Radioactive Waste Management

DSSC/407/01

Inventory for geological disposal

Implications of the 2016 IGD for the generic Disposal System Safety Case

October 2018

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

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

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

Executive Summary

RWM has updated its inventory for geological disposal (IGD) to take account of the 2016 UK Radioactive Waste Inventory. This report contains an assessment of the implications of the changes to the IGD, including the alternative inventory scenarios, for the findings of RWM's generic Disposal System Safety Case (DSSC).

The inventory changes are small and the implications of these changes are:

- no impact on RWM's Disposal System Specification as the scope of the inventory has not changed
- small changes to RWM's illustrative generic Geological Disposal Facility (GDF) designs
  - changes of -1% to +1% to the GDF footprint (host rock dependent)
  - slight changes to the operational programme
- no change to the conclusions of RWM's generic Transport Safety Case, as the number of disposal units is very similar and there are no significant changes to the activities
- no change to the conclusions of RWM's generic Operational Safety Case, which is based on bounding source terms that are unaffected by the inventory changes
- no change to the conclusions of RWM's generic Environmental Safety Case as the changes to the inventory are small
- no change to the Disposability Assessment process, as there are no significant changes to the findings of the generic DSSC

Overall, the inventory changes do not affect the conclusions of RWM's 2016 generic DSSC.

A key objective of the work described in this report was to identify any new research needs arising as a result of the changes to the IGD. No new research needs were identified. However, the scope of existing tasks has been extended to cover the inclusion of UK Advanced Boiling Water Reactor (ABWR) spent fuel in the areas of criticality safety and spent fuel dissolution.

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1 Introduction

1.1 The generic Disposal System Safety Case

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

A geological disposal facility (GDF) will be a highly-engineered facility, located deep underground, where the waste will be isolated within a multi-barrier system of engineered and natural barriers designed to prevent the release of harmful quantities of radioactivity and non-radioactive contaminants to the surface environment. To identify potentially suitable sites where a GDF could be located, the Government is developing a 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.

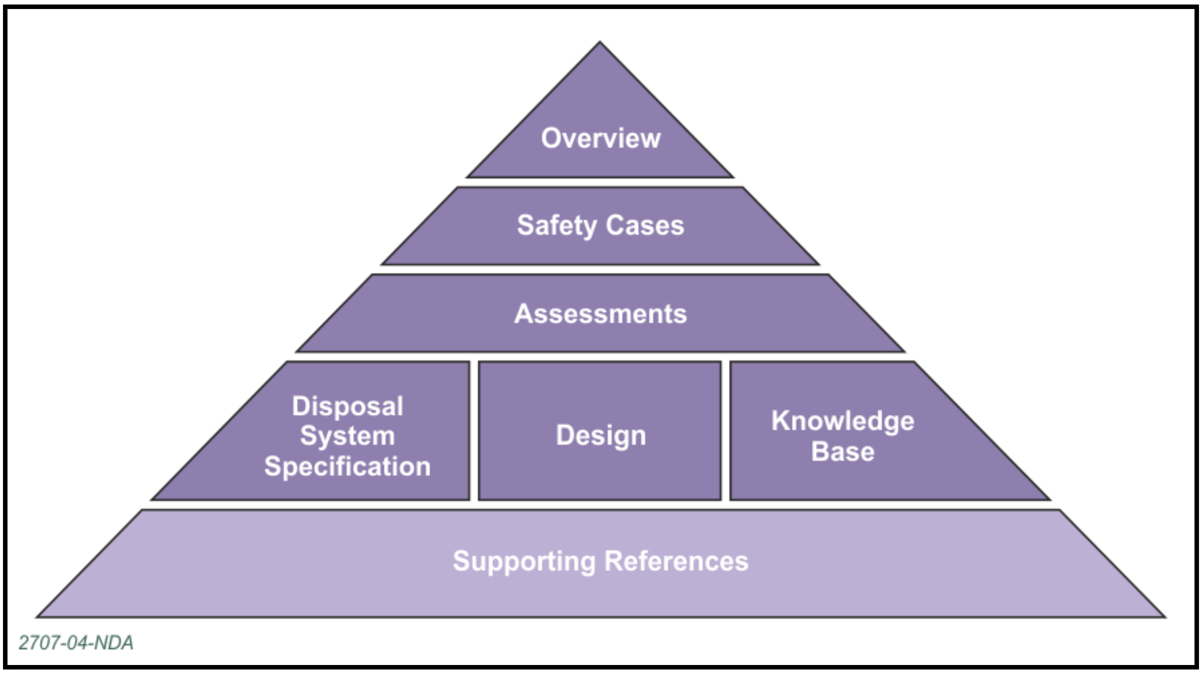
High level information on the inventory for disposal, the illustrative disposal concepts and other aspects of the disposal system is collated in a technical background document (the Technical Background) [3] that supports this generic Disposal System Safety Case.

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 'Implications Report'

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

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

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

Currently, the UK RWI is updated every three years, after which the IGD is updated. The most recent version of the UK RWI [9] is based on a stock date of 1st April 2016 and is referred to here as the 2016 UK RWI. The generic DSSC was published in 2017 and was based on the 2013 IGD [10], which in turn was based on the previous 2013 UK RWI [9]. The 2016 IGD is based on the 2016 UK RWI and is a 'light update' of the 2013 IGD.

This report describes the implications of the 2016 IGD for the generic DSSC. The report is new to the generic DSSC suite of documents.

1.3 Objective

The objective of the work described in this report is to review the differences between the 2013 and 2016 IGDs and:

- set out how the changes to the IGD affect the findings of the generic DSSC
- identify future research needs required as a result of the changes to the IGD

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

1.4 Scope

This report presents the changes to the IGD and the implications of these changes for the technical documents within the generic DSSC suite. A consideration of the implications for documents that sit outside of the generic DSSC is excluded from the scope of this report, as is a detailed discussion of the inventory changes (these are presented in the Differences report [6]).

1.4.1 Iterative development of the generic DSSC

RWM's safety cases are continually refined and improved through the use of an iterative method for their production (as illustrated in Figure 2). The process starts with the key inputs, which include the IGD, and the Disposal System Specification. These inform the illustrative designs of the geological disposal facility, with the assessments and safety cases based on these designs.

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

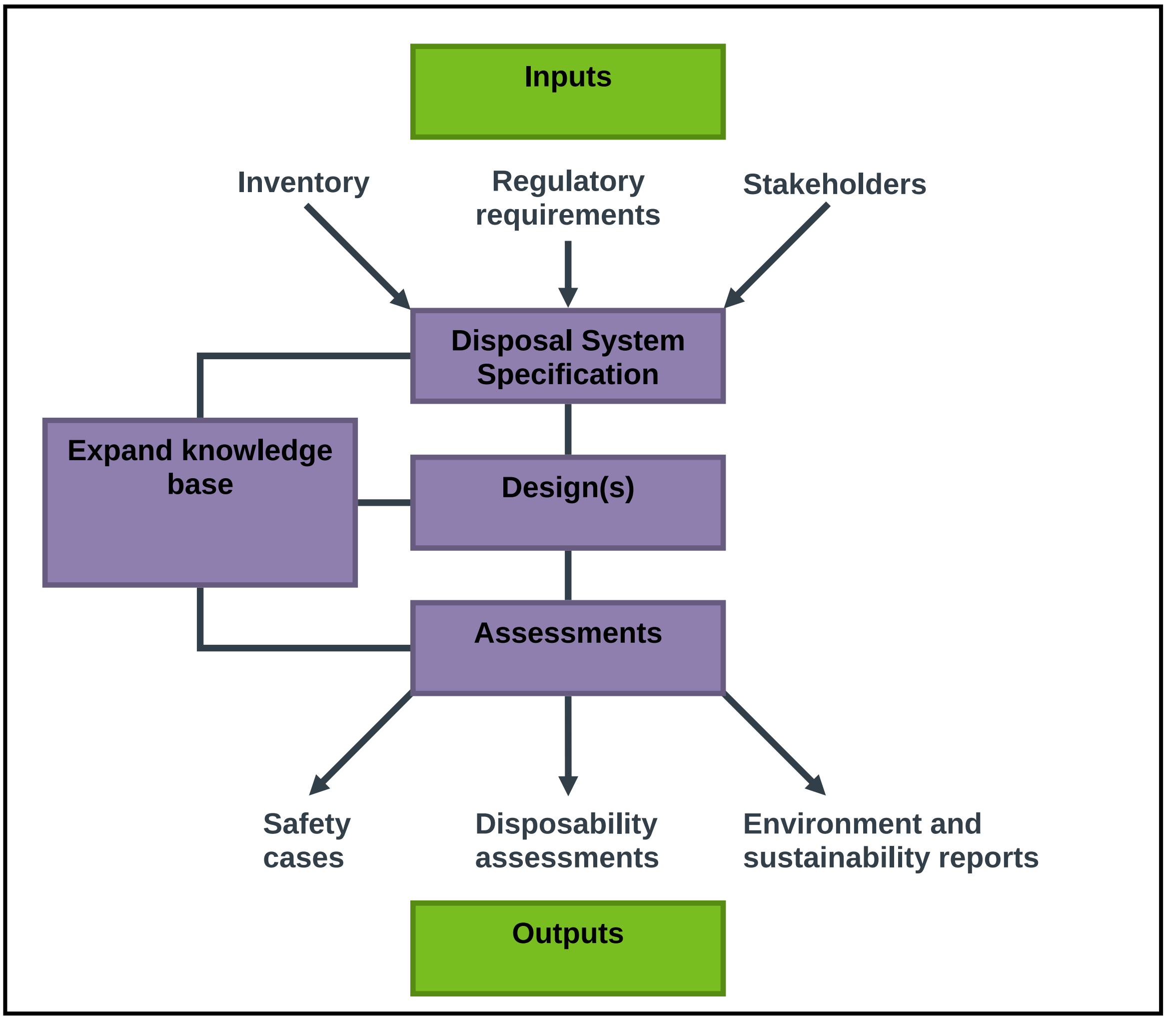
As part of the iterative development of the safety cases, RWM operates a 'needs-driven' research programme: the need for additional research is highlighted during the different phases of producing the safety cases and new tasks are added to RWM's research programme [11, 12].

Each iteration of the safety cases incorporates learning from:

- the production of the previous iteration of the safety cases
- the needs-driven research programme
- other industries (for example mining)

This document reports a key part of the iterative process: the IGD has been updated following the production of the 2016 UK RWI and the implications for the safety case need to be assessed and any further research that is required as a result of these inventory changes needs to be identified.

Figure 2 The iterative model for the development of RWM's safety cases



1.4.2 Status of Research

The generic DSSC is supported by eight research status reports that present the scientific and engineering understanding that supports geological disposal in the UK; these reports are summarised in Table 1. RWM's scientific and engineering understanding is not altered by changes to the inventory. However, changes to the inventory could result in additional knowledge being required in order to underpin the production of RWM's safety cases.

In this report knowledge gaps arising from considering the implications of the inventory changes for the generic DSSC are identified. The report includes new or updated task sheets that detail the additional work required to address these gaps. These task sheets will be incorporated in a future update to RWM's Science and Technology Plan.

Table 1 The status reports and the current state of knowledge that they present

Status report	Current state of knowledge presented
Waste package evolution [13]	The evolution of waste packages (wasteforms and waste containers) during storage and after disposal in the GDF
Engineered barrier system (EBS) [14]	The evolution processes affecting the EBS from the construction of the GDF until after its closure
Geosphere [15]	The role of the geosphere in providing isolation and containment of the waste as part of a multi-barrier system
Biosphere [16]	The understanding of the biosphere and RWM's approach to representing it in the generic DSSC
Gas [17]	Understanding of gas generation and migration in the context of GDF safety
Behaviour of radionuclides and non-radiological species in groundwater [18]	How radionuclides and non-radiological species may behave in a GDF, focussing on the post-closure phase
Waste package accident performance [19]	The performance of waste packages under accident conditions (fire and impact) during transport and disposal operations
Criticality safety [20]	Studies that support the demonstration of criticality safety in RWM's safety cases

1.5 Report structure

The remainder of this report will be structured as follows:

- Section 2: changes to the inventory
- Section 3: implications for the Disposal System Specification
- Section 4: implications for the illustrative GDF designs
- Section 5: implications for the generic Transport Safety Case
- Section 6: implications for the generic Operational Safety Case
- Section 7: implications for the generic Environmental Safety Case
- Section 8: implications for the disposability assessment process
- Section 9: conclusions
- Appendix A : new and updated science and technology plan task sheets

2 Changes to the inventory

Summary of changes to the inventory

The IGD has been updated following the publication of the 2016 UK RWI. The key assumptions are unchanged between the 2013 and 2016 IGDs. Changes to the packaged volume of waste (-3%), activity (+2% at 2200) and number of disposal units (<1%) are small and are associated with improved assumptions for the packaging of DNLEU, changes to the waste producers' plans and improved waste characterisation.

A number of alternative scenarios are used to explore the effects on the IGD of changes in assumptions and uncertainties in data. The definitions of these scenarios and the assessment of their effects have been updated for the 2016 IGD. The results show that the impacts of most of the scenarios are unchanged or are reduced.

No new knowledge gaps, and therefore no additional research needs have been identified.

The IGD scenario represents RWM's best estimate of how the wastes and materials in the IGD will arise and there have been no significant changes to this. However, the quantities of the waste and material types have changed as a result of, for example, improvements to the estimates of waste that will arise from planned operations and decommissioning programmes. The changes between the 2013 and 2016 IGDs have been reported [6] and are summarised in the rest of this section.

2.1 Changes to the quantity of waste

Table 2 shows the percentage changes to the stored quantities of waste in the 2016 IGD relative to the 2013 IGD. The key changes to the quantities of wastes are:

- DNLEU (+16%) from changes to the assumed period of uranium enrichment
- legacy SF (+16%) from advanced gas cooled reactor (AGR) lifetime extensions
- HLW (+6%) from a revised estimate of the arisings from post-operational clean out (POCO) of the reprocessing facilities

Table 2 Changes to stored waste and material quantities between the 2013 and 2016 IGDs

Waste type [unit]	2013 IGD	2016 IGD	Difference [%]
Legacy LLW [m^3]	9,330	8,880	-5%
Legacy ILW [m^3]	259,000	265,000	2%
HLW [WVP cans]	7,200	7,650	6%
Legacy SFs [tHM]	6,300	7,320	16%
DNLEU [tU]	185,000	215,000	16%
HEU [tU]	22.9	22.9	0%
Pu [tHM]	5.75	5.75	0%
New build ILW [m^3]	8,440	8,440	0%
New build SFs [tU]	14,300	14,300	0%
MOX SF [tHM]	1,460	1,460	0%

Changes to the packaged volumes of the wastes in the IGD are presented in **Table 3**. The key changes to the packaged volume are:

- robust shielded containers (RSCs) (-63%) as a result of changes to the waste producer's plans for the packaging of these wastes
- DNLEU (-12%) as a result of more realistic packaging assumptions being adopted, despite the increase in the quantity of DNLEU
- Legacy SF (+14%) as a result of AGR lifetime extensions

Despite the changes to the quantity and packaged volume of waste in the different waste groups, the overall number of disposal units has remained relatively constant at around 165,000. Table 4 shows that there have been small changes to the number of LHGW (-0.4%) and HHGW (+4%) disposal units.

Table 3 Changes to the packaged volume of each waste group

Waste group	Packaged volume [m^3]		Difference [%]
	2013 IGD	2016 IGD	
Legacy SILW / SLLW	93,000	99,300	7%
Legacy UILW / ULLW	327,000	329,000	1%
RSCs	7,280	2,730	-63%
DNLEU	217,000	191,000	-12%
New build SILW	18,900	18,900	0%
New build UILW	22,100	22,100	0%
HLW	9,290	9,860	6%
Legacy SF	14,800	16,900	14%
New build SF	39,400	39,400	0%
MOX SF	11,900	11,900	0%
HEU	2,470	2,470	0%
Pu	620	620	0%
Total	764,000	744,000	-3%

Table 4 Difference in the number of LHGW and HHGW disposal units between the 2013 and 2016 IGDs

Waste category	Disposal units [-]		Difference [%]
	2013 IGD	2016 IGD	
LHGW	146,300	145,800	-0.4%
HHGW	18,600	19,300	4%
Total	164,900	165,100	<0.1%

2.2 Changes to the activity of the waste

The evolution of the total activity is shown in Figure 3 as a log-log plot and the total activity of the inventory at 2200 is presented by waste group in Table 5. The increase in the total activity of the inventory is small (2% at 2200) and it can be seen from Figure 3 that the difference remains small at later times. However, as shown in Table 5, there are some significant changes to individual waste groups:

- the activity of DNLEU has increased in-line with the change in quantity

- the activity of the legacy SFs has increased as a result of AGR lifetime extensions
- the activity of HLW has increased as a result of changes to the radionuclide fingerprint and an increased estimate of the HLW from POCO activities

Figure 3 The evolution of the total activity in the 2013 and 2016 IGDs

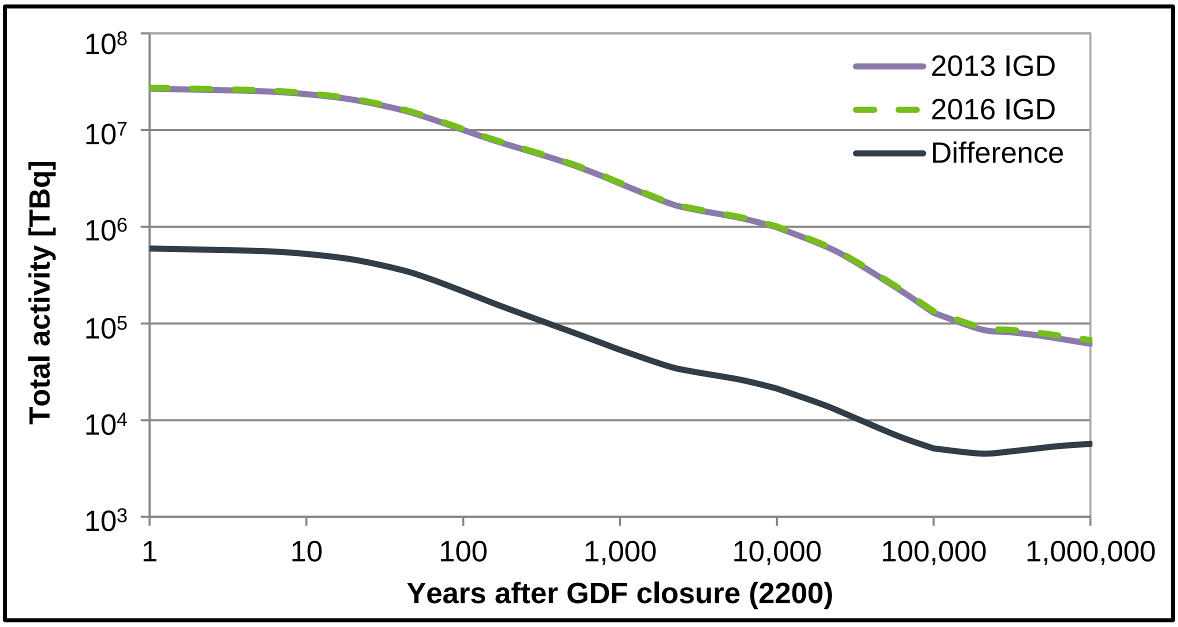
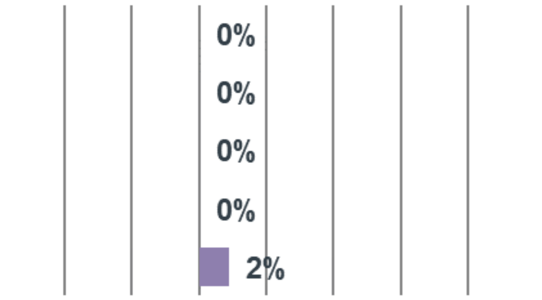


Table 5 Changes to the waste group activities at 2200 between the 2013 and 2016 IGDs

Waste group	Activity at 2200 [TBq]		Difference [%]
	2013 IGD	2016 IGD	
Legacy SILW / SLLW	15,900	13,800	-14%
Legacy UILW / ULLW	355,000	372,000	5%
RSCs	1,180	1,110	-6%
DNLEU	8,370	9,560	14%
New build SILW	154	154	0%
New build UILW	793,000	793,000	0%
HLW	1,090,000	1,200,000	11%
Legacy SF	2,250,000	2,730,000	21%

Waste group	Activity at 2200 [TBq]		Difference [%]
	2013 IGD	2016 IGD	
New build SF	19,000,000	19,000,000	0%
MOX SF	3,700,000	3,700,000	0%
HEU	54	54	0%
Pu	43,700	43,700	0%
Total	27,300,000	27,900,000	2%

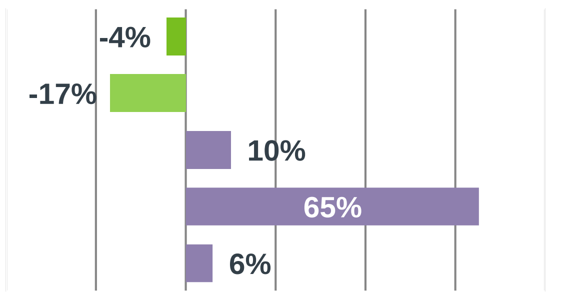


2.3 Changes to the material composition of the waste

The IGD reports the material masses associated with a variety of different materials; these materials are grouped into three categories: metals, organics and others. Table 6 presents a summary of the changes to these categories between the 2013 and 2016 IGDs. The increase in 'unspecified' materials is largely a result of the fact that the 2016 IGD is a 'light update' and so does not include the full review and enhancement process.

Table 6 Changes to the material masses between the 2013 and 2016 IGDs

Material type	Mass [t]		Difference [%]
	2013 IGD	2016 IGD	
Metals	135,000	129,000	-4%
Organics	16,400	13,600	-17%
Others	418,000	460,000	10%
Unspecified	1,020	1,680	65%
Total	570,000	604,000	6%



2.4 Changes to the alternative scenarios

A number of alternative inventory scenarios have been used to explore the effects of changes in assumptions and uncertainties in data on the IGD. The definitions of these scenarios and the assessment of their impacts have been updated for the 2016 IGD [8]. The results show that the impacts of most of the scenarios are unchanged or are reduced. A summary of the changes to the impacts of those scenarios that have been assessed quantitatively is provided below:

- the impact of less Magnox reprocessing is decreased as the mass of Magnox spent fuel not reprocessed is less for the 2016 IGD
- the impact of lifetime extensions for existing reactors has decreased as the AGR lifetime extensions have been included in the 2016 IGD
- the overall impact of using UK RWI uncertainty factors has decreased, although the uncertainty associated with I-129 has increased significantly as a result of changes to a waste stream with a high uncertainty factor specified for this radionuclide

- the impact of excluding graphite wastes has increased as a result of an increase in AGR graphite fuel assembly components from the lifetime extensions
- the impact of excluding ILW / LLW boundary wastes has decreased as a result of changes to some waste streams

In addition, the consideration of potential changes to a new build programme now includes inventory data for one UK ABWR. These data would enable the effects on the IGD of including UK ABWRs in the new build programme to be assessed in due course.

2.5 Knowledge gaps and research needs

No new knowledge gaps and therefore no additional research needs have been identified.

3 Implications for the Disposal System Specification

Summary of implications for the Disposal System Specification

The Disposal System Specification (DSS) has been developed to describe the requirements on the disposal system and is core to RWM's design and assessments work. The waste and material types that are contained in each package type are defined in the Implementing Geological Disposal White Paper and have not changed. The DSS does not impose any requirement that is dependent on the quantities of the packages. As a result, the DSS is robust to a range of changes in the number of waste packages.

No new knowledge gaps, and therefore no additional research needs, have been identified.

The generic DSS has been developed to describe the requirements on the disposal system and is core to RWM's design and assessments work. The primary objective of the DSS is to provide the designers of the disposal system with the requirements that must be satisfied and thereby define the scope and bounds of the engineering design work. Two documents form the DSS:

- Disposal System Specification Part A – High Level Requirements [21], which documents the high-level external requirements on the disposal system that derive from the contents of waste packages for disposal, legislative and regulatory requirements, and the stakeholder requirements. Part A includes requirements on the activities required to transport, receive and emplace waste packages in a GDF
- Disposal System Specification Part B – Technical Requirements [22], which captures the technical requirements defined by RWM to frame the development of a disposal solution to meet the requirements of Part A. This enables RWM's work programme to develop in line with the functional needs of a GDF. It is envisaged that Part B will be updated when site specific information becomes available, allowing the designs to be refined to meet site specific requirements

The DSS requires that the IGD includes data on the contents of the waste packages for disposal. The DSS does not impose any requirement that is dependent on the numbers of waste packages.

The DSS requires that the disposal system designs and assessments:

- use the inventory for geological disposal as the source of waste package information
- take account of inventory scenarios in order to understand the impacts of inventory uncertainties

Although the DSS remains robust, the requirements highlight a number of areas in which the implications of the inventory changes on the disposal system designs and assessments need to be checked; this is done in the remainder of the document.

The changes to the inventory do not result in any new research needs in order to ensure that the DSS remains robust.

4 Implications for the generic illustrative designs

Summary of implications for the generic illustrative designs

Generic illustrative designs for the GDF have been produced for each of three types of host rock. The changes to the IGD would have the following impact on these designs

- small changes to the number of disposal vaults and disposal tunnels
- overall changes to the GDF footprint are in the range -1% to +1%
- no significant impact on the operational programme
- no impact on the transport system design

The effect of updating the definitions of the alternative inventory scenarios to be consistent with the 2016 IGD is to reduce their impact on the volumes of waste for disposal.

No new knowledge gaps or research needs have been identified.

The generic Transport Systems Designs report [23] describes the operations required, commencing at waste producers' sites, to ensure safe and efficient carriage of transport packages through the public domain to the GDF. The report describes both the requirements and potential logistics associated with the transport operation based on road, rail and sea scenarios. As there are no new sites and no new waste package or transport container types, the inventory changes have no implications for the generic Transport System Design.

Generic illustrative designs for a GDF in each of three types of host rock are described in the generic Disposal Facility Designs report [24], which describes the processes of construction, waste package receipt, handling and emplacement, and the design characteristics that the disposal facility will need to include for the inventory.

Developing the illustrative designs allows an understanding of the aspects of constructing a GDF such as the underground layout, the disposal schedule and the likely cost. These aspects are affected by many factors, one of the most significant of which is the inventory (both quantity and timing of waste arising). The impact of the inventory changes on the generic illustrative designs is reported below.

4.1 Disposal Facility Design

The implications of the inventory changes on the generic facility designs are set out in terms of the estimated number of disposal vaults and tunnels, the estimated GDF footprint and the assumed operational programme and throughput rates. In order to assess the implications of the inventory changes, a number of assumptions have been made. These assumptions and the subsequent design philosophy have remained the same as those which underpinned the designs based on the 2013 IGD.

4.1.1 Number of disposal vaults and tunnels and footprint

In the illustrative generic designs for all three of the geologies LHGW are disposed of in disposal vaults, while the HHGW are disposed of in disposal tunnels[3]. Due to the variation in the size of the disposal vaults and tunnels, the impact varies for each host rock. A summary of the changes is presented in Table 7. The key points are:

[3] It is noted, however, that the disposal concepts differ in each of the geologies.

- the small (<1%) decrease in the number of LHGW disposal units, coupled with changes to the number of each disposal unit type results in a small (3% to 6%) reduction in the number of disposal vaults
- the small (4%) increase in the number of HHGW disposal units results in a small increase in the number of disposal tunnels (3% to 4%)
- the overall changes to the estimated underground area, or "footprint", required to accommodate the IGD are minimal[4] (-1% to +1%)

Table 7 The impact of the changes between the 2013 and 2016 IGDs on the footprint and numbers of disposal vaults and disposal tunnels in the different rock types: higher strength rock (HSR), lower strength sedimentary rock (LSSR) and evaporite

Rock	Parameter [unit]	IGD 2013	IGD 2016	Difference [%]
HSR	No. LHGW disposal vaults [-]	38	36	-5.3%
	No. HHGW disposal tunnels [-]	310	321	3.5%
	GDF footprint [km²]	7.6	7.7	1.3%
LSSR	No. LHGW disposal vaults [-]	114	107	-6.1%
	No. HHGW disposal tunnels [-]	341	352	3.2%
	GDF footprint [km²]	15.3	15.2	-0.7%
Evaporite	No. LHGW disposal vaults [-]	93	90	-3.2%
	No. HHGW disposal tunnels [-]	327	338	3.4%
	GDF footprint [km²]	10.3	10.4	1.0%

4.1.2 Operational programme

The overall programme for the 2016 IGD is consistent with that for the 2013 IGD; the start of waste emplacement (2040) and end of operations (2190) remain the same, with any changes accommodated within this period.

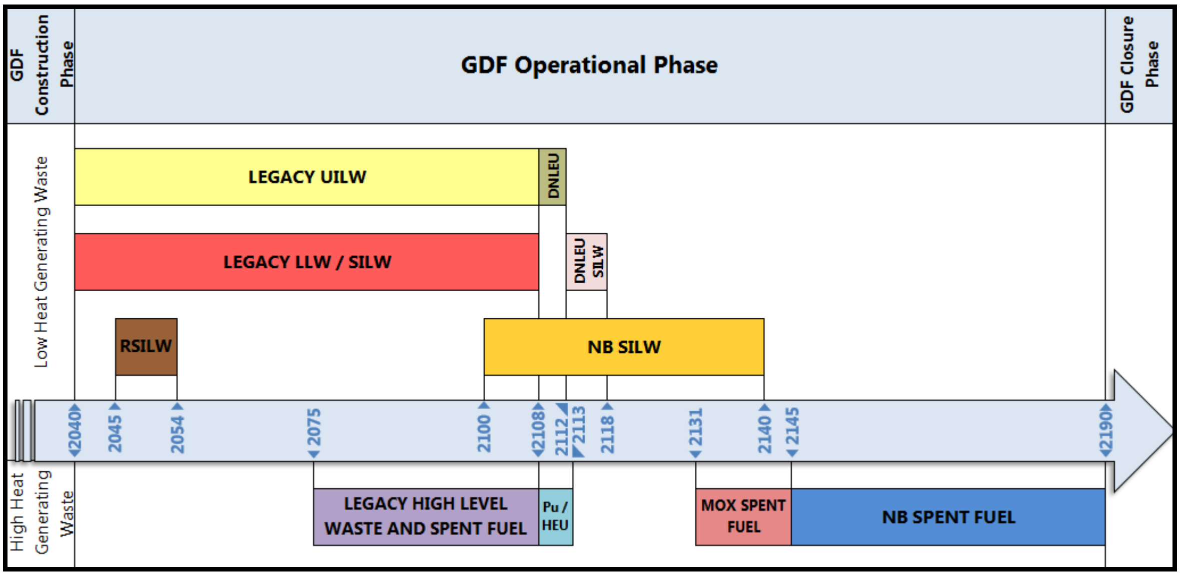
The total number of LHGW disposal units is similar in each of the inventories and, assuming similar throughput rates, the timings for emplacements are the same as for the disposal of the 2013 IGD.

The number of HLW and AGR SF disposal units has increased and, adopting the same throughput rate as for the 2013 IGD (200 disposal units / year), the emplacement of these wastes will continue for an extra 3 years, until 2108. The HEU and Pu will continue for 5 years after this until 2113.

The inventory changes do not introduce any significant changes to the operational programme and a schematic of the revised operational programme is shown in Figure 4.

4 It should be noted that these estimated footprints are illustrative and highly idealised; in reality the layout and configuration of the underground disposal areas will depend on a range of factors, in particular the characteristics of the geology of the site.

Figure 4 The operational programme for the 2016 IGD



4.2 Alternative Inventory scenarios

The definitions of the alternative inventory scenarios have been updated to be consistent with the 2016 IGD. The effect of the changes to the definitions is to reduce their impact on the volumes of waste in the inventory for disposal [8].

The consideration of alternative scenarios now includes inventory data, on a per reactor basis, for UK ABWR ILW and SF. These data are provided to allow the effects of including UK ABWRs in the assumed new build programme to be assessed in due course.

4.3 Knowledge gaps and research needs

The inclusion of wastes and SF from the UK ABWR in the IGD would require additional work to develop a disposal container design that is consistent with RWM's disposal concepts. This work is already included in task 163 (maintain and develop the disposal container designs) in RWM's Science and Technology plan [11]. There are no new knowledge gaps or new research tasks that are required as a result of the changes to the IGD.

5 Implications for the generic Transport Safety Case

Summary of implications for the generic Transport Safety Case

The generic transport safety case (TSC) demonstrates the confidence that safe transport will be provided to move all of the waste from the various storage sites to the GDF. No significant implications for the generic TSC have been identified as a result of the changes to the IGD. Because there are no new package types or increases to bounding package inventories introduced in the 2016 IGD, there are no implications for the transport package safety report. The bounding assessment in the generic TSC will not change as the number of disposal units is roughly constant. The best estimate assessment will be affected by the inventory changes, however the proportional increase in some package types will be offset by the decreases in other package types.

The changes to the alternative scenarios require the scope of RWM's criticality safety work to be extended to cover UK ABWR SF.

The generic Transport Safety Case (TSC) demonstrates the confidence that safe transport will be provided to move all of the waste from the various storage sites to the GDF. The generic TSC covers radioactive waste and materials transport only and not conventional transport associated with construction or operations. The generic TSC main report [25] draws together the main safety arguments and evidence from two supporting reports:

- the Transport Package Safety (TPS) report [26] which describes the means by which safe transport of waste to the GDF will be provided, by describing the procedures, assessments and approvals that are, or will be, in place. The TPS therefore presents a qualitative safety assessment, principally through demonstrating that compliance with the IAEA transport regulations can be achieved
- the Transport System Safety Assessment (TSSA) [27] which provides an assessment of the dose to operators from the transport operation as a whole

The implications of the 2016 IGD on the TPS and TSSA are presented in Sections 5.1 and 5.2 respectively. As the generic TSC main report summarises the safety arguments of the TPS report and TSSA, the implications for the generic TSC main report are the same as those described in Sections 5.1 and 5.2.

5.1 Transport package safety

The generic TSC is underpinned by the description of the radioactive waste transport system presented in the generic Transport System Design (TSD) report [23]. As discussed in Section 4, there are no implications for the TSD as a result of the differences between the 2013 and 2016 IGDs. As a result of this, there are no implications for the qualitative safety assessment presented in the TPS report.

5.2 Transport system safety assessment

The TSSA presents an illustrative dose assessment for operators from routine operations with both bounding and best estimate assumptions and compares these results to the targets and limits in the RWM Radiological Protection Criteria Manual (RPCM) [28]. The assessment calculates the dose to operators for moving the wastes in the IGD from the sites at which they are stored to a GDF. As a site for a GDF is yet to be identified, the TSSA assesses seven notional locations distributed throughout England and Wales.

The quantitative safety assessment presented in the TSSA is sensitive to changes in the number of transport packages and activities of the waste. The total number of disposal units remains unchanged between the 2013 and 2016 IGDs. However there are changes in the proportion of each waste type.

The bounding assessment will not change because the maximum dose rate of a package is constrained by the Carriage of Dangerous Goods Regulations [29]. The analysis simplistically assumes that all packages have the maximum permissible external dose rate as specified by the regulations, and takes no account of the package contents.

The best estimate assessment is dependent on the inventory; therefore the change in proportions of the waste types will have an impact as some waste types tend to have higher external dose rates than others. However the proportional increase in some package types will be offset by the decreases in other package types.

Consequently there is no impact to the generic TSC caused by the differences between the 2013 and 2016 IGDs. The average and maximum annual doses to individual operators is anticipated to be similar to the 2013 Derived Inventory. The 2016 Derived Inventory would not be expected to challenge the annual individual operator design target of 1.0 mSv y^{-1}, as set out in RWM's RPCM and no implications for the findings of the TSSA have been identified as a result of changes to the IGD.

5.3 Alternative Inventory scenarios

The changes that the 2016 IGD introduces to the inventory scenarios reduce the variations in the number of transport units. As such, the existing analysis of inventory scenarios in the TSSA is bounding of the updated scenarios.

The definitions of the alternative inventory scenarios have been updated to be consistent with the 2016 IGD. The effect of the changes to the definitions is to reduce their impact on the number of disposal units [8] and hence the generic Transport Safety Case.

As previously noted, the consideration of alternative scenarios now includes inventory data, on a per reactor basis, for UK ABWR ILW and SF. These data are provided to allow the effects of including UK ABWRs in the assumed new build programme to be assessed in due course.

5.4 Knowledge gaps and future research needs

The fuel used in UK ABWRs is similar to that used in PWRs (ie Zircaloy clad UO_2 pellets) with enrichments and burn-ups that are similar to other fuels in the IGD. However, there are differences in the arrangement and properties of fuel pins and neutron poisons in the fuel assemblies. RWM's knowledge of criticality safety [20] does not explicitly cover the UK ABWR SF during transport to a GDF and tasks 074 and 078 in RWM's Science and Technology Plan [11] have been updated to address this (see Appendix A).

6 Implications for the generic Operational Safety Case

Summary of implications for the generic Operational Safety Case

The generic OSC radiological hazard analysis is based on a bounding source term methodology which is insensitive to small changes in the IGD. The changes introduced by the 2016 IGD do not affect the validity of the extant bounding source terms or the conclusions of the generic OSC.

The changes to the alternative scenarios require the scope of RWM's criticality safety work to be extended to cover ABWR SF.

6.1 Structure of the generic Operational Safety Case

The generic OSC main report [30] is supported by 4 detailed volumes:

- Volume 1: non-radiological and construction safety assessment, [31]
- Volume 2: normal operations safety assessment, [32]
- Volume 3: accident safety assessment, [33]
- Volume 4: criticality safety assessment, [34]

The non-radiological and construction safety assessment covers conventional safety and will be unaffected by changes to the IGD. The implications on the radiological aspects are discussed below.

6.2 Radiological safety

In the current phase of the GDF programme, detailed designs are neither available nor appropriate. The generic OSC is therefore based on a Process Flow Description which represents emplacement operations functionally without assuming specific design solutions or technologies. The generic OSC radiological hazard analysis identifies a bounding source term for each emplacement route and each principal hazard type (external dose, internal dose and off-site discharge). These source terms are used in the radiological consequence assessments for the design basis faults, to determine requirements for engineered safety measures[5]. This approach does not identify worst case packages but instead develops a source term that bounds all waste streams with respect to risk. The bounding source term methodology accounts for inventory uncertainties and variability within waste streams, and can efficiently accommodate small changes to the IGD.

Analysis of the 2016 IGD has confirmed that the extant bounding source terms remain valid and that there are no implications for the generic OSC radiological hazard analysis.

6.3 Knowledge gaps and future research needs

The fuel used in UK ABWRs is similar to that used in PWRs (ie Zircaloy clad UO_2 pellets) with enrichments and burn-ups that are similar to other fuels in the IGD. However, there are differences in the arrangement and properties of fuel pins and neutron poisons in the fuel assemblies. RWM's knowledge of criticality safety [20] does not explicitly cover the UK ABWR SF during the operation of a GDF and tasks 074 and 078 in RWM's Science and Technology Plan [11] have been updated to address this (see Appendix A).

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5 Design basis faults are the accident scenarios which cannot be precluded by design and therefore require the provision of engineered safety measures to make the associated risk as low as reasonably practicable; they are identified as per the Nuclear Operational Safety Manual (RWM14-31).

7 Implications for the generic Environmental Safety Case

Summary of implications for the generic Environmental Safety Case

The implications of the inventory changes on the generic Environmental Safety Case, which summarises the findings of the generic Operational Environmental Safety Assessment (OESA) and the generic Post-Closure Safety Assessment (PCSA), have been considered. No implications have been identified for either the OESA or the PCSA.

The changes to the alternative scenarios will require the scope of RWM's criticality safety and spent fuel dissolution work to be extended to cover UK ABWR SF.

The generic Environmental Safety Case (ESC) [35] considers the environmental safety of the illustrative GDF designs at the time of disposal and after GDF closure. The generic ESC is supported by the generic Operational Environmental Safety Assessment (OESA) [36], which addresses environmental safety during the operational phase of the GDF, and the generic Post-Closure Safety Assessment (PCSA) [37], which includes a quantitative analysis of how radionuclides could be released from waste packages and migrate through the engineered and geological barrier system in the long-term after GDF closure.

The implications of the 2016 IGD on the OESA and PCSA are described in Sections 7.1 and 7.2 respectively. The generic ESC main report is not considered separately as it summarises the safety arguments of the OESA and PCSA; the implications on the generic ESC main report are therefore covered in Sections 7.1 and 7.2.

7.1 Operational environmental safety assessment

The scope of the generic OESA includes consideration of the impacts of offsite radioactive and non-radioactive releases on the public and to non-human biota. Qualitative arguments are presented to discount consideration of:

- solid, liquid and gaseous non-radioactive releases
- solid and liquid radioactive releases

These arguments will also apply to the 2016 IGD and it is recognised that, in the future, the OESA will need to address these in a quantified fashion. At this stage the generic OESA focuses on the dose from aerially discharged gaseous radionuclides (H-3, C-14 and Rn-222, which is the short-lived progeny of Ra-226 and will exist in secular equilibrium with its parent). This calculated dose is sensitive to changes in: the IGD; the arrangement for the ventilation system or the discharge stack; and the host rock's natural background radiation. Table 8 shows the change in the maximum activity of the key gaseous radionuclides in LHGW during the operational period for the 2016 and 2013 IGDs. The impact of these changes is:

- the calculated doses to non-human biota were determined to be at a level that did not require further consideration; this conclusion is unchanged for the 2016 IGD
- HHGW are assumed to be packaged in durable containers that will retain any gaseous radionuclides throughout the operational phase. As a result HHGW are excluded from further consideration
- the total average public dose from LHGW that is presented in the OESA is dominated by H-3 (70% of the estimated dose) with C-14 and Ra-226 providing lesser contributions. Consequently, the overall effect of the inventory changes shown in Table 8 would be anticipated to be a reduction in the estimated dose due to a reduction in the H-3 and C-14 inventories.

At this generic stage, the changes to the IGD have no implications for findings of the OESA (based on the current assumptions for the ventilation system and the discharge stack).

Table 8 The change in the maximum activity of the key gaseous radionuclides in LHGW between 2040 and 2200 in the 2013 and 2016 IGDs

Radionuclide	Max. activity [TBq]		Difference [%]
	2013 IGD	2016 IGD	
H-3	33,200	33,100	
C-14	14,500	14,400	
Ra-226	9.14	9.42	

Alternative inventory scenarios that lead to more or less of the same inventory only affect the peak doses if they concern the waste streams that make significant contributions to releases of particular radionuclides. In addition, uncertainties in the radionuclide inventories of those waste streams that make significant contributions to the peak release rates of each radionuclide will result in similar uncertainties in the peak release rates.

7.2 Post-closure safety assessment

The PCSA includes illustrative calculations of post-closure radiological risk associated with the disposal of the 2013 IGD. Changes to calculated radionuclide risks would be expected to be proportional to changes in the inventory, except where the release of the radionuclide (or its parent) from the wasteform into groundwater is solubility limited, in which case the inventory changes would be of less significance. Figure 3 shows that the difference in the activity of the 2013 and 2016 IGDs is small at all times. However, the individual waste groups show larger activity changes (in the range -14% to +21% at 2200; see Table 5). The following sub-sections examine the impact of the inventory changes on the illustrative calculations of radiological risk presented in the PCSA.

7.2.1 Radiological risk via the groundwater pathway

The groundwater pathway assessment for the PCSA includes generic assessments for the illustrative disposal concepts in higher strength rock and lower strength sedimentary rock. The generic PCSA does not include calculations of risks via groundwater for disposal in evaporite, because such host rocks are not expected to include groundwater transport pathways.

The total mean risks calculated for LHGW and HHGW in lower strength sedimentary rock over the assessment period of 300,000 years are several orders of magnitude below the risk guidance level (RGL) of 10^{-6} / year, primarily because radionuclide transport through the host rock is assumed to be limited to the slow process of diffusion; these calculations will not be affected by the modest changes to the IGD.

The total mean risks calculated for the illustrative concept for LHGW waste groups in higher strength rock, where advective transport is assumed to occur, are of the same order of magnitude as the RGL, but only when exposure via a hypothetical well pathway is considered. These calculated mean risks via the well pathway are:

- close to the RGL in the case of SILW (legacy SILW / SLLW and new build SILW). The key contribution is from Cl-36 (+1% in the 2016 IGD)

- close to the RGL in the case of UILW (legacy UILW / ULLW and new build UILW). The key contributors are I-129 (+11% in the 2016 IGD) and Cl-36 (negligible increase). If there is assumed to be limited radionuclide sorption in the host rock, then Ra-226 (+4%), U-233 (-5%), U-234 (-2%) and U-238 (-1%) also contribute significantly to calculated mean risk after around 200,000 years
- a factor of around 5 lower than the RGL in the case of DNLEU. The key contributors to the calculated mean risk are U-234 (+5% in the 2016 IGD) and U-238 (+16%)[6]
- several orders of magnitude lower than the RGL in the case of the RSC waste group

Organic materials can effectively increase radionuclide solubility through complexation and can result in reductions in sorption. Because of better estimates by waste producers, the organics content of the UILW group decreases by 17% in the 2016 IGD; this reduces the potential for radionuclide transport enhancement by complexation. The organic content of other LHGW groups is insignificant.

The inventory changes detailed above are too small to have a significant impact on the total calculated mean risk via the groundwater pathway for LHGW in a higher strength rock.

In the concept for HHGW disposal in higher strength rock, the expected long-term integrity of the container (several hundred thousand years or more) is important in terms of post-closure environmental safety. The PCSA includes illustrative calculations of mean risk based on the assumed early failure of single containers of each type of HHGW. Although the 2016 IGD indicates increases in the total activities of HLW (11%) and legacy spent fuel (21%) requiring disposal (see Table 5), the expected activity per container will not change significantly and so the illustrative calculations of risk for these HHGW groups will not change. The activities of other HHGW groups have not changed.

7.2.2 Risks from radioactive gases

The main radioactive gases that require consideration in the PCSA are C-14 and Rn-222. Any tritiated gas (H-3) generated in a disposal facility after closure is not significant because tritium has a short half-life (about 12 years).

The results of the illustrative calculations of risk from exposure to C-14 discussed in the generic PCSA are dependent on assumptions about the fraction of C-14 that is released in the gas phase and the area of release of the gas in the biosphere. At the generic stage, these uncertainties are of greater significance to the evaluation of risk than uncertainties and changes in the C-14 inventory. Table 9 shows a small change (-1%) in the activity of C-14 in LHGW between the 2013 and 2016 IGDs. In addition, the short-term release of C-14 is likely to be dominated by the C-14 present in irradiated reactive metals (for example Magnox, aluminium); the quantities of these materials have decreased slightly between the 2013 and 2016 IGDs. Thus, the changes to the IGD that are important to the generation of gases in ILW and LLW are small, and will not affect the conclusions of the PCSA.

If long-lived radionuclides in the uranium series migrate to the near-surface environment in groundwater, where they accumulate, then Rn-222 in-growth may be significant in terms of potential radiological risk. The rate of generation of Rn-222 will gradually increase over very long post-closure periods as U-238 and its daughters decay. DNLEU represents the most significant source of Rn-222 generation because of the large U-238 inventory. The increase in U-238 (+16%) in DNLEU in the 2016 IGD implies that the risk associated with exposure to Rn-222 may increase to a small extent, although the limited solubility of uranium in the disposal vaults will mitigate such impacts.

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[6] The 12% reduction in package volume implies a greater density of DNLEU in the disposal vaults, but in many probabilistic total system model calculations, uranium release from the wasteform is solubility limited and so any increases in calculated risk will not be proportional to the increase in inventory activity.

The 2016 IGD indicates increases in the total activities of HLW (11%) and legacy spent fuel (21%) requiring disposal, but these changes in total activity will not affect behaviour at the package scale. The generic ESC and generic PCSA present qualitative arguments about gas generation from HHGW and these arguments will not be affected by the changes to the inventory.

Table 9 Changes to the activity of key gas pathway radionuclides in LHGW

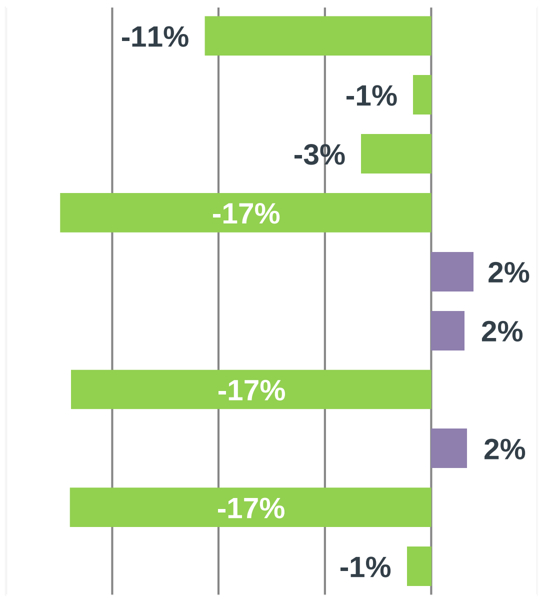
Radionuclide	Activity at 2200 [TBq]		Difference [%]
	2013 IGD	2016 IGD	
C-14	14,400	14,300	-1.0%
Ra-226	8.63	8.90	3.1%
U-238	2,310	2,680	16.1%

The effects of bulk gases

Bulk gases that may be generated in a GDF include hydrogen, carbon dioxide and methane formed by metal corrosion, microbial action and radiolysis. Generation of bulk gases could affect disposal system performance through, for example, pressurisation and disruption of barriers. The rates of gas generation and the effects of these gases on barrier system performance will depend on factors such as barrier permeability to gas and water availability, which are wasteform and disposal concept specific. Therefore, the effects of changes in inventory cannot be readily evaluated. However, Table 10 shows that none of the materials considered in bulk gas generation calculations for LHGW have changed significantly between the 2013 and 2016 IGDs (the masses of a number of materials have decreased). The inventory of potential gas generating materials in HHGW will not change at the individual waste package level. Thus, the assessment of the potential impacts of bulk gas generation from LHGW and HHGW is not affected significantly by the inventory changes.

Table 10 Mass of the metals in the ILW and LLW for the 2013 and 2016 IGDs

Material	Mass [t]		Difference [%]
	2013 IGD	2016 IGD	
Stainless steel	38,200	34,100	-11%
Aluminium	1,750	1,730	-1%
Magnox	6,370	6,160	-3%
Cellulose	2,620	2,170	-17%
Graphite	76,800	78,400	2%
Zircaloy	1,280	1,310	2%
Uranium	1,690	1,410	-17%
Other ferrous metal	56,000	56,900	2%
Polymers	13,100	10,900	-17%
Other organics	481	475	-1%



7.2.3 Human intrusion

Human intrusion calculations were not included in the generic PCSA because such calculations were considered to have little merit at the generic stage of GDF development. The generic ESC was instead concerned with strategies that may be employed to ensure that inadvertent human intrusion into a GDF will be extremely unlikely. The inventory update has no impact on such considerations.

7.2.4 Criticality safety

The potential effects of criticality on the post-closure performance of the GDF, as discussed in the generic PCSA, are based on the results of research on the likelihood and consequences of criticality, and an assessment of the consequences of criticality on the overall performance of the GDF [38]. The 2016 IGD does not introduce significant changes in the activities of fissile isotopes (mainly U-235 and Pu-239) to be disposed of in the GDF or changes in wasteforms. Therefore, the inventory update will not affect the analysis of the likelihood of criticality, or the results of the 'what-if' calculations that showed that the effects of hypothetical criticality on GDF performance would be insignificant.

7.3 Alternative Inventory scenarios

With one exception, the updated alternative scenarios have similar or reduced impacts. The exception arises because the uncertainty associated with I-129 in UILW has increased significantly [6, page 32]. The generic ESC notes that if a well pathway is assumed to be present in the illustrative assessment of LHGW disposal in higher strength rock, then, depending on assumptions made about I-129 diffusion in the host rock and the properties of an assumed near-surface aquifer and well, the mean calculated risk could exceed the

RGL. This conclusion remains valid, but with increased uncertainties in the illustrative calculation of risk.

As previously noted, the consideration of alternative scenarios now includes inventory data, on a per reactor basis, for UK ABWR ILW and SF. These data are provided to allow the effects of including UK ABWRs in the assumed new build programme to be assessed in due course.

The fuel used in UK ABWRs is similar to that used in PWRs (ie Zircaloy clad UO_2 pellets) with enrichments and burn-ups that are similar to other fuels in the IGD. However, there are differences in the arrangement and properties of fuel pins and neutron poisons in the fuel assemblies. Although there are similarities, RWM's knowledge of criticality safety [20] and spent fuel dissolution [13] does not explicitly cover the post-closure behaviour of UK ABWR SF and tasks 074, 078 and 552 in RWM's Science and Technology Plan [11] have been updated to address this (see Appendix A).

8 Implications for the Disposability Assessment process

Summary of Implications for the Disposability Assessment process

The Disposability Assessment process supports waste packagers that plan to dispose of higher activity wastes in a GDF. The Disposability Assessment process follows established RWM procedures. These have not been affected by the differences between the 2013 and 2016 IGDs.

No new knowledge gaps, and therefore no additional research needs, have been identified.

The RWM Disposability Assessment process exists to support waste packagers that plan to condition and package higher activity wastes (and nuclear materials) in a form that is compatible with emplacement in a GDF. The 'Waste packages and assessment of their disposability' report [39] provides a description of the methods by which RWM ensure that packaged radioactive waste and nuclear materials:

- have the characteristics necessary for safe transport to, and disposal in, a GDF
- are compliant with the assumptions made in the generic DSSC

If a disposability assessment concludes that the implementation of the packaging proposal would result in disposable waste packages which *'are assessed to be compliant with published RWM packaging specifications'* [40], the Assessment Report can be accompanied by a 'Letter of Compliance' endorsing the packaging proposal. Because the changes to the IGD do not affect the Disposal System Specification (see Section 3), there are no implications for RWM's waste package specifications.

The Disposability Assessment process also plays an important role in underpinning the generic DSSC as it provides confidence that the safety cases, which are based on generic assumptions regarding the wastes and the form of packaging, encompass 'real' waste packages being developed by industry.

The continued validity of RWM's existing packaging endorsements is maintained through an ongoing programme of Periodic Review, which allows those endorsements to be tested against the current safety case (DSSC) and basis for disposability assessment. Periodic Reviews are undertaken with a periodicity of approximately ten years.

There is a continuing trend for waste packagers to develop innovative packaging proposals[7]. The system of analysis and evaluation of these innovative proposals is based on formal RWM procedures for the assessment of innovative proposals and disposal system change management [41, 42]. Such proposals add complexity to the disposability assessment process. The range of package types that RWM is aware of bounds those that are used in the 2016 IGD. Further innovative packaging proposals will be carefully monitored for any implications.

The changes to the IGD do not result in any new research needs in order to ensure that the Disposability Assessment process remains robust.

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[7] For the purposes of RWM's Disposability Assessment process, proposed packages are treated as innovative if they meet one or more of three criteria:

- they are not designed to, or are not expected to, comply with an existing detailed Waste Packaging Specification (Level 3 of the hierarchical RWM Packaging Specifications)
- they are not designed to, or are not expected to, comply with a Generic (Level 2) Waste Packaging Specification for a defined waste type
- they are expected to require the use of safety functions or arguments that are not adequately encompassed by existing safety case arguments in the DSSC

9 Conclusions

Summary of Conclusions

The objective of this report is to assess the implications of the changes to RWM's inventory for geological disposal on the findings of the generic DSSC. It has been found that the inventory changes do not affect the conclusions of the generic DSSC.

No new research needs have been identified as a result of the changes to the IGD. However, the scope of existing tasks needs to be extended to include UK ABWR SF in the areas of criticality safety and spent fuel dissolution.

9.1 Implications of inventory changes on the findings of the generic DSSC

The purpose of this report is to assess the implications of the changes to the IGD, including the alternative inventory scenarios, on the findings of the generic DSSC [1]. The inventory changes have been assessed [6] and found to be small. The implications of these small changes in the inventory result in the following:

- no impact on RWM's Disposal System Specification as the scope of the inventory has not changed
- small changes to RWM's illustrative generic GDF designs
  - Changes of -1% to +1% to the GDF footprint (host rock dependent)
  - Slight changes to the operational programme
- no change to the conclusions of RWM's generic Transport Safety Case, as the number of disposal units is very similar and there are no significant changes to the activities
- no change to the conclusions of RWM's generic Operational Safety Case, which is based on bounding source terms that are unaffected by the inventory changes
- no change to the conclusions of RWM's generic Environmental Safety Case as the changes to the inventory are small
- no change to Disposability Assessment process, as there are no significant changes to the findings of the generic DSSC

Overall, the inventory changes do not affect the conclusions of RWM's generic DSSC.

9.2 New research needs

A key objective of this report was to identify any new research needs arising as a result of the changes to the IGD. No new research needs were identified. However, the scope of existing tasks needs to be extended to include UK ABWR SF in the areas of criticality safety and spent fuel dissolution. The updated task sheets are presented in Appendix A and will be included in a future update to RWM's Science and Technology Plan [11].

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Glossary

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

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

Term	Definition
PCSA	Post-closure safety assessment
PCSR	Pre-construction Safety Report
PFA	Pulverised fuel ash
PFR	Prototype fast reactor
POCO	Post-operational clean-out
ppm	Parts per million
Priority 1 radionuclide	Highest priority score for those radionuclides having greatest effect on, wasteform, packaging, transport, criticality and GDF design
PWR	Pressurised Water Reactor
Pu	Plutonium
PVC	Polyvinyl chloride
PWR	Pressurised water reactor
RAL	Rutherford Appleton Laboratory
RGL	Regulatory guidance level
RPCM	Radiological protection criteria manual
RS	Robust shielded
RSC	Robust shielded container
SF(s)	Spent fuel(s): nuclear fuel removed from a reactor following irradiation that is no longer usable in its present form because of depletion of fissile material, poison build-up or radiation damage.
SILW	Shielded ILW
SILW waste package	Waste package not requiring additional shielding
SLLW	Shielded LLW
SRL	Scientific readiness level: A scale calibrating the scientific maturity of underpinning science between 1 and 6 where 1 is the least mature and 6 the most established understanding
SS	Stainless steel
Superplasticiser	Commonly used to improve the flow characteristics of cements and concrete and also allow the water to cement ratio to be reduced (this produces stronger concretes). Superplasticisers could enhance the solubility of actinides.
SWTC	Standard Waste Transport Container

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

Appendix A – New and updated science and technology plan task sheets

There are three updated task sheets (all of which relate to UK ABWR SF) but no new task sheets. The task sheets include assessment of the scientific readiness level (SRL) at the start and end of the task. Further information on SRLs and how RWM uses them can be found in [A1].

<table>
<tr><td>Task Number</td><td colspan="2">074</td><td>Status</td><td colspan="2">Start date in future</td></tr>
<tr><td>PBS level 4</td><td colspan="5">Criticality Safety</td></tr>
<tr><td>PBS level 5</td><td colspan="5">Criticality Safety Assessment for Spent Fuel Disposal</td></tr>
<tr><td colspan="6">Title</td></tr>
<tr><td colspan="6">Disposal Container – CSA for Legacy Fuels</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">To date, most of RWM’s criticality safety assessment studies have been made for transport of ILW to a GDF and its subsequent emplacement and disposal. A significant component of this work programme is to assess the safety of operations and disposal of spent fuel and separated uranium (U) and plutonium (Pu), which will also be disposed of if declared as waste. Recent work by RWM has demonstrated that, for any materials potentially requiring disposal, the likelihood and consequences of a criticality event over the next million years are both very low.

At this current generic phase, RWM plans to demonstrate the principles that are used to assure criticality safety of ILW, HLW, spent fuel, Pu and U during transport, operations and following facility closure. Additional work is needed to support and evaluate changes to the design of the disposal system, for example the potential use of multi-purpose containers for spent fuel, Pu and U disposal.

Having identified the factor(s) which may be relied upon in order to provide criticality control for a UK disposal container containing legacy spent pressurised water reactor (PWR) or advanced gas-cooled reactor (AGR) fuel in Task 069, this task will comprise a criticality safety assessment which can be used to demonstrate criticality safety.</td></tr>
<tr><td colspan="6">Research Need</td></tr>
<tr><td colspan="6">To support safety case development by identifying and documenting the factor(s) relied upon in order to provide criticality control for a UK disposal container containing legacy spent PWR and AGR fuel.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To undertake a full criticality safety assessment to demonstrate criticality safety for the disposal of legacy spent fuels (eg PWR and AGR) in the UK disposal container.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">Now that UK disposal container designs have been developed and after a criticality control options study has been completed (under Task 378), a full criticality safety assessment is required to demonstrate criticality safety for the disposal of legacy spent fuels (eg PWR and AGR) in the UK disposal container design. If possible/practical a combined CSA should be developed in such a way as to cover potential future UK new build light water reactor (LWR) spent fuels (eg AP1000, EPR and UK Advanced Boiling-Water Reactor (ABWR) spent fuel). Existing legacy spent fuel is however the priority.

The criticality safety assessment should comprise a computational study conducted on a set of normal operation and accident condition scenarios (covering transport, operation and post-closure phases of GDF), likely utilising the MCNP or MONK criticality codes.</td></tr>
<tr><td>SRL at task start</td><td>4</td><td>SRL at task end</td><td>6</td><td>Target SRL</td><td>6</td></tr>
<tr><td>End point</td><td colspan="5">No Further Research Planned</td></tr>
<tr><td>Customer</td><td colspan="5">Disposal System Safety Case, Design</td></tr>
<tr><td colspan="6">Further information</td></tr>
<tr><td colspan="6">RWM has recently developed two illustrative designs, one featuring a copper-shell with a cast iron insert (Variant 1, based on a Swedish design) and one featuring a carbon steel single body (Variant 2, similar to a design considered in Switzerland). Both designs now consider disposal of 16 ‘slotted cans’ of AGR fuel (48 fuel elements) and 4 PWR assemblies in each container. Relevant publications include:

T.W. Hicks and T.D. Baldwin, 2014, The Likelihood of Criticality: Synthesis Report, AMEC Report 17293-TR-023 for the Nuclear Decommissioning Authority, Version 2.</td></tr>
</table>

R.M. Mason and P.N. Smith, 2014, Modelling of Consequences of Hypothetical Criticality: Synthesis Report for Post-closure Criticality Consequence Analysis, AMEC Report AMEC/SF2409/013 Issue 2.

<table>
<tr><td>Task Number</td><td colspan="2">078</td><td colspan="2">Status</td><td>Start date in future</td></tr>
<tr><td>PBS level 4</td><td colspan="5">Criticality Safety</td></tr>
<tr><td>PBS level 5</td><td colspan="5">Criticality Safety Assessment for Spent Fuel Disposal</td></tr>
<tr><td colspan="6">Title</td></tr>
<tr><td colspan="6">Disposal Container – Criticality Safety Assessment for Future Higher Enriched New Build Fuels</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">To date, most of RWM’s criticality safety assessment studies have been made for transport of ILW to a GDF and its subsequent emplacement and disposal. A significant component of this work programme is to assess the safety of operations and disposal of spent fuel and separated uranium (U) and plutonium (Pu), which will also be disposed of if declared as waste. Recent work by RWM has demonstrated that, for any materials potentially requiring disposal, the likelihood and consequences of a criticality event over the next million years are both very low.

At this current generic phase, RWM plans to demonstrate the principles that are used to assure criticality safety of ILW, HLW, spent fuel, Pu and U during transport, operations and following facility closure. Additional work is needed to support and evaluate changes to the design of the disposal system, for example the potential use of multi-purpose containers for spent fuel, Pu and U disposal.

Having identified the factor(s) which may be relied upon in order to provide criticality control for a UK disposal container containing legacy spent fuel in Task 074, this task will comprise expanding the existing criticality safety assessment to demonstrate criticality safety of future higher enriched fuels (eg some exotics or mixed oxide (MOX) spent fuels) in this container.</td></tr>
<tr><td colspan="6">Research Need</td></tr>
<tr><td colspan="6">To support safety case development by identifying and documenting the factor(s) relied upon in order to provide criticality control for a UK standardised disposal container containing legacy spent pressurised water reactor, advanced gas-cooled reactor and higher enriched spent fuels.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To undertake a full criticality safety assessment (CSA) to demonstrate criticality safety for the disposal of higher enriched spent fuels in the UK disposal container.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">To expand the scope of the existing criticality safety assessment (produced under Task 074) to spent fuels with higher enrichments, eg mixed oxide fuel (MOX) or future UK new build light water reactor (LWR) fuels.

The new or revised criticality safety assessment will again comprise a computational study conducted on a set of normal operation and accident condition scenarios (covering transport, operations and post-closure phases of GDF) likely utilising the MCNP or MONK criticality codes).</td></tr>
<tr><td>SRL at task start</td><td>4</td><td>SRL at task end</td><td>6</td><td>Target SRL</td><td>6</td></tr>
<tr><td>End point</td><td colspan="5">No Further Research Planned</td></tr>
<tr><td>Customer</td><td colspan="5">Design, Disposal System Safety Case</td></tr>
<tr><td colspan="6">Further information</td></tr>
<tr><td colspan="6">RWM has recently developed two variant designs for the UK disposal container, one featuring a copper-shell with a cast iron insert (Variant 1, based on a Swedish design) and one featuring a carbon steel single body (Variant 2, similar to a design considered in Switzerland). Both designs now consider disposal of 16 ‘slotted cans’ of AGR fuel (48 fuel elements) and 4 PWR assemblies in each container. Relevant publications include:

T.W. Hicks and T.D. Baldwin, 2014, The Likelihood of Criticality: Synthesis Report, AMEC Report 17293-TR-023 for the Nuclear Decommissioning Authority, Version 2.

R.M. Mason and P.N. Smith, 2014, Modelling of Consequences of Hypothetical Criticality: Synthesis Report for Post-closure Criticality Consequence Analysis, AMEC Report AMEC/SF2409/013 Issue 2.</td></tr>
</table>

Task Number	552	Status	Start date in future
PBS level 4	Package Evolution		
PBS level 5	Spent Fuel		

Title

Further Work on SimFuel to Understand Dissolution Behaviour of Spent Fuel

Background

Based on extensive international research there is good understanding of the behaviour of light water reactor (LWR) spent fuel under conditions relevant to geological disposal. However, the UK inventory contains spent fuels from a number of different reactor types with characteristics that are unique to the UK, for example advanced gas-cooled reactor (AGR) fuel. RWM plans to study a variety of spent fuels arising from commercial and research reactors that have been operated in the UK, initially focusing on fuels that are likely to require disposal in significant quantities (AGR and, to a lesser extent, pressurised water reactor (PWR) fuels).

Scoping studies will be aimed at developing an initial understanding of the typical leaching rates and identifying the key factors controlling the leaching behaviour. In the case of AGR fuel, which currently makes up the greatest proportion of the disposal inventory, testing methodologies are being developed. The mechanistic understanding gained from these studies is expected to be applicable to a good fraction of the remaining spent fuel inventory.

Initial studies will be more substantial in scope and carried out in two stages (first oxic, then anoxic conditions). These will be followed by additional ('further') studies aimed at proving additional understanding and at underpinning data for use in safety assessments. In this context, RWM will consider recent advances in mechanistic understanding and modelling of spent fuel evolution achieved internationally and its applicability to UK spent fuels. This task comprises further work on SimFuel (following on from task 547), manufactured to replicate relevant spent fuel, whose behaviour will be evaluated on the basis of a variety of scoping experiments and atomistic models. SimFuel is made by doping UO_2 with non-radioactive isotopes as surrogates of the fission products expected to form in spent fuels.

Research Need

To develop a mechanistic understanding of the evolution and dissolution behaviour (instant release and long-term dissolution rate) of UK spent fuels in near-neutral and, to a lesser degree, alkaline groundwater. This is to support:

- the assessment of packaging solutions

- the development of suitable disposal concepts

- the development of the safety case and, where appropriate, strategic decisions on suitable waste management strategies for these materials

Research Objective

To determine whether it is possible to manufacture inactive simulants of spent fuel (SimFuel) with chemical composition, characteristics (with the exception of self-irradiation) and leaching behaviour which are sufficiently representative of UK spent fuels (eg AGR, LWR or MOX) to justify their use in leaching experiments aimed at evaluating the leaching behaviour of the fuel. In particular to determine whether:

- the morphology of SimFuel is similar enough to that observed in spent fuel

- The partitioning of fission product surrogates in the UO_2 microstructure and the resulting oxidation state of the fuel is consistent with experimental observations on spent fuels

- the dissolution behaviour of SimFuel is similar to that of spent fuels, including sensitivity to the groundwater chemistry, temperature, fuel composition (representing the post-discharge 'age' of the fuel) and redox conditions, including tests to specifically document the effect of alkaline groundwater

- the presence of radiation damage induced ex-situ has an effect on the ensuing dissolution behaviour of SimFuel

- the presence of the stainless steel / zircaloy representative of fuel cladding in leaching experiments affects the dissolution behaviour of the SimFuel

- secondary uranium minerals form on SimFuel upon leaching, which are similar to those expected in UO_2 spent fuels (which would indicate retention of uranium and non-radioactive isotopes or surrogates of some

important radionuclides)					
Scope					
To be developed on the basis of the outcome of task 547.					
SRL at task start	3	SRL at task end	4	Target SRL	4
End point	Site Specific Validation				
Customer	Waste Package Disposability Assessments, Concept Development, Disposal System Safety Case				
Further information					
Relevant publications include: N. Rauff-Nisthar et al, 2013, Corrosion Behaviour of AGR Simulated Fuels – Evolution of the Fuel Surface, ECS Transactions, Volume 53, pages 95-104. This task will be carried out through academic partners. The opportunity for co-funding from the relevant research council (EPSRC) may be investigated.					

References

A1 Radioactive Waste Management, *Geological Disposal: Science and Technology Plan*, NDA/RWM/121, 2016.

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