie equivalent to three SF assemblies).

Table A20 UK EPR SF components in a disposal container

Component	Material	Mass (t)
Fuel	UO_2 (U)	1.79 (1.58)
Cladding, grids & guide tubes within active region	Zircaloy M5	0.438
Cladding, grids & guide tubes outside active region	Zircaloy M5	$3.39\ 10^{-2}$
Upper & lower plug for fuel pin	Zircaloy M5	$3.87\ 10^{-3}$
Additional zircaloy M5 mass	Zircaloy M5	$1.03\ 10^{-2}$
Inconel 718 grid spring within active zone	Inconel 718	$1.98\ 10^{-3}$
Top nozzle spring	Inconel 718	$3.90\ 10^{-3}$
Plenum springs	Inconel 718	$7.20\ 10^{-3}$
Top & bottom nozzle	ALSL 304 L St. Steel	$4.38\ 10^{-2}$
Alumina insulating pellets	Al_2O_3	$1.79\ 10^{-2}$

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[43] The estimate in the GDA contains the maximum number of fuel assemblies (derived assuming a burn-up of 50 GWd/tU) and the maximum radionuclide inventory (derived assuming a burn-up of 65 GWd/tU).

[44] This estimate is based on the ratio of the output electrical energy (1.14 / 1.6) of the two reactors.

Table A21 Spent AP1000 fuel components in a disposal container

Component	Material	Mass (t)
Fuel	UO_2 (U)	1.84 (1.62)
Cladding	Zirlo	0.374
Cladding, grids & guide tubes outside active region	Zirlo	$8.79\ 10^{-2}$
Upper & lower plug for fuel pin	Inconel 718	$6.21\ 10^{-3}$
Additional zircaloy M5 mass	Inconel 718	$3.87\ 10^{-3}$
Inconel 718 grid spring within active zone	St Steel Type 304	$4.37\ 10^{-2}$
Top nozzle spring	Zirlo	$6.93\ 10^{-3}$
Plenum springs	Inconel 718	$5.46\ 10^{-3}$
Top & bottom nozzle	Al_2O_3	$1.70\ 10^{-3}$

A6 MOX

A6.1 MOX SF

Following discussions with NDA Strategy, RWM has assumed that the MOX fuel is irradiated to 50 GWd/tU in a PWR in order to create an illustrative radionuclide inventory. The composition of the unirradiated fuel is assumed to be as follows:

- 8 wt% plutonium
- the bulk of the fuel will be depleted uranium with an enrichment of 0.3%
- Am241 is present as 3.8 wt% of the mass of plutonium

The calculations for the MOX SF radionuclide inventory were carried out using ORIGEN and assumed a reactor thermal rating of 38 MW/tHM (roughly half-way between an AP1000 (40.1 MW/tHM) and a UK EPR (35.4 MW/tHM)[45]).

Since the illustrative calculations assume that the fuel is irradiated in a PWR, and since the parameters for the AP1000 and UK EPR fuel assemblies are similar, it has been decided to base the MOX fuel assemblies on the AP1000 and the UK EPR fuel assemblies. The parameters have been chosen as follows:

- the heavy metal mass per assembly will be the same as that in an AP1000 [A8] fuel assembly; this will maximise the inventory of fission products in a disposal container
- the amounts of cladding and other assembly components will be the same as that in a UK EPR [A7]; this will maximise the inventory of activation products in a disposal container

A summary of the material content of a MOX fuel assembly is presented in Table A22.

While the radionuclide inventory for the SF is appropriate to a burn-up of 50 GWd/tU, the cladding and impurities inventories are based on a burn-up of 61 GWd/tU. The apparent discrepancy between the burn-up assumed for the fuel and that assumed for the other components is assumed to be insignificant.

Table A22 MOX fuel assembly components used for calculations

Material	Mass (t)
UO_2 / PuO_2 (U / Pu)	0.613 (0.540)
Zircaloy M5	0.162
Inconel 718	$4.36\ 10^{-3}$
AISI 304L Stainless Steel	$1.46\ 10^{-2}$
Al_2O_3	$5.95\ 10^{-4}$

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[45] AP1000 and UK EPR ratings calculated from data in the GDA reports [A7, A8].

A7 Gas generation data

A7.1 Metal geometry data

Many ILW streams contain reactive metals that, through corrosion after disposal, generate gas. The consequences of the release of any gas to the human environment are determined in performance assessment calculations. The reactive metals are Magnox, aluminium and uranium. Other metals, including stainless and mild steels and Zircaloy, may also be important because of their large quantities in the wastes. Waste containers also comprise significant amounts of metals (mainly stainless steel, but some cast iron and mild steel are also used).

Mass and geometry information for each of the above metal types is used to analyse the rate of hydrogen production from the waste. Geometry is a determining factor because the exposed surface area of a material affects the rate of gas production.

Legacy waste mass and geometry information for the gas pathway assessment were prepared for the 2007 Derived Inventory. This information has been updated for the 2013 Derived Inventory using data from the 2013 UK RWI. A simple approach is used to derive a single plate thickness and single sphere thickness for each metal type; this is detailed below.

1. Consider the 2013 UK RWI mass data for stainless steel, mild steel (other ferrous metals), Magnox, aluminium, Zircaloy and uranium.
2. For each metal type, rank the streams by mass with the highest contributors to the total mass first. The top contributor streams are selected from the list until 90% of the mass is accounted for; only these streams are examined further.
3. Where waste stream properties are the same as in the 2007 Derived Inventory the existing calculated geometry and material thickness is retained.
4. Where new waste streams are included in the top contributors, or where waste stream properties are different, geometry and material thickness data are derived by examining the 2013 UK RWI data, comparing physical properties against analogous streams with similar geometry and applying expert judgement.
5. An average thickness / radius is calculated using a weighted average for each material in each waste group.
6. The results are scaled up to account for 100% of the material masses by assuming that the average effective plate thicknesses, sphere radii and plate to sphere ratio determined for those streams comprising 90% of the mass are indicative of the whole.

In addition, the metal content of waste disposal containers is considered. Certain waste containers are manufactured from stainless steel or cast iron (see Table C1 and Table C2). The stainless steel stillages disposed of with the 500 l drums are also taken into account.

As the 2013 UK RWI does not contain waste streams from new build reactors the methodology is to review publicly available reference material, and where no data can be found to adopt the equivalent data for Sizewell B waste streams. The outcome has been to adopt Sizewell B data for operational ILW streams (though the mass of metal in the operational ILW streams is very low) and specific data for the UK EPR and AP1000 reactor for decommissioning wastes [A14, A15].

A7.2 Breakdown of H3 and C14 by material type

A feature of ILW and LLW streams is that they contain materials that produce gas when they corrode, degrade or interact with radiation. Thus gas is generated by corrosion of metals, degradation of organic wastes (particularly cellulose) and by radiolysis. The most important gases volumetrically are hydrogen, carbon dioxide and methane. A small proportion of the gas generated can be radioactive, containing H3 and C14.

As part of the assessment of the gas pathway, an analysis of the material types associated with H3 and C14 inventories in wastes for the 2013 Derived Inventory is carried out. This information provides an important input to calculations to determine the rate of gas generation from ILW and LLW in the GDF environment. Since the current assumption is that the GDF will close in 2200, activities are considered at 2200.

A7.2.1 Method to calculate C14 by material type

The approach to the analysis comprises the following stages:

1. Rank waste streams in order of total C14 activity. Priority is given to streams that are the major contributors to the total C14 activity. (Approximately 90% of the C14 activity is in the top 20 waste streams that contribute to the C14 activity.)
2. Assign streams to a list of 14 material types (shown in Table A23).
3. Where there is more than one material type associated with significant fractions of C14 activity, methods are used to apportion the total stream activity between the material types.

Table A23 Material types used in the breakdown of C14 activity

Material code	Material description
G	Graphite
SS	Stainless Steel
MS	Other ferrous based alloys most likely to be low carbon / mild steel
Z	Zircaloy and Zirconium
NIM	Nimonic (nickel based) alloys such as Nimonic PE16 & 80A
MX	Magnox alloys AL80, ZR55, MN80, MN150
U	Uranium metal
MX – corroded	Magnox alloy corrosion products most likely to be $Mg(OH)_2$
U – corroded	Uranium metal corrosion products, ie UOx
Non Metal	Materials such as desiccant, ion exchange resin and barium carbonate arising from THORP operations
GEH	Specific GE Healthcare waste streams rich in C14 (1A07 & 1B05)
N/A	Not Assessed

Method A: When the waste stream contains more than one activated material

The apportioning of C14 activity assumes that this activity is generated by the thermal neutron activation of the nitrogen impurity content of the materials. This is calculated from the product of three factors:

M: the fraction of the waste stream associated with the material

N: the concentration (in ppm) of nitrogen in the material (the assumption is that C14 is primarily produced by the N14(n,p)C14 activation route)

F: the relative thermal neutron flux to which the material is exposed

The material fractions, M, are obtained from inventory waste stream data. The nitrogen concentration values, N, were largely taken as the 50th percentile values derived from the upper and lower bound precursor concentration data. The relative thermal flux data were derived in several ways, as follows:

- where all materials are irradiated in the fuelled region of the reactor core, F is taken as unity for all material types
- for AGR stringer debris streams that contain Nimonic PE16 tie bars that pass through the fuelled core region, and also graphite and steel components from outside the fuelled regions, Cl35(n, γ)Cl36 activation rates developed for Nirex's Cl36 project [A16] were used as a surrogate for thermal flux data (such an approach is valid as the energy dependence of the N14(n,p)C14 and Cl35(n, γ)Cl36 reactions are similar)
- in a small number of cases, such as with the steam generating heavy water reactor decommissioning stream 5G302, where detailed flux or activation rate information is not available but it is known that some of the activated materials have been irradiated in the fuelled core region and others were located just outside this region, F is taken as 0.1 for the ex-core materials and 1.0 for the in core materials

Method B: Apportioning Magnox and uranium to metal and corrosion products

A number of waste streams contain Magnox and / or uranium metal stored under water. In such cases these reactive metals undergo corrosion to oxide and / or hydroxide forms. The UK RWI generally does not quantify the fraction of uranium and Magnox metal that has been subject to corrosion while in wet storage. However, for the five MSSS streams (2D08, 2D09, 2D22, 2D24 and 2D35), a quantification is provided. For these waste streams the fractions of corrosion products are used to apportion the amounts of C14 between remaining metal and corrosion product.

Since the MSSS streams contain both Magnox and uranium metal, it is necessary to first apply Method A to estimate the fraction of the total stream activity initially present in the form of Magnox and uranium metal. These initial metal totals were then apportioned between the remaining metal and corrosion product according to the corrosion factors (see Table A24).

4. Develop estimates where waste streams contain irradiated U and Magnox metal but do not have C14 activity values.
5. When the total C14 activity associated with a waste stream is small, and it was not clear what material type the C14 is associated with, the activity contribution is assigned to a ‘Not Assessed – N/A’ category (The activity associated with the N/A waste streams amounts to less than 1% of the total C14 activity in the 2013 Derived Inventory).

Table A24 The fraction of the reactive metals that are corroded

Waste Stream ID	Material	Uncorroded (% of stream)	Corroded (% of stream)	Uncorroded + corroded (% of stream)	Corrosion factor [corroded / (uncorroded + corroded)]
2D08	Magnox	3.0	38.8	41.8	0.928
2D09	Magnox	6.0	38.0	44.0	0.864
2D24	Magnox	25.3	17.3	42.6	0.406
2D22	Magnox	21.0	25.1	46.1	0.544
2D35	Magnox	79.4	15.3	94.7	0.162
2D08	Uranium	1.0	1.7	2.7	0.630
2D09	Uranium	2.0	3.0	5.0	0.600
2D24	Uranium	7.9	4.7	12.6	0.373
2D22	Uranium	4.3	3.7	8.0	0.463
2D35	Uranium	2.7	2.6	5.3	0.491

A7.2.2 Method to calculate H3 by material type

A similar approach to that for C14 is carried out for H3. There are a small number of thermal neutron activation reactions with reactor materials and impurities that can result in H3 production. The principal mode of production is activation of lithium impurities present in uranium fuel and fuel structural materials. The nuclear reaction is Li6(n,α)H3[46].

Tritium exhibits complex behaviour during fuel irradiation and reprocessing. Tritium is particularly mobile, and can migrate for example through the fuel and fuel cladding. Tritium can also be absorbed by, or react with, solid material surfaces.

Lithium precursor concentrations in materials present in UK ILW and LLW subject to thermal neutron activation in reactors are given in Table A25 . These concentrations are largely 50th percentile values derived from upper and lower precursor concentration data. Most fuel structural materials show concentrations around 1 ppm.

Although the production of tritium is somewhat different from that of C14 (and tritium is mobile in reactor materials), a similar approach has been used for apportioning the H3 inventory to material types.

The apportioning of H3 activity where there is more than one activated material is determined by the following factors:

M: the fraction of waste stream mass associated with the material

N: the concentration (in ppm) of lithium in the material (it is assumed that the major H3 production route is the Li6(n,α)H3 activation reaction) with the exception of uranium where a nominal value of 1.0 ppm has been assumed

F: the relative thermal neutron flux to which the material has been exposed (the same values used for the C14 calculations are adopted)

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[46] Tritium is also produced in significant quantities in fuel as a ternary fission product and can be ‘manufactured’ by irradiation of Li6.

Table A25 Average lithium concentrations in reactor materials

Material	Lithium concentration (ppm)
Stainless steel 304	0.63
Stainless steel 20/25/Nb	0.79
Stainless steel 18/9	0.63
Mild steel	0.63
Magnox	~0.06
Zircaloy	0.51
Nimonic	0.85
Uranium	1.0 (nominal)
UO_2 (AGR)	0.2
UO_2 (LWR)	1.0 (nominal)
Reactor graphite (Magnox)	0.06
Reactor graphite (AGR)	0.17
Fuel graphite	0.67
Sintox	1.6

A8 Conditioning and capping materials

There are no conditioning or capping materials associated with legacy or new build SFs, or with RSCs. The methodology for assigning the conditioning and capping materials for the remaining wastes is described in the sections below.

A8.1 Legacy ILW and LLW conditioning materials

A review of the 2007 Derived Inventory methodology for quantifying the mass of conditioning materials in the legacy ILW and LLW packages has been carried out. The result is a revised methodology that utilises more of the data reported in the 2013 UK RWI. The main change is that for the majority of waste streams the mass of grout per cubic metre of payload is determined at an individual waste stream level with no categorisation (in the 2007 Derived Inventory waste steams were allocated to one of six categories). This is derived from disposal container waste loading volumes provided by the waste producers, or uses a surrogate waste stream that has the same or very similar characteristics. The revised methodology is detailed below.

1. For waste streams that are reported to be encapsulated directly in a cementitious matrix, calculate the volume of conditioning grout. This is the reported container payload volume minus the waste loading volume (Note: any capping grout is not part of the reported container payload volume).
2. For waste streams that undergo a pre-treatment volume change or have no estimate of waste loading, the volume of grout will be based on a surrogate stream. Surrogate streams will be selected as a ‘best match’ (ie those with the same, or very similar, characteristics).
3. Convert volume of conditioning grout to mass using a grout density of 1.8 t/m^3. (If a non-typical grout composition is reported an alternative density is used).
4. Use cement constituents (ie OPC, BFS / PFA) as reported in the 2013 UK RWI. Where no information is given, assume the following:
    - 3:1 BFS:OPC for solid wastes
    - 9:1 BFS:OPC for ion exchange materials, sludges and liquids
5. For the grout make-up, assume a typical water / cement (w / c) ratio of 0.4 (equivalent to 29% by mass water is cement grout).
6. Grout loadings for overpacked waste streams are calculated individually with 4 m boxes used to overpack type 1803 drums and 3 m^3 boxes to overpack non-standard drums.
7. For wastes conditioned in a polymer matrix encapsulant, loadings are calculated in the same way as for grout loadings and the relevant polymer density is used to calculate the mass.
8. Uncertainties in masses of conditioning grout are determined using the waste stream volume uncertainty factors reported in the 2013 UK RWI.
9. Waste streams packaged in 500 l RS drums and 3 m^3 RS boxes have no conditioning matrix.

A8.2 Legacy ILW and LLW capping materials

The steps used to enhance the data for capping materials are listed below.

1. Assign the volume and mass of capping grout to each waste stream according to the container type allocation (see Table A26).

2. The component make up of OPC and PFA are those used in the 2007 Derived Inventory (see Table A27). Full elemental compositions, including concentrations of minor components, are taken from the 2007 Derived Inventory.

Table A26 Volumes and masses of capping grout for waste containers

Waste container type	Capping grout		
	Volume (m^3)	Mass (t)	Type
UILW			
500 l drum	$3.5\ 10^{-5}$	0.06	Cement grout
Enhanced 500 l drum (pre-cast)	$3.5\ 10^{-5}$	0.06	Cement grout
Enhanced 500 l drum (basket)	$3.5\ 10^{-5}$	0.06	Cement grout
3 m^3 box (side lifting)	$2.0\ 10^{-4}$	0.33	Cement grout
3 m^3 box (corner lifting)	$2.0\ 10^{-4}$	0.33	Cement grout
3 m^3 drum	$1.83\ 10^{-4}$	0.3	Cement grout
MBGWS box	$2.0\ 10^{-4}$	0.33	Cement grout
3 m^3 Sellafield box	$2.0\ 10^{-4}$	0.33	Cement grout
3 m^3 Enhanced Sellafield box	$2.0\ 10^{-4}$	0.33	Cement grout
SILW			
2 m box (0 mm concrete)	$4.25\ 10^{-4}$	2.47	Iron-shot concrete
2 m box (100 mm concrete)	$3.46\ 10^{-4}$	2.01	Iron-shot concrete
2 m box (200 mm concrete)	$5.50\ 10^{-4}$	3.19	Iron-shot concrete
2 m box (300 mm concrete)	$6.36\ 10^{-4}$	3.69	Iron-shot concrete
4 m box (no shielding)	$8.97\ 10^{-4}$	5.2	Iron-shot concrete
4 m box (100 mm concrete)	$7.77\ 10^{-4}$	4.51	Iron-shot concrete
4 m box (200 mm concrete)	$1.33\ 10^{-3}$	7.71	Iron-shot concrete
4 m box (300 mm concrete)	$1.68\ 10^{-3}$	9.77	Iron-shot concrete
6 m^3 concrete box (SD)	$2.0\ 10^{-4}$	0.33	Cement grout
6 m^3 concrete box (HD)	$2.0\ 10^{-4}$	0	Cement grout

The volume and mass of capping grout for each container are given in Table A26. All capping grout is assumed to comprise OPC, PFA and water in the ratio 1:3:0.7, with the exception of 2 m and 4 m boxes, where the capping grout is iron-shot concrete (comprising 75% iron and 25% concrete by mass).

Table A27 Composition of materials used in waste conditioning grout

Waste container type	Typical composition (% by mass)		
	OPC	PFA	BFS
CaO	64.1	41.4	1.7
SiO_2	21.0	32.9	51.0
Al_2O_3	5.1	13.5	25.6
Fe_2O_3	3.1	0.8	9.6
MgO	2.5	8.3	1.6
SO_3	2.2	-	0.7
K_2O	0.7	0.4	3.8
Na_2O	0.3	0.2	-
C	-	-	2.8
Chloride	0.03	0.03	-
Sulphide	-	0.9	-
Free lime	0.8	-	-
Insolubles	0.3	-	-

Appendix A References

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Appendix B Waste Packaging

B1 Waste packaging rules

B1.1 Legacy ILW and LLW waste containers

RWM's illustrative geological disposal concept examples are based on three general waste container types: unshielded, shielded and robust shielded. The range of waste containers for which RWM has standardised designs is shown in Table B1. Where a transport container is required, a re-usable standard waste transport container (SWTC) is used; these transport containers have either 70 mm or 285 mm of steel shielding to satisfy dose rate requirements. However, in the case of the miscellaneous beta gamma waste store (MBWGS) box and the 500 l RS drum an SWTC with 150 mm of steel shielding will be used.

A number of the waste containers come with internal shielding:

- 500 l RS drums can have a range of thicknesses of internal lead shielding
- 2 m and 4 m boxes can have a range of thicknesses of internal concrete shielding

The 500 l RS drum and 3 m^3 RS box have not been included in previous Derived Inventories; the 3 m^3 RS Boxes are used for any ILW except higher activity items while the 500 l RS drums are used for higher activity items as additional lead shielding can be inserted. The properties of the full range of legacy ILW and LLW waste containers are listed in Table B2.

Table B1 Legacy waste containers for which RWM has standardised designs

Waste container	Transport container
500 l drum	SWTC with 70 mm or 285 mm of steel shielding
3 m^3 drum	
3 m^3 box (side lifting)	
3 m^3 box (corner lifting)[47]	
Miscellaneous Beta Gamma Waste store box	SWTC with 150 mm of steel shielding
500 l RS drum	
3 m^3 RS box	Transport container design to be based on that of an ISO freight container
2 m box	Waste containers are both waste and transport packages. A transport container is not required.
4 m box	
6 m^3 box	

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[47] The Sellafield 3 m^3 box and the Sellafield enhanced 3 m^3 box are instances of this container type.

Table B2 Legacy ILW and LLW waste containers in the 2013 Derived Inventory and their properties

Waste container	Preferred Material	Payload (m^3)	Displaced Volume (m^3)	Empty weight (t)
Unshielded ILW (UILW)				
500 l drum [48]	316L Stainless Steel	0.47	0.571	0.13
Enhanced 500 l drum (pre-cast) [49]	316L Stainless Steel / Concrete	0.40	0.571	0.40
Enhanced 500 l drum (basket) [50]	316L Stainless Steel	0.47	0.571	0.13
3 m^3 box (side lifting) [48]	316L Stainless Steel	2.7	3.27	0.75
3 m^3 box (corner lifting) [48]	316L Stainless Steel	2.8	3.61	0.75
3 m^3 drum [48]	316L Stainless Steel	2.2	2.61	0.40
MBGWS box	Mild Steel	3.5	4.7	2.0
3 m^3 Sellafield box [51]	Duplex 1.4462 SS / Concrete	2.8	3.3	1.3
3 m^3 Enhanced Sellafield box [52]	Duplex 1.4462 SS / Concrete	2.3	3.3	2.6
Shielded ILW (SILW)				
2 m box (0 mm concrete) [53]	316L Stainless Steel	9.5	10.2	3.0

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[48] Payload derived assuming a 200 mm gap between the top of the waste matrix and the underside of the lid; this gap will contain capping grout and ullage.

[49] Payload defined by Research Sites Restoration Ltd for B462 drums; empty weight includes 0.13 t of steel.

[50] Payload is the same as for a 500 l drum.

[51] Empty weight includes 0.7 t of steel.

[52] Empty weight includes 1.5 t of steel.

[53] Payload and displacement volumes are for 2 m boxes with flat side panels. Payload for 2 m box (no shielding) assumes 100 mm thick capping and ullage between the waste matrix and underside of the lid. Payloads for the shielded boxes assume the thickness of the capping and ullage between the waste matrix and underside of the lid are the same as the shielded thickness of the side and base panels. The empty mass of the shielded variants includes 3 t of steel.

Waste container	Preferred Material	Payload (m^3)	Displaced Volume (m^3)	Empty weight (t)
2 m box (100 mm concrete) [53]	316L Stainless Steel / Concrete	6.9	10.2	10.0
2 m box (200 mm concrete) [53]	316L Stainless Steel / Concrete	4.9	10.2	15.0
2 m box (300 mm concrete) [53]	316L Stainless Steel / Concrete	3.4	10.2	18.5
4 m box (0 mm concrete) [54]	316L Stainless Steel	18.9	20.0	5.0
4 m box (100 mm concrete) [54]	316L Stainless Steel / Concrete	14.3	20.0	17.5
4 m box (200 mm concrete) [54]	316L Stainless Steel / Concrete	10.9	20.0	22.5
4 m box (300 mm concrete) [54]	316L Stainless Steel / Concrete	8.1	20.0	29.5
6 m^3 concrete box (SD) [51]	Reinforced Concrete / mild steel	5.76	11.9	14.0
6 m^3 concrete box (HD) [51]	Magnetite concrete / mild steel	5.76	11.9	26.0
RSCs				
3 m^3 RS box	Cast Iron	2.547	5.44	18.3
500 l RS drum (0 mm Pb)	Cast Iron	0.441	1.32	5.73
500 l RS drum (20 mm Pb)	Cast Iron / lead	0.364	1.32	6.5
500 l RS drum (30 mm Pb)	Cast Iron / lead	0.335	1.32	6.85
500 l RS drum (60 mm Pb)	Cast Iron / lead	0.262	1.32	7.77
500 l RS drum (80 mm Pb)	Cast Iron / lead	0.219	1.32	8.31
500 l RS drum (90 mm Pb)	Cast Iron / lead	0.20	1.32	8.55
500 l RS drum (120 mm Pb)	Cast Iron / lead	0.149	1.32	9.23

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[54] Payload and displacement volumes are for 4 m boxes with corrugated side panels. Payloads for 4 m box (no shielding and shielded) are based on the same assumptions as for the 2 m box. The empty mass of the shielded variants includes 5 t of steel.

B1.2 Waste container review

The 2013 UK RWI provides information on the waste container types that the waste producers are using for the waste that is being packaged or are proposing to use for wastes that will be packaged in the future. Where the waste producer has specified a particular container type or types for a waste stream, this allocation is used for the 2013 Derived Inventory unless specifically identified for modification.

There are a number of categories of waste stream where information in the 2013 UK RWI is subject to further consideration and potential amendment:

- where the container type has not been specified
- where RWM has decided that it is appropriate to review the waste container type
- where another / bespoke / non-standard container is specified and this might be overpacked
- where a waste stream has been allocated more than one container type

These four categories are discussed further below.

B1.2.1 Waste streams with an unspecified container type

Where the waste producer has not specified the waste container type in the 2013 UK RWI, the following assumptions are made:

- operational ILW streams are packaged in 500 l drums except for the following:
    - compactable waste streams (eg plutonium contaminated materials) are packaged in enhanced (annular grouted) 500 l drums with a pre-cast annulus (note no waste streams in the 2013 UK RWI fall into this category)
    - waste streams comprising larger components unsuitable for 500 l drums are packaged in 3 m^3 boxes (side lifting)
- decommissioning ILW streams are packaged in 4 m ILW boxes or 3 m^3 boxes (side lifting). The allocation is made with reference to the packaging of similar waste streams or other waste streams from the same site

Where the waste stream was in the 2010 Derived Inventory and its characteristics are unchanged, that allocation is adopted. Since waste container allocations are carried over from previous inventories (where appropriate), some of the allocations have been made using a methodology that differs slightly from that outlined above[55]. Applying these rules to the waste streams with no specified container type allocated gives the allocations shown in Table B3.

Table B3 Waste steams with no specified waste container in the 2013 UK RWI

Waste stream	Waste type	Description	2013 DI container
1A10	ILW	ILW containing radium	500 l drum
2F26	ILW	LWR pond sludge	500 l drum
2F27	ILW	AGR pond sludge	3 m^3 drum
2N01	ILW	PCM[56]; drummed (legacy drums)	3 m^3 box (side lifting)
2S11	ILW	Windscale uranic residues	500 l drum

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[55] For example, the waste container for 2F27 was assigned as part of the 2004 Derived Inventory.

[56] Plutonium contaminated materials

Waste stream	Waste type	Description	2013 DI container
2S310	ILW	AGR examination caves ILW	Sellafield 3 m^3 box
5C08	ILW	ILW concrete lined drums	Sellafield 3 m^3 box
5C310	ILW	Decommissioning waste handling facilities ILW	Sellafield 3 m^3 box
5C317	ILW	Harwell contact handled ILW drums	Sellafield 3 m^3 box
5H08	ILW	ILW hard non-compactable materials	500 l drum
6K101	ILW	Am / Be sources	Sellafield 3 m^3 box
6K102	ILW	Cadmium and aluminium linings	Sellafield 3 m^3 box
6K103	ILW	Control rods	Sellafield 3 m^3 box
6K104	ILW	Core support plate	Sellafield 3 m^3 box
6K105	ILW	Graphite columns	Sellafield 3 m^3 box
6K106	ILW	Irradiation tubes	Sellafield 3 m^3 box
6K107	ILW	Miscellaneous stainless steel items	Sellafield 3 m^3 box
7A23	LLW	Operational LLW above the LLWR limit	500 l drum
7A36	ILW	Pyrochemical wastes	500 l drum
7A40	ILW	Experimental metallic vessels	3 m^3 box (side lifting)
7A108	LLW	Decommissioning LLW above the LLWR limit	4 m box (0 mm concrete)
7J27	ILW	Intermediate level tritium waste	500 l drum
7V24	ILW	Metallic ILW from Vulcan	3 m^3 box (side lifting)
7V25	ILW	Resin from decontamination operations	500 l drum
8A01	ILW	Feed filter material	500 l drum
9E61	ILW	Fuel skips in pond	3 m^3 box (side lifting)
9F39	ILW	AETP filters – sand and gravel	3 m^3 box (side lifting)
9G55	ILW	Oil	500 l drum
9G64	ILW	Miscellaneous contaminated items	3 m^3 box (side lifting)

B1.2.2 Waste streams where the 2013 UK RWI container allocation is reviewed

The considerations below are made.

- For higher radiation level AGR waste streams (these include tie bars, fuel stringer debris and miscellaneous activated components), any 2013 UK RWI waste container allocation of a 4 m box with 100 mm of shielding is reviewed with reference to dose rates at the time of packaging (these are waste streams being stored on site until final site clearance). Where dose rate limits are not satisfied, a change in waste container allocation is made. Table B4 lists the waste streams where the waste container allocations have been changed along with the revised waste container allocations; Table B5 lists the waste streams that have been reviewed and have not had their waste container allocations changed (all container allocations are 4 m box (100 mm concrete shielding)). All waste streams considered are ILW.

- Wastes allocated to 2 m or 4 m ILW boxes with 300 mm of concrete shielding are reallocated to 3 m^3 boxes (side lifting), as 300 mm of shielding is considered to give a non-practical payload volume. Table B6 lists the waste streams and gives the revised container allocations.
- The allocation of container type for Sizewell B final decommissioning ILW streams arising near the time of reactor shutdown are reviewed with reference to dose rates. Table B7 lists the waste streams and container allocations.

The waste container allocations for all wastes streams, including those for which radionuclide data have been enhanced, were reviewed to ensure they are suitable for meeting the maximum dose rate and heat output criteria. As a result the container for three waste streams for Winfrith was changed (see Table B8).

Table B4 Waste streams with higher radiation levels that have had their waste container reassigned

Waste stream	Description	2013 UK RWI container	2013 DI container
3J24	Neutron Scatter Plugs	4 m box (100 mm concrete)	3 m^3 box (side lifting)
3J26	Miscellaneous activated components – debris vault 1	4 m box (100 mm concrete)	3 m^3 box (side lifting)
3J27	Miscellaneous activated components & fuel stringer debris – debris vault 2	4 m box (100 mm concrete)	3 m^3 box (side lifting)
3K24	Miscellaneous activated components – spalled oxide & dust	4 m box (100 mm concrete)	4 m box (200 mm concrete)
3K25	Miscellaneous activated components – debris vault 4	4 m box (100 mm concrete)	3 m^3 box (side lifting)
3K28	Miscellaneous activated components – tie bars &end nuts	4 m box (100 mm concrete)	3 m^3 box (side lifting)
3K30	Miscellaneous activated components & fuel stringer debris – debris vault 2	4 m box (100 mm concrete)	3 m^3 box (side lifting)
3L20	Miscellaneous activated components – debris vault 3	4 m box (100 mm concrete)	4 m box (200 mm concrete)
3L21	Miscellaneous activated components - spalled oxide and dust	4 m box (100 mm concrete)	4 m box (200 mm concrete)
3L22	Fuel stringer debris - debris vault 4	4 m box (100 mm concrete)	3 m^3 box (side lifting)
3L23	Miscellaneous activated components - tie bar ends & nuts	4 m box (100 mm concrete)	3 m^3 box (side lifting)
3L25	Miscellaneous activated components & fuel stringer debris - debris vault 2	4 m box (100 mm concrete)	3 m^3 box (side lifting)
3M22	Miscellaneous activated components & fuel stringer debris	4 m box (100 mm concrete)	4 m box (200 mm concrete)
3N38	Miscellaneous activated components & fuel stringer debris - debris vault 1	4 m box (100 mm concrete)	3m^3 box (side lifting)
3S09	Miscellaneous activated components	4 m box (100 mm concrete)	3m^3 box (side lifting)

Table B5 AGR waste streams with higher radiation levels that have not had their waste container reassigned (all streams packaged in a 4 m box (100 mm shielding))

Waste stream	Description
3J09	Miscellaneous activated components – debris vault 3
3K09	Miscellaneous activated components – debris vault 1
3K23	Miscellaneous activated components – debris vault 3
3L09	Miscellaneous activated components – debris vault 1
3N39	Miscellaneous activated components & fuel stringer debris - debris vault 2
3N40	Miscellaneous activated components - debris vault 3
3N41	Miscellaneous activated components - debris vault 4

Table B6 Waste streams packaged in 2 m or 4 m boxes with 300 mm of concrete shielding

Waste stream	Waste type	Description	2013 UK RWI container	2013 DI container
9A312	ILW	Miscellaneous metal (reactor) ILW	4 m box (300 mm concrete)	3 m^3 box (side lifting)

Table B7 Sizewell B final decommissioning ILW streams

Waste stream	Waste type	Description	2013 UK RWI container	2013 DI container
3S02	ILW	Decommissioning: Mild Steel ILW	4 m box (100 mm concrete)	3 m^3 box (side lifting)
3S306	ILW	Decommissioning: Stainless Steel ILW	4 m box (100 mm concrete)	3 m^3 box (side lifting)
3S307	ILW	Decommissioning: Concrete ILW	4 m box (100 mm concrete)	3 m^3 box (side lifting)

Table B8 Waste streams with reassigned container following review

Waste stream	Waste type	Description	2013 UK RWI container	2013 DI container
5G01	ILW	Miscellaneous Reactor Hardware ILW	6 m^3 concrete box (SD)	6 m^3 concrete box (HD)
5G04	ILW	Miscellaneous ILW	6 m^3 concrete box (SD)	6 m^3 concrete box (HD)
5G302	ILW	SGHWR[57] Decommissioning ILW	6 m^3 concrete box (SD)	6 m^3 concrete box (HD)

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[57] Steam generating heavy water reactor

B1.2.3 Waste streams in non-standard containers

Waste streams where another / bespoke / non-standard container is specified in the 2013 UK RWI are considered with respect to overpacking in a standard waste container. These waste streams are presented in Table B9. Comparisons are made with similar waste streams or other waste streams from the same site, and where the waste stream is in the 2010 Derived Inventory that allocation is taken into account.

Table B9 Waste streams with a non-standard container type

Waste stream	Waste type	Description	2013 UK RWI container	2013 DI container
1A08	ILW	Decay Stored Waste	Half-height ISO	3 m³ box (side lifting)
2A303	LLW	Final Dismantling & Site Clearance: Graphite LLW	Half-height ISO	4 m box (0 mm concrete)
2D42	ILW	Magnox Pond Furniture	Half-height ISO	3 m³ box (side lifting)
2F15	ILW	LWR Pond Furniture (MEBs[58])	Half-height ISO	3 m³ box (side lifting)
3J04	ILW	Desiccants ILW	Half-height ISO	3 m³ drum
3J20	ILW	Catalysts ILW	Half-height ISO	3 m³ drum
3J25	ILW	Gag Pistons	Half-height ISO	500 l drum
3K04	ILW	Desiccant	Half-height ISO	3 m³ drum
3K22	ILW	Catalyst	Half-height ISO	3 m³ drum
3K29	ILW	Bypass Blowdown Filters	Half-height ISO	3 m³ box (side lifting)
3L04	ILW	Desiccant	Half-height ISO	3 m³ drum
3L19	ILW	Catalyst	Half-height ISO	3 m³ drum
3L24	ILW	Bypass Blowdown Filters	Half-height ISO	3 m³ box (side lifting)
3M04	ILW	Desiccant	Half-height ISO	3 m³ drum
3M17	ILW	Catalysts	Half-height ISO	3 m³ drum
3N04	ILW	Desiccants and Catalysts	Half-height ISO	3 m³ drum
3S03	ILW	Spent Cartridge Filters (ILW)	Shielded 500-litre drum	3 m³ box (side lifting)
7D24	ILW	ILW Reactor Components	Half-height ISO	4 m box (100 mm concrete)
7D29	ILW	Intermediate Level Waste Resin from Plant Decontamination	Half-height ISO	500 l drum

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[58] Multi-element bottles

Waste stream	Waste type	Description	2013 UK RWI container	2013 DI container
		(MODIX)		
7D40	ILW	ILW PCD Ion Exchange Resin	Half-height ISO	3 m³ drum
7D41	ILW	ILW Submarine Ion Exchange Resin	Half-height ISO	3 m³ drum
7E27	ILW	Submarine Ion Exchange Resin	Half-height ISO	3 m³ drum
7E29	ILW	Intermediate Level Ion Exchange Resin (Decontamination)	Half-height ISO	3 m³ drum
9A18	ILW	Desiccant	Half-height ISO	3 m^3 RS box
9B13	ILW	Desiccant	Half-height ISO	3 m^3 RS box
9B13/C	ILW	Desiccant	Half-height ISO	3 m^3 RS box
9C14	ILW	Desiccant	Half-height ISO	3 m^3 RS box
9C44	ILW	Fuel Skips in Pond	Half-height ISO	3 m³ box (side lifting)
9C45	ILW	Fuel Skips in Pond	Half-height ISO	3 m³ box (side lifting)
9C63	ILW	AETP Sludge	Third-height ISO	3 m^3 RS box
9D18	ILW	Desiccant	Half-height ISO	3 m^3 RS box
9E47	ILW	Desiccant	Half-height ISO	3 m^3 RS box
9F14	ILW	Desiccant and Catalyst from Gas Conditioning Plant	Half-height ISO	3 m^3 RS box
9F42	ILW	AETP Filters - Sand and Gravel	Half-height ISO	3 m^3 RS box
9G113	ILW	CDVAR Plates	Half-height ISO	4 m box (0 mm concrete)
9H02	ILW	Desiccant	Half-height ISO	3 m^3 RS box

B1.2.4 Waste streams where more than one container type has been allocated

RWM's DIQuest database currently accommodates only one container type per waste stream. Hence, waste streams which are reported in the 2013 UK RWI as being packaged using two container types are split into two streams with suffixes 'a' and 'b'. There are no streams with more than two container types specified. Waste volumes are allocated to the 'a' and 'b' waste streams on the following basis:

- Information in the 2013 UK RWI
- A 50: 50 volume split

Applicable waste streams (all of which are ILW streams) are listed in Table B10.

Table B10 Waste streams with more than one container type

Waste stream	Description	2013 Derived Inventory container
2S312a	Other facilities decommissioning ILW	Assumed 80% Sellafield 3 m^3 box based on 2010 UK RWI
2S312b	Other facilities decommissioning ILW	Assumed 20% MBGWS box based on 2010 UK RWI
6C31a	NDS Contact Handled ILW	Assumed 50% 500 l drum (basket)
6C31b	NDS Contact Handled ILW	Assumed 50% 3 m^3 box (side lifting)
9A60a	FED Magnox from Post Irradiation Examination	95% 3 m^3 RS box
9A60b	FED Magnox from Post Irradiation Examination	5% 500 l RS drum (120 mm Pb)
9A61a	FED Magnox from Post Irradiation Examination	95% 3 m^3 RS box
9A61b	FED Magnox from Post Irradiation Examination	5% 500 l RS drum (120 mm Pb)
9A62a	FED Magnox from Post Irradiation Examination	95% 3 m^3 RS box
9A62b	FED Magnox from Post Irradiation Examination	5% 500 l RS drum (120 mm Pb)
9A63a	FED Magnox from Post Irradiation Examination	95% 3 m^3 RS box
9A63b	FED Magnox from Post Irradiation Examination	5% 500 l RS drum (120 mm Pb)
9A64a	FED Magnox from Post Irradiation Examination	95% 3 m^3 RS box
9A64b	FED Magnox from Post Irradiation Examination	5% 500 l RS drum (120 mm Pb)
9A65a	FED Magnox from Post Irradiation Examination	95% 3 m^3 RS box
9A65b	FED Magnox from Post Irradiation Examination	5% 500 l RS drum (120 mm Pb)

B1.3 New Build ILW

Based on PWR operational experience in France, it is envisaged that operational ILW from a UK EPR will be packaged in reinforced 500 l and 1 m^3 concrete drums. There is no capping grout associated with the 500 l and 1 m^3 concrete drums. Proposals for the packaging of decommissioning ILW are based on the use of larger waste containers consistent with the 3 m^3 box (side lifting) and 4 m box (100 mm concrete).

The GDA report for the AP1000 states that operational ILW will be packaged in 3 m^3 boxes (side lifting) and 3 m^3 drums. Decommissioning ILW will be packaged in 3 m^3 boxes (side lifting). The properties of the 500 l and 1 m^3 concrete drums that are used are presented in Table B11; properties for the other proposed containers for new build ILW have been presented in Table A26 and Table B2.

Table B11 Properties of the 500 l and 1 m^3 concrete drums used for new build ILW

Waste container	Preferred Material	Payload (m^3)	Displaced Volume (m^3)	Empty weight (t)
Shielded ILW (SILW)				
1 m^3 concrete drum (0 mm steel)	Concrete / Mild Steel	0.883	2.00	2.65
1 m^3 concrete drum (40 mm steel)	Concrete / Mild Steel	0.621	2.00	4.06
1 m^3 concrete drum (70 mm steel)	Concrete / Mild Steel	0.509	2.00	4.94
500 l concrete drum (40 mm steel)	Concrete / Mild Steel	0.291	1.24	2.75

B1.4 Verification of ILW and LLW waste and transport container allocations

Legacy and new build ILW and LLW stream container allocations are entered into the 2013 Derived Inventory dataset in DIQuest, which is then used to generate package dose rates, heat outputs, A_2 values, and the fissile status of packages. These are then compared with numerical limits given in specifications and regulations.

It is assumed that all waste streams packaged in unshielded containers (eg 500 l drums, 3 m^3 boxes, 3 m^3 drums) will be transported to the GDF in SWTCs. This transport container will have 70 mm, 150 mm (MBGWS boxes and 500 l RS drums only) or 285 mm of steel shielding in order to meet limits on dose rates. DIQuest automatically assigns the appropriate transport container (to meet IAEA regulations) for a waste stream packaged in an unshielded waste container.

The waste and transport container numerical limits that DIQuest checks are shown in Table B12. If these limits are exceeded by greater than 25% on the expected date of transport then the waste container allocations are revised. For shielded containers an extra 100 mm of concrete shielding is taken to reduce dose rates by a factor of 1.5 (a conservative assumption based on the high energy gamma emissions from Co60). Waste streams in a 2 m box or 4 m box where 200 mm of concrete shielding is insufficient are reallocated to a 3 m^3 box (side lifting). Where waste streams in unshielded containers exceed dose rate limits for a transport container with 285 mm of steel shielding, the waste loading volume in the container is reduced so that dose rates are below the limits.

Table B12 Waste package dose rate and heat output limits applied in verification of container allocations

Package[59, 60]	Heat output limit at transport	Dose rate limit[61]
500 l drum [B1] (standard or enhanced)	100 W per drum	1 m outside surface of SWTC containing 4 drums = 0.1 mSv hr^{-1} 0 m from surface of SWTC containing 4 drums = 2 mSv hr^{-1}
3 m^3 box (side lifting) [B2] 3 m^3 box (corner lifting) [B3] 3 m^3 drum [B4] MBGWS box [B5]	400 W	1 m outside surface of SWTC containing 1 box = 0.1 mSv hr^{-1} 0 m from surface of SWTC containing 1 box = 2 mSv hr^{-1}
4 m box [B6]	200 W	1 m outside surface of box = 0.1 mSv hr^{-1} 0 m from surface of box = 2 mSv hr^{-1} 3 m outside unshielded waste = 10 mSv hr^{-1}
2 m box [B7] 6 m^3 concrete box [B8]	60 W	
500 l RS drum [B9]	400 W	
3 m^3 RS box [B10] 500 l concrete drum [B11] 1 m^3 concrete drum [B12]	No information available	

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[59] If multiple units are handled in an overpack then there may be a more constraining limit.

[60] The waste package specifications for RSCs, the 500 l concrete drum and the 1 m^3 concrete drum were not available at the time this work was carried out.

[61] The dose rates shown are the dose rates against which the waste packages were reviewed, which assumed that transport would take place under the conditions of non-exclusive use. However, since this work was carried out, use of the dose rate limits appropriate to exclusive use of a transport consignment have been approved through RWM's change management process. This changes the dose rate limits: the 0.1 mSv hr^{-1} limit applies at 2 m from the surface of the transport container rather than 1 m from the transport container; and the dose rate limit on the surface of the transport container increases from 2 mSv hr^{-1} to 10 mSv hr^{-1}. The limits used in this work are conservative.

B2 Containers for nuclear materials

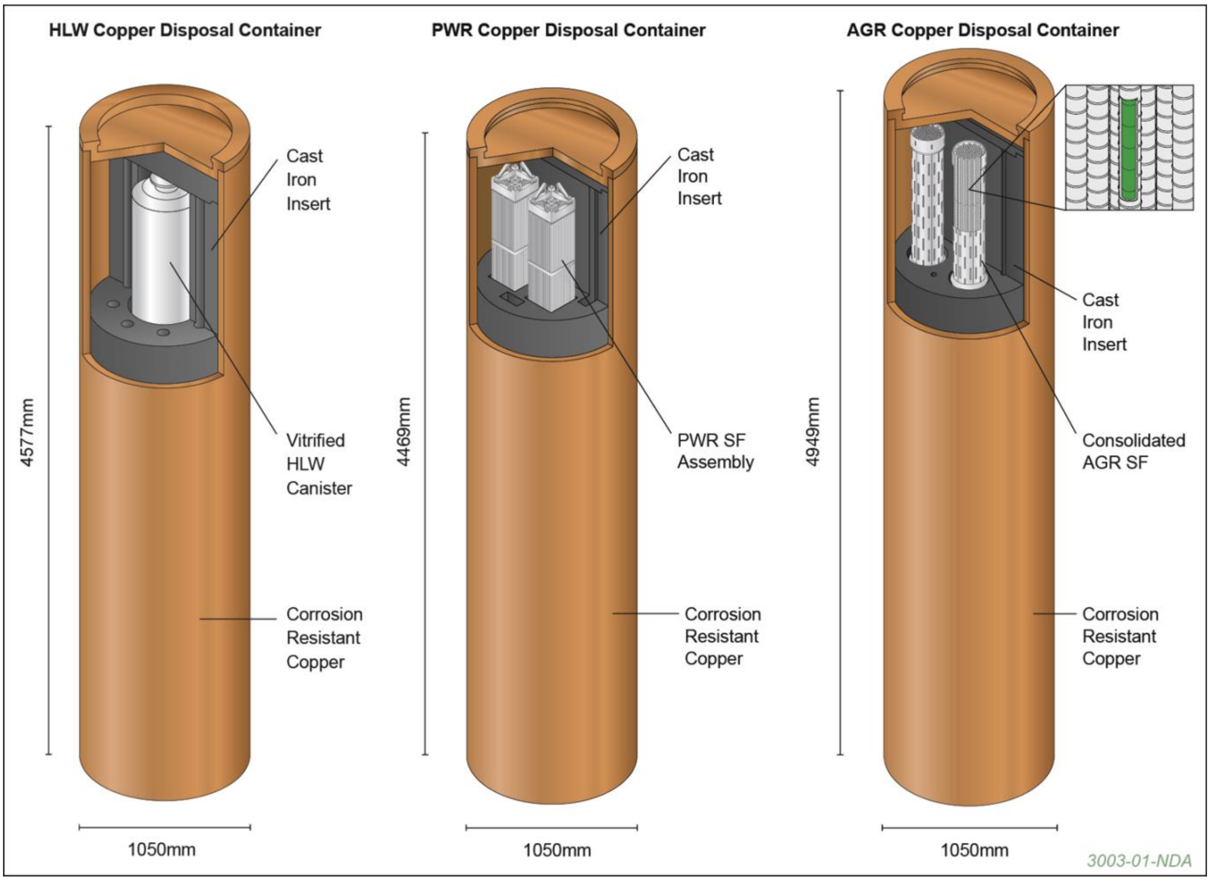
B2.1 Containers for SFs, HLW, plutonium and highly enriched uranium

RWM has two variant designs of the disposal containers for AGR SF, PWR SF and HLW [B13]:

- Variant 1: a long lived disposal container designed for a higher strength host rock and based on SKB's copper / cast iron KBS-3 disposal canister concept [B14]
- Variant 2: a short lived disposal container designed for a lower strength sedimentary host rock and based on NAGRA's mild steel disposal canister concept [B15]

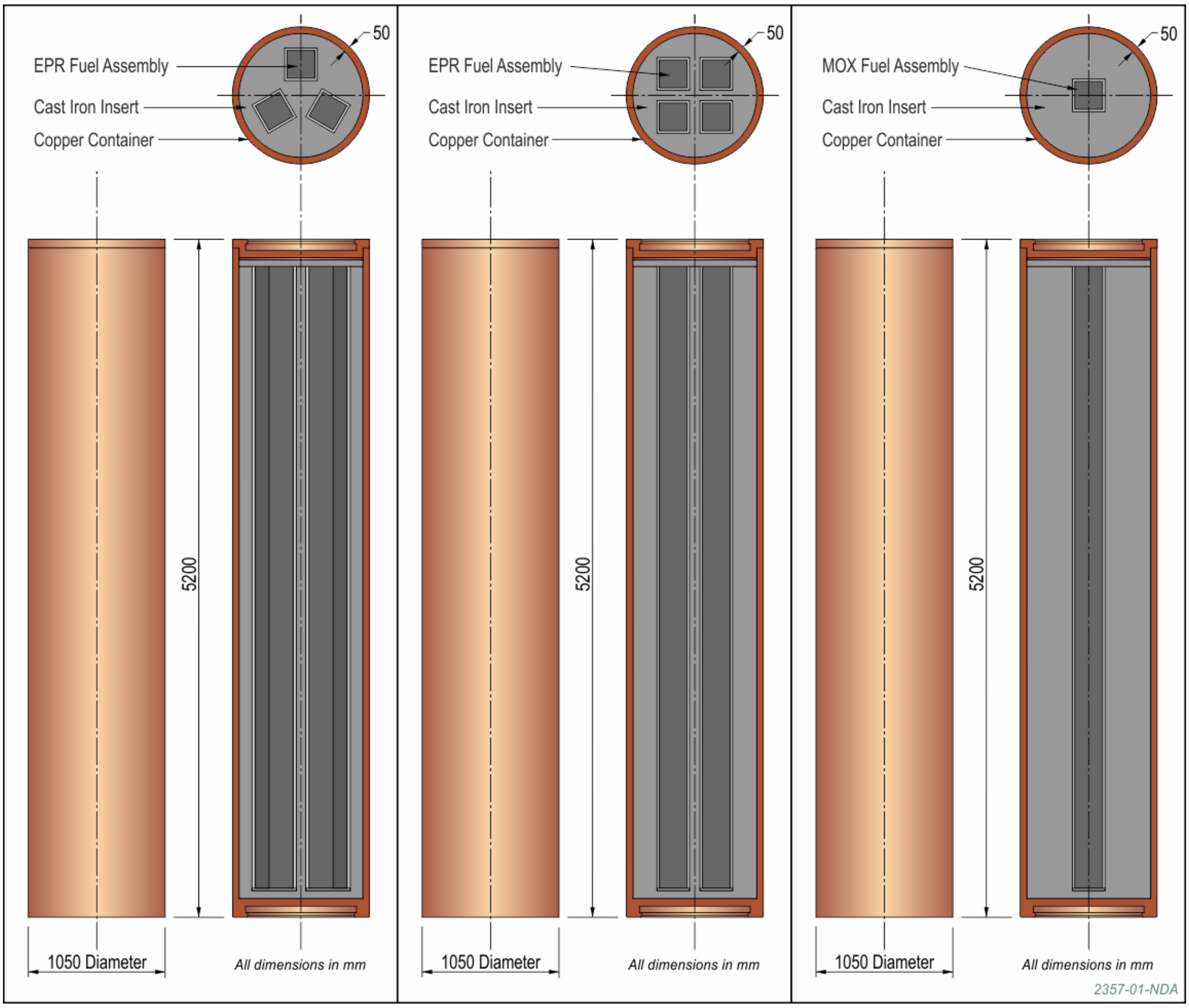
For the purposes of quantifying a single inventory for disposal, it is assumed that the Variant 1 disposal container is used. However, since the packages are similar in terms of dimensions, the only Derived Inventory parameters that would change significantly are the material masses and elemental compositions.

Figure B1 Drawings of the disposal containers for HLW, PWR SF and AGR SF



HLW is conditioned by immobilising it in glass (vitrification) in stainless steel WVP canisters. Three WVP canisters are assumed to be packaged into a single disposal container, while four spent PWR fuel assemblies are assumed to be disposed of, intact, 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 B1 shows the disposal containers for HLW, AGR SF and PWR SF.

Figure B2 Disposal containers for the new build and MOX SFs



It is assumed that other SFs would also be disposed of in similar disposal containers. The new build programme is assumed to consist of only UK EPR and AP1000 reactors[62] and the fuel assemblies for these reactors have very similar dimensions[63]. It is assumed that a single disposal container design will be used for both types of SF assemblies. Thermal constraints, combined with the (assumed) high burn-up of 65 GWd/tU of these fuels mean that three rather than four SF assemblies will be disposed of in a single disposal container. If the SF assemblies had a lower burn-up then it would be possible to dispose of four in a single disposal container. Illustrations for both are presented in Figure B2.

MOX fuel assemblies are assumed to have similar dimensions to the UK EPR and AP1000 fuel assemblies. As a result of thermal constraints and the high thermal output of a spent MOX fuel assembly, it is currently assumed that there is only a single assembly in a disposal container (shown in Figure B2).

Although the Sellafield legacy ponds fuels are likely to comprise various fuel types from a number of sources, the majority are likely to be Magnox reactor fuel. It is assumed that 26

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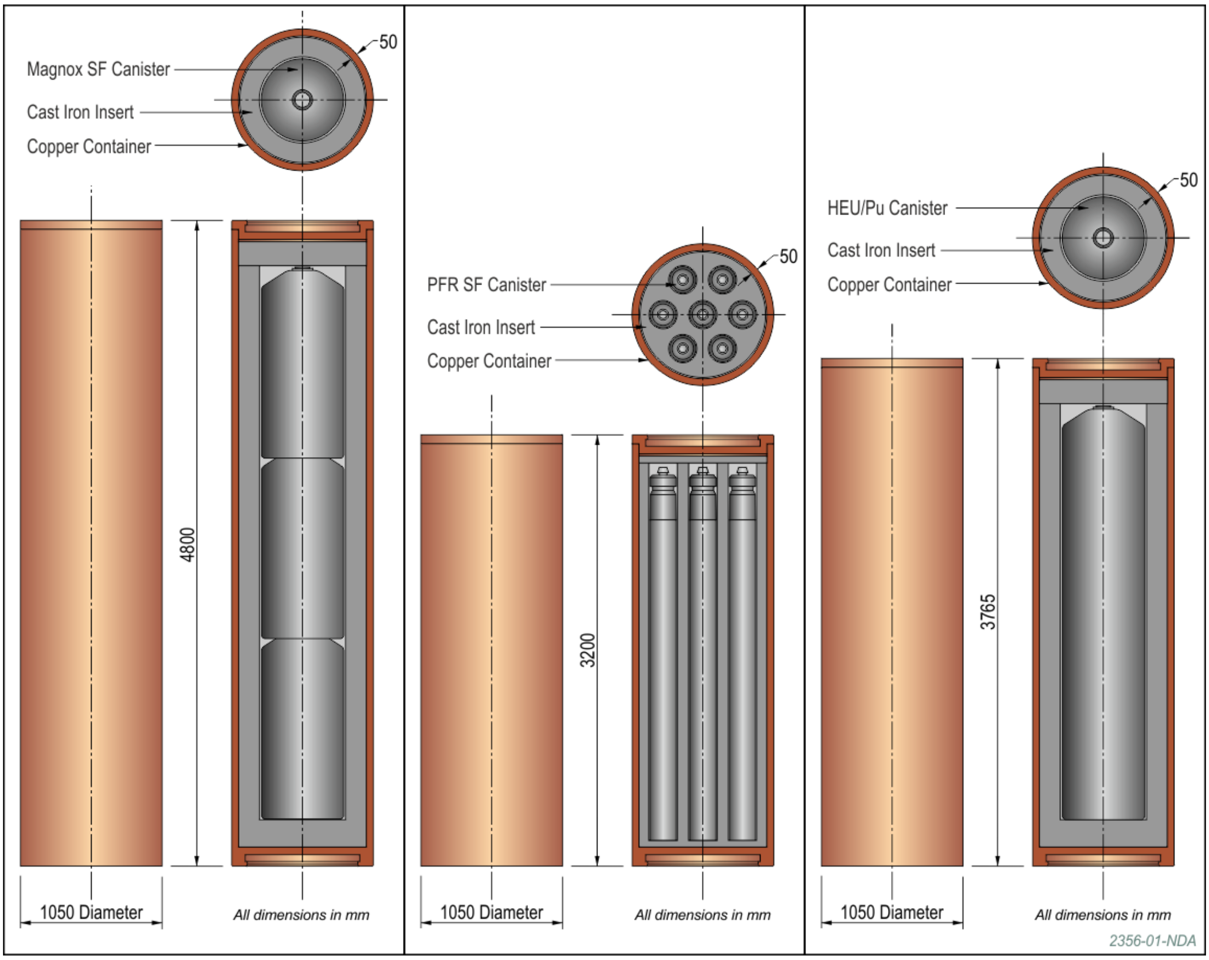
[62] As discussed in Section 2.3, UK ABWRs have not been included as a generic design assessment disposability assessment report has not been published for this reactor type.

[63] Both UK EPR and AP1000 fuel assemblies have the same cross sectional area as (and are about 700 mm longer than) Sizewell B fuel assemblies.

Magnox fuel elements will be packaged inside a fuel canister, and that three fuel canisters are stacked in a single disposal container, as shown in Figure B3.

It is assumed that seven PFR SF assemblies are disposed of in a single disposal container, as shown in Figure B3.

Figure B3 Disposal containers for legacy ponds fuels, PFR SF and Pu / HEU



The can-in-canister concept is assumed for HEU and residual plutonium (that plutonium which is not suitable for fabrication into MOX). 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 the disposal container, as shown in Figure B3.

The packaging assumptions for SFs, HLW and Pu / HEU have not been optimised and do not foreclose other options. As a result, the packaging assumptions are subject to change.

B2.1.1 Package materials data

The materials used in the disposal containers are shown in Table B13 along with the payload volumes and the packaged volumes of the disposal containers. The data for the HLW, AGR SF and PWR SF disposal containers are based on technical drawings, while the data for the other disposal containers are based on the illustrative drawings shown in Figure B2 and Figure B3. The material masses have been calculated for the disposal containers assuming the density of copper to be 8.90 t/m^3, the density of cast iron to be 7.20 t/m^3 and the density of carbon steel to be 7.85 t/m^3.

Table B13 The materials used in the disposal containers

Disposal container	Payload (m^3)	Package volume (m^3)[64]	Copper mass (t)	Cast iron mass (t)	Carbon steel mass (t)	Total mass (t)
HLW	0.583	3.87	7.41	15.8	1.06	24.2
AGR SF	0.885	4.19	7.93	16.7	0.25	24.9
PWR SF	0.744	3.78	7.26	14.3	0.25	21.8
Magnox SF	1.20	4.06	7.66	14.1	0.00	21.7
PFR SF	0.597	2.68	5.43	9.96	0.00	15.4
MOX SF	0.220	4.41	8.23	23.3	0.00	31.6
3 assembly new build SF	0.659	4.41	8.23	19.9	0.00	28.1
4 assembly new build SF	0.878	4.41	8.23	18.1	0.00	26.4
HEU / Pu	0.890	3.17	6.22	11.1	0.00	17.3

The material grades assumed for the disposal containers are based on those chosen by SKB [B14] and Posiva [B16]. The grade of copper is an oxygen-free, high conductivity grade deliberately alloyed with a small amount of phosphorus (30 – 100 ppm) to improve creep ductility in the anticipated service temperature range. The material is described by EN1976:1988 for the grades of Cu-OFE or Cu-OF1 with the additional requirements of: O < 5 ppm; P30 – 100 ppm; H < 0.6 ppm; and S < 8 ppm. For the inserts, cast iron grade EN-GJS-400-15U has been chosen with some composition restrictions introduced to reduce the risk of radiation embrittlement. Steel guide tubes were cast integrally with the iron insert to provide an accurate guide for the SF structure and these were made from tubular hot finished hollow section steel to EN10210-1 [B17].

A number of assumptions have had to be made regarding the can-in-canister concept for Pu / HEU, and these are detailed in Table B14, which shows the composition of the titanate based pucks, and Table B15, which contains the assumptions of materials and dimensions.

Table B14 Composition of the titanate based ceramic

Oxide	Composition (% by mass)
PuO_2 (or HEU dioxide)	11.9
UO_2	23.7
HfO_2	10.6
Gd_2O_3	7.9
CaO	10.0
TiO_2	35.9

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[64] The packaged volumes presented in this table are displacement volumes (which take account of the handling features) and not envelope volumes.

Table B15 Assumptions used in the derivation of masses of waste and packaging materials for the Pu / HEU disposal container

Item	Assumptions	Mass (t)
Ceramic pucks	69 mm diameter; 25 mm thickness Mass 500 g; volume 93.5 cm^3 20 pucks per can; 28 cans per canister	0.280 UO_2 / PuO_2: 3.33 10^{-2} U / Pu: 2.94 10^{-2}
Stainless steel cans	Length 510 mm; 76 mm outer diameter; wall thickness 3 mm; end thickness 5 mm Made of SS316; density 7.8 t/m^3 Assumed to be supported by internal canister furniture	0.085
Steel canister	Length 3060 mm; 610 mm outer diameter; external volume 0.89 m^3; wall thickness 50 mm Made of SS316; density 7.8 t/m^3	2.26
Glass encapsulant	Borosilicate glass; density 2.5 t/m^3; volume 0.525 m^3	1.31

B2.2 DNLEU

It is assumed that the wasteform and package for miscellaneous DNLEU, TPU and defence DNLEU are the same as the assumptions for all DNLEU in the 2007 and 2010 Derived Inventories. The U_3O_8 is mixed with a PFA / OPC encapsulant and packaged in a 500 l drum. Table B16 gives the masses of the components that make up a single DNLEU 500 l drum.

The revised packaging assumptions for MDU and depleted uranium tails (based on the preferred options identified by RWM's uranium integrated project team [B18]) are that:

- the current / planned wasteform for storage would be used for disposal (ie unencapsulated UO_3 and U_3O_8 powders)
- the powders would not be repackaged, ie they will remain in their current / planned storage containers[65]:
    - depleted uranium tails (which will be deconverted from UF_6 to U_3O_8 powder in the tails management facility at Capenhurst[66]) in mild steel DV-70s
    - older MDU (UO_3 powder) in mild steel 200 l drums that have been overpacked in large (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 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 ~500 l drums for older MDU
    - 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

Data regarding the masses of the components that comprise the ~500 l overpack for older MDU and the grout-filled TDCs are provided in Table B17 to Table B19.

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[65] There is a degree of uncertainty in the future packaging of uranium. RWM has currently assumed that the quantity of uranium per container is at the lower end of the possible range. These packaging assumptions are not optimised and may be revised in a future inventory.

[66] The Tails Management Facility is due to commence operations in 2017.

Table B16 Properties of the ~500 l drum for DNLEU

Item	Mass (t)	Material composition	Notes
U_3O_8 (equivalent mass of U)	1.14 (0.967)	U_3O_8	Density of U_3O_8 is 8.3 t/m^3
Encapsulating grout	0.44	1:1 PFA / OPC	
Water (for encapsulating grout)	0.19		
Capping grout (includes water)	0.09	3:1 PFA / OPC	
Steel (lost paddle)	0.01		
Steel drum	0.13	SS 316L	
Total	2.0		500 l drum payload volume of 0.47 m^3, displacement volume of 0.57 m^3 and a 2 t mass limit

Table B17 Properties of the TDC for MDU (current stocks)

Item	Mass (t)	Material composition	Notes
UO_3 (equivalent mass of U)	9.6 (8.17)	UO_3	Density of UO_3 is 7.3 t/m^3
200 l drums	0.70	Mild steel	28 200 l drums per TDC
Polythene bags (200 l drums)	0.007	LDPE	
500 l overpack	1.890	Stainless steel	28 500 l drums per TDC
Polythene bags (500 l overpack)	0.038	HDPE	
Encapsulating grout	9.76	3:1 BFS/PFA:OPC	
Water (for encapsulating grout)	3.99		
TDC	3.5		
Total	29.5		Payload volume of 21.92 m^3, displacement volume of 29.03 m^3

Table B18 Properties of the TDC for MDU (future arisings)

Item	Mass (t)	Material composition	Notes
UO_3 (equivalent mass of U)	30.7 (25.6)	UO_3	Density of UO_3 is 7.3 t/m^3
210 l drums	1.62	Stainless steel	54 210 l drums per TDC
Polythene bags (210 l drums)	0.014	LDPE	
Encapsulating grout	5.87	3:1 BFS/PFA:OPC	
Water (for encapsulating grout)	2.39		
TDC	3.5		
Total	44.1		Payload volume of 18.79 m^3, displacement volume of 25.41m^3

Table B19 Properties of the TDC for depleted uranium tails

Item	Mass (t)	Material composition	Notes
U_3O_8 (equivalent mass of U)	38.7 (32.8)	U_3O_8	Density of U_3O_8 is 8.3 t/m^3
DV70 container	3	Mild steel	4 DV70s per TDC
Encapsulating grout	5.49	3:1 BFS/PFA:OPC	
Water (for encapsulating grout)	2.24		
TDC	3.5		
Total	52.9		Payload volume of 19.84 m^3, displacement volume of 27.83m^3

Appendix B References

B1 Radioactive Waste Management, *Geological Disposal: Waste Package Specification for 500 litre drum waste packages*, WPSGD No. WPS/300/03, 2013.

B2 Radioactive Waste Management, *Geological Disposal: Waste Package Specification for side-lifting variants of the 3 cubic metre box waste package*, WPSGD No. WPS/310/04, 2013.

B3 Radioactive Waste Management, *Geological Disposal: Waste package Specification for corner-lifting variants of 3 cubic metre box waste package*, WPSGD No. WPS/315/03, 2013.

B4 Radioactive Waste Management, *Geological Disposal: Waste Package Specification for 3 cubic metre drum waste packages*, WPSGD No. WPS/320/04, 2013.

B5 Radioactive Waste Management, *Geological Disposal: Specification for Miscellaneous Beta Gamma Waste Store box waste packages*, WPS/340/01, 2014.

B6 Radioactive Waste Management, *Geological Disposal: Waste Package Specification for 4 metre box waste packages*, WPSGD No. WPS/330/03, 2013.

B7 Radioactive Waste Management, *Geological Disposal: Waste Package Specification for 2 metre box waste packages*, WPSGD No. WPS/350/03, 2013.

B8 Radioactive Waste Management, *Geological Disposal: Waste Package Specification for 6 cubic metre cocrete box waste packages*, WPSGD No. WPS/360/01, 2013.

B9 Radioactive Waste Management, *Geological Disposal: Waste Package Specification for 500 litre robust shielded drum waste packages to be transported in a SWTC-150*, WPSGD No. WPS/380/01, 2015.

B10 Radioactive Waste Management, *Geological Disposal: Waste Package Specification for 3 cubic metre robust shielded box waste packages for transport as part of a Type IP-2 package*, WPSGD No. WPS/381/01, 2015.

B11 Radioactive Waste Management, *Geological Disposal: Waste Package Specification for 500 litre concrete drum waste packages*, WPSGD No. WPS/361/01, 2014.

B12 Radioactive Waste Management, *Geological Disposal: Waste Package Specification for 1 cubic metre concrete drum waste packages*, WPSGD No. WPS/362/01, 2014.

B13 Arup, *NDA: Standardised Disposal Container for HLW and Spent Fuel Conceptual Design Report*, 218762-01-03 issue 3, 2014.

B14 SKB, *Design, Production and initial state of the canister*, SKB TR-10-14, 2010.

B15 L. Johnson and F. King, *Canister Options for the Disposal of Spent Fuel*, Nagra Technical Report 02-11, 2003.

B16 L. Nolvi, *Manufacture of Disposal Canisters*, Posiva 2009-03, 2009.

B17 British Standards Institution, *Hot finished structural hollow sections of non-alloy and fine grain steels. Part 1: Technical delivery requirements*, BS EN 10210-1:2006, 2006.

B18 Radioactive Waste Management, *Geological Disposal: Investigating the Implications of Managing Depleted, Natural and Low Enriched Uranium through Geological Disposal*, NDA/RWM/142, 2016

Appendix C Waste package data

C1.1 Waste package materials

Table C1 presents the bulk materials in the waste containers for LHGW (excluding the RSCs). As the RSCs are a new family of waste containers that contain different materials, the bulk materials for the RSCs are presented separately in Table C2.

Table C1 The materials used in the legacy LHGW waste containers. Data presented includes the mass (M), thickness (T) and external area (A)

Waste container type	Stainless steel			Carbon Steel			Concrete		
	M (t)	T (m)	A (m^2)	M (t)	T (m)	A (m^2)	M (t)	T (m)	A (m^2)
UILW / ULLW									
500 l drum	0.13	0.003	4						
Enhanced 500 l drum (pre-cast)	0.13	0.005	4				0.27	0.04	4
Enhanced 500 l drum (basket)	0.13	0.005	4						
3 m^3 box (side lifting)	0.75	0.006	14.5						
3 m^3 box (corner lifting)	0.75	0.006	14.5						
3 m^3 drum	0.4	0.005	11.2						
MBGWS box				2	0.006	16.5			
3 m^3 Sellafield box	0.7	0.006	14				0.6	0.03	14
3m^3 Enhanced Sellafield box	1.5	0.014	14				1.1	0.05	14
SILW / SLLW									
2 m box (100 mm concrete)	3	0.006	29				7	0.1	29
4 m box (0 mm concrete)	5	0.003	48						
4 m box (100 mm concrete)	5	0.003	48				12.5	0.1	48

Waste container type	**Stainless steel**			**Carbon Steel**			**Concrete**		
	M (t)	**T (m)**	**A (m^2)**	**M (t)**	**T (m)**	**A (m^2)**	**M (t)**	**T (m)**	**A (m^2)**
4 m box (200 mm concrete)	5	0.003	48				17.5	0.2	48
6 m^3 concrete box (SD)				0.7	0.0025	31	13.3	0.24	31
6 m^3 concrete box (HD)				0.7	0.0025	31	25.3	0.24	31
New build UILW									
3 m^3 box (side lifting)	0.75	0.006	14.5						
3 m^3 drum	0.4	0.005	11.3						
New build SILW									
4 m box (100 mm concrete)	5	0.003	48				12.5	0.1	48
1 m^3 concrete drum (0 mm steel)				0.158			2.49		
1 m^3 concrete drum (40 mm steel)				1.57			2.49		
1 m^3 concrete drum (70 mm steel)				2.45			2.49		
500 l concrete drum (40 mm steel)				0.989			1.76		
DNLEU									
500 l drum (DNLEU)	0.13	0.005	4						
Transport Disposal Container (2.1m)	3.5	0.007	58.0						
Transport Disposal Container (2.3m)	3.5	0.007	61.2						
Transport Disposal Container (2.4m)	3.5	0.007	62.8						

Table C2 The materials used in the new build SILW waste containers. Data presented includes the mass (M), thickness (T) and external area (A)

Waste container type	Cast Iron			Lead		
	M (t)	T (m)	A (m^2)	M (t)	T (m)	A (m^2)
RSCs						
3 m^3 RS box	18.3					
500 l RS drum (0 mm Pb)	5.73					
500 l RS drum (20 mm Pb)	5.73			0.768	0.02	
500 l RS drum (30 mm Pb)	5.73			1.12	0.03	
500 l RS drum (60 mm Pb)	5.73			2.04	0.06	
500 l RS drum (80 mm Pb)	5.73			2.58	0.08	
500 l RS drum (90 mm Pb)	5.73			2.82	0.09	
500 l RS drum (120 mm Pb)	5.73			3.5	0.12	

Table C3 presents the bulk materials in the HHGW containers based on an assumed copper / cast iron disposal container. The materials used would change if alternative waste container designs were assumed.

Table C3 The materials used in the HHGW waste containers. Data presented includes the mass (M), thickness (T) and external area (A)

Waste container type	Carbon steel			Cast Iron			Copper		
	M (t)	T (m)	A (m^2)	M (t)	T (m)	A (m^2)	M (t)	T (m)	A (m^2)
HLW Disposal Container	1.06	0.2		15.8			7.41	0.05	
AGR SF Disposal Container	0.25	0.05		16.7			7.93	0.05	
PWR SF Disposal Container	0.25	0.05		14.3			7.26	0.05	
Magnox Disposal Container				14.1			7.66	0.05	
PFR SF Disposal Container				9.96			5.43	0.05	
New build SF Disposal Container				19.9			8.23	0.05	
MOX SF Disposal Container				23.3			8.23	0.05	
HEU / Pu Disposal Container				11.1			6.22	0.05	

C1.2 Waste package numbers

Table C4 presents the numbers of waste packages and disposal units for each waste container type. The data are presented by waste group, and the conditioned and packaged volumes are also shown.

Table C4 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				
2 m box (100 mm concrete)	75	75	334	758
4 m box (0 mm concrete) LLW	2,760	2,760	52,100	55,300
4 m box (100 mm concrete)	1,190	1,190	17,100	23,900
4 m box (200 mm concrete)	399	399	4,350	7,990
6 m^3 box (High density)	96	96	544	1130
6 m^3 box (Standard density)	330	330	1,900	3,910
Total SILW	4,850	4,850	76,300	93,000
UILW / ULLW				
3 m^3 box (side lifting)	4,770	4,770	12,700	15,600
3 m^3 box (corner lifting)	402	402	1,120	1,450
3 m^3 drum	563	563	1,260	1,470
3 m^3 Sellafield box	54,300	54,300	147,000	179,000
3 m^3 Enhanced Sellafield box	16,300	16,300	35,100	53,900
500 l drum	91,800	22,900	42,800	52,400
MBGWS box	1,500	1,500	5,270	7,070
Enhanced 500 l drum (basket)	26,100	6,530	13,200	14,900
Enhanced 500 l drum (pre-cast)	893	223	363	510
Total UILW	197,000	108,000	259,000	327,000
New build UILW				
3 m^3 box (side lifting)	960	960	2,550	3,140
3 m^3 drum	7,270	7,270	16,200	19,000
Total new build UILW	8,230	8,230	18,800	22,100
New build SILW				
4m box (100 mm concrete)	60	60	858	1,200
1 m^3 concrete drum (0 mm steel)	1,800	1,800	1,590	3,600
1 m^3 concrete drum (40 mm steel)	2,880	2,880	1,790	5,760
1 m^3 concrete drum (70 mm steel)	2,160	2,160	1,100	4,320

Waste container	No. packages	No. Disposal Units	Conditioned Volume (m^3)	Packaged Volume (m^3)
500 l concrete drum (40 mm steel)	3,240	3,240	942	4,000
Total new build SILW	10,100	10,100	6,280	18,900
DNLEU				
500 l drum (DNLEU)	23,800	5,950	11,200	13,600
TDC (2.1m ht)	581	581	10,900	14,800
TDC (2.3m ht)	3,780	3,780	75,000	105,000
TDC (2.4m ht)	2,890	2,890	63,300	83,800
Total DNLEU	31,000	13,200	160,000	217,000
RSCs				
3 m^3 RS box	1,040	1,040	2,920	5,650
500 l RS drum (0 mm Pb)	683	683	335	901
500 l RS drum (20 mm Pb)	369	369	149	488
500 l RS drum (30 mm Pb)	146	146	54.3	193
500 l RS drum (60 mm Pb)	2	2	0.444	2.02
500 l RS drum (80 mm Pb)	1	1	0.0668	0.362
500 l RS drum (90 mm Pb)	6	6	1.14	6.8
500 l RS drum (120 mm Pb)	28	28	4.56	36.2
Total RSCs	2,270	2,270	3,460	7,280
HLW				
HLW Disposal Container	2,400	2,400	1,410	9,290
Legacy SFs				
AGR SF Disposal Container	2,190	2,190	1,930	9,160
Magnox SF Disposal Container	836	836	999	3,390
PFR SF Disposal Container	19	19	10.9	48.7
PWR SF Disposal Container	571	571	425	2,160
Total Legacy SFs	3,610	3,610	3,370	14,800
New build SFs				
New build SF Disposal Container	8,940	8,940	5,890	39,400
MOX SF				
MOX SF Disposal Container	2,710	2,710	594	11,900
HEU				
HEU / Pu Disposal Container	779	779	694	2470
Pu				
HEU / Pu Disposal Container	196	196	174	620

Appendix D Results of enhancements

D1 Comparison of UK RWI waste streams

It is only possible to compare the results of the enhancements process for those wastes for which detailed information is included in the UK RWI (ie SFs, uranium, plutonium and any new build wastes are excluded). The results of this comparison section are, therefore, limited to those LLW, ILW and HLW waste streams that appear in both the UK RWI and the Derived Inventory. An overview of the results of the enhancements is presented below.

The impact of the enhancement process on the volumes of waste is small:

- ILW conditioned volume has increased by 0.09% to approximately 328,000 m^3
- LLW conditioned volume has increased by 0.02% to approximately 11,100 m^3
- ILW packaged volume has decreased by 0.41% to approximately 415,000 m^3
- LLW packaged volume has decreased by 0.87% to approximately 11,800 m^3

The activities of the priority radionuclides at 2200 are shown in Table D1 for both the 2013 UK RWI and the 2013 Derived Inventory. As noted above, contributions are limited to those LLW, ILW and HLW waste streams that appear in both the UK RWI and the Derived Inventory. The impact of the enhancements on the total activity is small, with the Derived Inventory showing a slightly higher activity. The results for the priority 1 radionuclides vary: some radionuclides, such as C14 have their activity reduced by the enhancement process; others like Cs137 have their activity increased by the enhancement process. For all priority 1 radionuclides, the changes are small (less than 5%).

Table D1 The total activity and activity of the priority 1 radionuclides at 2200

Radionuclide	UK RWI activity (TBq)	DI activity (TBq)	Radionuclide	UK RWI activity (TBq)	DI activity (TBq)
C14	7,800	7,750	Cs135	183	190
Cl36	37.1	37.1	Cs137	259,000	270,000
Co60	$2.67\ 10^{-3}$	$2.70\ 10^{-3}$	U233	1.18	1.23
Se79	16.7	17.1	U235	0.595	0.593
Kr85	$2.50\ 10^{-2}$	$2.53\ 10^{-3}$	U238	18.6	18.6
Tc99	3,480	3,380	Np237	157	154
I129	0.707	0.709			

The results of the enhancement of the bulk waste material composition data are shown in Table D2, which presents the total masses of the bulk materials in the legacy LLW, ILW and HLW streams that are included in the 2013 Derived Inventory. The total mass of each material has been calculated by multiplying the mass of each waste stream by the mass fraction contribution for the material and then summing the resultant masses over all streams. The masses and differences are presented both before and after enhancement and the differences are highlighted. Priority materials have been highlighted green.

The most significant difference between the UK RWI data and the Derived Inventory data is that the majority of the unassigned mass has been assigned to a material type. Table D2 shows that:

- the total mass of metal is about 102,000 t (~35.5% of the total mass), with approximately 89,100 t being ferrous metal (stainless steels and other ferrous metals)
- the total mass of organic materials is about 12,900 t (~4.6% of the total mass), comprising mostly plastics and cellulose
- the total mass of inorganic materials is nearly 172,000 t (~59.6% of the total mass), comprising mostly graphite, cement / concrete / sand and sludges / flocs
- approximately 1,020 t (~0.4% of the total mass) remains unassigned as there is insufficient information in the UK RWI to support an enhancement
- enhancements have increased the total mass of metal by over 10%, while the total masses of organic and inorganic materials have not changed significantly

It is noted that the mass of cement / concrete / sand includes the conditioning grout for those streams that are reported as conditioned waste. Similarly, the mass of glass includes the mass of the boro-silicate glass that is used to encapsulate the HLW that has already been reprocessed.

There is insufficient information to enable all of the mass to be allocated to materials. The unquantified mass is approximately 1,020 t, or approximately 0.4% of the total mass.

In addition to the priority materials highlighted in Table D2, there are a number of other priority materials (see Appendix A1). These components are referred to as secondary materials as their masses are included in bulk material components quantified within Table D2. Apart from the inorganic anions, numerical data on these materials are not reported in the 2013 UK RWI and so their masses before enhancement are not calculated. The masses of some species remain unquantified in the 2013 Derived Inventory as there is insufficient information to support enhancement. The secondary materials are reported in Table D3.

Table D2 The impact of bulk material enhancements on the total mass of materials in legacy wastes (LLW, ILW & HLW). Priority materials have been highlighted

	Material	Total mass (t)			Change (%)
		2013 UK RWI	2013 DI	Change	
Metals	Aluminium	1,740	1,750	3.92	0.225
	Beryllium	43.1	43.3	0.2	0.464
	Cadmium [67]	Not estimated	4.39	4.39	-
	Copper	390	399	8.71	2.23
	Lead	1,070	1,130	61.2	5.73
	Magnox	6,440	6,370	-65.2	-1.01
	Mercury [67]	Not estimated	0	-	-
	Other ferrous metals	48,800	53,100	4,300	8.82
	Stainless steel	28,300	36,000	7,640	27
	Uranium	909	941	32.5	3.57
	Zinc	74.2	74.2	0	0
	Zircaloy	1,280	1,280	6.44	0.504
	Brass	7.7	7.7	0	0
	Boral	179	179	0	0
	Bronze	5.68	5.68	0	0
	Dural	0	0	0	0
	Inconel	73.6	73.6	0.01	0.0136
	Monel	0.08	0.08	0	0
	Nimonic	32.8	199	166	507
	Stellite	0.07	0.07	0	0
	Other metals	1470	130	-1340	-91.2
	Total metals	90,800	102,000	10,800	11.9
Organics	Cellulose	2,600	2,610	9.92	0.382
	Halogenated plastics	4,540	4,750	213	4.69
	Non-halogenated plastics	2,650	2,630	-17.1	-0.645
	Organic ion exchange resins	355	526	171	48.2
	Rubber	1,980	1,960	-18.4	-0.931
	Other organics	661	473	-188	-28.4
	Total organics	12,800	12,900	171	1.34

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[67] Includes materials in wastes. This includes conditioning materials in those waste streams reported as conditioned.

	Material	Total mass (t)			Change (%)
		2013 UK RWI	2013 DI	Change	
Inorganics	Asbestos	298	298	0	0
	Graphite	76,500	76,800	303	0.396
	Aqueous liquids	7,480	8,860	1,380	18.4
	Cement / concrete / sand [68]	53,500	53,900	390	0.729
	Ceramic	208	211	2.88	1.38
	Desiccants [69]	Not estimated	648	648	-
	Glass	3,070	3,070	9.01	0.294
	Ion exchange materials	2,410	3,440	1,030	42.6
	Rubble	2580	2580	0	0
	Sludge / flocs	23,700	22,500	-1,250	-5.27
	Soil	11.2	5.31	-5.86	-52.5
	Other inorganics [69]	Not estimated	2.49	2.49	-
	Total inorganics	170,000	172,000	2,510	1.48
	Total not assigned	14,000	1,020	-13,000	-92.7
	Total	287,000	288,000	548	0.191

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

[69] Mass is not calculated in the 2013 UK RWI because the component has no numeric data field.

Table D3 Total mass of other priority materials in wastes

	Material	Total mass (t)
Metals	Beryllium (all forms)	64.6
	Cadmium (all forms)	13.4
	Mercury (all forms)	4.82
	Tin (all forms)	0.633
	Uranium (all forms)	1,690
Organics	Amorphous cellulose [70]	1,360
	Chlorinated solvents	Not estimated
	Hydrocarbon oils [71]	9.55
	Phenol	295
	Polyethylene & polypropylene	1,160
	PVC [72]	4,670
	Rubble	2,580
	Small organic molecules	Not estimated
	Styrene divinyl benzene resins	175
	Toluene	Not estimated
	Trichloroethylene	Not estimated
	Vinyl Chloride monomer	Not estimated
	Vinyl styrene	Not estimated
Inorganic anions [73]	Borate	Not estimated
	Fluoride	288
	Nitrate	243
	Nitrite	1.72
	Phosphate	69.4
	Selenate	Not estimated
	Sulphate	184
Other species	Ammonium species	1.51
	Eutectics	2.26
	Ferrocyanates	Not estimated
	Potassium hydroxide	Not estimated

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[70] Comprises paper and cotton.

[71] Comprises NAPLs.

[72] PVC is assumed to contain 30% – 40% by mass diethylhexyl phthalate ($C_{24}H_{38}O_4$).

[73] For nearly all waste streams inorganic anion concentrations reported in the 2013 UK RWI are upper estimates.

Appendix E Materials data

E1 Bulk materials data by waste group

Three sets of data are presented for the bulk materials:

- data for bulk materials in the waste
- data for bulk materials in the capping and conditioning materials
- data for bulk materials in the waste containers

The data are presented for the LHGW in Table E1 – Table E3. For the HHGW the data are presented in Table E4 and Table E5. For the high heat generating wastes, there are no capping materials, and the conditioning materials are limited to the glass and ceramic used to encapsulate the HLW, Plutonium and HEU. Since 500 l RS drums and 3 m^3 RS boxes contain raw waste, there are no capping or conditioning materials associated with the RSC waste group.

Table E1 The bulk materials in the LHGWs. Priority materials are highlighted and new build has been abbreviated as NB

	Material	Total mass (t)					
		UILW / ULLW	SILW / SLLW	RSC	NB UILW	NB SILW	DNLEU
Metals	Aluminium	1,720	23.9	1.5	0	0	0
	Beryllium	24.9	18.4	0.1	0	0	0
	Cadmium	4.23	0.158	0	0	0	0
	Copper	376	23.5	0.1	0	0	0
	Lead	1,120	5.79	0.1	0	0	0
	Magnox	6,270	16	90.7	0	0	0
	Other ferrous metals	38,300	14,500	251	1,840	1,080	13,400
	Stainless steel	32,300	2,900	187	2,290	517	6,400
	Uranium	941	0	0.2	0	0	0
	Zinc	74.1	0	0.1	0	0	0
	Zircaloy	1,240	16.6	28.9	0	0	0
	Other metals	557	15.1	3.0	0	0	0
	Total metals	82,900	17,500	562	4,130	1,600	19,800
Organics	Cellulosics	2,570	3.3	24	0	15.8	0
	Halogenated Plastics	4,720	1.2	17.8	0	25.9	0
	Non-halogenated plastics	2,330	267	22.7	2.7	116	137
	Organic ion exchange resins	51.9	97.4	377	2,030	1,080	0
	Rubbers	1,950	0.2	5.5	0.1	6.6	0
	Other organics	456	0.2	17.6	0	7.2	0
	Total organics	12,100	370	465	2,030	1,250	137

	Material	Total mass (t)					
		UILW / ULLW	SILW / SLLW	RSC	NB UILW	NB SILW	DNLEU
Other Materials	Asbestos	295	0	2.6	0	0	0
	Graphite	13,900	51,600	493	0	0	0
	Aqueous liquids	8,850	0	17.2	2.7	37	0
	Cement / concrete / sand	52,100	1,650	164	0	0	0
	Ceramic	211	0	0.1	0	7.2	0
	Desiccants	587	0	61.5	0	0	0
	Glass	218	0.2	7.7	0.4	5.4	0
	Heavy Metal Oxide	0	0	0	0	0	219,000
	Ion exchange materials	3,230	167	39.3	2,030	0	0
	Rubble	2,180	0	391	0	1.4	0
	Sludge / flocs	22,200	0	319	0	432	0
	Soil	5.2	0	0.1	0	0	0
	Other inorganics	2.5	0	0	0	0	0
	Total Other Materials	104,000	53,400	1,500	2,030	483	219,000

Table E2 The bulk materials in the LHGW capping and conditioning materials. New build has been abbreviated as NB and none of the rows have been highlighted as there are no priority materials

Material component [74]	Total mass (t)					
	UILW / ULLW	SILW / SLLW	RSC [75]	NB UILW	NB SILW	DNLEU
Conditioning materials						
Stainless steel	0	0	0	0	0	238
OPC	39,100	4,570	0	2,160	532	18,300
BFS or PFA	138,000	13,700	0	15,800	1,810	44,500
Polymer	207	205	0	7,340	955	0
Water	72,400	7,460	0	0	850	25,900
Total conditioning materials	250,000	25,900	0	25,300	4,140	89,000
Capping materials						
OPC	6,980	23.2	0	531	0	456
PFA	20,900	69.5	0	1,590	0	1,370
Water	4,890	16.2	0	372	0	319
Iron shot concrete	0	19,900	0	0	271	0
Total capping materials	32,800	20,000	0	2,500	271	2,140

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

[75] 500 l RS drums and 3 m^3 RS boxes do not have any capping or conditioning.

Table E3 The bulk materials in LHGW containers. Priority materials are highlighted and new build has been abbreviated as NB

Material component	Total mass (t)					
	UILW / ULLW [76]	**SILW / SLLW**	**RSC**	**DNLEU[77]**	**NB UILW**	**NB SILW**
Metals						
Stainless Steel	82,100	22,000	0	28,500	3,630	300
Lead	0	0	562	0	0	0
Carbon Steel	3,010	298	0	0	0	13,300
Cast Iron	0	0	26,100	0	0	0
Total metals	85,100	22,300	26,600	28,500	3,630	13,600
Other materials						
Concrete [78]	50,800	22,400	0	0	0	750
Reinforced concrete [78]	0	4,390	0	0	0	22,700
Magnetite concrete [78]	0	2,410	0	0	0	0
Total other materials	50,800	29,200	0	0	0	23,500

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[76] Excludes 16,500 t of stainless steel associated with 500 l drum stillages.

[77] Excludes 3, 320 t of stainless steel associated with 500 l drum stillages.

[78] All concrete is assumed to contain 0.5 wt% superplasticiser.

Table E4 The bulk materials in the HHGWs. Priority materials are highlighted and new build has been abbreviated as NB

Material component	Total mass (t)								
	HLW [79]	AGR SF	PWR SF	Metallic SF	Exotic SF	NB SF	MOX SF	HEU [79]	Pu [79]
Metals									
Magnox	0	0	0	133	0	0	0	0	0
Other ferrous metals	1.18	0	0	0	0	0	0	0	0
Stainless steel	612	1,020	36.3	318	8.87	391	39.5	1,820	457
Uranium	0	0	0	740	0	0	0	0	0
Zircaloy	0	0	269	0	0	4,280	438	0	0
Inconel	20.6	0	15.1	0	0	126	11.8	0	0
Nimonic	0	0	0	0	3.02	0	0	0	0
Total metals	634	1,020	320	1,190	11.9	4,800	490	1,820	457
Other materials									
Heavy metal oxide	0	5,100	1,190	0	11.3	16,200	1,660	26	6.52
Ceramics	0	35.1	0	0	0	15.6	1.61	196	49.3
Glass	2,850	0	0	0	0	0	0	1,020	257
Total other materials	2,850	5,140	1,190	0	11.3	16,200	1,660	1,250	313

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[79] 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 E5 presents the bulk materials in the HHGW containers based on a copper disposal container concept.

Table E5 The bulk materials in HHGW containers. Priority materials are highlighted and new build has been abbreviated as NB

Material component	Total mass (t)								
	HLW	AGR SF	PWR SF	Metallic SF	Exotic SF	NB SF	MOX SF	HEU	Pu
Metals									
Copper	17,800	17,300	4,150	6,400	98.6	73,600	22,300	4,850	1,220
Carbon steel	2,540	546	143	0	0	0	0	0	0
Cast iron	37,800	36,600	8,170	11,800	181	178,000	63,100	8,610	2,160
Total metals	58,100	54,400	12,500	18,200	280	251,000	85,400	13,500	3,380

E2 Elemental composition data

Table E6 – Table E17 present the elemental composition data of each of the waste groups. The mean material compositions have not been enhanced by the addition of Earth's crustal abundance data because it is more than likely that to do so would significantly overestimate the mass of many minor elemental components. This has resulted in some elements having no value for the mean concentration but values for the upper and lower uncertainty estimates. This can lead to the best estimate value for an element in the elemental composition tables being less than the value for the lower uncertainty.

Table E6 Elemental composition for legacy SILW / SLLW (waste, conditioning, capping and container materials). Priority metallic species are highlighted

Element	Mass (tonnes)			Element	Mass (tonnes)		
	Best estimate	Upper uncertainty	Lower uncertainty		Best estimate	Upper uncertainty	Lower uncertainty
H	1,210	1,660	1,020	Cd	0.89	1.22	0.7
He	3.19 10^{-4}	5.89 10^{-3}	1.38 10^{-4}	In	0.403	0.66	0.401
Li	0.771	3.61	0.488	Sn	4.81	10.8	2.19
Be	18.5	57.2	18.8	Sb	1.45	3.51	0.724
B	31.3	65.7	1.44	Te	9.44 10^{-5}	2.57 10^{-2}	3.15 10^{-4}
C	63,300	64,200	63,200	I	2.22 10^{-2}	4.21	4.75 10^{-2}
N	23	41	11.3	Xe	4.85 10^{-3}	5.56 10^{-2}	5.57 10^{-4}
O	30,100	31,300	29,500	Cs	0.235	2.12	7.77 10^{-2}
F	26.6	558	12.1	Ba	38.5	253	12.4
Ne	0.156	1.57	1.57 10^{-2}	La	1.18	4.36	0.8
Na	421	731	195	Ce	18.9	40.8	7.48
Mg	583	744	537	Pr	0.425	43.1	0.536
Al	2,500	3,390	1,790	Nd	1.18	4.21	0.937
Si	10,300	14,800	4,720	Sm	0.213	1.95	0.153
P	173	227	26.5	Eu	8.76 10^{-2}	0.579	7.64 10^{-2}
S	154	223	107	Gd	0.279	6.4	0.131
Cl	32.9	46.8	30.6	Tb	5.86 10^{-2}	0.601	2.9 10^{-2}
Ar	0.118	69.3	0.722	Dy	0.186	1.68	0.141
K	521	997	294	Ho	4.58 10^{-2}	0.631	3.38 10^{-2}
Ca	8,480	14,200	5,680	Er	0.358	1.2	7.52 10^{-2}
Sc	0.626	3.52	0.503	Tm	9.22 10^{-2}	0.737	2.7 10^{-2}
Ti	202	425	128	Yb	0.142	1.04	8.15 10^{-2}
V	27.6	65.9	11.5	Lu	4.25 10^{-2}	0.279	2.02 10^{-2}
Cr	8,760	9,430	7,680	Hf	0.134	1.08	8.85 10^{-2}

Element	Mass (tonnes)			Element	Mass (tonnes)		
	Best estimate	Upper uncertainty	Lower uncertainty		Best estimate	Upper uncertainty	Lower uncertainty
Mn	850	1,150	588	Ta	0.334	0.643	0.309
Fe	50,600	58,700	46,600	W	9.25	23.3	2.56
Co	63.6	164	16.2	Re	1.12 10^{-3}	1.89 10^{-2}	2.07 10^{-4}
Ni	5,320	5,940	4,410	Os	1.06 10^{-3}	1.08 10^{-2}	3.44 10^{-4}
Cu	204	425	84	Ir	2.71 10^{-2}	0.12	1.58 10^{-3}
Zn	24	82	3.92	Pt	1.01 10^{-3}	8.48 10^{-2}	1.1 10^{-3}
Ga	7.3	31.3	1.28	Au	0.261	0.326	0.262
Ge	6.86 10^{-2}	50	0.517	Hg	3.6 10^{-3}	6.22	6.31 10^{-2}
As	12.3	47.2	2.29	Tl	3.27 10^{-2}	8.13	8.94 10^{-2}
Se	0.725	2.4	8.89 10^{-2}	Pb	11	34.1	6.5
Br	0.199	7.4	0.157	Bi	8.72 10^{-3}	0.33	7.14 10^{-3}
Kr	4.09 10^{-2}	0.416	4.17 10^{-3}	Po	4.73 10^{-12}	8.72 10^{-11}	2.04 10^{-12}
Rb	3.12	11.3	1.66	Rn	9.46 10^{-15}	1.74 10^{-13}	4.08 10^{-15}
Sr	20.5	36.8	13.2	Ra	2.37 10^{-8}	4.36 10^{-7}	1.02 10^{-8}
Y	1.44	6.85	0.754	Ac	1.3 10^{-11}	2.4 10^{-10}	5.61 10^{-12}
Zr	22.4	34.9	20.4	Th	1.05	6.58	0.822
Nb	4.31	16.2	0.996	Pa	0.261	0.261	0.261
Mo	613	803	468	U	0.21	1.27	9.72 10^{-2}
Tc	0	0	0	Np	0	0	0
Ru	4.73 10^{-5}	1.34 10^{-2}	1.46 10^{-4}	Pu	0	0	0
Rh	0.144	1.55	1.55 10^{-2}	Am	0	0	0
Pd	0.111	0.212	9.42 10^{-3}	Cm	0	0	0
Ag	1.05	1.86	0.872	Cf	0	0	0

Table E7 **Elemental composition for legacy UILW / ULLW (waste, conditioning, capping and container materials). Priority metallic species are highlighted**

Element	Mass (tonnes)			Element	Mass (tonnes)		
	Best estimate	Upper uncertainty	Lower uncertainty		Best estimate	Upper uncertainty	Lower uncertainty
H	13,500	14,500	13,100	Cd	12.6	13.4	12.1
He	2.01 10^{-3}	1.57 10^{-2}	1.61 10^{-3}	In	2.9	3.07	2.89
Li	5.27	8.7	4.6	Sn	36.8	52.6	26.8

Element	Mass (tonnes)			Element	Mass (tonnes)		
	Best estimate	Upper uncertainty	Lower uncertainty		Best estimate	Upper uncertainty	Lower uncertainty
Be	28.1	127	28	Sb	71	120	24.1
B	109	185	41	Te	$1.05\ 10^{-3}$	$3.92\ 10^{-2}$	$1.35\ 10^{-3}$
C	23,700	25,700	23,600	I	0.14	6.52	0.166
N	130	167	101	Xe	$7.09\ 10^{-3}$	0.587	$5.88\ 10^{-3}$
O	226,000	229,000	225,000	Cs	0.831	2.29	0.637
F	168	1,370	135	Ba	343	829	279
Ne	0.229	2.8	$2.89\ 10^{-2}$	La	9.61	16.4	8.75
Na	2,740	3,440	2,220	Ce	57.9	109	30
Mg	17,900	18,300	17,700	Pr	2.66	107	3
Al	24,000	26,100	22,400	Nd	9.77	13.7	9.18
Si	57,900	68,100	45,400	Sm	1.72	3.69	1.57
P	592	625	255	Eu	1.14	1.69	1.11
S	927	1,080	816	Gd	1.72	13.9	1.37
Cl	2,760	2,780	2,750	Tb	0.348	2.5	0.279
Ar	0.743	163	2.16	Dy	1.51	3.18	1.39
K	3,800	4,880	3,290	Ho	0.343	1.39	0.311
Ca	64,000	77,100	57,700	Er	1.43	2.46	0.78
Sc	5.95	11.4	5.69	Tm	0.33	1.68	0.156
Ti	1,630	2,140	1,470	Yb	0.906	3.75	0.765
V	97.4	184	57.4	Lu	0.228	0.613	0.174
Cr	20,900	22,300	19,300	Hf	0.982	2.27	0.839
Mn	2,370	3,150	1,730	Ta	6.76	8.46	5.91
Fe	135,000	154,000	129,000	W	29.3	64.5	12.4
Co	179	432	51.8	Re	$4.97\ 10^{-3}$	$3.85\ 10^{-2}$	$7.87\ 10^{-4}$
Ni	14,000	16,100	11,900	Os	$3.11\ 10^{-3}$	$1.37\ 10^{-2}$	$1.03\ 10^{-3}$
Cu	867	1,420	563	Ir	$6.97\ 10^{-2}$	0.256	$3.78\ 10^{-3}$
Zn	154	295	102	Pt	$1.19\ 10^{-2}$	0.148	$7.88\ 10^{-3}$
Ga	22	66.2	6.56	Au	5.3	5.4	5.3
Ge	0.441	112	1.44	Hg	$2.26\ 10^{-2}$	9.15	0.108
As	32.3	103	6.29	Tl	0.233	11.8	0.276
Se	1.88	6.03	0.232	Pb	1,070	1,170	1,020
Br	0.991	5.22	0.751	Bi	$7.5\ 10^{-2}$	1.02	$1.73\ 10^{-2}$
Kr	$5.93\ 10^{-2}$	1.11	$1.11\ 10^{-2}$	Po	$2.97\ 10^{-11}$	$2.33\ 10^{-10}$	$2.38\ 10^{-11}$

Element	Mass (tonnes)			Element	Mass (tonnes)		
	Best estimate	Upper uncertainty	Lower uncertainty		Best estimate	Upper uncertainty	Lower uncertainty
Rb	21.5	35.2	18	Rn	5.95 10^{-14}	4.66 10^{-13}	4.76 10^{-14}
Sr	116	151	99.5	Ra	1.49 10^{-7}	1.17 10^{-6}	1.19 10^{-7}
Y	9.28	21.3	7.61	Ac	8.18 10^{-11}	6.41 10^{-10}	6.55 10^{-11}
Zr	1,320	1,340	1,310	Th	14.8	24.7	14.3
Nb	29.3	58.7	16.7	Pa	5.3	5.3	5.3
Mo	2,160	2,700	1,710	U	943	945	941
Tc	2.34	2.34	2.34	Np	0	0	0
Ru	10.1	10.1	10.1	Pu	0	0	0
Rh	1.42	4.87	1.07	Am	0	0	0
Pd	1.97	2.08	1.72	Cm	0	0	0
Ag	17.4	18.3	17.2	Cf	0	0	0

Table E8 **Elemental composition for new build UILW (waste, conditioning, capping and container materials). The priority metallic species are highlighted**

Element	Mass (tonnes)			Element	Mass (tonnes)		
	Best estimate	Upper uncertainty	Lower uncertainty		Best estimate	Upper uncertainty	Lower uncertainty
H	1,090	1,090	1,090	Cd	4.84 10^{-2}	8.56 10^{-2}	2.39 10^{-2}
He	1.36 10^{-4}	1.36 10^{-4}	1.36 10^{-4}	In	4.59 10^{-3}	5.28 10^{-3}	4.24 10^{-3}
Li	0.377	0.385	0.373	Sn	0.666	1.31	0.283
Be	4.72 10^{-2}	4.7	9.37 10^{-2}	Sb	0.163	0.29	8.01 10^{-2}
B	0.453	0.804	0.273	Te	2.01 10^{-5}	1.57 10^{-3}	3.56 10^{-5}
C	2,110	2,120	2,110	I	9.45 10^{-3}	0.242	1.18 10^{-2}
N	2.85	4.51	1.7	Xe	3.07 10^{-4}	3.06 10^{-3}	3.11 10^{-5}
O	16,100	16,100	16,100	Cs	5.09 10^{-2}	5.33 10^{-2}	4.97 10^{-2}
F	11.3	19.1	11.4	Ba	9.94	13.1	8.27
Ne	9.92 10^{-3}	9.85 10^{-2}	1.06 10^{-3}	La	0.735	0.738	0.734
Na	239	240	239	Ce	3.47	5.86	2.06
Mg	596	602	596	Pr	0.18	4.44	0.223
Al	1,990	1,990	1,990	Nd	0.75	0.762	0.749
Si	4,300	4,350	4,270	Sm	0.132	0.134	0.131
P	23.5	28.8	21.2	Eu	3.84 10^{-2}	3.88 10^{-2}	3.82 10^{-2}

Element	Mass (tonnes)			Element	Mass (tonnes)		
	Best estimate	Upper uncertainty	Lower uncertainty		Best estimate	Upper uncertainty	Lower uncertainty
S	51.1	52.7	50.1	Gd	0.116	0.118	0.115
Cl	30.6	30.6	30.6	Tb	$2.52\ 10^{-2}$	$5.81\ 10^{-2}$	$2.19\ 10^{-2}$
Ar	$5.02\ 10^{-2}$	7.8	0.128	Dy	0.116	0.118	0.115
K	356	357	356	Ho	$2.56\ 10^{-2}$	$2.65\ 10^{-2}$	$2.52\ 10^{-2}$
Ca	4,200	4,200	4,200	Er	$6.69\ 10^{-2}$	$7.11\ 10^{-2}$	$6.54\ 10^{-2}$
Sc	0.483	0.484	0.482	Tm	$1.92\ 10^{-2}$	$3.45\ 10^{-2}$	$1.18\ 10^{-2}$
Ti	127	133	124	Yb	$6.63\ 10^{-2}$	$7.9\ 10^{-2}$	$6.11\ 10^{-2}$
V	5.95	8.94	4.17	Lu	$1.66\ 10^{-2}$	$2.25\ 10^{-2}$	$1.4\ 10^{-2}$
Cr	1,080	1,160	1,000	Hf	$6.53\ 10^{-2}$	$6.98\ 10^{-2}$	$6.36\ 10^{-2}$
Mn	126	165	94	Ta	$4.04\ 10^{-2}$	$4.47\ 10^{-2}$	$3.81\ 10^{-2}$
Fe	6,620	6,870	6,380	W	1.19	2.94	0.308
Co	9.16	21.7	2.74	Re	$1.69\ 10^{-4}$	$1.39\ 10^{-3}$	$4.67\ 10^{-5}$
Ni	695	799	600	Os	$1.69\ 10^{-4}$	$3.78\ 10^{-4}$	$6.45\ 10^{-5}$
Cu	24.2	52.5	8.76	Ir	$3.43\ 10^{-3}$	$1.26\ 10^{-2}$	$1.76\ 10^{-4}$
Zn	4.17	10.4	1.75	Pt	$4.22\ 10^{-4}$	$4.3\ 10^{-3}$	$4.61\ 10^{-4}$
Ga	1.27	3.18	0.487	Au	$7.13\ 10^{-5}$	$3.95\ 10^{-3}$	$1.1\ 10^{-4}$
Ge	$2.91\ 10^{-2}$	5.46	$8.34\ 10^{-2}$	Hg	$1.53\ 10^{-3}$	0.389	$5.4\ 10^{-3}$
As	1.65	5.07	0.312	Tl	$1.39\ 10^{-2}$	0.479	$1.85\ 10^{-2}$
Se	$9.49\ 10^{-2}$	0.301	$1.14\ 10^{-2}$	Pb	0.737	1.51	0.355
Br	$6.5\ 10^{-2}$	$8.93\ 10^{-2}$	$5.54\ 10^{-2}$	Bi	$6.81\ 10^{-4}$	$3.8\ 10^{-2}$	$7.73\ 10^{-4}$
Kr	$2.56\ 10^{-3}$	$2.56\ 10^{-2}$	$2.58\ 10^{-4}$	Po	$2.01\ 10^{-12}$	$2.01\ 10^{-12}$	$2.01\ 10^{-12}$
Rb	1.58	1.68	1.52	Rn	$4.02\ 10^{-15}$	$4.02\ 10^{-15}$	$4.02\ 10^{-15}$
Sr	7.37	7.42	7.34	Ra	$1\ 10^{-8}$	$1\ 10^{-8}$	$1\ 10^{-8}$
Y	0.666	0.751	0.63	Ac	$5.53\ 10^{-12}$	$5.53\ 10^{-12}$	$5.53\ 10^{-12}$
Zr	3.02	3.13	2.97	Th	0.17	0.196	0.159
Nb	0.861	1.74	0.454	Pa	$1.42\ 10^{-8}$	$1.42\ 10^{-8}$	$1.42\ 10^{-8}$
Mo	104	130	83.7	U	$5.33\ 10^{-2}$	$6.72\ 10^{-2}$	$4.68\ 10^{-2}$
Tc	0	0	0	Np	0	0	0
Ru	$2.01\ 10^{-5}$	$7.95\ 10^{-4}$	$2.78\ 10^{-5}$	Pu	0	0	0
Rh	$1.98\ 10^{-2}$	0.198	$2\ 10^{-3}$	Am	0	0	0
Pd	$3.76\ 10^{-3}$	$8.17\ 10^{-3}$	$1.32\ 10^{-3}$	Cm	0	0	0
Ag	$1.29\ 10^{-2}$	$3.27\ 10^{-2}$	$3.67\ 10^{-3}$	Cf	0	0	0

Table E9 **Elemental composition for new build SILW (waste, conditioning, capping and container materials). The priority metallic species are highlighted**

Element	Mass (tonnes)			Element	Mass (tonnes)		
	Best estimate	Upper uncertainty	Lower uncertainty		Best estimate	Upper uncertainty	Lower uncertainty
H	519	886	361	Cd	9.48 10^{-2}	0.175	4.78 10^{-2}
He	1.74 10^{-4}	4.77 10^{-3}	2.37 10^{-5}	In	0.236	0.289	0.236
Li	0.363	1.13	0.135	Sn	1.33	2.85	0.512
Be	7.09 10^{-2}	10.8	0.101	Sb	0.715	1.71	0.274
B	25	50.3	0.973	Te	2.58 10^{-5}	3.77 10^{-3}	3.41 10^{-5}
C	1,710	2,410	1,680	I	1.21 10^{-2}	0.808	6.41 10^{-3}
N	3.09	6.15	0.678	Xe	5.95 10^{-4}	5.96 10^{-3}	5.95 10^{-5}
O	14,800	15,700	14,300	Cs	5.19 10^{-2}	0.289	1.55 10^{-2}
F	14.5	413	2.13	Ba	19.5	178	5.63
Ne	1.92 10^{-2}	0.194	1.93 10^{-3}	La	0.477	1.54	0.159
Na	215	470	28.3	Ce	1.1	2.75	0.382
Mg	211	311	173	Pr	0.231	15	0.118
Al	915	1,650	331	Nd	0.472	1.38	0.262
Si	5,840	9,430	1,350	Sm	8.32 10^{-2}	0.504	2.86 10^{-2}
P	124	131	4.85	Eu	1.94 10^{-2}	0.132	8.12 10^{-3}
S	76.6	125	40.5	Gd	0.149	4.33	2.31 10^{-2}
Cl	15.9	25.8	14	Tb	1.89 10^{-2}	0.155	6.43 10^{-3}
Ar	6.46 10^{-2}	16.9	0.16	Dy	7.8 10^{-2}	0.436	3.18 10^{-2}
K	233	623	45.7	Ho	2.1 10^{-2}	0.311	9.15 10^{-3}
Ca	3,920	8,680	1,600	Er	0.246	0.422	1.33 10^{-2}
Sc	0.18	0.995	7.87 10^{-2}	Tm	3.08 10^{-2}	0.416	5.87 10^{-3}
Ti	65.2	219	20.8	Yb	4.72 10^{-2}	0.257	2.01 10^{-2}
V	5.2	17.9	1.41	Lu	9.48 10^{-3}	5.55 10^{-2}	4.5 10^{-3}
Cr	219	258	104	Hf	5.81 10^{-2}	0.312	2.54 10^{-2}
Mn	161	241	97	Ta	1.74 10^{-2}	8.5 10^{-2}	8.3 10^{-3}
Fe	15,600	20,700	14,800	W	0.681	1.88	0.145
Co	2.67	7.93	1.1	Re	3.05 10^{-4}	3.87 10^{-3}	3.32 10^{-5}
Ni	132	149	70	Os	3.04 10^{-4}	1.93 10^{-3}	6.73 10^{-5}
Cu	39	67.5	20.1	Ir	6.81 10^{-3}	2.46 10^{-2}	3.85 10^{-4}
Zn	3.06	11.5	0.714	Pt	5.89 10^{-4}	2.35 10^{-2}	1.76 10^{-4}
Ga	0.963	3.44	0.135	Au	1.39 10^{-4}	1.03 10^{-2}	1.06 10^{-4}

Element	Mass (tonnes)			Element	Mass (tonnes)		
	Best estimate	Upper uncertainty	Lower uncertainty		Best estimate	Upper uncertainty	Lower uncertainty
Ge	$3.75\ 10^{-2}$	11.6	0.11	Hg	$1.96\ 10^{-3}$	0.81	$7.83\ 10^{-3}$
As	2.26	4.58	1.36	Tl	$1.81\ 10^{-2}$	1.42	$1.18\ 10^{-2}$
Se	0.126	0.356	$2.22\ 10^{-2}$	Pb	2.33	15.9	0.376
Br	$7.41\ 10^{-2}$	0.318	$3.35\ 10^{-2}$	Bi	$5.13\ 10^{-4}$	0.3	$2.97\ 10^{-3}$
Kr	$4.97\ 10^{-3}$	$4.97\ 10^{-2}$	$4.97\ 10^{-4}$	Po	$2.58\ 10^{-12}$	$7.07\ 10^{-11}$	$3.51\ 10^{-13}$
Rb	1.38	5.47	0.289	Rn	$5.16\ 10^{-15}$	$1.41\ 10^{-13}$	$7.03\ 10^{-16}$
Sr	12	23.6	6.04	Ra	$1.29\ 10^{-8}$	$3.53\ 10^{-7}$	$1.76\ 10^{-9}$
Y	0.67	3.49	0.156	Ac	$7.1\ 10^{-12}$	$1.94\ 10^{-10}$	$9.66\ 10^{-13}$
Zr	3.66	6.96	2.06	Th	0.133	3.26	$4.09\ 10^{-2}$
Nb	0.569	3.16	0.124	Pa	$1.82\ 10^{-8}$	$4.98\ 10^{-7}$	$2.48\ 10^{-9}$
Mo	17.3	26.3	12.5	U	$8.72\ 10^{-2}$	0.519	$3.63\ 10^{-2}$
Tc	$4.57\ 10^{-2}$	$4.57\ 10^{-2}$	$4.57\ 10^{-2}$	Np	0	0	0
Ru	0.196	0.199	0.196	Pu	0	0	0
Rh	$5.83\ 10^{-2}$	0.403	$2.38\ 10^{-2}$	Am	0	0	0
Pd	0.11	0.12	$3.52\ 10^{-2}$	Cm	0	0	0
Ag	$5.43\ 10^{-2}$	0.27	$1.42\ 10^{-2}$	Cf	0	0	0

Table E10 Elemental composition for DNLEU (waste, conditioning, capping and container materials). The priority metallic species are highlighted

Element	Mass (tonnes)			Element	Mass (tonnes)		
	Best estimate	Upper uncertainty	Lower uncertainty		Best estimate	Upper uncertainty	Lower uncertainty
H	3,050	3,050	3,050	Cd	0.293	0.527	0.141
He	$4.36\ 10^{-4}$	$4.36\ 10^{-4}$	$4.36\ 10^{-4}$	In	$1.62\ 10^{-2}$	$2.05\ 10^{-2}$	$1.40\ 10^{-2}$
Li	1.23	1.28	1.20	Sn	3.78	7.23	1.63
Be	0.152	29.2	0.443	Sb	1.07	1.94	0.509
B	2.24	4.42	1.11	Te	$6.47\ 10^{-5}$	$9.76\ 10^{-3}$	$1.62\ 10^{-4}$
C	836	879	808	I	$3.04\ 10^{-2}$	1.48	$4.49\ 10^{-2}$
N	123	133	116	Xe	$1.92\ 10^{-3}$	$1.91\ 10^{-2}$	$1.93\ 10^{-4}$
O	82,300	82,400	82,300	Cs	0.169	0.184	0.161
F	730	779	731	Ba	38.6	58.3	28.3
Ne	$6.18\ 10^{-2}$	0.616[1]	$6.41\ 10^{-3}$	La	2.37	2.39	2.36
Na	597	598	597	Ce	17.1	31.3	8.79

Element	Mass (tonnes)			Element	Mass (tonnes)		
	Best estimate	**Upper uncertainty**	**Lower uncertainty**		**Best estimate**	**Upper uncertainty**	**Lower uncertainty**
Mg	1,680	1,730	1,680	Pr	0.579	27.2	0.845
Al	5,220	5,230	5,210	Nd	2.42	2.49	2.41
Si	11,600	11,800	11,500	Sm	0.427	0.437	0.422
P	76.3	86.0	70.3	Eu	0.124	0.127	0.123
S	271	281	265	Gd	0.376	0.392	0.369
Cl	80.0	80.0	80.0	Tb	$9.21\ 10^{-2}$	$2.98\ 10^{-1}$	$7.15\ 10^{-2}$
Ar	0.162	48.6	0.646	Dy	0.379	0.395	0.371
K	891	893	890	Ho	$8.40\ 10^{-2}$	$9.03\ 10^{-2}$	$8.13\ 10^{-2}$
Ca	15,900	15,900	15,900	Er	0.220	0.246	0.211
Sc	1.56	1.56	1.55	Tm	$9.06\ 10^{-2}$	$1.86\ 10^{-1}$	$4.41\ 10^{-2}$
Ti	418	457	400	Yb	0.231	0.307	0.199
V	27.2	45.4	16.4	Lu	$6.15\ 10^{-2}$	$9.75\ 10^{-2}$	$4.63\ 10^{-2}$
Cr	6,340	6,710	5,990	Hf	0.216	0.244	0.205
Mn	725	958	535	Ta	0.139	0.165	0.125
Fe	39,900	41,400	38,500	W	7.11	17.64	1.78
Co	62.0	149	17.2	Re	$9.55\ 10^{-4}$	$8.59\ 10^{-3}$	$1.92\ 10^{-4}$
Ni	4,370	5,120	3,690	Os	$9.55\ 10^{-4}$	$2.26\ 10^{-3}$	$3.03\ 10^{-4}$
Cu	147	318	51.8	Ir	$2.14\ 10^{-2}$	$7.85\ 10^{-2}$	$1.06\ 10^{-3}$
Zn	20.8	57.7	6.4	Pt	$1.36\ 10^{-3}$	$2.56\ 10^{-2}$	$1.60\ 10^{-3}$
Ga	6.63	18.2	1.86	Au	$2.30\ 10^{-4}$	$2.45\ 10^{-2}$	$4.72\ 10^{-4}$
Ge	$9.38\ 10^{-2}$	34.0	0.433	Hg	$4.91\ 10^{-3}$	2.43	$2.91\ 10^{-2}$
As	9.99	30.4	1.97	Tl	$4.46\ 10^{-2}$	2.95	$7.37\ 10^{-2}$
Se	0.577	1.83	0.0673	Pb	3.86	8.64	1.49
Br	0.240	0.387	0.182	Bi	$3.13\ 10^{-3}$	0.274	$4.16\ 10^{-3}$
Kr	$1.60\ 10^{-2}$	0.160	$1.61\ 10^{-3}$	Po	$6.47\ 10^{-12}$	$6.47\ 10^{-12}$	$6.47\ 10^{-12}$
Rb	5.30	6.00	4.96	Rn	$1.29\ 10^{-14}$	$1.29\ 10^{-14}$	$1.29\ 10^{-14}$
Sr	23.8	24.1	23.7	Ra	$3.23\ 10^{-8}$	$3.23\ 10^{-8}$	$3.23\ 10^{-8}$
Y	2.29	2.87	2.05	Ac	$1.78\ 10^{-11}$	$1.78\ 10^{-11}$	$1.78\ 10^{-11}$
Zr	9.90	10.6	9.59	Th	0.583	0.738	0.516
Nb	4.30	10.2	1.69	Pa	$4.56\ 10^{-8}$	$4.56\ 10^{-8}$	$4.56\ 10^{-8}$
Mo	862	1,060	695	U	184,000	184,000	184,000
Tc	$2.38\ 10^{-3}$	$2.38\ 10^{-3}$	$2.38\ 10^{-3}$	Np	0	0	0
Ru	$6.47\ 10^{-5}$	$4.91\ 10^{-3}$	$1.13\ 10^{-4}$	Pu	0	0	0

Element	Mass (tonnes)			Element	Mass (tonnes)		
	Best estimate	Upper uncertainty	Lower uncertainty		Best estimate	Upper uncertainty	Lower uncertainty
Rh	0.124	1.24	0.0124	Am	0	0	0
Pd	2.29 10^{-2}	5.05 10^{-2}	7.57 10^{-3}	Cm	0	0	0
Ag	8.48 10^{-2}	0.218	2.12 10^{-2}	Cf	0	0	0

Table E11 Elemental composition for RSCs (waste, conditioning, capping and container materials). The priority metallic species are highlighted

Element	Mass (tonnes)			Element	Mass (tonnes)		
	Best estimate	Upper uncertainty	Lower uncertainty		Best estimate	Upper uncertainty	Lower uncertainty
H	49.2	51.7	48.8	Cd	0.164	0.293	8.13 10^{-2}
He	6.6 10^{-7}	9.41 10^{-6}	4.17 10^{-7}	In	3.44 10^{-3}	1.98 10^{-2}	3.94 10^{-3}
Li	1.83 10^{-3}	0.17	5.99 10^{-3}	Sn	0.136	7.05	0.299
Be	2.86 10^{-2}	15.9	0.169	Sb	33.7	58.7	11.7
B	1.55	2.76	0.815	Te	2.62 10^{-7}	5.43 10^{-3}	5.46 10^{-5}
C	1,830	1,830	1,830	I	4.59 10^{-5}	0.82	8.22 10^{-3}
N	2.58	5.26	1.27	Xe	1.07 10^{-3}	1.12 10^{-2}	1.12 10^{-4}
O	384	421	379	Cs	2.96 10^{-3}	6.24 10^{-2}	2.43 10^{-3}
F	6.03 10^{-2}	27.2	0.301	Ba	8.73 10^{-2}	13	1.42
Ne	3.44 10^{-2}	0.345	3.45 10^{-3}	La	2.82 10^{-3}	0.187	4.72 10^{-3}
Na	2.3	3.12	2.11	Ce	1.42 10^{-2}	0.256	1.49 10^{-2}
Mg	224	225	224	Pr	8.85 10^{-4}	14.7	0.147
Al	52.7	63.3	46.7	Nd	3 10^{-3}	0.174	4.22 10^{-3}
Si	679	934	472	Sm	9.58 10^{-4}	8.26 10^{-2}	1.31 10^{-3}
P	0.328	225	5.51	Eu	1.93 10^{-3}	2.7 10^{-2}	1.43 10^{-3}
S	0.39	16.1	4.68	Gd	4.39 10^{-3}	9.07 10^{-2}	1.36 10^{-3}
Cl	7.59	7.74	7.58	Tb	1.89 10^{-4}	0.161	1.67 10^{-3}
Ar	2.44 10^{-4}	26.5	0.265	Dy	2 10^{-2}	0.12	5.76 10^{-3}
K	3.35	5.3	2.5	Ho	1.47 10^{-4}	3.21 10^{-2}	9.98 10^{-4}
Ca	20.2	49.5	17.5	Er	6.39 10^{-4}	6.05 10^{-2}	9.42 10^{-4}
Sc	1.78 10^{-3}	0.172	3.4 10^{-3}	Tm	3.02 10^{-4}	9.09 10^{-2}	7 10^{-3}
Ti	0.933	32.7	2.28	Yb	3.34 10^{-4}	9.46 10^{-2}	5.32 10^{-3}
V	5.56 10^{-2}	9.35	1.18	Lu	1.02 10^{-4}	2 10^{-2}	8.91 10^{-4}
Cr	67.8	110	21.5	Hf	1.92 10^{-3}	5.63 10^{-2}	3.4 10^{-3}

Element	Mass (tonnes)			Element	Mass (tonnes)		
	Best estimate	Upper uncertainty	Lower uncertainty		Best estimate	Upper uncertainty	Lower uncertainty
Mn	51.5	110	16.9	Ta	1.09 10^{-2}	4.09 10^{-2}	1.08 10^{-2}
Fe	24,900	24,900	24,800	W	2.47 10^{-2}	2.68	0.208
Co	4.02	8.18	1.63	Re	2.49 10^{-5}	4.76 10^{-3}	4.85 10^{-5}
Ni	60.9	146	11.4	Os	3.69 10^{-6}	1.27 10^{-3}	1.08 10^{-4}
Cu	67.6	113	35.7	Ir	1.35 10^{-4}	4.29 10^{-2}	5.55 10^{-4}
Zn	0.178	3.98	0.715	Pt	1.15 10^{-4}	1.4 10^{-2}	1.79 10^{-4}
Ga	1.25 10^{-2}	4.19	9.79 10^{-2}	Au	7.3 10^{-3}	2.09 10^{-2}	7.36 10^{-3}
Ge	3.37 10^{-4}	18.5	0.186	Hg	7.43 10^{-6}	1.36	1.36 10^{-2}
As	4.12 10^{-2}	4.7	2.42	Tl	6.27 10^{-4}	1.62	1.65 10^{-2}
Se	1.57 10^{-3}	0.518	2.76 10^{-2}	Pb	529	555	506
Br	4.2 10^{-4}	0.163	5.21 10^{-3}	Bi	2.83 10^{-2}	0.556	5.34 10^{-3}
Kr	8.95 10^{-3}	8.99 10^{-2}	8.99 10^{-4}	Po	9.77 10^{-15}	1.39 10^{-13}	6.18 10^{-15}
Rb	1.22 10^{-2}	1.58	9.55 10^{-2}	Rn	1.95 10^{-17}	2.79 10^{-16}	1.24 10^{-17}
Sr	4.38 10^{-2}	0.539	6.71 10^{-2}	Ra	4.89 10^{-11}	6.97 10^{-10}	3.09 10^{-11}
Y	0.312	1.34	1.6 10^{-2}	Ac	2.69 10^{-14}	3.83 10^{-13}	1.7 10^{-14}
Zr	28.6	29.9	28.6	Th	3.07 10^{-2}	0.16	1.98 10^{-2}
Nb	1.48 10^{-2}	1.05	4.23 10^{-2}	Pa	7.19 10^{-3}	7.19 10^{-3}	7.19 10^{-3}
Mo	0.763	3.89	0.712	U	0.21	0.274	0.194
Tc	0	0	0	Np	0	0	0
Ru	9.77 10^{-8}	2.72 10^{-3}	2.73 10^{-5}	Pu	0	0	0
Rh	5.34 10^{-4}	0.674	6.74 10^{-3}	Am	0	0	0
Pd	3.23 10^{-4}	2.81 10^{-2}	3.79 10^{-3}	Cm	0	0	0
Ag	9.02 10^{-2}	0.194	5.48 10^{-2}	Cf	0	0	0

Table E12 Elemental composition for HLW (waste, conditioning, capping and container materials). The priority metallic species are highlighted

Element	Mass (tonnes)			Element	Mass (tonnes)		
	Best estimate	Upper uncertainty	Lower uncertainty		Best estimate	Upper uncertainty	Lower uncertainty
H	0.297	2.9	3.95 10^{-2}	Cd	0.275	0.472	0.146
He	0	1.69 10^{-5}	1.69 10^{-7}	In	1.87 10^{-4}	6.62 10^{-3}	6.44 10^{-4}
Li	35.7	35.8	35.7	Sn	0.301	10.4	0.455
Be	0	24.2	0.242	Sb	0.197	3.85	0.819

Element	Mass (tonnes)			Element	Mass (tonnes)		
	Best estimate	Upper uncertainty	Lower uncertainty		Best estimate	Upper uncertainty	Lower uncertainty
B	206	207	204	Te	3.56 10^{-2}	4.36 10^{-2}	3.56 10^{-2}
C	1,400	1,410	1,400	I	0	1.21	1.21 10^{-2}
N	2.81	6.8	0.763	Xe	1.61 10^{-3}	1.61 10^{-2}	1.61 10^{-4}
O	1,530	1,590	1,530	Cs	7.29 10^{-4}	3.24 10^{-2}	2.14 10^{-3}
F	0	40.4	0.404	Ba	0.67	19.6	2.18
Ne	5.19 10^{-2}	0.519	5.19 10^{-3}	La	3.22 10^{-4}	3.32 10^{-2}	1.32 10^{-3}
Na	241	241	241	Ce	0.197	0.548	7.99 10^{-2}
Mg	0.189	2.97	9.35 10^{-2}	Pr	0	22.2	0.222
Al	10.4	24.3	2.81	Nd	5.36 10^{-4}	9.66 10^{-2}	9.66 10^{-4}
Si	2,060	2,150	1,490	Sm	7.47 10^{-4}	1.83 10^{-2}	3.26 10^{-4}
P	20.8	328	9.26	Eu	1.38 10^{-3}	8.4 10^{-3}	3.4 10^{-4}
S	1.09	24.3	6.94	Gd	5.88 10^{-3}	3.44 10^{-2}	6.02 10^{-4}
Cl	1.31 10^{-2}	5.29 10^{-2}	4.8 10^{-3}	Tb	1.45 10^{-3}	0.196	1.96 10^{-3}
Ar	0	40.4	0.404	Dy	2.99 10^{-2}	8.93 10^{-2}	7.34 10^{-3}
K	1.05	2.87	0.202	Ho	5.26 10^{-4}	2.78 10^{-2}	1.19 10^{-3}
Ca	0.731	32.6	1.91	Er	6.41 10^{-4}	3.85 10^{-2}	6.09 10^{-4}
Sc	2.35 10^{-4}	3.47 10^{-2}	7.35 10^{-4}	Tm	3.74 10^{-3}	0.132	1.07 10^{-2}
Ti	1.32	49.1	2.91	Yb	1.6 10^{-3}	4.64 10^{-2}	6.91 10^{-3}
V	0.609	14.5	1.88	Lu	6.28 10^{-4}	1.99 10^{-2}	1.21 10^{-3}
Cr	199	271	156	Hf	7.48 10^{-4}	2.92 10^{-2}	3.33 10^{-3}
Mn	220	233	42.5	Ta	8.06 10^{-4}	2.39 10^{-2}	3.3 10^{-3}
Fe	37,600	38,400	37,600	W	0.191	4.25	0.322
Co	6.89	13.9	2.69	Re	5.36 10^{-5}	7.16 10^{-3}	7.16 10^{-5}
Ni	166	319	95.2	Os	5.36 10^{-5}	1.82 10^{-3}	1.66 10^{-4}
Cu	17,900	18,000	17,800	Ir	1.35 10^{-3}	6.62 10^{-2}	8.54 10^{-4}
Zn	0.459	6.43	0.969	Pt	0	2.02 10^{-2}	2.02 10^{-4}
Ga	0.183	6.3	0.153	Au	0	2.02 10^{-2}	2.02 10^{-4}
Ge	0	28.3	0.283	Hg	0	2.02	2.02 10^{-2}
As	0.538	7.54	3.8	Tl	0	2.42	2.42 10^{-2}
Se	7.76 10^{-2}	0.864	9.63 10^{-2}	Pb	0.271	6.01	0.677
Br	2.69 10^{-3}	8.86 10^{-2}	6.13 10^{-3}	Bi	1.78 10^{-2}	0.825	2.59 10^{-2}
Kr	1.35 10^{-2}	0.135	1.35 10^{-3}	Po	0	2.51 10^{-13}	2.51 10^{-15}
Rb	5.22 10^{-2}	2.22	0.138	Rn	0	5.02 10^{-16}	5.02 10^{-18}

Element	Mass (tonnes)			Element	Mass (tonnes)		
	Best estimate	Upper uncertainty	Lower uncertainty		Best estimate	Upper uncertainty	Lower uncertainty
Sr	$1.49\ 10^{-2}$	0.523	$5.36\ 10^{-2}$	Ra	0	$1.25\ 10^{-9}$	$1.25\ 10^{-11}$
Y	0.475	1.8	$1.97\ 10^{-2}$	Ac	0	$6.9\ 10^{-13}$	$6.9\ 10^{-15}$
Zr	$3.13\ 10^{-2}$	1.67	$2.37\ 10^{-2}$	Th	$2.05\ 10^{-2}$	$8.42\ 10^{-2}$	$2.56\ 10^{-3}$
Nb	0.116	1.64	$7.54\ 10^{-2}$	Pa	0	$1.77\ 10^{-9}$	$1.77\ 10^{-11}$
Mo	13.5	21.6	10.7	U	$2.86\ 10^{-2}$	$8.83\ 10^{-2}$	$4.63\ 10^{-3}$
Tc	0	0	0	Np	0	0	0
Ru	0	$4.04\ 10^{-3}$	$4.04\ 10^{-5}$	Pu	0	0	0
Rh	$7.84\ 10^{-3}$	1.04	$1.04\ 10^{-2}$	Am	0	0	0
Pd	$1.4\ 10^{-3}$	$4.2\ 10^{-2}$	$5.81\ 10^{-3}$	Cm	0	0	0
Ag	0.506	0.646	0.451	Cf	0	0	0

Table E13 **Elemental composition for legacy SFs (waste, conditioning, capping and container materials). The priority metallic species are highlighted**

Element	Mass (tonnes)			Element	Mass (tonnes)		
	Best estimate	Upper uncertainty	Lower uncertainty		Best estimate	Upper uncertainty	Lower uncertainty
H	0.433	4.14	$6.04\ 10^{-2}$	Cd	0.884	1.17	0.698
He	$3.66\ 10^{-2}$	$3.66\ 10^{-2}$	$3.66\ 10^{-2}$	In	$1.18\ 10^{-2}$	$2.08\ 10^{-2}$	$1.25\ 10^{-2}$
Li	$2.22\ 10^{-3}$	$9.86\ 10^{-2}$	$8.6\ 10^{-3}$	Sn	4.52	20.2	4.23
Be	$1.75\ 10^{-2}$	35.3	0.358	Sb	0.246	5.64	1.25
B	2.89	5.21	1.36	Te	3.26	3.28	3.26
C	2,100	2,100	2,100	I	1.4	3.16	1.41
N	4.33	10.1	1.29	Xe	34.9	34.9	34.9
O	709	788	701	Cs	11.3	11.3	11.3
F	$7.54\ 10^{-3}$	58.5	0.588	Ba	19.3	47.3	21.8
Ne	$7.51\ 10^{-2}$	0.751	$7.54\ 10^{-3}$	La	8.37	8.66	8.37
Na	$2.29\ 10^{-2}$	0.635	0.28	Ce	16.8	17.8	16.5
Mg	162	164	162	Pr	7.7	40	8.02
Al	35.4	55.4	24.7	Nd	28.1	28.2	28.1
Si	1,820	1,950	975	Sm	5.67	5.67	5.67
P	30.5	490	13.7	Eu	0.803	0.807	0.802
S	0.642	34.8	9.91	Gd	0.865	0.885	0.857
Cl	$1.99\ 10^{-2}$	$4.12\ 10^{-2}$	$7.54\ 10^{-3}$	Tb	$1.78\ 10^{-2}$	0.33	$1.99\ 10^{-2}$

Element	Mass (tonnes)			Element	Mass (tonnes)		
	Best estimate	Upper uncertainty	Lower uncertainty		Best estimate	Upper uncertainty	Lower uncertainty
Ar	8.21 10^{-8}	58.7	0.587	Dy	5.48 10^{-2}	0.119	2.25 10^{-2}
K	1.5	4.1	0.289	Ho	1.5 10^{-3}	3.64 10^{-2}	2.99 10^{-3}
Ca	0.261	46.4	2.75	Er	9.87 10^{-4}	4.42 10^{-2}	1.31 10^{-3}
Sc	1.37 10^{-4}	0.162	2.17 10^{-3}	Tm	2.5 10^{-3}	0.188	1.54 10^{-2}
Ti	0.961	70.3	4.32	Yb	1.5 10^{-3}	0.143	1.06 10^{-2}
V	0.792	21.3	2.83	Lu	4.51 10^{-4}	2.59 10^{-2}	1.7 10^{-3}
Cr	354	461	289	Hf	1.61 10^{-2}	5.44 10^{-2}	1.42 10^{-2}
Mn	304	312	48.4	Ta	0.146	0.813	4.04 10^{-2}
Fe	53,600	54,800	53,600	W	0.283	6.35	0.487
Co	9.94	20.2	3.85	Re	1.66 10^{-4}	1.07 10^{-2}	1.11 10^{-4}
Ni	355	584	250	Os	2.52 10^{-5}	2.69 10^{-3}	2.36 10^{-4}
Cu	28,100	28,200	28,100	Ir	1.02 10^{-3}	9.53 10^{-2}	1.25 10^{-3}
Zn	0.751	10	1.42	Pt	6.81 10^{-5}	2.95 10^{-2}	3.18 10^{-4}
Ga	0.216	9.46	0.23	Au	6.67 10^{-5}	2.95 10^{-2}	3.17 10^{-4}
Ge	3.45 10^{-3}	41.1	0.414	Hg	0	2.94	2.94 10^{-2}
As	0.545	11.3	5.43	Tl	3.34 10^{-4}	3.52	3.53 10^{-2}
Se	0.483	1.64	0.522	Pb	0.28	8.66	0.987
Br	0.148	0.321	0.155	Bi	2.81 10^{-2}	1.18	3.95 10^{-2}
Kr	2.4	2.58	2.39	Po	3.14 10^{-10}	3.14 10^{-10}	3.14 10^{-10}
Rb	2.69	5.81	2.86	Rn	1.15 10^{-11}	1.15 10^{-11}	1.15 10^{-11}
Sr	2.46	3.43	2.53	Ra	1.79 10^{-6}	1.79 10^{-6}	1.79 10^{-6}
Y	3.96	6.09	3.31	Ac	1.12 10^{-8}	1.12 10^{-8}	1.12 10^{-8}
Zr	293	296	293	Th	3.59 10^{-2}	0.102	8.82 10^{-3}
Nb	5.88	9.36	4.75	Pa	1.87 10^{-5}	1.87 10^{-5}	1.87 10^{-5}
Mo	42.5	54.7	38.2	U	6,050	6,050	6,050
Tc	3.12	3.12	3.12	Np	4.05	4.05	4.05
Ru	14.4	14.4	14.4	Pu	40.5	40.5	40.5
Rh	2.92	4.4	2.93	Am	4.13	4.13	4.13
Pd	8.34	8.4	8.35	Cm	1.18 10^{-2}	1.18 10^{-2}	1.18 10^{-2}
Ag	1.23	1.43	1.15	Cf	1.91 10^{-8}	1.91 10^{-8}	1.91 10^{-8}

Table E14 **Elemental composition for new build SFs (waste, conditioning, capping and container materials). The priority metallic species are highlighted**

Element	Mass (tonnes)			Element	Mass (tonnes)		
	Best estimate	Upper uncertainty	Lower uncertainty		Best estimate	Upper uncertainty	Lower uncertainty
H	1.32	12.6	0.184	Cd	3.85	4.7	3.28
He	0.417	0.417	0.417	In	3.02 10^{-2}	6.37 10^{-2}	3.23 10^{-2}
Li	2.55 10^{-3}	0.303	2.39 10^{-2}	Sn	57.3	111	47.1
Be	0	109	1.09	Sb	0.514	17.5	3.79
B	8.9	16	4.19	Te	12.4	12.5	12.4
C	6,570	6,570	6,570	I	5.07	10.5	5.13
N	11.8	29	3.02	Xe	138	138	138
O	1,950	2,200	1,930	Cs	38.4	38.7	38.4
F	2.57 10^{-2}	178	1.78	Ba	73.2	162	82.5
Ne	0.232	2.32	2.33 10^{-2}	La	31.4	35.7	31.5
Na	2.93 10^{-2}	1.88	0.865	Ce	61.9	66.9	61.9
Mg	0.922	2.45	0.334	Pr	28.7	129	29.7
Al	53.4	115	20.9	Nd	105	105	105
Si	5,690	6,080	3,040	Sm	21	21	21
P	93.8	1,530	41.7	Eu	3.45	3.46	3.44
S	0.817	108	30.4	Gd	4.75	4.82	4.73
Cl	8.08 10^{-2}	0.16	3.28 10^{-2}	Tb	6.67 10^{-2}	1.29	7.87 10^{-2}
Ar	0	182	1.82	Dy	0.167	0.366	6.7 10^{-2}
K	4.59	12.6	0.886	Ho	2.73 10^{-3}	0.112	7.79 10^{-3}
Ca	7.62 10^{-2}	143	8.39	Er	1.2 10^{-3}	0.134	3.35 10^{-3}
Sc	3.1 10^{-5}	2.18	2.35 10^{-2}	Tm	6.51 10^{-4}	0.57	4.67 10^{-2}
Ti	1.4	215	13.5	Yb	4.54 10^{-4}	1.32	4.15 10^{-2}
V	0.326	62.4	8.01	Lu	2.74 10^{-4}	7.79 10^{-2}	5.16 10^{-3}
Cr	320	614	155	Hf	0.263	0.492	0.174
Mn	895	897	109	Ta	0.893	5.99	0.187
Fe	164,000	167,000	164,000	W	0.215	18.2	1.36
Co	27.5	54.5	11.1	Re	9.28 10^{-4}	3.5 10^{-2}	3.42 10^{-4}
Ni	394	1,040	129	Os	9.05 10^{-6}	8.37 10^{-3}	7.25 10^{-4}
Cu	74,000	74,300	73,800	Ir	1.89 10^{-3}	0.294	3.85 10^{-3}
Zn	0.547	25.7	4.19	Pt	0	9.12 10^{-2}	9.12 10^{-4}
Ga	7.09 10^{-2}	31.1	0.686	Au	0	9.12 10^{-2}	9.12 10^{-4}

Element	Mass (tonnes)			Element	Mass (tonnes)		
	Best estimate	Upper uncertainty	Lower uncertainty		Best estimate	Upper uncertainty	Lower uncertainty
Ge	9.64 10^{-3}	128	1.29	Hg	0	9.12	9.12 10^{-2}
As	0.49	33.9	16.7	Tl	0	10.9	0.109
Se	1.59	5.11	1.77	Pb	0.551	26.5	2.95
Br	0.525	1.56	0.557	Bi	7.36 10^{-2}	3.71	0.11
Kr	8.69	9.23	8.63	Po	1.18 10^{-9}	1.18 10^{-9}	1.18 10^{-9}
Rb	9.35	19.2	9.93	Rn	4.39 10^{-11}	4.39 10^{-11}	4.39 10^{-11}
Sr	8.62	15.1	8.89	Ra	6.81 10^{-6}	6.81 10^{-6}	6.81 10^{-6}
Y	13.6	23.5	11.6	Ac	2.7 10^{-8}	2.7 10^{-8}	2.7 10^{-8}
Zr	4,300	4,310	4,290	Th	9.8 10^{-2}	0.292	1.79 10^{-2}
Nb	52.8	59.4	35.4	Pa	4.54 10^{-5}	4.54 10^{-5}	4.54 10^{-5}
Mo	91.8	113	91.4	U	13,200	13,200	13,200
Tc	19.1	19.1	19.1	Np	23.9	23.9	23.9
Ru	59.7	59.7	59.7	Pu	151	151	151
Rh	10.6	15.1	10.6	Am	23.1	23.1	23.1
Pd	39.3	39.5	39.3	Cm	0.138	0.138	0.138
Ag	4.04	4.68	3.8	Cf	2.6 10^{-7}	2.6 10^{-7}	2.6 10^{-7}

Table E15 Elemental composition for MOX SF (waste, conditioning, capping and container materials). The priority metallic species are highlighted

Element	Mass (tonnes)			Element	Mass (tonnes)		
	Best estimate	Upper uncertainty	Lower uncertainty		Best estimate	Upper uncertainty	Lower uncertainty
H	0.46	4.44	5.94 10^{-2}	Cd	0.414	0.718	0.215
He	0	0	0	In	8.21 10^{-5}	1.02 10^{-2}	9.95 10^{-4}
Li	2.6 10^{-4}	0.106	8.41 10^{-3}	Sn	6.41	24.1	5.86
Be	0	38.2	0.382	Sb	8.99 10^{-2}	6.03	1.25
B	3.16	5.68	1.49	Te	4.45 10^{-2}	5.73 10^{-2}	4.47 10^{-2}
C	2,340	2,340	2,340	I	0	1.91	1.91 10^{-2}
N	4.12	10.1	1.03	Xe	2.51 10^{-3}	2.51 10^{-2}	2.51 10^{-4}
O	207	292	198	Cs	1.98 10^{-3}	6.05 10^{-2}	3.4 10^{-3}
F	2.63 10^{-3}	63.2	0.632	Ba	1.64 10^{-2}	30.5	3.35
Ne	8.08 10^{-2}	0.808	8.08 10^{-3}	La	1.03 10^{-5}	0.451	6.04 10^{-3}
Na	2.03 10^{-3}	0.647	0.305	Ce	1.9 10^{-2}	0.666	2.6 10^{-2}

Element	Mass (tonnes)			Element	Mass (tonnes)		
	Best estimate	Upper uncertainty	Lower uncertainty		Best estimate	Upper uncertainty	Lower uncertainty
Mg	0.319	0.718	0.115	Pr	0	35	0.35
Al	16.7	38.3	5.26	Nd	3.69 10^{-5}	0.111	1.11 10^{-3}
Si	2,020	2,160	1,080	Sm	1.08 10^{-3}	2.8 10^{-3}	2.45 10^{-4}
P	33	544	14.6	Eu	2.27 10^{-3}	5.98 10^{-3}	4.78 10^{-4}
S	0.201	37.9	10.8	Gd	9.1 10^{-3}	3.11 10^{-2}	7.11 10^{-4}
Cl	2.07 10^{-2}	4.37 10^{-2}	7.27 10^{-3}	Tb	2.42 10^{-5}	0.338	3.38 10^{-3}
Ar	0	63.6	0.636	Dy	4.68 10^{-2}	0.117	1.13 10^{-2}
K	1.62	4.42	0.314	Ho	5.97 10^{-6}	3.86 10^{-2}	1.82 10^{-3}
Ca	9.15 10^{-3}	50.9	2.98	Er	1.51 10^{-5}	4.7 10^{-2}	8.15 10^{-4}
Sc	3.08 10^{-6}	0.234	2.94 10^{-3}	Tm	6.49 10^{-5}	0.202	1.66 10^{-2}
Ti	0.131	75.9	4.57	Yb	4.5 10^{-5}	0.177	1.18 10^{-2}
V	3.14 10^{-2}	22	2.81	Lu	2.73 10^{-5}	2.74 10^{-2}	1.83 10^{-3}
Cr	88.7	191	32.6	Hf	2.56 10^{-2}	7.15 10^{-2}	2.06 10^{-2}
Mn	316	317	37.7	Ta	8.73 10^{-2}	0.591	2.24 10^{-2}
Fe	58,000	59,400	58,000	W	1.79 10^{-2}	6.31	0.47
Co	9.6	18.9	3.87	Re	8.73 10^{-5}	1.14 10^{-2}	1.13 10^{-4}
Ni	113	341	20.4	Os	8.98 10^{-7}	2.86 10^{-3}	2.56 10^{-4}
Cu	22,400	22,500	22,400	Ir	1.93 10^{-4}	0.103	1.33 10^{-3}
Zn	0.114	8.9	1.47	Pt	0	3.18 10^{-2}	3.18 10^{-4}
Ga	7.03 10^{-3}	9.92	0.231	Au	0	3.18 10^{-2}	3.18 10^{-4}
Ge	0	44.5	0.445	Hg	0	3.18	3.18 10^{-2}
As	0.123	11.4	5.91	Tl	0	3.82	3.82 10^{-2}
Se	6.75 10^{-2}	1.3	0.133	Pb	0.131	9.25	1.02
Br	8.18 10^{-5}	0.194	1.01 10^{-2}	Bi	2.23 10^{-2}	1.29	3.5 10^{-2}
Kr	2.1 10^{-2}	0.21	2.1 10^{-3}	Po	0	0	0
Rb	2.26 10^{-3}	3.45	0.214	Rn	0	0	0
Sr	2.09 10^{-4}	1.21	8.72 10^{-2}	Ra	0	0	0
Y	0.741	3.21	3.39 10^{-2}	Ac	0	0	0
Zr	431	434	430	Th	3.1 10^{-2}	9.75 10^{-2}	3.59 10^{-3}
Nb	4.99	7.19	5.03	Pa	0	0	0
Mo	0.5	7.7	0.644	U	1,340	1,340	1,340
Tc	0	0	0	Np	0	0	0
Ru	0	6.36 10^{-3}	6.36 10^{-5}	Pu	117	117	117

Element	Mass (tonnes)			Element	Mass (tonnes)		
	Best estimate	Upper uncertainty	Lower uncertainty		Best estimate	Upper uncertainty	Lower uncertainty
Rh	$1.95\ 10^{-4}$	1.61	$1.62\ 10^{-2}$	Am	4.44	4.44	4.44
Pd	$2.35\ 10^{-5}$	$6.53\ 10^{-2}$	$8.98\ 10^{-3}$	Cm	0	0	0
Ag	0.647	0.864	0.565	Cf	0	0	0

Table E16 Elemental composition for HEU (waste, conditioning, capping and container materials). The priority metallic species are highlighted

Element	Mass (tonnes)			Element	Mass (tonnes)		
	Best estimate	Upper uncertainty	Lower uncertainty		Best estimate	Upper uncertainty	Lower uncertainty
H	$7.6\ 10^{-2}$	0.733	$1.02\ 10^{-2}$	Cd	$7.07\ 10^{-2}$	0.121	$3.79\ 10^{-2}$
He	0	0	0	In	$1.11\ 10^{-4}$	$1.56\ 10^{-3}$	$1.63\ 10^{-4}$
Li	12.8	12.9	12.8	Sn	0.156	2.54	0.141
Be	0	6.26	$6.26\ 10^{-2}$	Sb	$4.18\ 10^{-2}$	0.859	0.191
B	73.7	74.1	73.4	Te	$9.7\ 10^{-3}$	$1.18\ 10^{-2}$	$9.72\ 10^{-3}$
C	320	322	319	I	0	0.313	$3.13\ 10^{-3}$
N	1.28	2.55	0.533	Xe	$4.12\ 10^{-4}$	$4.12\ 10^{-3}$	$4.12\ 10^{-5}$
O	609	623	608	Cs	$3.8\ 10^{-4}$	$6.43\ 10^{-3}$	$5.47\ 10^{-4}$
F	0	10.4	0.104	Ba	0.582	5.51	0.607
Ne	$1.33\ 10^{-2}$	0.133	$1.33\ 10^{-3}$	La	$3.66\ 10^{-4}$	$2.94\ 10^{-3}$	$2.51\ 10^{-4}$
Na	86.5	86.7	86.6	Ce	0.677	1.44	0.246
Mg	$4.31\ 10^{-2}$	1.91	$3.37\ 10^{-2}$	Pr	0	5.74	$5.74\ 10^{-2}$
Al	2.33	5.53	0.637	Nd	$3.19\ 10^{-4}$	$1.83\ 10^{-2}$	$1.83\ 10^{-4}$
Si	584	610	451	Sm	$3.74\ 10^{-4}$	$1.1\ 10^{-3}$	$5.8\ 10^{-5}$
P	4.97	75	2.25	Eu	$3.41\ 10^{-4}$	$9.06\ 10^{-4}$	$7\ 10^{-5}$
S	0.314	5.78	1.57	Gd	13.2	13.2	13.2
Cl	$3.34\ 10^{-3}$	$7.1\ 10^{-3}$	$1.16\ 10^{-3}$	Tb	$8.61\ 10^{-4}$	$4.93\ 10^{-2}$	$4.93\ 10^{-4}$
Ar	0	10.4	0.104	Dy	$6.43\ 10^{-3}$	$1.61\ 10^{-2}$	$1.55\ 10^{-3}$
K	0.26	0.717	$4.81\ 10^{-2}$	Ho	$2.46\ 10^{-5}$	$5.33\ 10^{-3}$	$2.52\ 10^{-4}$
Ca	15.4	22.4	15.8	Er	$3.82\ 10^{-4}$	$7.76\ 10^{-3}$	$1.35\ 10^{-4}$
Sc	$1.09\ 10^{-4}$	$2.36\ 10^{-3}$	$1.18\ 10^{-4}$	Tm	$2.23\ 10^{-3}$	$3.34\ 10^{-2}$	$2.73\ 10^{-3}$
Ti	48	59.8	48	Yb	$1.6\ 10^{-3}$	$1.32\ 10^{-2}$	$1.6\ 10^{-3}$
V	0.788	4.59	0.682	Lu	$8.01\ 10^{-4}$	$6.2\ 10^{-3}$	$3.48\ 10^{-4}$
Cr	339	371	314	Hf	19.8	19.8	19.8

Element	Mass (tonnes)			Element	Mass (tonnes)		
	Best estimate	Upper uncertainty	Lower uncertainty		Best estimate	Upper uncertainty	Lower uncertainty
Mn	70.7	79.8	25.1	Ta	8.55 10^{-4}	6.02 10^{-3}	9.11 10^{-4}
Fe	9,200	9,460	9,130	W	0.34	1.7	0.147
Co	4.37	10.1	1.3	Re	3.19 10^{-5}	1.83 10^{-3}	1.83 10^{-5}
Ni	240	310	193	Os	3.19 10^{-5}	4.64 10^{-4}	4.22 10^{-5}
Cu	4,870	4,900	4,860	Ir	8.04 10^{-4}	1.69 10^{-2}	2.18 10^{-4}
Zn	0.806	3.86	0.273	Pt	0	5.22 10^{-3}	5.22 10^{-5}
Ga	0.25	2.07	6.11 10^{-2}	Au	0	5.22 10^{-3}	5.22 10^{-5}
Ge	0	7.3	7.3 10^{-2}	Hg	0	0.522	5.22 10^{-3}
As	0.447	2.98	0.847	Tl	0	0.626	6.26 10^{-3}
Se	3.97 10^{-2}	0.264	2.61 10^{-2}	Pb	0.144	1.57	0.175
Br	2.91 10^{-3}	2.66 10^{-2}	1.54 10^{-3}	Bi	4.95 10^{-3}	0.177	6.59 10^{-3}
Kr	3.44 10^{-3}	3.44 10^{-2}	3.44 10^{-4}	Po	0	0	0
Rb	1 10^{-2}	0.49	3.24 10^{-2}	Rn	0	0	0
Sr	7.42 10^{-3}	0.124	1.29 10^{-2}	Ra	0	0	0
Y	0.108	0.392	6.02 10^{-3}	Ac	0	0	0
Zr	1.09 10^{-2}	0.377	7.12 10^{-3}	Th	7.88 10^{-3}	2.42 10^{-2}	1.01 10^{-3}
Nb	0.144	0.702	3.57 10^{-2}	Pa	0	0	0
Mo	44.9	55.6	36.3	U	68.8	68.8	68.8
Tc	0	0	0	Np	0	0	0
Ru	0	1.04 10^{-3}	1.04 10^{-5}	Pu	0	0	0
Rh	4.66 10^{-3}	0.267	2.67 10^{-3}	Am	0	0	0
Pd	8.34 10^{-4}	1.07 10^{-2}	1.48 10^{-3}	Cm	0	0	0
Ag	0.136	0.169	0.123	Cf	0	0	0

Table E17 Elemental composition for Pu (waste, conditioning, capping and container materials). The priority metallic species are highlighted

Element	Mass (tonnes)			Element	Mass (tonnes)		
	Best estimate	Upper uncertainty	Lower uncertainty		Best estimate	Upper uncertainty	Lower uncertainty
H	1.91 10^{-2}	0.184	2.56 10^{-3}	Cd	1.78 10^{-2}	3.03 10^{-2}	9.5 10^{-3}
He	0	0	0	In	2.8 10^{-5}	3.91 10^{-4}	4.09 10^{-5}
Li	3.22	3.23	3.22	Sn	3.92 10^{-2}	0.638	3.54 10^{-2}
Be	0	1.57	1.57 10^{-2}	Sb	1.05 10^{-2}	0.215	4.8 10^{-2}

Element	Mass (tonnes)			Element	Mass (tonnes)		
	Best estimate	Upper uncertainty	Lower uncertainty		Best estimate	Upper uncertainty	Lower uncertainty
B	18.5	18.6	18.4	Te	2.43 10^{-3}	2.96 10^{-3}	2.44 10^{-3}
C	80.4	80.8	80.1	I	0	7.86 10^{-2}	7.86 10^{-4}
N	0.321	0.641	0.134	Xe	1.03 10^{-4}	1.03 10^{-3}	1.03 10^{-5}
O	153	156	152	Cs	9.53 10^{-5}	1.61 10^{-3}	1.37 10^{-4}
F	0	2.62	2.62 10^{-2}	Ba	0.146	1.38	0.152
Ne	3.33 10^{-3}	3.33 10^{-2}	3.33 10^{-4}	La	9.17 10^{-5}	7.38 10^{-4}	6.3 10^{-5}
Na	21.7	21.7	21.7	Ce	0.17	0.361	6.17 10^{-2}
Mg	1.08 10^{-2}	0.48	8.45 10^{-3}	Pr	0	1.44	1.44 10^{-2}
Al	0.584	1.39	0.16	Nd	8.01 10^{-5}	4.58 10^{-3}	4.58 10^{-5}
Si	147	153	113	Sm	9.39 10^{-5}	2.77 10^{-4}	1.45 10^{-5}
P	1.25	18.8	0.565	Eu	8.55 10^{-5}	2.27 10^{-4}	1.76 10^{-5}
S	7.89 10^{-2}	1.45	0.394	Gd	3.3	3.3	3.3
Cl	8.38 10^{-4}	1.78 10^{-3}	2.91 10^{-4}	Tb	2.16 10^{-4}	1.24 10^{-2}	1.24 10^{-4}
Ar	0	2.62	2.62 10^{-2}	Dy	1.61 10^{-3}	4.04 10^{-3}	3.88 10^{-4}
K	6.52 10^{-2}	0.18	1.21 10^{-2}	Ho	6.18 10^{-6}	1.34 10^{-3}	6.33 10^{-5}
Ca	3.86	5.62	3.96	Er	9.58 10^{-5}	1.95 10^{-3}	3.38 10^{-5}
Sc	2.75 10^{-5}	5.92 10^{-4}	2.95 10^{-5}	Tm	5.59 10^{-4}	8.37 10^{-3}	6.86 10^{-4}
Ti	12.1	15	12	Yb	4.01 10^{-4}	3.31 10^{-3}	4.03 10^{-4}
V	0.198	1.15	0.171	Lu	2.01 10^{-4}	1.56 10^{-3}	8.73 10^{-5}
Cr	85.1	93	78.8	Hf	4.96	4.96	4.96
Mn	17.7	20	6.31	Ta	2.14 10^{-4}	1.51 10^{-3}	2.29 10^{-4}
Fe	2,310	2,370	2,290	W	8.52 10^{-2}	0.426	3.69 10^{-2}
Co	1.1	2.54	0.325	Re	8.01 10^{-6}	4.58 10^{-4}	4.58 10^{-6}
Ni	60.3	77.7	48.4	Os	8.01 10^{-6}	1.17 10^{-4}	1.06 10^{-5}
Cu	1,220	1,230	1,220	Ir	2.02 10^{-4}	4.24 10^{-3}	5.47 10^{-5}
Zn	0.202	0.97	6.86 10^{-2}	Pt	0	1.31 10^{-3}	1.31 10^{-5}
Ga	6.27 10^{-2}	0.519	1.53 10^{-2}	Au	0	1.31 10^{-3}	1.31 10^{-5}
Ge	0	1.83	1.83 10^{-2}	Hg	0	0.131	1.31 10^{-3}
As	0.112	0.747	0.213	Tl	0	0.157	1.57 10^{-3}
Se	9.96 10^{-3}	6.62 10^{-2}	6.56 10^{-3}	Pb	3.62 10^{-2}	0.394	4.39 10^{-2}
Br	7.3 10^{-4}	6.67 10^{-3}	3.86 10^{-4}	Bi	1.24 10^{-3}	4.45 10^{-2}	1.65 10^{-3}
Kr	8.64 10^{-4}	8.64 10^{-3}	8.64 10^{-5}	Po	0	0	0
Rb	2.52 10^{-3}	0.123	8.13 10^{-3}	Rn	0	0	0

Element	Mass (tonnes)			Element	Mass (tonnes)		
	Best estimate	Upper uncertainty	Lower uncertainty		Best estimate	Upper uncertainty	Lower uncertainty
Sr	1.86 10^{-3}	3.12 10^{-2}	3.24 10^{-3}	Ra	0	0	0
Y	2.7 10^{-2}	9.84 10^{-2}	1.51 10^{-3}	Ac	0	0	0
Zr	2.73 10^{-3}	9.47 10^{-2}	1.79 10^{-3}	Th	1.98 10^{-3}	6.08 10^{-3}	2.54 10^{-4}
Nb	3.61 10^{-2}	0.176	8.95 10^{-3}	Pa	0	0	0
Mo	11.3	13.9	9.12	U	11.5	11.5	11.5
Tc	0	0	0	Np	0	0	0
Ru	0	2.62 10^{-4}	2.62 10^{-6}	Pu	5.75	5.75	5.75
Rh	1.17 10^{-3}	6.69 10^{-2}	6.69 10^{-4}	Am	0	0	0
Pd	2.09 10^{-4}	2.69 10^{-3}	3.72 10^{-4}	Cm	0	0	0
Ag	3.41 10^{-2}	4.23 10^{-2}	3.08 10^{-2}	Cf	0	0	0

E3 Gas generation data

E3.1 Metals geometry data

Mass and geometry information for use in the gas pathway analysis has been prepared using the methodology outlined in Appendix A7.1. The results are presented in Table E18 and Table E19. Only the LHGW waste streams contribute to the gas pathway analysis.

Table E18 presents the total masses, effective plate thicknesses and sphere diameters for all metals. Table E19 presents the mass of metals in the waste containers.

Table E18 Summary of gas generating metals in the LHGW waste streams. New build has been abbreviated as NB

Waste package category	Material	Total mass in plate (tonnes)	Total mass in sphere (tonnes)	Effective thickness plate (m)	Effective diameter (m)
UILW / ULLW	Stainless steel	32,300	-	$4.51\ 10^{-3}$	-
SILW / SLLW	Stainless steel	2,900	-	$9.63\ 10^{-3}$	-
RSCs	Stainless steel	187	-	$9.63\ 10^{-3}$	-
NB UILW	Stainless steel	2,290	-	$1.54\ 10^{-2}$	-
NB SILW	Stainless steel	517	-	$4.29\ 10^{-3}$	-
UILW / ULLW	Mild steel	38,200	104	$1.86\ 10^{-3}$	$2.50\ 10^{-2}$
SILW / SLLW	Mild steel	11,000	3,570	$1.24\ 10^{-2}$	$1.00\ 10^{-2}$
RSCs	Mild steel	189	61.6	$1.24\ 10^{-2}$	$1.00\ 10^{-2}$
NB UILW	Mild Steel	1,840	-	0.2	-
NB SILW	Mild steel	1,080	-	0.2	-
UILW / ULLW	Zircaloy	1,240	-	$6.00\ 10^{-4}$	-
SILW / SLLW	Zircaloy	16.6	-	$6.00\ 10^{-4}$	-
RSCs	Zircaloy	28.9	-	$6.00\ 10^{-4}$	-
UILW / ULLW	Aluminium	1,720	-	$1.60\ 10^{-3}$	-
SILW / SLLW	Aluminium	23.9	-	$1.60\ 10^{-3}$	-
RSCs	Aluminium	1.53	-	$1.60\ 10^{-3}$	-
UILW / ULLW	Magnox	6,220	45.3	$1.48\ 10^{-3}$	$2.00\ 10^{-3}$
SILW / SLLW	Magnox	16.0	-	$1.80\ 10^{-3}$	-
RSCs	Magnox	90.7	-	$1.80\ 10^{-3}$	-
UILW / ULLW	Uranium	329	613	$1.20\ 10^{-3}$	$4.90\ 10^{-3}$
SILW / SLLW	Uranium	-	-	-	-
RSCs	Uranium	0.191	-	$1.20\ 10^{-3}$	-

Table E19 **Summary of metal quantities in LHGW waste containers with given thicknesses. New build has been abbreviated as NB**

Waste package category	Material	Total mass in plate (tonnes)	Effective thickness plate (m)
UILW / ULLW	Stainless steel [80]	98,700	$5.78\ 10^{-3}$
SILW / SLLW	Stainless steel	22,000	$3.02\ 10^{-3}$
DNLEU	Stainless steel[81]	31,800	$6.60\ 10^{-3}$
NB UILW	Stainless steel	3,630	$5.17\ 10^{-3}$
NB SILW	Stainless steel	300	$3.00\ 10^{-3}$
UILW	Mild steel	3,010	$6.00\ 10^{-3}$
SILW	Mild steel	298	$2.50\ 10^{-3}$
NB SILW	Mild steel	13,300	$2.52\ 10^{-2}$
RSCs	Cast iron	26,100	0.140

E3.2 H3 and C14 by material type

The methodology for deriving H3 and C14 activities associated with different types of material in wastes is presented in Appendix A7.2. The results of the material breakdown analysis are given in Table E20 and Table E21. Only the LHGW waste streams contribute to the gas pathway analysis.

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[80] Includes 500 l drum stillages (15,600 t)

[81] Includes 500 l drum stillages (3,320 t)

Table E20 Activity of H3 associated with materials in LHGW waste streams in the 2013 Derived Inventory. New build has been abbreviated as NB

Material component	H3 activity at 2200 (TBq)				
	UILW / ULLW	SILW / SLLW	RSC	NB UILW	NB SILW
Graphite	$5.44\ 10^{-2}$	0.314	$1.34\ 10^{-3}$	0	0
Stainless steel	0.231	1.78	$6.81\ 10^{-6}$	890	0
Other ferrous based alloys most likely to be low carbon / mild steel	$8.68\ 10^{-2}$	0.311	$1.46\ 10^{-3}$	0.093	0.279
Zircaloy / zirconium	0.188	$4.17\ 10^{-3}$	$6.68\ 10^{-4}$	0	0
Nimonic (nickel based) alloys such as Nimonic PE16 & 80A	$1.65\ 10^{-4}$	$2.84\ 10^{-4}$	$1.93\ 10^{-5}$	0	0
Magnox alloys AL80, ZR55, MN80 & MN150	$5.05\ 10^{-2}$		$4.04\ 10^{-5}$	0	0
Uranium metal	0.139		0	0	0
Magnox alloy corrosion products most likely to be $Mg(OH)_2$	$2.21\ 10^{-2}$		0	0	0
Uranium metal corrosion products, ie UO_x	$8.56\ 10^{-2}$		0	0	0
Materials such as desiccant and ion exchange materials, and barium carbonate arising from THORP operations	$7.61\ 10^{-2}$	$4.94\ 10^{-8}$	$1.06\ 10^{-3}$	$4.57\ 10^{-3}$	$1.34\ 10^{-3}$
GE Healthcare streams containing H3	$1.83\ 10^{-3}$		0	0	0
Not assessed	$2.05\ 10^{-2}$	$8.71\ 10^{-6}$	$1.98\ 10^{-4}$	0	0
Total	0.809	2.41	$4.80\ 10^{-3}$	891	0.280

Table E21 Activity of C14 associated with materials in LHGW waste streams in the 2013 Derived Inventory. New build has been abbreviated as NB

Material component	C14 activity at 2200 (TBq)				
	UILW / ULLW	SILW / SLLW	RSC	NB UILW	NB SILW
Graphite	735	6,190	1.75	0	0
Stainless steel	151	58.9	$7.09\ 10^{-1}$	6,660	3.32
Other ferrous based alloys most likely to be low carbon / mild steel	42.0	137	$7.35\ 10^{-1}$	1.14	0.223
Zircaloy / zirconium	28.0	0.770	$4.82\ 10^{-1}$	0	0
Nimonic (nickel based) alloys such as Nimonic PE16 & 80A	27.4	5.03	$4.67\ 10^{-2}$	0	0
Magnox alloys AL80, ZR55, MN80 & MN150	66.3	0	$1.13\ 10^{-2}$	0	0
Uranium metal	17.7	0	0	0	0
Magnox alloy corrosion products most likely to be $Mg(OH)_2$	22.2	0	0	0	0
Uranium metal corrosion products, ie UO_x	8.89	0	0	0	0
Materials such as desiccant and ion exchange materials, and barium carbonate arising from THORP operations	41.6	1.30	3.26	3.10	1.90
GE Healthcare streams containing C14	204	0	0	0	0
Not assessed	2.04	3.09	0.434	0	0
Total	1,350	6,400	7.43	6,670	5.44

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